Tropical Agricultural Research Vol. 22 (1): 54 - 65 (2010)

Growth Stage Based Economic Injury Levels for Two Spotted Spider Mite, *Tetranychus urticae* Koch (Acari, Tetranychidae) on Tomato, *Lycopersicon esculentum* Mill.

G.G. Jayasinghe* and B. Mallik[1]

Cinnamon Research Station
Department of Export Agriculture, Palolpitiaya
Thihagoda, Sri Lanka

ABSTRACT. *Study on relationship between infestation of two spotted spider mite, Tetranychus urticae Koch (Acari: Tetranychidae) and yield loss in tomato, Lycopersicon esculentum Mill. revealed that one mite released to a tomato plant 6 weeks after planting and allowed to feed for 3, 6, 9 and 12 weeks, reduced the final yield by 0.233, 0.689, 1.291 and 1.624 g per plant, respectively. Under similar conditions with same treatments a mite day reduced 16.4, 1.80, 0.96 and 1.18 mg of the final yield, respectively. Middle stage of the crop was the most critical period and mite infestation initiated at this stage can contribute to more than 50% of total yield loss due to leaf defoliation and reduction of chlorophyll content of the leaves. Economic injury levels (EILs) for tomato has been calculated based on the number of mites initially released and mite days during different growth stages. Though calculations based on these two parameters yielded similar information, for predictive purpose, the number of mites is more useful in quick decision making. This study was able to provide quantifiable decision making tools, by which the EILs can be fixed to enable the farmers to time their by application of acaricides.*

Key words: *Economic injury level, mite day, Tetranychus urticae, tomato, two spotted spider mite.*

INTRODUCTION

Tomato, (*Lycopersicon esculentum* Mill) is grown in protected houses and in open fields for direct consumption and processing. In the world, tomato is cultivated over an area of 3.989 million hectares with a total production of 108.499 million tons and productivity of 27202 kg/ha. In India, it is cultivated on 0.52 million hectares with production of 7.42 million tons (productivity 14269 kg/ha) (Anonymous, 2004). In Sri Lanka, tomato is grown over an area of 5300 ha with total production of 40400 tons and productivity of 7574 kg/ha (Anonymous, 2003).

All parts of the tomato plant offer food, shelter and reproductive sites for many kinds of arthropods. On protected as well as field grown tomato, one of the predominant pest species is the two spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae) (Lange and Bronson, 1981). This mite has been reported infesting over 200 species of plants (Perry *et al.,* 1998).

1* To whom correspondence should be addressed : ggjaya2005@yahoo.co.in
Department of Entomology, University of Agricultural Sciences, GKVK, Bangalore, Karnataka, India

The two spotted spider mite prefers hot, dry weather of the summer and fall months, however, may occur anytime during the year. The mite generally feeds underneath the leaves and causes yellowing of the leaves due to mesophyll collapse and necrotic spots occur in the advanced stages of the attack.

Although tomato is an important vegetable crop grown in South Asia and frequently attacked by two spotted spider mite, detailed studies on the economic injury level and crop losses are scanty. This study was undertaken to estimate the yield loss in tomato due to the two spotted spider mite and establish the economic injury level of two spotted spider mite on tomato under controlled conditions.

MATERIALS AND METHODS

This study was carried out in the laboratory and polycarbonate house at the Acarology section of the Department of Entomology, University of Agricultural Sciences, GKVK, Bangalore, and Karnataka, India during the period of June to October 2008.

Maintenance of *Tetranychus urticae* Koch culture in laboratory and polycarbonate house

Leaves of tomato plant infested by the two spotted spider mites in the field were brought to the laboratory and observed under a stereo microscope. After confirming the identity of the mite, the leaves were kept on mulberry leaf bits measuring 8 cm x 8 cm spread on a layer of moist sponge in plastic trays, to enable multiplication of mites. The mulberry leaf bits were changed every week with fresh leaf bits. These cultures were maintained in ambient temperature (20 – 32°C) and 50% RH in the lab. Mulberry leaf bits were regularly examined to eliminate predators. In addition, a two spotted spider mite culture was also maintained as a stock culture on potted French bean plants in the glass house.

Establishment of tomato plants in polycarbonate house

Tomato plants, variety Abhinav (Syngenta India, Limited), were used in this study. Three week old seedlings procured from commercial nursery were planted in 22 cm diameter earthen pots containing pot mixture prepared with red soil and farm yard manure (FYM) in 1:1 ratio. In each pot, one seedling was planted. One and four weeks after transplanting, *Trichoderma harzianum* (a beneficial fungus) culture was added to the pots to manage pathogenic soil inhabiting fungi. Chemical fertilizers (3 g of diammonium phosphate, 2 g of muriate of potash per pot) were added two, five and eleven weeks after planting. The moisture level of pots was kept at field capacity using a drip irrigation system and temperature inside the polycarbonate house was maintained below 35°C using blower-wet pad system, especially during day time. Metal wire and jute threads were used to train tomato plants.

Treatments

To assess the yield loss of tomato due to feeding by the two spotted spider mites, at different densities (M) and varying durations of exposure of the plants to mite feeding, at different ages of the plant (A), the following treatments were imposed with three replications in a factorial design. In factor I (A), growth stage and feeding duration were considered. They were 3, 6, 9, 12 weeks of mite feeding from 6 -9 (A_1), 6-12 (A_2), 6-15 (A_3), 6-18 (A_4) weeks after planting, respectively and 9, 6, 3 weeks of mite feeding from 9- 18 (A_5), 12 -18 (A_6)

and 15 – 18 (A_7) weeks after planting, respectively. Initially introduced mite densities per plant such as no mite or control (M_0), 100 (M_1), 200 (M_2) and 400 (M_3) mites were established as factor II (M).

Since six potted tomato plants were used for each treatment, 504 pots were arranged in groups of six, in the glass house, and the treatments were imposed randomly. Dicofol and Fenazaquin (10% EC) were sprayed to avoid the mites feeding after the specified period.

Observations were recorded from each plot (6 plants/ plot) by randomly selecting 15 leaflets from different canopy levels (five each from top, middle and bottom of the canopy) once a week after the release of mites.

The number of eggs, immature stages and adults were counted under a stereo microscope and the data were used for calculation of cumulative mite days, CMD (one day feeding duration of a mite) per plant as follow:

$$\text{CDM (adults)} = \sum \frac{\text{Adult mites at observation 1} + \text{Adult mites at observation 2}}{2} \text{ X } \text{Days between observations}$$

$$\text{CDM (immature)} = \sum \frac{\text{Adult mites at observation 1} + \text{Adult mites at observation 2}}{4} \text{ X } \text{Days between observations}$$

In addition, the number of leaves per plant, height of the plants (cm) and chlorophyll content of leaves were estimated. Chlorophyll extraction was made using dimethyl sulphoxide and acetone (80%) at 1:1 ratio and estimated using a spectrophotometer (Thermo Spectronic Genesys 10 µv) at 645 and 663 nm wave lengths and formula as suggested by Arnon (1949). Cumulative tomato yield of 13, 14, 15, 16, 17 and 18 weeks after transplanting, was recorded.

Estimation of the economic injury levels in controlled conditions

Economic Injury Level (EIL) at different growth stages of tomato was estimated as per the following equation explained by Pedigo (2002):

$$\mathbf{EIL = C/(V.\ I.\ D.K)}$$

where, C is the cost of management, V the market value of tomato, I the unit injury per pest (mite or mite day in this study), D the damage per unit injury, and K the control efficacy or proportional reduction in potential injury or damage by management.

Data analysis

Data on counts of immature stages and adults of spider mites were used to estimate the cumulative mite days of each treatment. Influence of mite days on growth parameters such as plant height, leaf numbers and fruit yield was investigated using Analysis of Variance (SAS Institute, 1989). Regression analysis (SAS Institute, 1989) was used to establish relationship between mite density, mite days and yield parameters.

RESULTS AND DISCUSSION

Mite days

Mite days (one mite feeding in one day) and initial number of mites per plant were used to quantify yield loss of tomato due to mite feeding. The cumulative mite days were directly proportional to the duration of mites feeding on plants and the number of mites initially introduced on to the plant as well (Table 1).

Table 1. Mean cumulative mite days in early and late growth stages of tomato plants with different levels of initial infestation of the mite.

Plant age during feeding (weeks)	Feeding duration (weeks)	Mite days per plant with different initial released			
		No mite (M_0)	100 (M_1)	200 (M_2)	400 (M_3)
6 – 9 (A_1)	3	1,157 ^{h}	961 ^{h}	2,446 ^{h}	5,084 ^{gh}
6 – 12 (A_2)	6	1,126 ^{h}	35,487 ^{gh}	57,047 ^{fgh}	1,44,923 ^{def}
6 – 15 (A_3)	9	829 ^{h}	1,36,702 ^{def}	3,03,177 ^{bc}	4,97,017 ^{a}
6 – 18 (A_4)	12	1,295 ^{h}	1,70,023 ^{de}	3,22,653 ^{b}	5,32,463 ^{a}
9 – 18 (A_5)	9	858 ^{h}	1, 69,314 ^{de}	3,19,174 ^{b}	4,96,353 ^{a}
12 – 18 (A_6)	6	1,097 ^{h}	92,852 ^{efg}	1,61,418 ^{de}	2,17,071 ^{cd}
15 – 18 (A_7)	3	1,027 ^{h}	2,963 ^{h}	10,150 ^{gh}	19,920 ^{gh}

Mean values in each column superscripted by the same letters are not significantly different ($P>0.05$)

The cumulative mite days (CMD) per plant were highest in treatments with higher feeding duration such as 12 and 9 weeks with higher densities of mites (400 mites per plant) initially released to the plants (Table 1). This relationship was true when the mites were released either during the early growth stage of the plant or later growth stage of the plant. Although there was a slight increment in CMD when mites were released during latte growth stage of the plant, this was not significantly different from early release of mites. In plants on which mites were not released and maintained as the control, a few mites were recorded as a result of cross infestation, but these were in very low numbers (Table 1).

The effect of mite days on growth of tomato plants

The effect of mite days on growth parameters of tomato such as plant height and number of leaves was examined. Plant height was not significantly affected by mite densities, feeding intervals or cumulative mite days.

Since mite feeding causes severe damage to leaves, which severely affected the number of leaves recorded 12 weeks after planting. Maximum number of leaves (44.3 per plant) was recorded in plants which were not infested by mites, whereas the plants which were infested for twelve weeks starting from 6 weeks age had the least number of leaves. When feeding duration and mite number initially released (mite days) increased, the number of leaves remaining on the plants decreased, especially 12 weeks after planting. The best fitted mathematical relationship between number of leaves per plant and mite days computed for 14, 15, 16 and 18 WAP was a logarithmic model presented in Fig. 1.

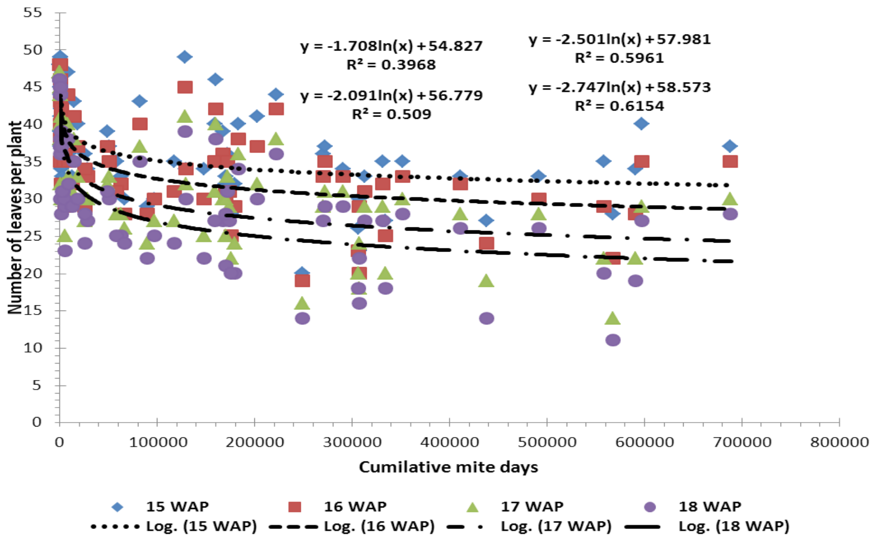

Fig. 1. **Relationship between cumulative mite days and numbers of leaves per plant 15 (♦), 16 (■), 17 (▲) and 18 (●) weeks after planting (WAP).**

The effect of mite days and feeding intervals on chlorophyll content

Leaf chlorophyll content was measured in mite infested tomato plants at 11 and 14 weeks after transplanting. Plants with early infestation and 12 weeks of mite feeding (A_4) and late infestation with 9 weeks mite feeding (A_5) had significantly low total chlorophyll (1.592, 1.597 mg/g) than other feeding durations at 11th week. Eleven weeks after transplanting, chlorophyll *b* content was statistically *on par* in all the treatments, but chlorophyll *a* showed significant differences among treatments similar to total chlorophyll content (Table 2). Early infested leaves with 12 weeks of feeding duration (A_4) showed significantly lowest total chlorophyll *a* and *b* content (1.016, 0.799, 0.217 mg/g) compared to other treatments 14 weeks after planting (Table 2).

Mite densities initially introduced and mite days significantly affected total chlorophyll, chlorophyll *a* and *b* content (Table 2). Plants on which 400 mites per plant were initially introduced had the lowest total chlorophyll, chlorophyll *a* and *b* contents in 11 week (1.363, 0.986 and 0.377 mg/g) and 14 week (0.898, 0.693 and 0.205 mg/g) old plants, followed by 200, 100 and no mites (control plot). Chlorophyll content was higher in 11 week old plants than in 14 week old plants, after transplanting, all the treatments (Table 2).

Damage to the plants by *T. urticae* is by several ways. First, feeding causes the destruction or disappearance of chloroplasts which then leads to basic physiological changes in the plant. Stomatal closure can be a primary host-plant response, and in such cases, uptake of CO_2 decreases resulting in a marked reduction in transpiration as well as photosynthesis (Sances *et al*., 1979). *T. urticae* injures individual leaf cells, causing the reduction of total chlorophyll content and net photosynthetic rate of leaves (Sances *et al.,* 1981; Park and Lee 2002). Such leaf cell damage and tissue injury alters carbon allocation patterns of plant organs (Wyman *et al.,* 1979), often causing deformity of plants (Avery and Briggs, 1968).

Table 2. Chlorophyll content of tomato leaves exposed to different durations of mite infestations and number of mites initially released during different growth stages.

Treatment	Chlorophyll content (mg/ g of leaf)					
	11 weeks after transplanting			14 weeks after transplanting		
	Chl. *a*	Chl. *b*	Total Chl.	Chl. *a*	Chl. *b*	Total Chl.
A_1 (6, 3)*	1.205 ^{c}	0.546	1.751 ^{a}	0.886 ^{ab}	0.291 ^{a}	1.177 ^{a}
A_2 (6, 6)	1.289 ^{a}	0.475	1.764 ^{a}	0.867 ^{b}	0.304 ^{a}	1.171 ^{a}
A_3 (6, 9)	1.207 ^{c}	0.488	1.695 ^{a}	0.869 ^{ab}	0.272 ^{a}	1.141 ^{a}
A_4 (6, 12)	1.142 ^{d}	0.450	1.592 ^{b}	0.799 ^{c}	0.217 ^{b}	1.016 ^{b}
A_5 (9, 9)	1.165 ^{d}	0.431	1.597 ^{b}	0.865 ^{b}	0.267 ^{a}	1.132 ^{a}
A_6 (12, 6)	1.259 ^{b}	0.507	1.766 ^{a}	0.867 ^{b}	0.287 ^{a}	1.154 ^{a}
A_7 (15, 3)	1.246 ^{b}	0.507	1.753 ^{a}	0.898 ^{a}	0.282 ^{a}	1.172 ^{a}
F(α = 0.05)	***	NS	***	***	**	***
SEM	0.0008	0.0085	0.0094	0.0013	0.0032	0.0039
LSD	0.0241	0.0755	0.0793	0.0295	0.0461	0.0511
CV %	2.418	18.950	5.689	4.171	20.669	5.487
M_0 (none)	1.408 ^{a}	0.601 ^{a}	2.009 ^{a}	1.029 ^{a}	0.355 ^{a}	1.383 ^{a}
M_1 (100)	1.299 ^{b}	0.522 ^{b}	1.821 ^{b}	0.908 ^{b}	0.283 ^{b}	1.186 ^{b}
M_2 (200)	1.173 ^{c}	0.447 ^{c}	1.621 ^{c}	0.833 ^{c}	0.248 ^{c}	1.081 ^{c}
M_3 (400)	0.986 ^{d}	0.377 ^{d}	1.363 ^{d}	0.693 ^{d}	0.205 ^{d}	0.898 ^{d}
F(α = 0.05)	***	***	***	***	***	***
SEM	0.0009	0.0085	0.0094	0.0013	0.0032	0.0039
LSD	0.0182	0.057	0.06	0.0223	0.0349	0.0386
CV %	2.418	18.950	5.689	4.171	20.669	5.487
A x M	***	NS	***	***	NS	**

Mean values in each column superscripted by the same letters are not significantly different (P>0.05).

*Figures in parentheses indicate age of plant at the time mites were released and the duration of feeding (weeks).

Effect of mite feeding on yield of tomato

Lowest cumulative yield was observed in plants, which were infested by mites early and were exposed to feed for a longer period (A_4). Cumulative yields increased with reduction of feeding period. Mite feeding on plants in early growth stages (A_2 and A_3) significantly contributed to reduction of yield than mites feeding on plants during later stages with same feeding duration (A_5 and A_6). Feeding on plants in very late growth stage had no significant contribution to yield reduction (A_7). All the yields were significantly different from each other except A_1 and A_7 (Table 3). Number of mites initially released in different treatments had significant influence on tomato yield compared to mite free treatment (M_0). Lowest cumulative yield was recorded in plants on which 400 mites per plant were initially released (M_3), followed by 200 (M_2) and 100 (M_1) mites, respectively (Table 3).

Table 3. Yield of tomato as affected by duration of mite infestation and number of mites initially released during different growth stages

Treatment	Mean yield of tomato from 6 plants (g)						
	13 WAP	14 WAP	15 WAP	16 WAP	17 WAP	18 WAP	Cumulative
A_1 (6, 3)	216.08	1516.0 ^{a}	1909.8 ^{a}	1700.7 ^{a}	1208.9 ^{a}	471.3 ^{b}	7022.6 ^{a}
A_2 (6, 6)	251.78	1323.0 ^{ab}	1835.1 ^{ab}	1472.0 ^{ab}	813.7 ^{bc}	520.2 ^{b}	6215.8 ^{c}
A_3 (6, 9)	232.88	925.1 ^{c}	1763.0 ^{ab}	1242.3 ^{bc}	611.1 ^{c}	530.0 ^{b}	5304.5 ^{e}
A_4 (6, 12)	133.33	987.3 ^{c}	1532.8 ^{b}	1142.6 ^{c}	758.1 ^{bc}	407.6 ^{b}	4961.7 ^{f}
A_5 (9, 9)	171.21	1066.5 ^{bc}	1782.9 ^{ab}	1176.3 ^{c}	934.9 ^{abc}	536.7 ^{b}	5868.6 ^{d}
A_6 (12, 6)	191.21	1337.3 ^{ab}	1920.8 ^{a}	1521.5 ^{a}	1050.6 ^{ab}	610.9 ^{b}	6632.3 ^{b}
A_7 (15, 3)	130.71	1365.3 ^{ab}	1894.9 ^{a}	1598.3 ^{a}	1004.7 ^{ab}	935.9 ^{a}	6929.7 ^{a}
F(α = 0.05)	NS	**	*	***	***	NS	***
SEM							110659
LSD	133.59	326.63	353.44	271.44	344.85	315.3	272.27
M_0 (no)	164.67	1539.4 ^{a}	2111.5 ^{a}	1488.0 ^{b}	1359.0 ^{a}	501.0	7163.5 ^{a}
M_1 (100)	196.19	1083.6 ^{b}	1757.9 ^{b}	1710.4 ^{a}	1046.9 ^{b}	578.0	6373.0 ^{b}
M_2 (200)	201.60	1166.9 ^{b}	1717.4 ^{b}	1396.7 ^{b}	635.0 ^{c}	621.7	5710.3 ^{c}
M_3 (400)	195.95	1078.8 ^{b}	1635.7 ^{b}	1035.7 ^{c}	606.0 ^{c}	592.1	5173.3 ^{d}
F(α = 0.05)	NS	**	*	***	***	NS	***
SEM							110659
LSD	100.98	246.91	267.18	205.19	260.69	238.34	205.82

WAP – Weeks after planting
Figures in parentheses indicate age of plant at the time mites were released and the duration of feeding (weeks).
Mean values in each column superscripted by the same letter are not significantly different (P>0.05).
Early infestation of mites for 3 weeks (A_1), 6 weeks (A_2), 9 weeks (A_3), 12 weeks (A_4) and late infestation of mites for 9 weeks (A_5), 6 weeks (A_6), 3 weeks (A_7) period.
Different initial number of mites released per plant were zero (M_0), 100 (M_1), 200 (M_2) and 400 (M_3).

Table 4. Tomato yield, percent yield loss and cumulative mite

Treatment	Growth stage	Feeding period (Weeks)	Mite density	Cumulative yield per 6 plants (g)	Yield loss (g)	Percent yield loss	Mite days
A_1M_0	E	3	0	7283.7^{a}	0	0	1157
A_1M_1	E	3	100	7146.8^{abc}	136.9	1.88	961
A_1M_2	E	3	200	6926.0^{abcde}	357.7	4.91	2246
A_1M_3	E	3	400	6734.0^{bcdef}	549.7	7.55	5084
A_2M_0	E	6	0	7044.8^{abc}	0	0	1126
A_2M_1	E	6	100	6401.5^{efg}	643.3	9.13	35487
A_2M_2	E	6	200	6088.3^{gh}	956.5	13.58	57047
A_2M_3	E	6	400	5328.4^{i}	1716.4	24.36	144923
A_3M_0	E	9	0	7101.4^{abc}	0	0	829
A_3M_1	E	9	100	5681.9^{hi}	1419.5	19.99	136702
A_3M_2	E	9	200	4534.5^{kl}	2566.9	36.15	303177
A_3M_3	E	9	400	3900.0^{m}	3201.4	45.08	497017
A_4M_0	EL	12	0	7271.6^{ab}	0	0	1295
A_4M_1	EL	12	100	5325.0^{ij}	1946.6	26.77	170023
A_4M_2	EL	12	200	4060.0^{lm}	3211.6	44.17	322653
A_4M_3	EL	12	400	3190.0^{n}	4081.6	56.13	532463
A_5M_0	L	9	0	7198.9^{abc}	0	0	858
A_5M_1	L	9	100	6212.3^{fgh}	986.6	13.70	169314
A_5M_2	L	9	200	4933.0^{jk}	2265.9	31.48	319174
A_5M_3	L	9	400	4330.0^{lm}	2868.9	39.85	496353
A_6M_0	L	6	0	7283.7^{a}	0	0	1097
A_6M_1	L	6	100	6783.0^{abcde}	500.7	6.87	92859
A_6M_2	L	6	200	6455.5^{defg}	828.2	11.37	161418
A_6M_3	L	6	400	6016.9^{gh}	1266.8	17.39	217071
A_7M_0	L	3	0	7060.5^{abcd}	0	0	1027
A_7M_1	L	3	100	7060.5^{abc}	0	0	2963
A_7M_2	L	3	200	6984.7^{abcd}	75.8	1.07	10150
A_7M_3	L	3	400	6713.4^{cdef}	347.1	4.92	19920

Mean values in each column superscripted by the same letter are not significantly different ($P>0.05$); E-early; L-late; EL- early and late

Percent yield loss due to mite infestation was calculated based on yield of plants on which no mites were released. There were combined effects of number of mite initially released, stage of plant when mite infestation was initiated (early or late stage) and feeding duration (mite days). The highest yield loss (56.1%) was recorded in plants in treatment A_4M_3, followed by A_3M_3 (45.1%), A_4M_2 (44.2%) and A_5M_3 (39.9%) (Table 4). Thus early mite infestation contributed more yield loss than the late infestation, though the feeding duration and initial numbers of mites released were same. Plants infested early (A_1, A_2, A_3) showed higher yield losses than late infested plants A_5, A_6, A_7 with similar mite feeding durations and initial mite densities (Table 4). Initial mite population positively correlated with reduction in yield in both early and late infested plants (Table 4). There was a positive correlation between yield reduction (crop loss) and mite days (R^2=0.911).

Stacey *et al*. (1985) studied tomato plants, which had been subjected to varying levels of red spider mite damage at different stages in the growth of the plants. 10% of leaf area damage by mite caused a 9% loss of yield with no apparent damage threshold. Similar results have been recorded by Sances *et al*. (1981) on strawberry plants under field conditions. Early season infestation affected physiological parameters at much lower population level than was necessary to cause similar injury later in the season. *T. urticae* infestations decreased leaf productivity by reducing the total number of leaves per plant. Approximately 14% reduction of total leaf area could result in a significant yield loss (Park and Lee, 2005). In the present study, 11% reduction in leaf numbers was observed.

Three major principles behind yield loss due to spider mite infestation in various crops have been established; (1) biomass reduction (2) disturbance of water conduction, dry matter partitioning and CO_2 gas exchange and (3) chlorophyll reduction and shedding of immature flowers (Sances *et al*., 1979; Sances *et al.,* 1981; Park and Lee, 2002; Park and Lee, 2005). Results of the present study agree with earlier studies. Significant defoliation occurred in tomato plants which were infested by mites for longer duration (12 or 9 weeks) and under higher mite population (400 mites per plants initially released) during early growth stages.

In this study, it was observed that plants infested with 100, 200 or 400 mites, when they were 6 weeks old, experienced higher loss in yield than plants on which mites were released 9, 12, 15 weeks after planting with the same number of mites. There was a negative relationship between duration of mite infestation and number of leaves. However, yield loss (%) could not be attributed to this relationship. This can be due to flower drop and movement of resources to the sink being affected by early infestation, whereas later infestations may depend more on unused resources in the leaf.

Estimation of economic injury levels for spider mite infestation at different growth stages of tomato, under controlled conditions

Yield loss per mite varied with the number of mites initially introduced, feeding durations and growth stage of plants when mites were released (early or late). Mite infestations during middle stage (9 to 15 weeks after planting) of tomato plant reduced the yield, maximum, whereas, infestation by a single mite, during early and later stage of growth affected the yield of plants to a lesser extent (Table 5). However, early infestation reduced the yield more than later infestation. Yield loss per mite day was also investigated. Short feeding duration during early growth stages of the plants caused high yield reduction (16.4, 1.8 and 0.9 mg per mite day) than similar feeding duration during the later growing stages (2.49, 0.9 and 0.85 mg per mite day) (Table 5).

Economic Injury Levels (EILs) varied with feed duration of mites and growth stages. EILs were calculated as mites per plant using the formula EIL=C/(V.I.D.K.) mentioned above for different growth stages of tomato. Average cost for chemical pest management (*C*) was Rs. 5000 per crop per hectare during the study period and farm gate price of tomato (*V*) varied from Rs 2 – 10 per kg. Yield loss per mite per plant (I. D) for different feeding durations and plant growth stages of tomato were obtained by the yield loss functions of different treatments (A_4, A_5, A_6 and A_7) for a mite and a mite day (Table 5). It was considered that 15000 plants/ ha. Since EIL values can differ with market prices. When farm gate price of tomato was increased, the EIL value decreased and *vice versa.* Efficacy of management (K) was considered as 1 (Table 6).

Table 5. Yield loss caused by a mite day, when a mite is introduced at different growth stages and allowed to feed for different durations.

Treatment	Growth stage (weeks after planting)	Feeding duration (weeks)	Yield loss per mite (g)	Yield loss per mite day (mg)
A_1	6	3	0.233	16.40
A_2	6	6	0.689	1.80
A_3	6	9	1.291	0.96
A_4	6	12	1.624	1.18
A_5	9	9	1.196	0.85
A_6	12	6	0.511	0.90
A_7	15	3	0.118	2.49

Table 6. Economic injury levels (EIL) for *T. urticae* on tomato at different growth stages, where V is price of tomato and K is efficacy of control measure

Treatment	Plant age during feeding (weeks)	EIL for different growth stages of tomato (number of mites initially infested / plant)
A4	6 – 18	EIL = 5000 x 1000/ 1.624 x 15000 x V*
A5	9 – 18	EIL = 5000 x 1000/ 1.196 x 15000 x V
A6	12 – 18	EIL = 5000 x 1000/ 0.511 x 15000 x V
A7	15 – 18	EIL = 5000 x 1000/ 0.118 x 15000 x V

*V is the price of tomato (Rs./ Kg)

The Economic Injury Level (EIL) is the most widely used decision making tool, specially in integrated pest management. There are no reports on economic injury levels of *T. urticae* on tomato. Park and Lee (2007) studied the Economic Injury Level for *T. urticae* on glasshouse cucumbers during four growing seasons based on one mite feeding and mite days.

EILs for tomato has been calculated based on the number of mites and mite days during different growth stages. Though calculations based on these two parameters yielded similar information, for predictive purpose, the number of mites is more useful since this can help in quick decision making. In fact, farmers are adopting the strategy of investing more on acaricides, if they anticipate good prices for the harvested fruits. However, this study was able to provide quantifiable decision making tools, using which the EIL can be fixed to enable the farmers to time their application of acaricides (Fig. 2).

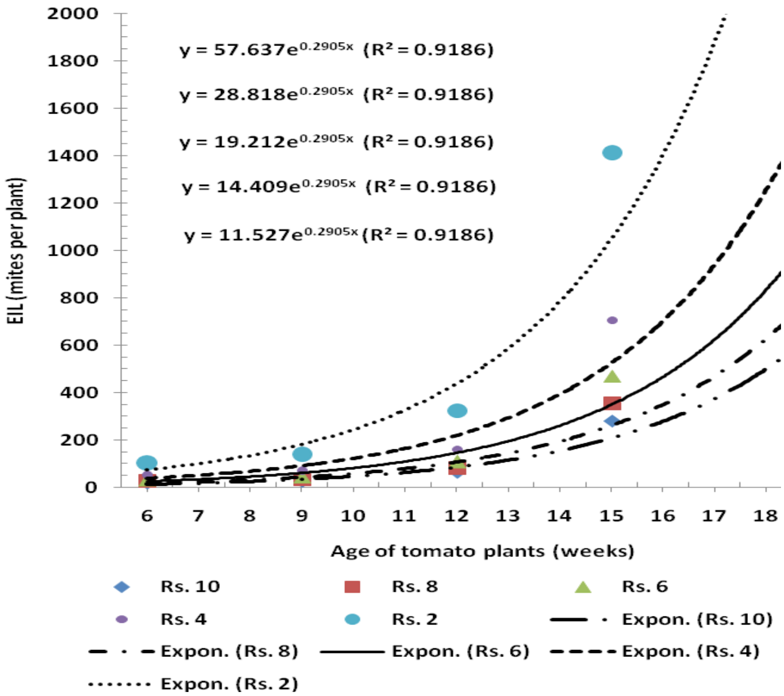

Fig. 2. **Predicted EILs for different age levels of tomato with different market prices of tomato. Each data point represents particular price of tomato (10, 8, 6, 4 and 2 Rs. / kg).**

CONCLUSIONS

Mite days (one mite feeding for a day) and number of mites per plant initially released were used to quantify the yield loss of tomato due to mite feeding. Middle stage of the tomato crop was the most critical period for mite damage and mite infestation, contributing to more than 50% of total yield loss due to severe damage to the leaves and reduction of chlorophyll content as well. Using yield loss per mite or mite day and considering other parameters such as cost of management and tomato prices, EIL values were estimated, for different growth stages of tomato with different feeding durations. The EIL values can be used as an effective decision making tool in spider mite management in each growth stage of the tomato crop.

ACKNOWLEDGEMENTS

The authors acknowledge the Department of Export Agriculture, Sri Lanka, University of Agricultural Sciences, GKVK, Bangalore, India, Indian Council for Agricultural Research and Council for Agricultural Research Policy, Colombo for providing opportunities, facilities and financial support for making this study a success.

REFERENCES

Anonymous (2003). Selected indicators of food and Agriculture development in Asia-Pacific region 1992 – 2002, RAP publication: 2003/10, FAO, Bangkok. [on line]. [Accessed on 16. 09. 2010]. http:/ www.fao.org/docrep/004/ad452e/ad452e00.htm#contents.

Anonymous (2004). Production Year Book 56. Food and Agriculture Organization, Rome, Italy, pp. 142-143.

Arnon, D. I. (1949). Copper enzymes in isolated chloroplasts: Polyphenoloxidase in *beta vulgaris*. Plant Physiol., 24*(1),* 1 - 15.

Avery, D. J. and Briggs, J. B. (1968). The etiology and development of damage in young fruit trees infested with fruit tree red spider mite, *Panonychus ulmi* (Koch). Ann. Appl. Biol*., 61*, 227-228.

Lange, W. H., and Bronson, L. (1981). Insect pests of tomatoes. Ann. Rev. Entomol., 26, 345 – 371.

Park, Y.L. and Lee, J. H. (2002). Leaf cell and tissue damage of cucumber caused by two spotted spider mite (Acari: Tetranychidae). J. Econ. Entomol. 95, 952–957.

Park, Y.L. and Lee, J. H. (2005). Impact of two spotted spider mite (Acari: Tetranychidae) on growth and productivity of glasshouse cucumbers. J. Econ. Entomol., 98, 457–463

Park, Y.L. and Lee, J.H. (2007). Seasonal dynamics of economic injury levels for *Tetranychus urticae* Koch (Acari: Tetranychidae) on *Cucumis sativus* L. J. Appl. Entomol., 131(8), 588 – 592

Pedigo, L. P. (2002). Entomology and Pest Management. 4th Ed. Prentice-Hall, Englewood Cliffs, NJ.

Perry, A. S., Yamamoto, I., Ishaya, I. and Perry, R. (1998). Insecticides in Agriculture and Environment – Retrospect and Prospects. Narosa Publishing House, New Delhi, India. p. 261.

Sances, F. V., Wyman, J.A. and Tinq, I. P. (1979). Physiological responses to spider mite infestations on strawberries. Environ. Entomol. 8, 711-714.

Sances, F. V., Wyman, J. A., Ting, I. P., Van Steenwyk, R. A. and Oatman, E. R. (1981). Spider mite interactions with photosynthesis, transpiration and productivity of strawberry. Environ. Entomol. 10, 442 – 448

SAS Institute (1989). Version 6.12. SAS institute Inc., Cary, NC.

Stacey, D. L., Wyatt, I. J. and Chambers. R. J. (1985). The effect of glasshouse red spider mite damage on the yield of tomatoes. J. Hort. Sci. 60, 517 - 523.

Wyman, J. A., Oatman, E. R. and Voth, V. (1979). Effects of varying two spotted spider mite infestation levels on strawberry yield. J. Econ. Entomol. 72, 747-753.