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RESEARCH ARTICLE

A New Scoring Technique for Assessing the Infestation of Maize Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith)

Srinivasan T[1*], Vinothkumar B[2], Shanmugam P S[1], Baskaran V[1], Arulkumar G[1], Prithiva J N[1], Sathyan T[1], Krishnamoorthy S V[1], Muthukrishnan N[3], Prabakar K[4], and Sathiah N[1]

[1]Department of Agricultural Entomology, Tamil Nadu Agricultural University, Coimbatore - 641 003, India
[2]Coconut Research Station, Tamil Nadu Agricultural University, Aliyarnagar - 641 003, India
[3]Agricultural College and Research Institute, Tamil Nadu Agricultural University, Vazhavachanur 606 753, India
[4]Centre for Plant Protection Studies, Tamil Nadu Agricultural University, Coimbatore - 641 003, India

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ABSTRACT

Maize fall armyworm, *Spodoptera frugiperda* (J.E. Martin) (Noctuidae: Lepidoptera), first recorded in the Americas spread to Africa during 2016 and later spread to more than 40 countries including India during July, 2018. Infestation by maize fall armyworm results in extensive defoliation besides damage to tassels and cobs at later stages of the crop. The infestation levels are measured through various injury rating scales of which the 1-9 whorl leaf injury rating scale (Davis *et al.,* 1992; Ni *et al.,* 2011) is the mostly used one. It was felt that, the Davis 1-9 scale proposed by Davis *et al.,* (1992) was prone to observer bias in field experiments conducted at Tamil Nadu Agricultural University by a team of researchers and students. Thus, a new TNAU 1-5 scale was evaluated which was more feasible, precise, easy and less time consuming compared to modified Davis *et al.,* (1992) 1-9 scale proposed by Ni *et al.,* (2011). The new scale will be helpful for researchers and students who take up screening and evaluation studies in future.

Keywords: *Maize; Fall armyworm; Spodoptera frugiperda; New scoring technique*

INTRODUCTION

Maize (*Zea mays* L.) is cultivated in an area of 3.55 lakh ha in Tamil Nadu during *kharif, rabi* and summer seasons with an annual production of 25.3 lakh tonnes and productivity of 7.1 tonnes/ha (Dept. of Economics and Statistics, 2015-16). Maize plant is affected by more than 140 insect pests out of which ten are important (Arabjafari and Jalali, 2007). The maize fall armyworm (FAW), *Spodoptera frugiperda* (J.E.Martin) (Noctuidae: Lepidoptera) was first recorded in the Americas (Johnson, 1987). Only by late 2016, it was reported outside Americas and since then spread to more than 40 countries (Sisay *et al.,* 2019) including India (Sharanabasappa *et al.,* 2018) around July 2018.

With regard to infestation by maize FAW, the larval stage which lasts for about 14-21 days are responsible for extensive defoliation in maize besides feeding upon tassels and cobs at later stages of the crop (Lamsal *et al.,* 2020). Out of the six larval instars the 1st to 3rd instars cause damage by scrapping, while the 4th to 6th instar stages tend to reside in the central whorls causing extensive feeding which will be clearly visible in the funnel leaves (top 3-4 leaves) (Tefera *et al.,* 2019). This leaf damage generally referred to as whorl damage or leaf/ whorl injury and is rated/ scored at different stages of crop growth starting from 7 days after emergence (DAE) to almost 45 DAE after which the tassel emerges.

Researchers and students use rating scales for screening experiments as well as to assess the level of fall armyworm infestation under field conditions (Toepfer *et al.,* 2021). Various types of rating scales are in vogue including the nominal scale (Aguirre *et al.,* 2019), cob damage rating scale (Prasanna *et al.,* 2018), assessment of damage severity in all leaves (Chinwada, 2018) and the mostly used Davis 1-9 scale (hereafter to be referred as Davis scale or Davis 1-9 scale or Davis score, all of which mean the same) for whorl injury rating. But, interpretation through these scales may often lead to observer biases (Tversky and Kahneman, 1974). As a result, the reproducibility of the results may vary with observer to observer which gets amplified with increasing scale values. For example, observing on a scale of 1-9 will have lesser reproducibility than on a 1-3 scale. Thus, we have planned to come out with a TNAU 1-5 scale which will be practically feasible, easy and less time consuming in place of the Davis 1-9 scale. The

*Corresponding author's e-mail: entosrini@gmail.com

new scale will be helpful for researchers and students to derive the desired results with better precision and reproducibility.

A visual rating scale of 1 to 9, where 1 = No damage or few pinholes; 2 = Few short holes (also known as shot holes) on several leaves; 3 = Shot holes on several leaves; 4 = Several leaves with shot holes and a few long lesions; 5 = Several holes with long lesions; 6 = Several leaves with lesions < 2.5 cm; 7 = Long lesions common on one half of the leaves; 8 = Long lesions common on one half to two thirds of leaves; 9= Most leaves with long lesions is being commonly used for this purpose which is a modified scale developed by Ni *et al.,* (2011) based on the original scale proposed was developed by Davis *et al.* (1992) (Table 1). Similarly, for maize kernel and ear damage too, a visual rating scale is used to score the harvested produce using the scale (1-9) where 1 = No damage to any ears, 2 = Tip (<3cm) damage to 1-3 ears, 3 = Tip damage to 4-7 ears; 4 = Tip damage to 7 and more ears and damage to 1-3 kernels below ear tips on 1 to 3 ears, 5 = Tip damage to 7 and more ears and damage to 1-3 kernels below ear tips on 1 to 3 ears, 6 = Ear tip damage 7-10 ears and damage to 1-4 kernels below tips of 7 to 10 ears, 7 = Ear tip damage to 7-10 ears and damage to 4-6 kernels destroyed on 7-8 ears, 8 = Ear tip damage to all ears and 4-6 kernels destroyed on 7-8 ears , 9= Ear tip damage to all ears and 5 or more kernels destroyed below tips of 9-10 ears (Table 2). The existing score system has been accepted worldwide and is being utilised by researchers all over the maize growing regions of the world.

However, a few difficulties do exist in following the scoring system of Davis *et al.* (1992). The scales though provide a means of rating plants with different intensities of damage by FAW, they lead to observer bias during the rating process (Tversky and Kahneman, 1974). The descriptions of different scores pose not-so-clear demarcation between scores, coupled with overlapping of two or more scores (Table 1). For example, with respect to whorl injury rating scale, the score 2 refers to 'few shot holes on several leaves' while score 3 is assigned to 'shot holes on several leaves'. The term several leaves gives no clear demarcation on the number of leaves that has to be taken into account. Further, maize plant suffers leaf infestation by FAW from 10 days after emergence (DAE) (2-3 leaf stage) to 45 DAE (14-15 leaf stage). But, it is the fresh whorl infestation that indicates the presence or absence of larva in the whorl and also decides whether the plant should be considered as infested or pest-free. Mere observing infestation in older leaves and assigning a score may not provide the actual levels of infestation. Similarly, for score 4 and 5, the term 'lesions' had been used. While the score 4 is assigned to several leaves with shot holes and few long lesions, score 5 specifies several holes with long lesions, which, again is confusing with respect to the length of the lesions and the extent/ number of holes in the plant. The score 6 provides details for the size of the lesions *i.e.* less than 2.5 cm. Assigning score 6 will be less confusing but assuming a 2.5 cm length without a physical measuring scale will lead to differences when different individuals score a plant. The maize fall armyworm, does not feed upon the unfurled leaves and always reside inside the funnels. Thus scoring based on infestation on one half leaves (score 7) and on two third of leaves (score 8) will lead to misleading conclusion as if the damage has been done to these leaves. The Davis scale is felt complicated with its overlapping descriptions between a few scores as mentioned above. Keeping the above points under consideration, there is a necessity to have a clear cut scoring system with distinguishing levels of infestation under each score which will yield more precision, reproducibility and credibility to the system of scoring. This paper is an attempt to evolve such a simplified scoring system on a 1-5 scale (Table 1a). Similar exercise of using simplified scales by various workers include a nominal scale (Yes or No damage) (Aguirre *et al.,* 2019), only cob damage scale suggested by Prasanna *et al.* (2018), leaf whorl and furl damage score (on a 1-9 scale) by Davis *et al.* (1992), the one which is attempted by most workers worldwide, whole plant damage scale by Williams *et al.* (1989), again on a 1-9 scale and a simple 0.0 to 4.0 leaf damage index scale by Toepfer *et al.* (2021).

Besides, whorl injury damage assessment following Davis scale, another ear and kernel damage rating (Table 2) scale for assessing the damage to cobs due to FAW damage is also being used by researchers (Williams *et al.,* 2006), which too has the same difficulties as encountered for whorl leaf damage assessment. Thus, cob injury rating score has also been revised on a 1-5 scale (Table 2a) in the present studies instead of the existing Williams *et al.* (2006) scale of 1-9. The new TNAU scoring technique and its applicability in the field is evaluated in the present investigation.

MATERIAL AND METHODS

A twenty two day old maize crop (Hybrid: NK606) raised at a spacing of 75 × 20 cm with adequate infestation by fall armyworm in the research farm of TNAU, Coimbatore was selected. The plot was divided into 10 blocks (Plot A to Plot J) with an approximate area of 40 m^2 per block with a population of ~ 250 plants. A team of 10 individuals including scientists and research fellows (treated as 10 subjects) evaluated the feasibility of the scores.

A total of 10 plants per plot was randomly selected and tagged, which represented varying scores. Each of the 10 subjects were allotted a plot of 40 m^2 who did scoring of the 10 tagged maize

plants as per the Davis scale. Every subject scored their assigned plot and moved on to the next plot and did the scoring again for four more times. For example, Subject 1 did a scoring in Plot A followed by Plot B and Plot C. Likewise, Subject 2 started scoring Plot B followed by Plot C and Plot D. Subject 3 followed scoring in a similar fashion. After a subject completes scoring in three plots, all the subjects moved on to their first scored plot to do the scoring for the second time and again for a third, fourth and fifth time. Thus, every subject would have scored three plots for five times under Davis 1-9 scale. Subjects scoring the same plot five times is to check verify the reproducibility of the results. Now, a waiting period of half an hour was given for the subjects to relax while removing traces of the Davis scale from their minds.

After half an hour all the subjects were positioned in the plots where they started first. The subjects were asked to score the same way as earlier with only a single modification i.e. this time, all the subjects followed TNAU 1-5 score. Thus every subject involved in this study would have scored 150 plants under Davis scale and 150 plants under TNAU score. With individual subject scoring 300 plants, a total of 3000 data were recorded by 10 subjects in all. Finally, in order to assess the subjects' perception on the two different types of scores, the ten scorers were instructed to provide their opinion on the two different scoring methods *viz*., the new score is advantageous, not-advantageous or neutral (do not feel any difference) over the Davis (1-9) scale The parameters included time consumption (whether the proposed score was more time consuming), reproducibility (whether the scorer felt that the scoring was reproducible even when done multiple times), difficulty (whether the proposed score was relatively easy for making eye judgement) and existence of overlapping (to see if any overlapping existing between different score levels).

In the present study two types of interpretations were derived. One, ten subjects scored a plot thrice under Davis 1-9 score and thrice under TNAU 1-5 score. The differences in the scores when the same subject scored the same plot was analysed using standard deviation. Similarly, each and every subject scored a plot under two different scales *viz*., Davis 1-9 score and TNAU 1-5 score.

Further, a plot will be scored by three subjects. There will be differences in the scores when a plot is scored by different individuals as this is a relative scoring system and eye judgement and individual's perception plays a major role in deciding the score. However, the scoring system which provides limited deviation even when scored by different subjects should be considered for further adoption. The deviation/ differences the subjects exhibited when scoring under two different systems had once again been analysed using standard deviation as a measure of dispersion. The scoring system which exhibited the least standard deviation would be considered the better among the two and will be recommended for adoption by stakeholders.

Subject	Davis *et al*. (1992) scale (five times each plot)			Proposed TNAU scale (five times each plot)		
Subject 1	Plot A	Plot B	Plot C	Plot A	Plot B	Plot C
Subject 2	Plot B	Plot C	Plot D	Plot B	Plot C	Plot D
Subject 3	Plot C	Plot D	Plot E	Plot C	Plot D	Plot E
Subject 4	Plot D	Plot E	Plot F	Plot D	Plot E	Plot F
Subject 5	Plot E	Plot F	Plot G	Plot E	Plot F	Plot G
Subject 6	Plot F	Plot G	Plot H	Plot F	Plot G	Plot H
Subject 7	Plot G	Plot H	Plot I	Plot G	Plot H	Plot I
Subject 8	Plot H	Plot I	Plot J	Plot H	Plot I	Plot J
Subject 9	Plot I	Plot J	Plot A	Plot I	Plot J	Plot A
Subject 10	Plot J	Plot A	Plot B	Plot J	Plot A	Plot B

Results and Discussion

Differences in scores when same plots were scored by different subjects

When Plot A to Plot J were scored by three different subjects (Subject 1, 2 and 3), the mean SD varied between 0.50 to 0.78 for Davis score while it was in the range of 0.16 to 0.45 for TNAU score. It reveals that, the deviations were more when following Davis score. It should be noted that, the SD was always low for TNAU 1-5 score when compared to Davis score for all the plots. Thus it can be interpreted that, there will be less deviation when following TNAU score which can be seen from the lesser SD when three different subjects scored the same plots. The mean SD for Davis scale varied between 0.50 and 0.78 while for that of TNAU scare varied between 0.16 and 0.45 (Table 3). The proposed TNAU 1-5 scale will be more useful for the farmers and researchers as the scale suggests to analyse only two parameters *viz.,* approximate size of the holes and shredding of whorl leaves. This type of scoring will provide information on the fresh infestation caused by fall armyworm against the Davis 1-9 scale which suggests analysing the infestation in several leaves. Generally, infestation in the older leaves are the manifestation of damage when they were whorl leaves (FAO, 2018). Thus, infestation in older leaves will not reveal the actual infestation levels in the field. It is only the fresh whorl infestation that should be considered for assessing damage by maize fall armyworm. The scores in the present study were done for five times by every subject. The SD presented here is the mean of 5 scores taken by different subjects. This again indicates the reproducibility of the results and hence the reliability.

Differences in scores when same subjects score different plots

When same subjects scored three different plots, the mean SD ranged between 0.48 to 0.80 under Davis (1-9) scale while it was only 0.19 to 0.40 (Table 4) when scored under TNAU 1-5 scale. Again, this reveals relatively lesser deviation under TNAU scale when compared to Davis scale. Lesser deviation in SD in turn indicates higher reproducibility and reliability of the scoring system. The different subjects scored each plots thrice in the present studies.

Advantages of TNAU scale as experienced by subjects

The subjects felt TNAU score advantageous over the Davis Score on the following counts. TNAU score is less confusing as it provide clear cut differentiation between different scores. TNAU score is less time consuming as the time spent per plant for recording the score is relatively less. Some of the difficulties encountered in Davis score are overcome in the revised score. While Davis score uses pinholes, shot holes, lesions, long lesions, on few leaves, several leaves, ½ of leaves, two-third leaves, etc. which provide lesser clarity to the scorer. On the other hand, TNAU score uses only two parameters i.e. holes (approximate sizes have been specified) and shredding (which can be mild or severe) which pose no confusion to a scorer. Similar observations on the difficulties of the 1—9 scale was evinced by Toepfer *et al.* (2021).

The relative advantage of the proposed 1-5 score was also assessed in the opinion of the scorers of this massive exercise. The assessment included four parameters *viz*., time consumption, reproducibility, difficulty and existence of overlapping between scales. It was found that, 100 per cent of the scorers felt that, the proposed 1-5 score was less time consuming and relatively easier for making judgment regarding a particular score while, 80 per cent of the scorers felt that it was more reproducible and nullified the overlapping issues of the Davis 1-9 score Figure 1. However, 20 per cent of the subjects felt that, the existing and proposed score revealed no much differences in terms of reproducibility and overlapping of different scores.

Table 1. Whorl leaf feeding rating scale for FAW by Davis *et al.* (1992)

Rating Scale	1-9 scale description
1	No damage or few pinholes
2	Few short holes (also known as shot holes) on several leaves
3	Shot holes on several leaves
4	Several leaves with shot holes and a few long lesions
5	Several holes with long lesions
6	Several leaves with lesions < 2.5 cm
7	Long lesions common on one half of the leaves
8	Long lesions common on one half to two thirds of leaves
9	Most leaves with long lesions

Table 1a. Proposed whorl leaf feeding rating scale for FAW

Rating Scale	Proposed TNAU 1-5 scale description for whorl leaf injury rating
1	Nil damage to pin hole damage
2	Circular / elongated holes less than 1 inch. on whorl leaves
3	Elongated holes > 1 inch. on whorl leaves
4	Elongated holes 1-2 inch. and mild shredding on whorl leaves
5	Severe shredding and defoliation of whorl and furl leaves

Table 2. Ear and kernel damage rating scale by Williams *et al.* (2006)

Rating Scale	1-9 scale description
1	No damage to any ears
2	Tip (<30 mm) damage to 1-3 ears
3	Tip damage to 4–6 ears
4	Tip damage to 7 or more ears and damage below ear tips to 1–3 kernels of 1–3 ears
5	Tip damage to 7 or more ears and damage to 1–3 kernels below tips of 4–6 ears
6	Ear tip damage to 7–10 ears and damage to 1–4 kernels below tips of 7–10 ears
7	Ear tip damage to 7–10 ears and 4–6 kernels destroyed on 4–6 ears
8	Ear tip damage to all ears and 4–6 kernels below tips destroyed on 7–8 ears
9	Ear tip damage to all ears and 5 or more kernels destroyed below tips of 9–10 ears

Table 2a. Proposed cob damage rating scale for FAW

Rating Scale	Proposed TNAU 1-5 rating scale for cob damage rating
1	Nil damage to slight damage to cobs at tips
2	< 25% of cob area showing FAW damage
3	26 - 50 % of cob area showing FAW damage
4	51 - 75 % of cob area showing FAW damage
5	< 75% of cob area showing FAW damage

Table 3. Maize fall armyworm damage assessment involving two scoring systems – Plot wise variations

	Davis scale (1-9)				TNAU scale (1-5)			
Plots	Subject1	Subject2	Subject3	Mean SD	Subject1	Subject2	Subject3	Mean SD
Plot A (N_1, N_2, N_3)	0.62	0.34	0.73	**0.56**	0.17	0.09	0.23	**0.16**
Plot B (N_1, N_3, N_4)	0.64	0.59	0.31	**0.51**	0.23	0.46	0.26	**0.32**
Plot C (N_5, N_3, N_4)	0.34	0.96	0.60	**0.63**	0.24	0.27	0.39	**0.30**
Plot D (N_5, N_6, N_4)	0.47	1.33	0.53	**0.78**	0.46	0.53	0.36	**0.45**
Plot E (N_5, N_6, N_7)	0.74	0.58	0.60	**0.64**	0.34	0.53	0.29	**0.39**
Plot F (N_1, N_2, N_8)	0.38	0.62	0.50	**0.50**	0.16	0.27	0.38	**0.27**
Plot G (N_9, N_2, N_8)	0.41	1.09	0.54	**0.68**	0.31	0.00	0.35	**0.22**
Plot H (N_9, N_{10}, N_8)	0.78	0.69	0.61	**0.69**	0.4	0.25	0.55	**0.40**
Plot I (N_7, N_9, N_{10})	0.60	0.65	0.55	**0.60**	0.19	0.77	0.27	**0.41**
Plot J (N_6, N_7, N_{10})	0.50	0.42	0.66	**0.53**	0.44	0.27	0.31	**0.34**

SD = Standard deviation

N_1, N_2, N_3.... N_{10} –Subjects involved in scoring five times each plot

1. Maize fall armyworm damage assessment involving two scoring systems - Opinion of the subjects on the TNAU 1-5 score

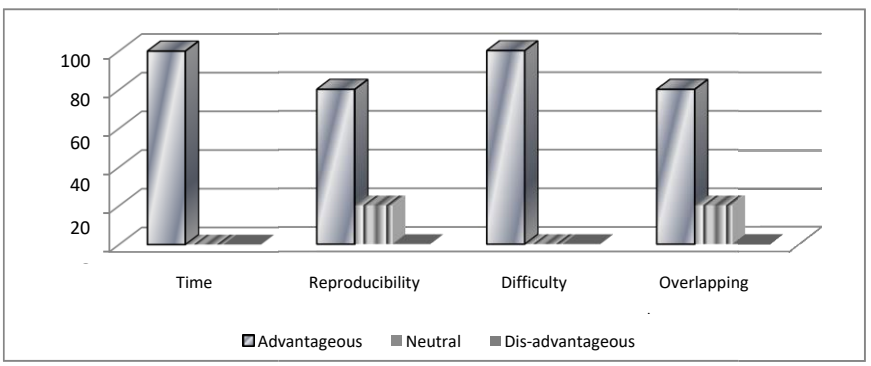

Table 4. Maize fall armyworm damage assessment involving two scoring systems – Subject wise variations

	Davis scale (1-9)				TNAU 1-5 scale			
Plots	Plot 1	Plot 2	Plot 3	Mean SD	Plot 1	Plot 2	Plot 3	Mean SD
Subject N_1 (A, B, F)	0.62	0.64	0.38	**0.55**	0.17	0.23	0.16	**0.19**
Subject N_2 (A, F, G)	0.34	0.62	1.09	**0.68**	0.09	0.27	0.00	**0.12**
Subject N_3 (A, B, C)	0.73	0.59	0.96	**0.76**	0.23	0.46	0.27	**0.32**
Subject N_4 (B, C, D)	0.31	0.60	0.53	**0.48**	0.26	0.39	0.36	**0.34**
Subject N_5 (C, D, E)	0.34	0.47	0.74	**0.52**	0.24	0.46	0.34	**0.35**
Subject N_6 (D, E, J)	1.33	0.58	0.50	**0.80**	0.53	0.53	0.44	**0.50**
Subject N_7 (E, I, J)	0.60	0.60	0.42	**0.54**	0.29	0.19	0.27	**0.25**
Subject N_8 (F, G, H)	0.50	0.54	0.61	**0.55**	0.38	0.35	0.55	**0.43**
Subject N_9 (G, H, I)	0.41	0.78	0.65	**0.61**	0.31	0.40	0.77	**0.49**
Subject N_{10} (H, I, J)	0.69	0.55	0.66	**0.63**	0.25	0.27	0.31	**0.28**

Plot A, B, C... J – 10 plots subjected to scoring by 10 different subjects each scoring 3 plots

CONCLUSION

Maize fall armyworm, *Spodoptera frugiperda* is an invasive pest infesting maize is an extensive defoliator during early crop growth stage besides damage to tassels and cobs at later stages of the crop. The infestation is measured through a 1-9 whorl leaf injury rating scale proposed by Davis *et al*. (1992) and Ni *et al.* (2011). It was felt that, the Davis 1-9 scale was prone to observer bias in field experiments at TNAU. Thus, a new TNAU 1-5 scale was evaluated which was more feasible, precise, easy and less time consuming compared to 1-9 scale of Davis *et al.* (1992). The new scale will be helpful for researchers and students who take up screening and evaluation studies in future.

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Ethics statement

No specific permits were required for the described field studies because no human or animal subjects were involved in this research.

Originality and plagiarism

The authors assure that the contents are written by us and were not plagiarised.

Consent for publication

All the authors agreed to publish the content.

Competing interests

There were no conflict of interest in the publication of this content

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