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Economic Injury level and yield loss assessment for carmine spider mite (*Tetranychus cinnabarinus* Boisduval) on tomato *Solanum lycopersicum* under greenhouse conditions

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A study was undertaken over two cropping seasons, 2018/2019 and 2019/2020, to determine the economic injury level for carmine spider mite, *Tetranychus cinnabarinus* (Boisduval) on tomato *Solanum lycopersicum* in Botswana. Tomato plants were infested with adult spider mites for durations of 0 (no exposure), 1, 2, 3, 4, 5, 6 and 7 weeks (complete exposure). The corresponding treatments were 7, 6, 5, 4, 3, 2, 1 and 0 sprays with Abamectin. The results showed a significant reduction in the number of spider mites per plant as the frequency of spraying increased. An inverse relationship between spider mite exposure and yield was also observed following three weeks exposure. Yield loss increased to more than 50% when the pesticide was not applied to control spider mites. Economic decision levels are fundamental components of cost effective IPM programs and can be effective tools for making decisions about the application of pesticides against carmine spider mite in Botswana.

Key words: Spider mite exposure, *Tetranychus cinnabarinus*, economic injury level, yield loss, *Solanum lycopersicum*.

INTRODUCTION

Tomato (*Solanum lycopersicum var. lycopersicum*) is one of the most commonly grown and economically important vegetable crops in Botswana (Madisa et al., 2010a) and is among the most widely consumed vegetables globally (Retta and Berhe, 2015, Ghaderi et al., 2019). It is a nutritionally well-balanced and dense food containing significant quantities of vitamin A and C, therefore, contributing enormously to food security and nutrition (FAO, 2020; Brasesco et al., 2019). Tomato is a valuable product for smallholder farmers and large-scale commercial producers, serving mainly as a commercial crop grown in both shade nets and open fields in many parts of Botswana.

At only 60 to 100 t ha^{-1} tomato production and productivity in Botswana is low when compared to other tomato producing countries in Africa (Badimo, 2000).

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Egypt is the leading producer of tomato in Africa at 7,297108 t, followed by Nigeria (4,100,000 t), Morocco (1,293,761 t), Tunisia (1,298,000 t), Cameroon (1,279,853 t), Algeria (1,286,286 t) and South Africa (608,306 t) (Dube et al., 2020). Among the many constraints to tomato production in Botswana, invertebrate pests are frequently cited as the most serious (Madisa et al., 2010a; Baliyan, 2012). These include the cutworm (*Agrotis* spp.), whitefly (*Bemisia tabaci*), African bollworm (*Helicoverpa armigera*), tomato semi-looper (*Chrysodeixis acuta*), tomato leaf miner (*Tuta absoluta*), and spider mites (Tetranychidae) (Bok et al., 2006; Munthali, 2009; Leungo et al., 2012). Tetranychid mites are a very important family of phytophagous mites worldwide (Cobanoglu et al., 2015). Two sibling species, the two-spotted spider mite (TSSM), *Tetranychus urticae* Koch and the carmine spider mite (CSM), *Tetranychus cinnabarinus* Boisduval are economically important agricultural pests that feed on various species of plants all around the world (Bi et al., 2016; Lu et al., 2018). The carmine spider mite (CSM) has been shown to be a serious pest of tomato plants in almost all production systems in Botswana (Bok et al., 2006; Obopile et al., 2008). CSM is documented among the most polyphagous plant pests feeding on over 1100 plant species, constituting more than 140 crops families (Grbić et al., 2011; Migeon and Dorkeld, 2006). Its adults and juveniles typically feed on the lower side of the leaves by inserting their stylets and sucking cell contents thereby damaging protective leaf surface, palisade layers and causing yellowing and curling of the leaves (Kaimal and Ramani, 2011). CSM spin thick webs that cover foliage (Picture 1A-B) thereby impeding photosynthetic ability and transpiration of host plants. Heavy spider mite infestations, as seen in Picture 1A-B, result in stunted growth; delay in flowering and fruit set, and in severe cases, death of the plant (Kaimal and Ramani, 2011).

In Botswana, the majority of farmers depend on pesticides to control a medley of invertebrate pests affecting their crops (Madisa et al., 2010a) and the decision to apply is mainly upon the sight of the pest on the crop (Munthali et al., 2004). The ease and speed of control provided by pesticides have promoted their widespread use, which is often followed by numerous complications including development of resistance, toxic effects on animals, humans and beneficial fauna (Pimentel, 2009; Roditakis et al., 2017). Moreover, spider mites have been documented to rapidly develop resistance to almost all pesticides used for their control (Van Leeuwen et al., 2010; Grbić et al., 2011; Dermauw et al., 2013; Bu et al., 2015). Large volumes of active ingredients are repeatedly applied to crops thereby, in addition to environmental damage and human health hazards, increasing the cost of production to the farmer. Therefore, the effective use of pesticides requires that they be applied only when economic loss occurs to minimize the cost to the farmer and the effect on beneficial fauna and the environment (Obopile, 2006). Pest management should, therefore, be based on proper economic decision making to ensure that appropriate quantities of pesticides are applied to control pests and avoid unnecessary wastage (Ghaderi et al., 2019). Determining the economic injury level (EIL) is one of the fundamentals to development of an integrated pest management (IPM) program (Pedigo et al., 1986; Higley and Pedigo, 1993).

Considering the seriousness of the spider mite problem in Botswana, it is necessary to carry out studies to determine yield loss due to CSM and develop economic injury levels for this pest under local conditions. This will help farmers to minimize the use of pesticides since they will only be applied when necessary. Despite its importance, little or no research studies have been carried out on the estimation of EIL for spider mites in Botswana. This study was conducted to determine the relationship between tomato infestation and yield loss due to CSM and consequently establish the EIL for CSM so that application can be economically justified.

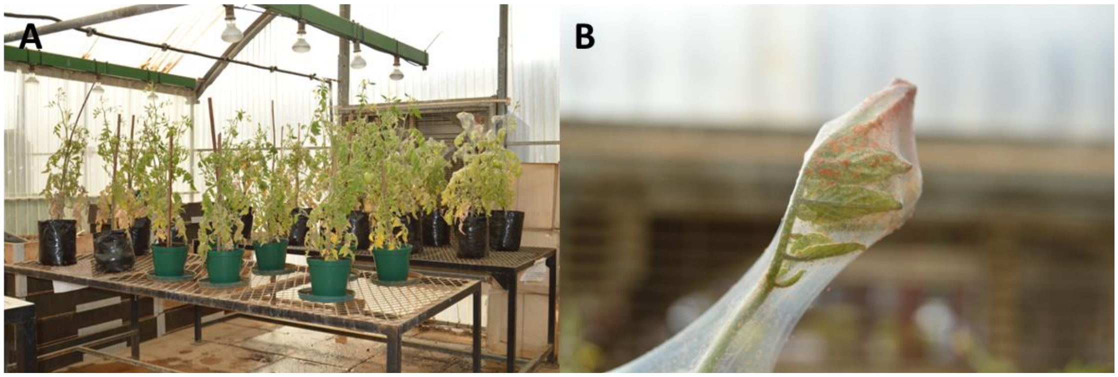
MATERIALS AND METHODS

The study was carried out in a greenhouse at the Botswana University of Agriculture and Natural Resources (BUAN) in Gaborone, Botswana (24°34'25" S, 25°95'0" E) at 30 ± 5°C. The experiment was laid out in a randomized complete block design with 4 replicates. Each replicate consisted of 8 tomato plants. Tomato seedlings (var. Rodade) initially sown in seedling trays were transplanted into plastic pots (12 cm wide and 15 cm deep) filled with 1.5 kg garden soil mixed with potting soil and left to establish for a week before the commencing of the experiment. The pots were watered *ad-lib* and no fertilizer was added. The pots were kept free of weeds by manual weeding. The CSM colony used in this study was obtained from a commercial tomato producing farm in Metsimotlhabe just outside of Gaborone, identified using taxonomic keys in the crop protection laboratory at BUAN and then reared in the greenhouse. Tomato seedlings were used to rear CSM and provide adequate plant material for reproduction.

At the beginning of the experiment, each seedling was infested with four to six female spider mites using a fine brush. Seedlings were exposed to feeding by CSM for duration of 0 (no exposure), 1, 2, 3, 4, 5 and 6 weeks and complete exposure (unsprayed control) following the procedure of Singh and Sachan (1997) and Obopile (2006). The corresponding treatments consisted of sequential applications of Agromectin (abamectin 18 g/L emulsifiable concentrate, Arysta Lifescience, South Africa) at 6, 5, 4, 3, 2, 1 and 0 sprays at 1.2 L ha^{-1}. A fines sprayer with a relatively narrow range of droplet size was used for applying treatment solutions. Each pot was labelled showing the date of spraying and treatment level.

Data collection

CSM population counts were conducted a day before each spray application on all plants per replicate. During harvest, all tomatoes from all treatments were weighed and yield data recorded. Fresh weight of tomatoes from each pot was expressed as yield in tonnes ha^{-1}. Data sets were transformed to stabilize the variance before analysis. Yield data were transformed to square root and percentage infestation subjected to arcsine transformation (Sokal and Rohlf, 1995), and spider mite counts to log (X+1) (Mosweu et al., 2015). Yield data and number of spider mites per plant in a treatment were used to calculate the linear regression:



Picture 1. A greenhouse experiment; (**A)** tomato plants under heavy infestation by spider mites. (**B)** Tomato leaves covered by heavy spider mite webbing.

$$Y = a - bx$$

Where Y = potential yield, a = expected yield loss at zero level of infestation, b = regression coefficient or yield loss in tonnes ha^{-1} caused by one mite per plant, and x = number of mites per plant.

The economic injury levels for CSM were determined based on estimation of the gain-threshold (GT), defined in terms of tonnes ha^{-1} as suggested by Pedigo (2004).

Gain threshold was calculated for each treatment using the equation:

$$\text{Gain threshold (GT)} = \frac{\text{Cost of protection (BWP/ha)}}{\text{Market value (BWP.tonne/ha)}}$$

The market price of Tomato in Botswana ranged from BWP 9,000 per tonne in 2018/19 to BWP 13,000 per tonne in 2019/20. The cost of insecticide applied by knapsack sprayer was on average BWP 780 per hectare for both 2018/19 and 2019/20 cropping seasons.

$$\text{Economic injury level (EIL)} = \frac{\text{Gain threshold } \left(\frac{\text{BWP}}{\text{ha}}\right)}{\text{b (regression coefficient)}}$$

Statistical analyses were performed using the SAS statistical software (version 9.4, SAS Institute, Cary, USA). Tukey's honestly significant difference test (Zar, 1984) was used to separate means.

RESULTS

Effect of exposure period and spray frequency on CSM population

During the 2018/19 season the number of CSM per plant varied significantly between exposure period and number of insecticide sprays ($F_{42, 165} = 20.18$; $P<0.0001$). The results in Table 1 revealed a significant reduction in spider mite population per plant as the frequency of spraying increased. The mean number of spider mites ranged from 0 where there was no exposure to 1134 where there was full exposure. Yield varied significantly among the exposure periods and also between the numbers of sprays. The mean yield ranged from 5.19 t ha^{-1} where there was full exposure to 7.32 tonnes ha^{-1} where there was no exposure. The yield infestation regression equation was obtained as Y = -0.0013x + 6.2531 (Figure 1A). Regression analysis showed an inverse relationship between spider mite exposure and yield (Figure 2A). The gain threshold (GT), economic injury levels (EIL) for CSM in respect of the different treatment modules are depicted in Table 1. The GT was computed on the basis of market price for tomato at BWP 9000 ha^{-1} and increased significantly with the number of spraying and ranged from 0.087 for one spray to 0.606 for 7 sprays. The EIL values ranged from as low as 66.92 for 1 spray to 466.15 for 7 sprays. There was also a direct relationship between the costs of protection, the gain threshold and economic injury level (Figures 3A and 4A). An increase in spray frequency resulted in cost of protection ranging from BWP 780.00 for one spray to BWP 5,460.00 in a period of 7 weeks.

During the 2019/20 season, the results revealed a significant reduction in CSM population per plant as the frequency of spraying increased (Table 1) ($F_{42, 165} = 64.90$; $P<0.0001$). The mean number of spider mites ranged from 0 where there was no exposure to 1188 where there was full exposure. Yield varied significantly among the exposure periods and also between the number of sprays and ranged from 4.32 t ha^{-1} where there was full exposure to 6.93 t ha^{-1} where there was no exposure (Table 1). Regression analysis showed an inverse relationship between spider mite exposure and yield (Figure 2B) and the yield infestation regression equation was obtained as Y = -0.0011x + 5.2316 (Figure 1B). The gain threshold (GT) computed on the basis of market price for tomato at BWP 13,000 ha^{-1} increased significantly with the number of spraying and ranged from 0.060 for one spray to 0.420 for 7 sprays (no exposure). The corresponding values of EIL ranged from as low as 54.55 for 1 spray to 381.82 for 7 sprays (no exposure) (Table 1). There was also a direct relationship between the costs of protection, the gain threshold and economic injury level (Figure 3B and 4B). An increase in spray frequency also resulted in cost of protection from BWP

Table 1. Infestation, yield and economic injury level for CSM on tomato at different durations of exposure.

Mite exposure (weeks)	No. of sprays	Number of spider mites		Yield (tonnes ha^{-1})		Cost of protection (BWP/ha)	Gain threshold (GT)		Economic injury level (EIL)	
		2018/19	2019/20	2018/19	2019/20		2018/19	2019/20	2018/19	2019/20
Full exposure	0	1134.00±41.86^{a}	1188.00±49.30^{a}	5.19^{bc}	4.32^{cd}	-	-	-	-	-
6	1	381.25±141.86^{b}	621.00±88.94^{b}	5.10^{bc}	4.26^{cd}	780.00	0.087	0.060	66.92	54.55
5	2	192.75±55.61^{bc}	292.50±85.50^{c}	4.98^{c}	4.14^{cd}	1,560.00	0.173	0.120	133.08	109.09
4	3	114.50±19.39^{c}	220.50±59.87^{cd}	4.86^{c}	4.05^{cd}	2,340.00	0.260	0.180	200.00	163.64
3	4	79.00±12.56^{c}	139.50±38.45^{cd}	6.33^{ab}	5.28^{bc}	3,120.00	0.347	0.240	266.92	218.18
2	5	12.00±12.00^{c}	112.50±22.50^{cd}	7.17^{a}	5.97^{ab}	3,900.00	0.433	0.300	333.08	272.73
1	6	0.00±0.00^{c}	54.00±19.44^{d}	4.71^{c}	3.93^{d}	4,600.00	0.511	0.354	393.08	321.82
0	7	0.00±0.00^{c}	27.00±11.62^{d}	7.32^{a}	6.93^{a}	5,460.00	0.606	0.420	466.15	381.82

** Means followed by the same letter within a column are not significantly different ($P \leq 0.05$, Tukey).
Source: Authors

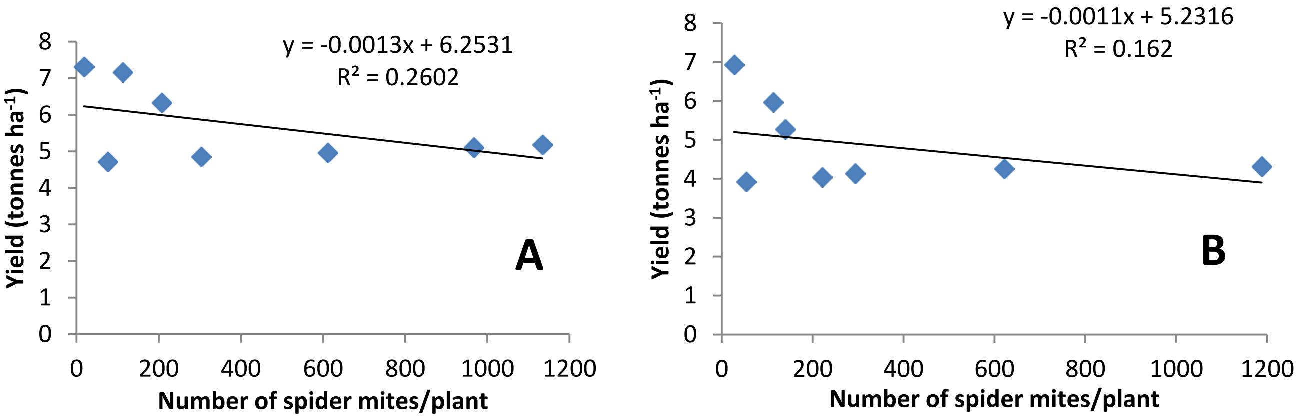


Figure 1. Relationship between rate of infestation and tomato yield during 2018/2019 (A) and 2019/2020 (B) seasons).
Source: Authors

780.00 for one spray to BWP 5,460.00 in a period of 7 weeks.

Table 2 shows the effect of exposure period and spray frequency on CSM population density recorded at weekly intervals during the 2018/19 growing season. The study revealed that exposure period and spray frequency interactions were significantly different ($F_{42, 165}$ = 20.18: P = 0.0001). When assessments were done at 7 weeks the following observations were made; the highest spider mite population of 1134 was found in treatments exposed to full exposure (0 sprays) and was significantly different from spider mite population level of 381.25 found following 6 weeks exposure (1 spray) (Tukey, $P \leq 0.005$). The spider mite population of 79.00 found following 3 weeks exposure (4 sprays) was not significantly different from 0.00 population found with 1 week exposure

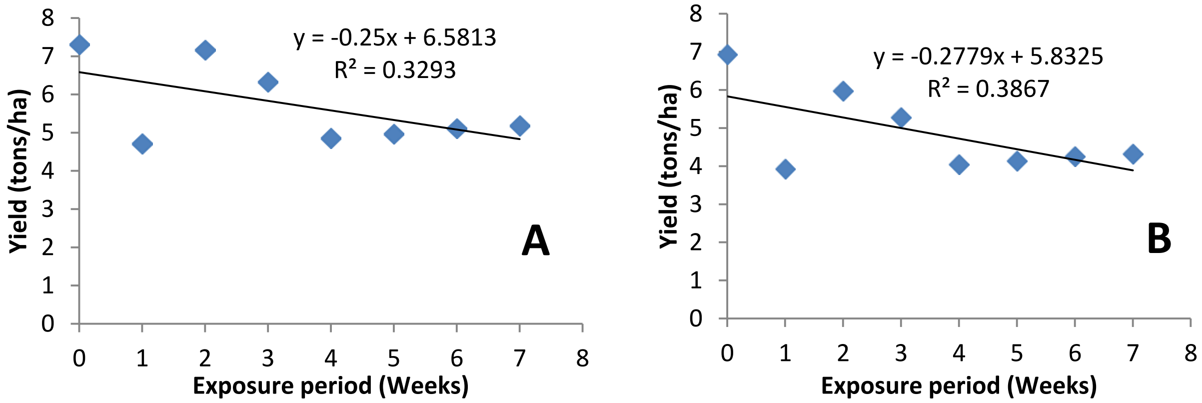


Figure 2. Relationship between CSM exposure period and yield of tomato assessed during the 2018/2019 (A) and 2019/2020 (B) seasons.
Source: Authors

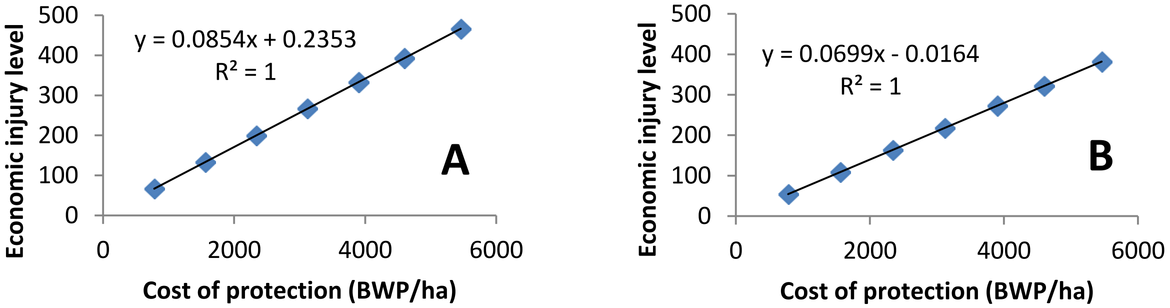


Figure 3. Relationship between cost of protection and Economic injury level assessed during 2018/19 (A) and 2019/20 (B) seasons.
Source: Authors

(6 sprays) and 0 weeks exposure (7 sprays) ($F_{42,165}$ = 20.18: P = 0.0001). When assessments were made at 6 weeks the following observations were made; spider mite population was 1034.50 which was similar to population of 1028.50 attained following 6 weeks exposure (1 spray) but significantly different from spider mite population (170.50) following 5 weeks exposure (Tukey, P ≤ 0.005). When assessment was done at 4 weeks; the highest spider mite population (782.00) was found at full exposure (no spray) and was not significantly different from 769.50, 767.50 and 700.25 spider mite populations following 6 (1 spray), 5 (2 sprays) and 4 weeks (3 sprays) exposure respectively (Table 2). The lowest population was 0.00 which was not significantly different from spider mite population of 41.50 and 12.00 achieved with 2 (5 sprays) and 1 week (6 sprays) exposure respectively during the assessment period.

Table 3 shows the effect of exposure period and spray frequency on CSM population density assessed at weekly intervals during the 2019/20 growing season. The results show that exposure period and spray frequency interactions were significantly different ($F_{42,\ 165}$ = 64.90: P = 0.0001). When assessments were done after 7 weeks the following observations were made; the highest spider mite population (1188) was found in treatments exposed to full exposure (0 sprays) and was significantly different from spider mite population level of 621 found following 6 weeks' exposure (1 spray) (Tukey, P ≤ 0.005). The spider mite population of 220.50 found following 4 weeks' exposure (3 sprays) was not significantly different from 139.50 and 112.50 found with 3 (4 sprays) and 2 weeks (5 sprays) exposure respectively ($F_{42,165}$ = 64.90: P = 0.0001). When assessments were made at 6 weeks the following observations were made; the highest spider mite population (1111.50) was found at full spider mite exposure (no spray) and was not significantly different from spider mite population (1125) following 6 weeks' exposure. The lowest population density was 0.00 was attained following 0 weeks exposure (7 sprays) and was not significantly different from spider mite population following 2 (5 sprays) and 1(6 sprays) week exposure during the same assessment period (Tukey, P ≤ 0.005).

Table 2. Effect of exposure period and spray frequency on CSM population per plant (2018/2019 season) ($F_{42, 165}$ = 20.18; P = 0.0001).

Exposure	Means ± SE							
	sprays	**Wk1**	**Wk2**	**Wk3**	**Wk4**	**Wk5**	**Wk6**	**Wk7**
Full	0	232.50^{eA}±40.77	408.25^{deA}±76.14	552.75^{cdAB}±56.32	782.00^{bcA}±70.26	944.25^{abA}±29.69	1034.50^{aA}±29.72	1134.00^{aA}±41.86
6	1	191.75^{dA}±35.69	375.75^{cdA}±81.16	649.50^{bcA}±25.08	769.50^{abA}±13.43	912.50^{aA}±42.24	1028.50^{aA}±54.55	381.25^{cdB}±141.86
5	2	210.75^{bA}±7.89	378.75^{abA}±23.13	551.00^{abAB}±30.76	767.50^{aA}±31.63	755.25^{aA}±229.52	170.50^{bB}±10.60	192.75^{bBC}±55.61
4	3	194.50^{dA}±14.27	345.00^{cA}±31.77	566.75^{bAB}±31.33	700.25^{aA}±39.27	144.50^{dB}±18.57	124.75^{dBC}±16.26	114.50^{dC}±19.39
3	4	149.00^{bcdA}±16.90	233.25^{bAB}±23.14	472.00^{aB}±24.17	202.75^{bcB}±25.72	119.75^{cdB}±21.00	77.50^{dBCD}±29.71	79.00^{dC}±12.56
2	5	181.00^{bA}±15.74	301.75^{aA}±36.94	70.00^{cC}±7.07	41.50^{cC}±15.46	31.00^{cB}±16.49	24.75^{cCD}±14.81	12.00^{cC}±12.00
1	6	171.00^{aA}±1.79	60.50^{bBC}±5.72	27.00^{cC}±10.60	12.00^{cdC}±5.61	5.00^{cdB}±5.00	5.00^{cdD}±5.00	0.00^{dC}±0.00
0	7	105.00^{aA}±57.82	1.50^{bC}±1.50	0.00^{bC}±0.00	0.00^{bC}±0.00	0.00^{bB}±0.00	0.00^{bD}±0.00	0.00^{bC}±0.00

**Means followed by the same small letter within a row are not significantly different ($P \leq 0.05$, Tukey). **Means followed by the same capital letter within a column are not significantly different ($P \leq 0.05$, Tukey).
Source: Authors

Table 3. Effect of exposure period and spray frequency on CSM population per plant (2019/2020 season) ($F_{42, 165}$ = 64.90; P = 0.0001).

Exposure	Sprays	Means ± SE						
		Wk1	**Wk2**	**Wk3**	**Wk4**	**Wk5**	**Wk6**	**Wk7**
Full	0	256.50^{eA}±59.87	396.00^{deA}±64.06	540.00^{dBC}±12.73	900.00^{cAB}±12.73	1008.00^{bcA}±41.57	1111.50^{aA}±22.50	1188.00^{aA}±49.30
6	1	198.00^{cAB}±18.00	297.00^{cAB}±15.59	702.00^{bA}±55.48	936.00^{aA}±72.75	1044.00^{aA}±36.00	1125.00^{aA}±18.74	621.00^{bB}±88.94
5	2	216.00^{deAB}±12.73	373.50^{dA}±25.85	558.00^{cBC}±25.46	760.25^{bBC}±28.57	1003.00^{aA}±26.88	184.50^{eB}±4.50	292.50^{deC}±85.50
4	3	220.50^{bcAB}±18.55	337.50^{bAB}±18.55	616.50^{aAB}±11.33	693.00^{aC}±9.00	180.00^{cB}±12.73	130.50^{cC}±4.50	220.50^{bcCD}±59.87
3	4	144.25^{bcdAB}±12.85	225.00^{bcBC}±21.42	508.50^{aC}±19.96	234.00^{bD}±14.70	130.50^{cdB}±8.62	63.00^{dD}±9.00	139.50^{bcdCD}±38.45
2	5	202.50^{bAB}±22.50	355.50^{aAB}±4.50	67.50^{cdD}±8.62	18.00^{deE}±10.39	9.00^{deC}±9.00	0.00^{eE}±0.00	112.50^{cCD}±22.50
1	6	207.00^{aAB}±27.00	90.00^{bCD}±0.00	40.50^{bcD}±4.50	45.00^{bcE}±9.00	18.00^{cC}±12.73	4.50^{cE}±4.50	54.00^{bcD}±19.44
0	7	108.00^{aB}±36.00	0.00^{bD}±0.00	0.00^{bD}±0.00	0.00^{bE}±0.00	0.00^{bC}±0.00	0.00^{bE}±0.00	27.00^{bD}±11.62

**Means followed by the same small letter within a row are not significantly different ($P \leq 0.05$, Tukey). **Means followed by the same capital letter within a column are not significantly different ($P \leq 0.05$, Tukey).
Source: Authors

When assessment was done at 4 weeks; the spider mite population was 900.00 at full exposure (no spray) which was not significantly different from 936.00 spider mite population following 6 (1 spray) (Table 3). The lowest spider mite population was 0.00 was not significantly different from 18.00 and 45.00 spider mite populations found following 2 (sprays) and 1 (6 sprays) weeks exposure.

Figures 1A and B show the yield versus spider mite infestation relationships for the 2018/19 (1A) and 2019/20 (1B) growing seasons. The figures reveal a negative relationship between spider mite infestation and tomato yield (correlation coefficients of 0.26 and 0.162 respectively) and gave yield infestation relationship regression equations of Y = -0.0013x + 6.2531 and Y = 0.0011x + 5.2316 respectively. Figure 1A shows that during 2018/19 season, at infestation rates of

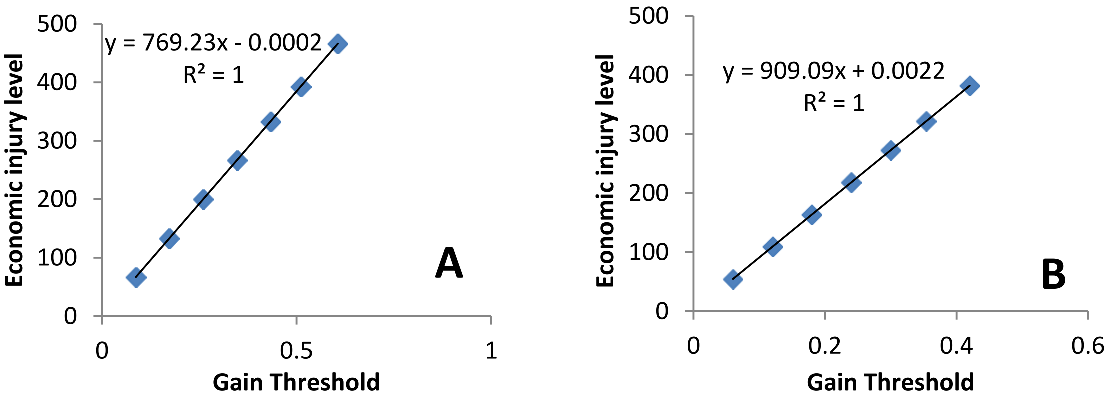


Figure 4. Relationship between gain threshold and economic injury level assessed during 2018/19 (A) and 2019/20 (B) seasons.
Source: Authors

0, 12, 79, 114.5 and 1134 spider mites per plant, average yields of 7.32, 7.17, 6.33, 4.86 and 5.19 t ha^{-1} respectively were attained. During the 2019/20 season, infestation rates of 27, 112.5, 139.5, 220.5 0, 12, 79, 114.5 and 1134 spider mites per plant, average yields of 7.32, 7.17, 6.33, 4.86 and 5.19 t ha^{-1} respectively were attained. During the 2019/20 season, infestation rates of 27, 112.5, 139.5, 220.5 and 1188 spider mites per plant gave average yields of 6.93, 5.97, 5.28, 4.05 and 4.32 t ha^{-1} respectively. There was a significant reduction in yield as the number of spider mites increased during both seasons.

Figures 2A and B reveal a negative relationship between spider mite exposure (weeks) and tomato yield when assessments were done during the 2018/19 and 2019/20 seasons (correlation coefficients of 0.2602 and 0.162 respectively). These figures show that yields of 7.32, 4.71, 6.33, 4.98 and 5.19 t ha^{-1} were achieved following spider mite exposure periods of 0, 1, 3, 5 and 7 weeks during the 2018/19 season while yields of 6.93, 3.93, 5.28, 4.14 and 4.32 t ha^{-1} were achieved during the 2019/20 season following the same exposure periods.

DISCUSSION

Farmers invest in crop protection to prevent and control crop losses due to pests both in the field and in storage (Oerke, 2016). The present paper focuses on pre-harvest losses, that is, the effect of CSM on crop production in the field, and the effectiveness of control measures applied by farmers to reduce losses to an acceptable level. Collection of yield loss data is vital for economic management of pests and for evaluating the efficacy of the current crop protection practices. Based on these data, strategies for the use of limited resources may be developed in order to optimize productivity (Nutter et al., 1993; Cooke, 1998).

In this study, tomato yield per hectare decreased as spider mite populations increased and ranged from 5.19 at the lowest spider mite population to 7.32 tonnes ha^{-1} at the highest population during the 2018/19 and from 4.32 tonnes ha^{-1} at the lowest spider mite population to 6.93 tonnes ha^{-1} at the highest spider mite population in 2019/20. The present findings are in line with those of earlier studies that found that yield reduction caused to tomato plants by spider mites can be correlated to spider mite population densities. Fadini et al. (2004) and Kalmosh (2016) observed that the injury caused by the two-spotted spider mite results from puncture of the lower epidermis cells. High infestations of spider mites have been reported to reduce the rate of photosynthesis and also damage the leaf mesophyll and cause the stomata to close. This reduces the ability of the leaves to manufacture sufficient food for desired development of the fruit (Fathipour and Maleknia, 2016). According to the study by Ghaderi et al. (2019) on tomato leaf miner, the average number of fruits per tomato plant could be influenced by the percentage leaf damage inflicted on the plant.

The gain threshold increased with frequency of spraying, ranging from 0.087 to 0.606 in 2018/19 and 0.060 to 0.420 in 2019/20. However, an increase in spraying frequency resulted in an increase in cost of protection from BWP 780 to BWP 5, 460 in both 2018/19 and 2019/20 seasons. The results indicate that the application of pesticide at lower pest population will have less gain threshold and, therefore, be uneconomical (Table 1). The cost of protection and gain threshold were directly related (Figures 3 and 4). An increase in spray frequency reduced the level of exposure of host plants to spider mites by reducing their densities. Maximum possible yield loss was observed when complete exposure to spider mite feeding was allowed. The results also reveal that regardless of how high spider mite populations reached, the tomato plants were still able to produce minimum yield levels. Similar results were observed by other studies on spider mites (Padilha et al., 2020). Suekane et al. (2012) working with two spotted spider mite, TSSM observed reduction in yield as spider mite exposure increased.

CONCLUSION AND RECOMMENDATION

This study shows that the determination of economic injury level and economic threshold levels for timely control of CSM under greenhouse conditions in Botswana is better than the most common current practice of pesticide applications under similar conditions. For tomato growers in Botswana producing tomatoes under greenhouse conditions, these results suggest that initiation control measures three to four weeks after appearance of CSM can reduce economic losses associated with the spider mites on tomato. During this period, high yield losses were observed suggesting the most economical time to apply the pesticide. Pedigo and Rice (2006) recommended the economic threshold (ET) to be 75% of the EIL, therefore between 136 and 182 spider mites per plant would necessitate control actions, every three to four weeks. Since the EIL is dependent on changes in market price of tomato, cost of pest management, pest injury inflicted on the plant by the pest, and susceptibility of the host plant to spider mite injury, this recommendation is expected to change depending on location and time. There is also need to develop EILs based on different growth stages of the tomato plant and under field conditions.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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