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Estimation of Avoidable Yield loss in Maize *Zea mays* L. caused by the fall armyworm *Spodoptera frugiperda* (JE Smith) (Noctuidae: Lepidoptera)

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ABSTRACT

Invasive fall armyworm *Spodoptera frugiperda* (JE Smith) (Noctuidae: Lepidoptera) has the potential to cause 70 – 80 per cent yield loss in maize. Field experiments to assess the avoidable yield loss due to invasive fall armyworm *S. frugiperda* (Noctuidae: Lepidoptera) was conducted across four major maize growing zones in Tamil Nadu, India. The treatments Complete Protection (T1), Window based insecticide application as per Tamil Nadu Agricultural University (TNAU) Integrated Pest Management capsule (T2) and Untreated Control (T3) were imposed in four maize zones of Tamil Nadu during 2020 - 21. In complete protection (T1) the recommended insecticides were applied as and when the incidence was noticed. Insecticides recommended for different widows *viz.,* Azadirachtin 1% EC @ 2 ml/lt. or Emamectin benzoate 5% SG @ 200 g ai/ ha for first window (15 – 20 days) and Spinetoram 11.7% w/w SC @ 30 g a.i/ha or Chlorantraniliprole 18.5% SC @ 40 g a.i/ha or Novaluron 10EC @ 100g a.i./ha were applied in the window based application (T2). The average avoidable yield loss for complete protection (T1) and window-based application (T2) was in the order Coimbatore > Madurai > Tirunelveli > Tiruchirappalli. The average avoidable yield loss in complete protection (T1) and window based application (T2) was 2600.25 and 2307.87 kgs/ha respectively. The number of insecticide sprays required to keep the fall armyworm population under control was ranged between 3 to 4, in complete protection (T1) whereas in window-based application (T2) two sprays were given. The average difference in avoidable yield loss between window based (T2) and complete protection (T1) was 292.38kgs/ha. Both complete protection (T1) and window-based application (T2) recorded same benefit cost ratio of 1.65 and average per hectare plant protection cost of Rs.11000/- and Rs.5413/- respectively. The timely interventions at critical stages of maize growth will check the fall

armyworm population from causing any economic damage to the maize. The crop care at critical stages will be the ideal strategy for the fall armyworm management.

Key words: *Avoidable yield loss, Complete protection, Spodoptera frugiperda, Window based application*

Introduction

Maize is the most important crop in the world after wheat and rice and grown in more than 70 countries (Chouraddi *et al*., 2017). The United States of America, China, Brazil, Mexico and India contribute to 4/5th of the worlds maize production. Maize production is constantly increasing because of rising demand from the industries. In India maize production has increased from 17.8 million tons in 1950 to 29 million tons in 2018-19 with a corresponding increase in area. The developments of new hybrids and management practices have contributed to the continuous increase in the productivity and production of maize. However biotic and abiotic factors hinder the attainment of the potential yield in India. About 250 insect species are reported to cause damage to the maize and among these *Chilo partellus* Swinhoe, *Sesamia inferens* Walker and shoot fly *Atherigona* spp. Rondani are important. The new threat to maize cultivation among the above insect pests is the incidence of the invasive fall armyworm (FAW), *Spodoptera frugiperda* (JE Smith).

The American origin polyphagous fall armyworm *S. frugiperda* infests over 350 commercial and non-commercial host plants across 76 families (Montezano *et al*., 2018). The incidence of FAW in West Africa was first noticed in 2016 (Goergen *et al*., 2016) and in India during 2018 (Deshmukh and Kalleshwaraswamy, 2018; Sharanabasappa *et al*., 2018). The young maize leaves or tender shoots are preferred by the FAW for egg laying. The incidence of fall armyworm in Tamil Nadu was noticed in 2018; since then its presence has been felt in all maize growing regions of the state because of its strong damage potential in maize. Apart from maize, the pest has been recorded in sorghum, pearl millet, barnyard millet, groundnut, cotton and some of the weed hosts. The freshly hatched larvae move vertically within the plant and horizontally to the adjacent plants. High dispersal ability of moths favours wide geographical dispersion. The direct and indirect yield loss and quality, cost of management, and impact on trade are some of the effects of FAW on agricultural crops.

Different management strategies are used against invasive insect pests for their effective management in the introduced area. The gregarious neonate and early stages of fall armyworm are comparatively easy to manage than the later instars which mostly feed inside the whorl and tassel (Hardeke *et al*., 2011). The assessment of yield loss due to the invasive pest is a prerequisite for making management decisions. This is the primary factor based on which modules for insect pest management have to be designed (Kumar *et al*., 2018). According to Overton *et al*. (2021) relatively less data on yield loss due to fall army worm in maize have been reported in Asia compared to Africa. Many African studies derive the fall army worm yield loss in maize and other crops based on the survey details collected from the farmers and extension officials. Yield loss estimation for particular pest through survey methods depend on many variables *viz.,* hybrid, soil, agronomic practices, weather conditions, number of survey undertaken during critical stages etc.

The avoidable yield loss derived from field experiments will give clear insight about the influence of target pests on the productivity of a particular crop. Analytical or paired plant, artificial infestation, use of chemical insecticides to obtain differences in infestation, simulation of insect damage and use of insect resistant or susceptible cultivars are the methods used for estimation of yield loss due to insect pests (Ampofo, 1988). The use of insecticides to obtain infestation difference is the most commonly used method to enumerate the avoidable yield loss in crops. The insecticide application at critical stage of crop growth and fall armyworm larval stage determines the effectiveness (Sisay *et al*., 2019). The present study was on to estimate the avoidable yield loss in maize due to FAW infestation across different maize growing regions of Tamil Nadu and this information is a prerequisite in making timely decisions on management options.

Materials and Methods

The field experiments to estimate the avoidable yield loss in maize due to FAW infestation were conducted in different maize growing regions of Tamil Nadu *viz.*, Coimbatore (Western Zone), Triuchirappalli (Cauvery Delta zone), Madurai and Tirunelveli (Southern zone) during 2020 – 21 *kharif* and *rabi* seasons. Based on the region, the experiments were conducted either in *kharif* (June – September) or *rabi* (October – January) or in both the seasons to account for the possible differences in infestation level, influence of weather parameters, types of hybrids and response of plants to the fall armyworm damage. The details of the experiments conducted at different centres are given in Table 1.

In Coimbatore location the experiments were conducted both in *kharif* and *rabi* seasons as the maize cultivation has been carried out in both seasons. In other areas the majority of maize cultivation is being carried out during *kharif* season and hence the experiments were conducted in *kharif* with two popular hybrids of that region which was decided in discussion with progressive farmers of that region. The land preparation and basal application of fertilizers were carried out as per the Tamil Nadu Agricultural University standard agronomic practices (TNAU Agritech portal, 2021). The plant to plant spacing of 25 cm and row to row spacing of 60 cm was adopted for the hybrids. Plot size of 40^2 was used for each treatment. In between the treatment plots one vacant row space was maintained in order to avoid any spray drift of insecticides between different treatments. Further, during spraying operation a long cloth stretched upon a wooden frame was positioned such that drift to adjacent plot was avoided. The spraying of insecticides was done using a battery operated knapsack sprayer and recommended volume of spray fluid of 500 liters per hectare was used. Three different treatments were imposed in the experimental plots and replicated three times. The details of the treatments are furnished Table 2.

The FAW damage was recorded at weekly interval duly following TNAU revised scoring system (Srinivasan *et al*., 2021). In addition to the FAW damage score, the percentage damage was also recorded to get a clear insight about the extent and distribution of damage in different treatments. Based on the FAW damage enumerated using TNAU revised scoring and percentage FAW incidence in 20 randomly selected plants at weekly intervals, the insecticide spraying was done in the treatment (T1) and continued. The insecticides rec-

Table 1. Details of experimental fields at different maize growing regions of Tamil Nadu

Location	Location of the experiment	Geo coordinates	Season	Name of the hybrid	Soil type	Plot size
Agricultural College & Research Institute, Coimbatore	Research Farm (Eastern Block), Tamil Nadu Agricultural University, Coimbatore	11.0086 N: 76.9404 E	*Kharif* & *Rabi*	Co (HM) 8	Clay loam	8 x 5 m
Anbil Dharmalingam College of Agriculture & Research Institute, Triuchirappalli	Cotton Research Station, Veppanthattai, Perambalur	11.3515 N: 78.8051 E	*Kharif*	Experiment 1: Pioneer 3401 Experiment 2: NK 6668	Black cotton soil	8 x 5 m
Agricultural College & Research Institute, Madurai	Research Farm, Agricultural College & Research Institute, Madurai	9.9737 N: 78.2088 E	*Kharif*	Experiment 1: Pioneer 3302 Experiment 2: DMH 8255	Clay loam	8 x 5 m
Agricultural College & Research Institute, Tirunelveli	Sangathakurichi, Karungulam Block, Thoothukudi district	8.7922 N; 77.7969 E	*Kharif*	Experiment 1: DKC 9133 Experiment 2: DMH 8255	Sandy loam	8 x 5 m

Table 2. Treatment details

T1: Complete Protection (Recommended insecticide as per existing practice applied as and when FAW incidence is noticed)
- First spray: Emamectin benzoate 5 SG @ 200 g a.i./ha
- Second spray: Chlorantraniliprole 18.5% SC @ 40 g a.i/ha
- Third spray: Spinetoram 11.7% w/w SC @ 30 g a.i/ha or Novaluron 10EC @ 100g a.i./ha
- Based on the need the insecticides used in the second and third spray have been used repeatedly to manage the FAW infestation in the treatment plots.

T2: Window based application of insecticides as per Tamil Nadu Agricultural University Integrated Pest Management capsule
- First window (15 – 25 days after emergence) : Azadirachtin 1% EC @ 2 ml/lt or Emamectin benzoate 5% SG @ 200 g ai/ ha
- Second window (40 – 45 DAE): Spinetoram 11.7% w/w SC @ 30 g a.i/ha or Chlorantraniliprole 18.5% SC @ 40 g a.i/ha or or Novaluron 10EC @ 100g a.i./ha
- Based on the need a third spray was given during cob formation from the insecticides recommended for second window.

T3: Untreated control
No insecticide spray

ommended in the window - based application (TNAU *ad hoc* management practices) have been followed in the treatment (T2). The incidence of other insect pests *viz*., stem borer *Chilo partellus* and *Rhopalosiphum maidis* were also recorded at weekly intervals. The crop was harvested at physiological maturity and the grain yield in plots replication wise was recorded. Based on the plot yield for each treatment, per hectare yield was worked out after deducting the moisture content in the cob. The avoidable yield loss in maize due to fall armyworm infestation was worked out as described by Pradhan 1964.

$$\text{Avoidable yield loss (\%)} = \frac{\text{(Yield of grain in kg in protected plots – Yield of grain in kg in unprotected plots)}}{\text{Yield of grain in kg in protected plots}} \times 100$$

The data pertaining to fall armyworm damage were subjected to statistical analysis using SPSS 16.0 software. Fishers least significant difference was used to differentiate the treatments.

Results

The avoidable yield loss experiments were conducted across different agro-ecological of major maize growing regions of Tamil Nadu. In all the zones the complete protection (T1) and window based application (T2) recorded lowest avoidable yield loss than the untreated control (T3) (Table 3 – 6). The FAW infestation was 29.68% in complete protection (T1), 47.9% in window based application and 61.4% in the untreated control (Table 3) in the maize hybrid Co HM 8 at Combatore centre. The mean FAW damage based on TNAU scale however was 1.25, 1.83 and 2.23 respectively in complete protection (T1), window - based application (T2) and untreated control (T3) respectively during rabi 2020 - 21. The per hectare avoidable yield loss in complete protection (T1) was 811 and 1228 kg/ha and in window - based application 293 and 680kg/ha during *kharif* and *rabi* respectively. The per cent avoidable yield loss in Complete protection (T1) and window - based application (T2) was 29.68 and 18.65 respectively. The benefit cost ratio in window based application (T2) during *kharif* and *rabi* was 1:1.50 and 1:1.40 respectively whereas in complete protection (T1) the BCR was 1:1.46 and 1:1.39.

Field experiments to assess yield loss in Madurai centre was conducted during *kharif* 2020 with two maize hybrids DMH 8255 and Pioneer 3302. The mean fall armyworm per cent infestation in DMH 8255 maize hybrid in complete protection (T1), window based application (T2) and untreated control (T3) was 3.57, 4.28 & 16.90 and overall mean TNAU damage score 1.25, 1.30 and 1.69, respectively (Table 4). The Pioneer 3302 recorded 5.00, 5.00 and 19.52 mean per cent fall armyworm infestation in complete protection (T1), window based application (T2) and untreated control (T3) during *kharif* 2020. The per hectare avoidable yield loss in complete protection (T1) was 1600kg and 1620 Kg respectively for DMH 8255 and Pioneer 3302 respectively. The window based application (T2) recorded per hectare avoidable yield loss of 1506 kg and 1580 kg for DMH 8255 and Pioneer 3302 hybrids and per cent

Table 3. Details of insecticides used in different treatments

Treatment	I Spray	II Spray	III Spray	IV Spray
Coimbatore Location				
T1: Complete Protection (Recommended insecticide has to be applied as and when FAW incidence is noticed)	Emamectin benzoate 5 SG @ 200g a.i/ha. at 12 DAE	Chlorantraniliprole 18.5 SC @ 40 g a.i / ha. at 28 DAE	Spinetoram 11.7 SC @ 30 g a.i / ha. at 42 DAE	Chlorantraniliprole 18.5 SC @ 40 g a.i/ha at 65 DAE
T2: Window based insecticide application as per TNAU IPM capsule	Emamectin benzoate 5 SG @ 200g a.i/ha. at 18 DAE	Chlorantraniliprole 18.5 SC @ 40 g a.i/ha. at 35 DAE	-	-
Madurai Location				
T1: Complete Protection (Recommended insecticide has to be applied as and when FAW incidence is noticed)	Emamectin benzoate 5 SG @ 200g a.i / ha. at 20 DAE	Spinetoram 11.7 SC @ 30 g a.i / ha. at 38 DAE	Chlorantraniliprole 18.5 SC @ 40 g a.i / ha. at 52 DAE	-
T2: Window based insecticide application as per TNAU IPM capsule	Emamectin benzoate 5 SG @ 200g a.i/ha. at 20 DAE	Chlorantraniliprole 18.5 SC @ 40 g a.i/ha. at 45 DAE	-	-
Tiruchirappalli Location				
T1: Complete Protection (Recommended insecticide has to be applied as and when FAW incidence is noticed)	Emamectin benzoate 5 SG @ 200g a.i / ha. at 10 DAE	Spinetoram 11.7 SC @ 30 g a.i/ha. at 22 DAE	Chlorantraniliprole 18.5 SC @ 40 g a.i/ha. at 37 DAE	Spinetoram 11.7 SC @ 30 g a.i / ha. at 54 DAE
T2: Window based insecticide application as per TNAU IPM capsule	Emamectin benzoate 5 SG @ 200g a.i/ha. at 15 DAE	Spinetoram 11.7 SC @ 30 g a.i/ha. at 38 DAE	-	-
Tirunelveli Location				
T1: Complete Protection (Recommended insecticide has to be applied as and when FAW incidence is noticed)	Emamectin benzoate 5 SG @ 200g a.i/ha. at 18 DAE	Chlorantraniliprole 18.5 SC @ 40 g a.i/ha. at 28 DAE	Spinetoram 11.7 SC @ 30 g a.i/ha. at 42 DAE	Novaluron 10 EC @ 100 g a.i./ha at 63 DAE
T2: Window based insecticide application as per TNAU IPM capsule	Emamectin benzoate 5 SG @ 200g a.i/ha. at 18 DAE	Chlorantraniliprole 18.5 SC @ 40 g a.i/ha. at 42 DAE	-	-

yield loss of 34.22 and 25.77 respectively (Table 4). The benefit cost ratio in complete protection (T1) and window based application (T2) for the DMH 8255 and Pioneer 3302 hybrids were 1:1.92, 1:1.94 and 1:1.81 and 1:1.89, respectively.

The complete protection (T1) and window based application (T2) recorded lower percentage of fall armyworm incidence than untreated control for both the maize hybrids *viz.,* NK 6668 and Pioneer 3302 in the yield loss experiments conducted during

Table 3. Avoidable yield loss and damage due to Fall armyworm in maize (Co (HM) 8) at Coimbatore location during *kharif* and *rabi* 2020 - 21

Treatment	*Kharif* 2020-21								*Rabi* 2020 -21							
	Overall mean infestation (%)#	Overall mean score$	Yield (kg/ha)	Avoidable yield loss (kg/ha)	Per cent avoidable yield loss	Plant Protection cost (Rs/ha)	Net return (Rs./ha)	BCR	Overall mean infestation (%)#	Overall mean score$	Yield (kg/ha)	Avoidable yield loss (kg/ha)	Per cent avoidable yield loss (Rs/ha)	Plant Protection cost (Rs/ha)	Net return	BCR
T1: Application of recommended insecticide as and when FAW incidence is noticed (Complete protection)	21.4 (27.6)	1.32 (1.34)	4409^{a}	811	22.50	12450	23573	1:1.46	20.0^{a} (26.6)	1.25^{a} (1.70)	4193 ^{a}	1228	29.68	12450	20081	1:1.39
T2: Window based application of insecticides as per TNAU IPM capsule	38.4 (38.3)	1.72 (1.48)	3891^{ab}	293	8.14	5250	22417	1:1.50	47.9^{b} (43.8)	1.83^{b} (1.79)	3645^{a}	680	18.65	5250	17965	1:1.40
T3: Untreated control	65.2 (53.8)	2.83 (1.82)	3598^{b}	-	-	-	16470	1:1.43	61.4^{c} (51.6)	2.23^{c} (1.84)	2965^{b}	-	-1.2	-	6975	1:1.18
SEd	1.24	0.12	282.7	-	-				1.05	0.03	650.6	-	-			
CD (P=0.05)	2.84	0.22	616.0	-	-				2.29	0.08	298.6	-	-			

** - Significant at5% level
# Values in parenthesis are arcsine transformed values
$ Values in parenthesis are square root transformed values
Means followed by a common letter are not significantly different by LSD ($p<0.05$)

kharif 2020 at Cotton Research Station, Vepanthattai (Table 5). The fall armyworm infestation mean damage score in complete protection (T1), window - based application (T2) and untreated control (T3) was 1.27, 1.67and 2.29 for NK 6668 maize hybrid and 1.28, 1.68 and 2.37 for Pioneer 3302 maize hybrid. The avoidable yield loss in complete protection (T1) and window - based application (T2) was 4583 and 3940 kg/ha for NK6668 and 4660 and 3932 kg/ha for Pioneer 3302. The per cent avoidable yield loss was 84.24 and 82.13 for NK 6668 and 82.37 and 79.77 for Pioneer 3402 in complete protection (T1) and window based application (T2). The incidence of other insect pests was negligible in treatments and untreated control. The benefit cost ratio for NK 6668 and Pioneer 3302 hybrid was 1:1.61 and 1:1.68 respectively in complete protection (T1) and 1:1.63 and 1:1.68 in window based application (T2) respectively.

In Tirunelveli, results on the avoidable yield loss experiments revealed 2.3, 7.0 and 50.5 mean per cent infestations in complete protection (T1), window based application (T2) and untreated control respectively for the hybrid DKC 9133 (Table 6). DMH 8255 maize recorded per cent infestation and mean TNAU damage score of 2.05 and 1.06 for complete protection (T1) and 6.88 and 1.20 for window based application (T2). The avoidable yield loss in Tirunelveli centre in complete protection (T1) and window - based application (T2) was 3140 kg/ha and 2785 kg/ha respectively for DKC 9133 and 3160 kg/ ha and 2750 kg/ha for DMH 8255 respectively. The per cent yield

Table 4. Avoidable yield loss and damage due to Fall armyworm in two maize hybrids at Madurai location during *kharif* 2020 - 21

Treatment	Maize hybrid - DMH 8255								Maize hybrid - Pioneer 3302							
	Overall mean infestation (%)$^{\#}$	Overall mean score$^{\$}$	Yield (kg/ha)	Avoidable yield loss (kg/ha)	Per cent avoidable yield loss	Plant Protection cost (Rs/ha)	Net return (Rs/ha)	BCR	Overall mean infestation (%)$^{\#}$	Overall mean score$^{\$}$	Yield (kg/ha)	Avoidable yield loss (kg/ha)	Per cent avoidable yield loss	Plant Protection cost (Rs/ha)	Net return (Rs/ha)	BCR
T1: Application of recommended insecticide as and when FAW incidence is noticed (Complete protection)	3.57 (10.89)^{a}	1.25 (1.12)^{a}	6000^{a}	1600	36.36	8750	45708	1:1.92	5.00 (12.92)^{a}	1.33 (1.15)^{a}	6170^{a}	1620	26.25	8750	48343	1:1.94
T2: Window based application of insecticides as per TNAU IPM capsule	4.28 (11.94)^{b}	1.30 (1.14)^{a}	5906^{b}	1506	34.22	5250	44251	1:1.81	5.00 (12.92)^{a}	1.37 (1.17)^{a}	6130^{b}	1580	25.77	5250	47723	1:1.89
T3: Untreated control	16.90 (24.27)^{c}	1.69 (1.30)^{b}	4400^{c}	-	-	-	33824	1:1.03	19.52 (26.22)^{b}	1.72 (1.31)^{b}	4550^{c}	-	-	23233	1:0.70	
SEd	0.37	0.04	43.29	-	-				0.50	0.03	16.01	-	-			
CD (P=0.05)	0.17	0.02	19.87	-	-				0.23	0.02	7.35	-	-			

** - Significant at5% level
$^{\#}$ Values in parenthesis are arcsine transformed values
$^{\$}$ Values in parenthesis are square root transformed values
Means followed by a common letter are not significantly different by LSD (p<0.05)

loss in DKC 9133 and DMH 8255 maize hybrids were 59.35 and 61.18 yield loss in complete protection and 56.43 and 57.83 in window - based application (T2). The untreated control recorded 2150 kg/ ha and 2005 kg/ha yield in DKC 9133 and DMH 8255 respectively. Hybrids DKC 9133 and DMH 8255 recorded 1:1.63 and 1:1.60 benefit cost ratio in complete protection (T1) and 1:1.71 and 1:1.64 in window based application (T2) respectively.

The season - wise and hybrid - wise mean of per hectare avoidable yield loss and per cent yield loss are presented in Table 7. The overall mean was also derived from the centre wise field experiments. The average avoidable yield loss for complete protection (T1) and window based application (T2) was in the order Coimbatore > Madurai > Tirunelveli > Tiruchirappalli (1019.50, 1610, 4621,50, 3150 (T1) and 486.50, 1543, 4434.50, 2767.50 (T2)). The avoidable yield loss was more in Tiruchirappalli centre with mean per cent avoidable yield loss of 83.30 in complete protection (T1) and 80.90 in window based application (T2) followed by Tirunelveli centre with percent avoidable yield loss of 60.26 and 57.13 respectively.

Discussion

The untreated control yield was much lower in Tiruchirappalli centre (857kg/ha), which indicates the higher incidence of fall armyworm damage in this region as the incidence of other insect pests *viz., Chilo partellus* and *Rhopalosiphum maidis* was negligible during the study period. This ultimately results in the higher avoidable yield loss compare to other centres which conducted the study more or less in the same period. Fall armyworm infes-

Table 5. Avoidable yield loss and damage due to Fall armyworm in two maize hybrids at Tiruchirappalli location during *kharif* 2020 - 21

Treatment	Maize hybrid – NK 6668								Maize hybrid - Pioneer 3302							
	Overall mean infestation (%)[#]	Overall mean score[$]	Yield (kg/ha)	Avoidable yield loss (kg/ha)	Per cent avoidable of yield loss	Plant Protection cost (Rs/ha)	Net return (Rs/ha)	BCR	Overall mean infestation (%)[#]	Overall mean score[$]	Yield (kg/ha)	Avoidable yield loss (kg/ha)	Per cent avoidable of yield loss	Plant Protection cost (Rs/ha)	Net return (Rs/ha)	BCR
T1: Application of recommended insecticide as and when FAW incidence is noticed (Complete protection)	10.18 (18.61)[a]	1.27 (1.13)[a]	5440[a]	4583	84.24	11750	31100	1:1.61	12.14 (20.39)[a]	1.28 (1.13)[a]	5657a	4660	82.37	11750	34355	1:1.68
T2: Window based application of insecticides as per TNAU IPM capsule	22.85 (28.56)[b]	1.67 (1.29)[b]	4797[b] (28.44)[b]	3940 1.68(1.30)[b]	82.13	5250	27955	1:1.63	22.68	4929[b]	3932	79.77	5250	29935	1:1.68	
T3: Untreated control	39.28 (38.81)[c]	2.29 (1.51)[c]	857[c]	-	-	-	-25895	1:0.33	41.43 (40.07)[c]	2.37 (1.54)[c]	997[c]	-	-	-	-23795	1:0.38
SEd	0.65	0.09	722.91	-	-				0.64	0.34	696.37	-	-			
CD (P=0.05)	0.30	0.04	331.79	-	-				0.30	0.16	319.61	-	-			

** - Significant at 5% level

[#] Values in parenthesis are arcsine transformed values

[$] Values in parenthesis are square root transformed values

Means followed by a common letter are not significantly different by LSD ($p<0.05$)

tation during whorl stage leads to severe infestation and ultimately leads to unprecedential yield loss if no attention was paid to the crop. Chouraddi and Mallapur (2017) recorded maximum yield loss of 85.30 and 84.72 percent when nine *Chilo partellus* larvae were released per maize plant. The yield loss was minimum (3.47 and 1.27%) in one *C. partellus* larva per plant. Higher yield loss due to insect pest has been recorded in maize and present results corroborate with the above findings. The natural enemies *viz*., egg and larval parasitoid and predator species and crops adjacent to the maize crops also contribute to the fall armyworm reduction in maize fields (Agboyi *et al*., 2020; Kalleshwaraswamy *et al*., 2019; Midegaa *et al*. 2018 and Shanmugam *et al*., 2020).

The average avoidable yield loss and per cent avoidable yield loss due to fall armyworm worked out across the four centres recorded 2600.25 kg/ha and 50.23 per cent for complete protection (T1) and 2307.87 kg/ha and 45.36 per cent for window based application (T2). In Nalagonda district of Telangana through the spectral analysis 33 per cent reduced yield was recorded due to fall armyworm (Arun Balla *et al*., 2019). The *S. frugiperda* damage yield loss estimation in maize in Ghana and Zambia recorded 22 – 67% and 26 – 35% loss respectively (Day *et al*., 2017; Rwomushana *et al*., 2018).

The percent yield loss recorded across the centres fall within the range recorded in Ghana and Zambia, where the yield loss records were collected from the farmers whereas in the present investigation per cent yield loss was derived from the field experiments. Koffi *et al*. (2020) in their extensive survey among maize farmers and extension officials in Ghana revealed that the yield loss was 73.70 and 20.90% respectively during 2017 and 2018 respectively. Baudron *et al*. (2019) revealed that 32 – 48% of fall armyworm damage resulted in 11.6% yield loss in small farmer holdings. These results are contrary to the present findings where the avoidable yield loss was 50.23% in complete protection and

Table 6. Avoidable yield loss and damage due to Fall armyworm in two maize hybrids at Tirunelveli location during *kharif* 2020 - 21

Treatment	Maize hybrid – DKC 9133								Maize hybrid – DMH 8255							
	Overall mean infestation (%)[#]	Overall mean score[$]	Yield (kg/ha)	Avoidable yield loss (kg/ha)	Per cent avoidable of yield loss	Plant Protection cost (Rs/ha)	Net return (Rs/ha)	BCR	Overall mean infestation (%)[#]	Overall mean score[$]	Yield (kg/ha)	Avoidable yield loss (kg/ha)	Per cent avoidable of yield loss	Plant Protection cost (Rs/ha)	Net return (Rs/ha)	BCR
T1: Application of recommended insecticide as and when FAW incidence is noticed (Complete protection)	2.3 (8.7) [a]	1.0 (1.2) [a]	5290 [a]	3140	59.35	11050	30800	1:1.63	2.05 (8.18)[a]	1.06 (1.25)[a]	5165 [a]	3160	61.18	11050	28925	1:1.60
T2: Window based application of insecticides as per TNAU IPM capsule	7.0 (15.3)[b]	1.1 (1.3)[b]	4935 [b]	2785	56.43	5900	30625	1:1.71	6.88 (15.18)[b]	1.20 (1.30)[b]	4755 [b]	2750	57.83	5900	27925	1:1.64
T3: Untreated control	50.5 (45.3)[c]	2.3 (1.7)[c]	2150 [c]	-		-	(-) 5250	1:0.86 (44.62)[c]	49.33 (1.70)[c]	2.31	2005 [c]	-	-		(-) 7425	1:0.80
SEd	1.01	0.03	208.28	-	-				1.01	0.02	140.14	-	-			
CD (P=0.05)	0.46	0.01	95.60	-	-				0.46	0.01	64.32	-	-			

** - Significant at5% level

[#] Values in parenthesis are arcsine transformed values

[$] Values in parenthesis are square root transformed values

Means followed by a common letter are not significantly different by LSD ($p<0.05$)

45.36% in window based application. The first application of insecticide 2 – 3 weeks after seedling emergence was recommended for the effective management of fall armyworm in regions which favours the continuous fall armyworm infestation (Da Silva, 1999).

S. frugiperda infestation in 55 – 100 per cent plants leads to yield loss of 15 – 73% in Nicaragua (Hruska and Gould, 1997). Overton *et al*. (2021) in their literature survey revealed that FAW yield losses were highest in maize where management practices were not specified (34 ± 2.35%), followed by unmanaged genetically modified (GM) crops (25.17 ± 2.06%) and non GM crops managed with insecticides (21.26 ± 2.06). From the literature sources they also revealed that mean yield losses were low for GM maize managed with (11.07±1.05%) and without (13.45 ± 3.62%) insecticides. In the present investigation the number of insecticide application is more in complete protection (T1) whereas in window based application it is less. More number of insecticide sprays to manage fall armyworm always doesn't increase the maize yield as compare to the critical stages interventions (Dal Pagetto *et al*. 2012). Rather than spraying insecticides at early stages seed treatment of maize seeds with insecticides will be useful in managing the fall armyworm foliar damage up to 15 days (Suganthi *et al*., 2022). Insecticide application at critical stages based on the fall armyworm infestation, apart from reducing the insect population also reduces the cost associated with the plant protection. The need-based application will also reduce the chance of resistance development in the fall armyworm.

In complete protection (T1), insecticide application was done within 2 weeks after emergence to keep the fall armyworm population under control. This will envisage the increase in plant protection cost and reduced benefit cost ratio. The infestation at early stage of the crop growth will not have no negative

Table 7. Mean per cent yield loss in maize due to fall armyworm damage across different location

Treatment	Coimbatore (mean of two seasons)		Madurai (mean of two hybrids)		Triuchirappalli (mean of two hybrids)		Tirunelveli (men of two hybrids)		Over all mean	
	Avoidable yield loss (kg/ha)	Per cent avoidable yield loss	Avoidable yield loss (kg/ha)	Per cent avoidable yield loss	Avoidable yield loss (kg/ha)	Per cent avoidable yield loss	Avoidable yield loss (kg/ha)	Per cent avoidable yield loss	Avoidable yield loss (kg/ha)	Per cent avoidable yield loss
T1: Application of recommended insecticide as and when FAW incidence is noticed (Complete protection)	1019.50	26.09	1610	31.30	4621.50	83.30	3150	60.26	2600.25	50.23
T2: Window based application of insecticides as per TNAU IPM capsule	486.50	13.40	1543	29.99	4434.50	80.90	2767.50	57.13	2307.87	45.36

impact in the overall quality and quantity of the crops and their yield (van der Berg *et al*. 2011). Dasilva (1999) revealed that the first application of insecticide should be postponed at-least 2 – 3 weeks after seedling emergence wherever the continuous fall armyworm infestation will occur due to favaourable environment conditions. The TNAU ad-hoc management practice of window based insecticide (T2) application recommends first insecticide application 2 – 3 weeks after emergence depending upon the incidence level.

Conclusion

The per hectare avoidable yield loss and per cent avoidable yield loss due to fall armyworm in window based application was 2307 kg and 45.36 and whereas in complete protection (T2) it was 2660.25 kg and 50.23. The difference in avoidable yield loss between window based (T2) and complete protection (T1) was 292.38 kgs/ha. The additional yield of 292.38kgs was achieved in complete protection (T1) with two to three additional insecticide sprays which increases the plant protection cost. The results clearly indicate that timely interventions are required to avoid the yield loss due to fall armyworm infestation. The results of field experiments conducted across different centres also show that window - based application will be an ideal strategy to avoid fall armyworm yield loss in maize.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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