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Estimation of the cotton mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae), populations and its relation to the okra yield.

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Abstract
The mealybug, known as *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae), is an important polyphagous sap-sucking insect pest attacking okra plants (*Abelmoschus esculentus* L. Family: Malvaceae), causing plant desiccation, deformation, and fruit drop. The present work focused on evaluating the relationship between *P. solenopsis* population numbers during the weeks 9, 15, and 20 from planting and the okra yield in Armant district, Luxor governorate, Egypt, during the 2021 and 2022 seasons. Data showed that as *P. solenopsis* population numbers increased, the okra yield gradually decreased at 9, 15, and 20 weeks of okra age after sowing in each season. Also, an increase of one individual of the pest/leaf resulted in a loss of okra production of 0.007, 0.004, and 0.004 kg per plot and 0.008, 0.005, and 0.004 kg/ plot (10.5 m^2) in the intervals of peak activity of the two seasons, respectively. Consequently, okra yield loss % was increased by 0.32, 0.19, and 0.18% and 0.33, 0.21, and 0.18%, respectively, in the aforementioned weeks in 2021 and 2022. The results support the assumption that *P. solenopsis* populations reached their peaks at 9 weeks from okra planting and caused the highest loss of okra production and yield. At week 20 However, the peak of *P. solenopsis* populations was less effective, resulting in maximum expected production and minimum expected loss of okra yield throughout the two years. Therefore, the *P. solenopsis* infestation, the severity, and the okra plant susceptibility to invasion are known to be among the most important factors contributing to okra fruit yield decline.

Keywords: *Phenacoccus solenopsis*, cotton mealybugs, population densities, okra yield, reduction

Introduction

Okra (*Abelmoschus esculentus* L) (Family: Malvaceae), is one of the most important vegetable crops cultivated in Egypt [1]. It is a well-liked fruit due to its nutritive value, and it is rich in vitamins and minerals [2]. Various pests are known to cause damage to okra plants [3]. Among them, the mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae), is regarded as the most harmful pest [4-8]. Mealybugs' damage significantly harms the okra by withdrawing cell sap from the lower side of the leaves, which destroys not only the leaves but also the entire plant [9-11].

This insect is causing damage to the okra plant by targeting its shoots, twigs, leaves, branches, and fruits. This results in deformities, loss of leaves, withering of young twigs, reduced flowering, and the eventual demise of twigs due to the harmful saliva produced by this pest [12-14]. Moreover, this pest negatively affects the commercial value of fruits because it builds up on affected parts of okra. Additionally, it has an impact on the quality and quantity of the crop. Mealybugs excrete honeydew when feeding, which aids in the establishment of sooty mold growth on all parts of the plant and decreases their capacity for photosynthetic activity. In addition to indirect damage caused by mealybugs in the plant that transport the virus [10, 11, 15].

Through the literature, there is scanty information regarding the adverse impacts of *P. solenopsis* infestations on okra yield. So, the goal of the current investigation was to evaluate the relationship between the overall population abundance of *P. solenoaspis* during three peaks of activity (independent parameters) and the percentage decrease in okra productivity (dependent parameter) throughout two seasons (2021 and 2022).

Materials and Methods

Experimental design

The research was conducted in a private okra field, specifically using the Balady cultivar, located in at Armant district, Luxor region, Egypt, situated (25º42'25" N, 32º36'38" E) to study the population estimates of the mealybug *P. solenopsis* (Hemiptera: Pseudococcidae) in relation to the resulting okra yield throughout two successive seasons (2021 and 2022).

The field size was approximately 4200 square meters, and it was divided into fifteen plots, which were sown on the proper date (1st week of February) per season. Each plot, which was (3 m x 3.5 m) i.e., 10.5 m^2, shaped into 6 ridges with a width 0.5 metres and a length of 3 metres. All plots in this field received the normal agronomic practices.

The selected okra area was divided into 15 plots (12 unsprayed plots and 3 sprayed plots). The unsprayed twelve plots, to spread a field infestation by pest, were left without application of any insecticide treatments (insecticide-free) as an inspection through the study period (from planting to harvest). The other three plots were treated with insecticides according to the recommendations of the Egyptian Ministry of Agriculture. Spraying time started with the first invasion of *P. solenopsis* in the study location after five weeks after sowing. The plots were directly sprayed three times during the season. Because the insect's life cycle is short (about 30 days), it can attack and infest it several times during the okra growing season. By the way, all the neighbouring fields around our experience were planted with okra infested with colonies of mealybugs.

The first spray of the Malathion pesticide (Malatox® 57% EC) was applied at a rate of 2.5 cm^3 per litre of water, with the first infestation damage occurring on okra plants. This technique is carried out five weeks after sowing in the two seasons. With the 9 week olds after sowing, *P. solenopsis* populations increased over the two seasons. Okra plants were sprayed with Pyriproxyfen (Admiral® 10% EC) at a rate of 0.5 cm^3 per litre of water. The last pesticide treatment of okra plants was done at 15 week olds after sowing in the two seasons and was sprayed with Acetamiprid pesticide (Mospilan® 20% SP) at a rate of 0.25 g per litre of water.

All pesticide spraying treatments were executed in the morning hours (from six to nine a.m.) using a knapsack motorized sprayer (capacity of 20 liters). The plants were covered from the outside and inside with pesticides. Moreover, the pesticide was directed to the lower surfaces of the leaves, where *P. solenopsis* settles, exists, and grows.

The notes was recorded after planting in the untreated and treated plots as soon as the infestation appears as the first mealybug attack to be found at the experiment site at weekly intervals. *P. solenopsis* invasion of okra plants occurs five weeks after planting, and the plants continue to be harvested.

The abundance of mealybugs' populations was recorded at a weekly interval through the morning hours. The estimation of mealybugs' population was based on the numerical counting technique described according to Bakry, [16]; Bakry and Fathipour, [7]. The total counts of mealybugs were estimated on the 10 okra leaves per plot, which were randomly selected from different areas within each plot and tagged. Then, all leaves from all tested plots were placed in polyethylene bags and transported to the laboratory for examination. The numbers of insects on leaf surfaces were recorded at weekly intervals. In all the plots under study, this was implemented. The insect was identified and classified by specialists at the Plant Protection Research Institute, Agricultural Research Center, Giza, Egypt.

To assess the populations of *P. solenopsis* in all plots tested based on mean counts per leaf, this was discussed across weekly records on okra plants, i.e., the mean of population plus or minus (±) standard error (SE), which was used to evaluate population estimates.

The total samples amounted to 3000 leaves, i.e., 10 leaves x 15 plots x 20 examination dates x 2 seasons. Each season had 1500 leaves.

Okra productivity was evaluated in both unsprayed (untreated) and sprayed (insecticide-treated) plots. The area of each plot is (3 m x 3.5 m = 10.5 m^2).

The amount of okra fruit losses caused by *P. solenopsis* population was counted according to Bakry and Abdel-Baky, [17] formula:

$$\text{Loss \%} = [(A-B)/A] \times 100$$

Where: A= average okra fruits per plot of treated (sprayed) plants,

while B= averages okra fruits per plot of untreated (unsprayed) plants.

* The average production of okra fruits per plot of sprayed plants was 2.17 and 2.23 kg/plot (area of 10.5 m^2) throughout the two seasons of the investigation, respectively.

Statistical analysis

To determine the concurrent effects of insect activity peaks at 9, 15, and 20 weeks after sowing on okra, the partial regression method was adopted. As well, to describe the variation in okra yield loss that could be mainly attributed to the insect throughout the three peaks of seasonal activity, a simple linear regression (Y = a + bx) was performed.

Where: Y is the okra productivity, and a = constant (y - intercept), b is regression coefficient.

It was possible to obtain some basic knowledge about the proportion of yield variability that might be attributed to these combined peaks of activity using the percentage of explained variance (E.V. %) technique. Partial regression values represent the average rate of variation in okra production resulting from unit variation in any of the three insect activity peaks. The MSTAT-C software programme [18]. statistically analyzed all the data**.** All data and figures were calculated and generated by Microsoft Excel 2007.

Results

P. solenopsis is a harmful pest that attacks plant sap, shoots, leaf veins, branches, and fruits, leading to dehydration and eventual fruit death (Fig. 1).

Populations of P. solenopsis on okra plants

Weekly numbers of live total of *P. solenopsis*, which infested okra plants in the study area, were registered during the 2021 and 2022 seasons. The weekly mean numbers for each season are therefore a better indicator to study and explain the peaks of seasonal abundance.

Data represented in Table (1), show that initial mealybug populations appeared 5 weeks after planting and continued until the plants were harvested. There were three peaks of counts of *P. ole P. solenopsis* activity on okra plants at the study site, which happened at 9, 15, 20 weeks after planting (WAP), as the general averages of counts were 8.62, 17.68, and 22.66 individuals per okra leaf in 2021 and 8.66, 15.46, and 20.67 individuals per okra leaf in 2022, respectively.

Furthermore, the third peak of *P. solenopsis* observed at the 20 weeks after planting exhibited the greatest magnitude in comparison to the other peaks occurring during the season. However, the peak at 9 WAP was the lowest over the two seasons; this period observed the beginning of invasion over each season. Also, the average peaks of *P. solenopsis* total counts in 2021 season were higher than those registered in 2022 season. The averages were 16.32±0.57 and 14.93±0.570 individuals per leaf in 2021 and 2022, respectively (Table 1). This could be attributed to environmental factors that were more favorable for the insect's growth and activity during the initial season.

Relationship between okra productivity and the populations of *P. solenopsis*

Results in Table (1) and illustrated in Figs. (2 and 3) showed that when the total numbers of *P. solenopsis* increased during the three seasonal activity peaks, okra production gradually decreased in the two seasons. These findings supported the inverse relationship between the overall population densities at the three peaks of activity and okra production in two seasons.

However, the relationship between the populations of *P. solenopsis* in okra leaves and the rates of decrease in okra productivity was positive at all seasonal occurrence peaks during the 2021 and 2022 seasons, as shown in Table (1) and Figs. (2 and 3). As well, increases in overall population densities at all peaks were accompanied by an increase in the percentage reduction in okra yield during the two seasons.

Impact of the total counts of *P. solenopsis* on the okra yield

Statistically, the simple correlation analysis between the okra productivity and the three seasonal peaks of pest activity showed a highly important negative correlation, namely -0.94, -0.94, and -0.97; and -0.96, -0.98, and -0.97 when the population peaks at 9, 15, and 25 weeks old after planting throughout the two seasons, respectively. In this context, the simple regression method showed that every increase of one mealybug per okra leaf leads to a decrease in okra productivity by 0.07, 0.04, and 0.04 kg per plot (10 m^2) during the first season and 0.08, 0.05, and 0.04 kg per plot in the second season, respectively (Table 2).

Likewise, the partial regression coefficients between the peaks of insect populations and okra productivity were insignificant (P. reg. were 0.02 and 0.09) during the activity peak at 9 WAP in the two seasons, respectively. However, when statistical analysis was performed for the peak at 15 WAP in relation to *P. solenopsis* populations, it was insignificantly negative relation (P. reg. was -0.01) in the first season and significantly negative (P. reg. was -0.07) through the second season. While this relation was significant negative (P. reg.; -0.04 and -0.03) during the seasonal peak at 20 WAP in the two seasons, respectively (Table, 2). The combined influences of *P. solenopsis* activity peaks and okra productivity were highly significant, where the "F" values were 40.85 and 108.90 in 2021 and 2022 seasons, respectively (Table 2). The percentages of explained variance were 93.87 in 2021 and 97.60% in 2022.

Prediction of okra productivity and its loss

The statistical examination of the two-season value of the data resulted in forecasting formulae for okra productivity and its losses due to *P. solenopsis* infestation. The mathematics' outcomes could be displayed as follows:

1- The total counts of *P. solenopsis* at the three seasonal peaks versus okra productivity:

$Y = 2.74^{**} + 0.02\ X_1 - 0.01\ X_2 - 0.04\ X_3^{*}$; E.V. = 93.87%

2- The total counts of *P. solenopsis* at the three seasonal peaks versus the percentages of productivity loss in okra:

$Y = 2.79^{**} + 0.09\ X_1 - 0.07\ X_2^{*} - 0.03\ X_3^{*}$; E.V. = 97.60%

Where: Y= Prediction value

E.V.% = Explained variance; X_1= the population means peak at 9 WAP;
X_2= the population means peak at 15 WAP;
X_3= the population means peak at 20 WAP
***** Significant at $p\leq0.05$; ****** Highly significant at $p\leq0.01$; WAP **=** Weeks after planting

The previously mentioned findings regarding the impact of the three peaks in pest population on mango yield and losses over two consecutive seasons underscore that the influence of these factors differed from one season to the next. This might be due to many variables *i.e*., environmental conditions, rate of infestation, time of infestation, and variety ability to infestation.

The estimated yield

A simple linear regression model was used to calculate the expected okra productivity. The data presented in Table (3) indicated the maximum weight of okra yield (2.09 and 2.06 kg per plot) was obtained with the lowest numbers of *P. solenopsis* in all seasonal peaks of activity over the two seasons. While the minimum okra productivity was estimated (1.63 and 1.63 kg per plot) with the highest counts of *P. solenopsis* in all seasonal activity peaks in the two seasons, respectively (negative or inverse relationship), as shown in Table (3).

The estimated reduction in yield

Mathematical equations of linear regression were used to estimate the expected reduction in okra productivity. The results in Table (4) showed that the lowest percentage of decrease in okra productivity (3.72 and 3.13%) was noticed with the lowest numbers of *P. solenopsis* in all seasonal activity peaks in the two seasons.

Whereas the highest rates of decline in okra productivity (24.96 and 24.50%) occurred with the highest numbers of *P. solenopsis* in the periods of the three population peaks (positive relationship) in the two seasons.

Estimated values of okra productivity and its decrease with increasing numbers of *P. solenopsis*

As for the comparison between the peaks of *P. solenopsis* populations and its influence on okra productivity throughout the two seasons (2021 and 2022), we have relied on the total numbers of *P. solenopsis* per okra leaf in three periods of activity (Table 5 and illustrated in Fig., 4).

The results exhibited that the total counts of *P. solenopsis* at their peak activity at 9 weeks of age after planting were more effective, resulting in lower expected values in okra productivity with averages of 2.33 and 2.43 kg per plot during the 2021 and 2022 seasons, respectively. However, the peak activity at 20 weeks post-planting was the least damaging, resulting in the highest expected values in okra productivity with an average of 2.64 and 2.68 kg per plot in both seasons, respectively (Table 5 and illustrated in Fig., 4).

In this context, the values were estimated as an increase or decrease in the percentage of decrease in okra productivity with the increase in the numbers of *P. solenopsis* at all population peaks (Table 5 and illustrated in Fig., 4).
The results revealed that the total counts of *P. solenopsis* during peak activity at 20 weeks after planting had the least effect, leading to the lowest percentage decrease in okra productivity with an average of -21.61 and -19.68% in 2021 and 2022 seasons, respectively. However, population estimates of *P. solenopsis* were most influential during peak activity 9 weeks after planting, resulting in the highest okra productivity loss, averaging -7.45 and -8.82% over the two consecutive seasons, respectively (Table 5 and illustrated in Fig., 4).

Discussions

Mealybug known as *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) is a large and harmful insect pest that infects all parts of the okra plant, causing the plant to dry out, deform and drop the fruit [6-16]. Mealybug infestations on okra crops in Egypt have sometimes led to significant losses in the commercial crop [7-8].
The literature does not provide any information or data regarding the adverse effects of *P. solenopsis* infestation on okra crop. Therefore, the aim of the current research was to evaluate the relationship between the total population abundance of *P. solenoaspis* during three activity peaks at 9, 15, and 20 week olds after planting (WAP) (independent parameters) and the percentage decline in okra productivity (dependent parameter) throughout two seasons (2021 and 2022).
Based on our results, the first observation of mealybug populations occurred when the crop was 5 weeks after planting and continued until the plants were harvested. As well, there were three peaks of *P. solenopsis* activity on okra plants at the study site, which occurred after 9, 15, and 20 weeks after planting (WAP). Moreover, the third peak of *P. solenopsis* observed 20 weeks after planting showed the largest magnitude compared to other peaks occurring during the season. However, the peak at 9 WAP was the lowest over the two seasons; this time saw the beginning of the invasion in each season [6-7].
Our study appears that, the average total peaks of *P. solenopsis* in 2021 season were higher than those recorded in 2022 season. This can be attributed to environmental factors that were more suitable for insect growth and activity during the first season. The same results were mentioned by Mohamed, [6]; Bakry and Fathipour, [7]; Bakry, *et al*., [8]; Bakry, *et al*., [11], they reported that *P. solenopsis* had three seasonal peaks in population numbers on okra plants.
The results showed that when the total number of *P. solenopsis* plants increased during the three seasonal activity peaks, okra production gradually decreased in the two seasons. These results supported the inverse relationship between total population density at the three activity peaks and okra production in two seasons. While, the relationship between the populations of *P. solenopsis* in okra leaves and the rates of decline in okra productivity was positive at all seasonal occurrence peaks during the 2021 and 2022 season. It is clear that the increases in total population densities of *P. solenopsis* in all activity peaks were accompanied by an increase in the percentage of decline in okra yield during the two seasons. These results are consistent with those made by Hernandez, *et al*., [19], who investigated the relationship between the total population densities of *Aonidiella aurantii* (Mask.) in relation to the yield of citrus trees. They discovered a statistically significant association between fruit infestation and yield loss at harvest among successive seasons. Mohamed and Asfoor, [20] in Egypt, they studied the influence of *A. aurantii* infestation on the citrus yield. They mentioned the insect caused a decrease in yield by an amount by 27.15 - 31.14%.
The previously mentioned findings regarding the influence of the three peaks in populations on okra output and associated losses in both the 2021 and 2022 seasons validate that these factors have differing effects across different seasons. This variability could be attributed to various factors like environmental conditions, infestation rate, timing of infestation, and the susceptibility of the okra cultivar.
The linear regression mathematical equations were used to estimate the expected decline in okra productivity. The results exhibited that the lowest percentage of decline in okra productivity (3.72 and 3.13%) was observed with the lowest numbers of *P. solenopsis* plants in all seasonal activity peaks in the two seasons. While the highest rates of decline in okra productivity (24.96 and 24.50%) occurred with the highest numbers of *P. solenopsis* in the periods of the three population peaks (positive relationship) in the two seasons. These findings are comparable to those made by Reddy-Seshu, [21], who discovered a linear relationship between infestation levels and crop productivity reduction and discovered that the earlier the infestation, the greater the yield loss. Salman and Bakry, [22] in Egypt, they mentioned that the negative relationship between the mealybug, *Icerya seychellarum* population density and mango yield of mango during two successive season, respectively. Bakry and Mohamed, [23] recorded that an increase in the red scale insect, *Aonidiella aurantii* numbers in the four seasonal peaks resulted in a gradual decrease in mango productivity over the season.
The results showed that total numbers of *P. solenopsis* at peak activity at 9 weeks post-planting were more effective, resulting in lower expected values in okra yields with averages of 2.33 kg per plot in 2021 season and 2.43 kg per plot during 2022 seasons. But the peak activity at 20 weeks after planting was the least damaging, resulting in the highest predicted values in okra yield with an average of 2.64 and 2.68 kg per plot in both seasons, respectively. Most authors have studied the relationship between pest numbers and productivity of some crops. They concluded that the early infection with the pest during vegetative growth period was more sensitive than other times, causing the greatest loss in crop yield. These results are agree with Salman and Bakry, [22]; Bakry and Mohamed, [23]; El-Said, [24]; Bakry, [25] and Bakry and Tolba, [26].
In this context, the values were estimated as an increase or decrease in the percentage decrease in okra productivity with an increase in the numbers of *P. solenopsis* at all population peaks. The results showed that the total population of *P. solenopsis* during peak activity at 20 weeks after planting had the least effect, resulting in the lowest percentage decrease in okra productivity with an average of -21.61 and -19.68% in the 2021 and 2022 seasons, respectively. However, *P. solenopsis* population estimates were most influential during peak activity 9 weeks after planting, resulting in the highest loss in okra productivity,

averaging -7.45 and -8.82% over the two successive seasons, respectively.

In general, it appears that the seasonal occurrence of *P. solenopsis* during peak activity 9 weeks after planting was the most destructive throughout the two seasons, causing the greatest loss in okra productivity, which coincided with the vegetative growth cycle of okra plants. These results are consistent with Bakry and Tolba, [26] stated that the rise in population density and occurrence of *Aulacaspis tubercularis* led to a gradual decline in mango productivity, which led to an increase in the percentage of yield loss when comparing yield data with the four peak pest population and infestation rates over the two seasons. El-Zoghby, *et al*., [27] mentioned that the population of *Parlatoria oleae* during the April peak resulted in the lowest expected mango fruit yield and the greatest mango yield loss. On the contrary, the peak occurring in July had a comparatively weaker impact, leading to the highest anticipated yield and the least reduction in mango fruit yield during both seasons.

Fig 1: *P. solenopsis* is a harmful pest that attacks leaves, branches, and fruits, leading to dehydration and eventual fruit death (Source: Samples collected from a field of the infested okra plants by Dr. Moustafa M.S. Bakry).

Table 1: Effect of damage by *P. solenopsis* total counts on the okra yield during three peaks of the populations of the mealybugs throughout the two seasons (2021 and 2022).

Season	Studied plots	Yield (kg)	Yield reduction (%)	Peaks of *P. solenopsis* total counts at			Average of population counts
				9 weeks after planting	15 weeks after planting	20 weeks after planting	
2021	1	2.09±0.01	3.72	6.00±0.33	13.13±0.42	17.70±0.35	12.28±0.58
	2	2.02±0.01	7.14	6.17±0.10	13.97±0.38	18.83±0.40	12.99±0.62
	3	2.00±0.01	7.81	6.60±0.33	14.23±0.62	19.07±0.34	13.30±0.62
	4	1.95±0.01	10.35	7.60±0.30	15.13±0.35	19.33±0.42	14.02±0.58
	5	1.92±0.04	11.57	7.77±0.67	16.47±0.47	20.17±0.51	14.80±0.63

	6	1.86±0.02	14.37	8.10±0.34	17.03±0.08	21.07±0.37	15.40±0.64
	7	1.82±0.01	16.00	8.20±0.37	17.23±1.50	22.20±0.37	15.88±0.73
	8	1.74±0.01	20.09	8.63±0.60	18.63±1.17	23.63±0.34	16.97±0.77
	9	1.71±0.02	21.46	9.83±0.31	19.17±0.48	25.33±0.63	18.11±0.76
	10	1.69±0.03	22.07	10.50±0.50	19.50±0.24	27.00±1.15	19.00±0.82
	11	1.65±0.02	24.03	11.27±0.87	22.63±1.17	28.43±0.30	20.78±0.88
	12	1.63±0.02	24.96	12.80±0.44	24.97±0.59	29.17±0.51	22.31±0.83
Average		1.84±0.01	15.30	8.62±0.07	17.68±0.11	22.66±0.11	16.32±0.57
2022	1	2.16±0.02	3.13	5.97±0.17	10.50±0.23	15.83±0.42	10.77±0.48
	2	2.09±0.01	6.57	6.17±0.33	10.93±0.20	16.93±0.34	11.34±0.53
	3	2.07±0.02	7.25	6.53±0.32	12.27±0.54	17.17±0.35	11.99±0.53
	4	2.02±0.01	9.80	7.10±0.23	13.20±0.23	17.50±0.44	12.60±0.51
	5	1.99±0.04	11.03	8.00±0.17	14.67±0.42	18.33±0.42	13.67±0.51
	6	1.93±0.02	13.84	8.40±0.23	15.17±0.10	19.17±0.42	14.24±0.53
	7	1.89±0.02	15.49	8.77±0.52	15.33±1.58	20.13±0.40	14.74±0.62
	8	1.80±0.02	19.61	9.27±0.32	16.83±1.17	21.67±0.35	15.92±0.64
	9	1.77±0.02	20.98	9.43±0.17	17.47±0.39	23.00±0.44	16.63±0.66
	10	1.75±0.03	21.59	10.10±0.82	17.67±0.25	25.00±0.33	17.59±0.73
	11	1.71±0.02	23.57	11.97±0.95	20.67±1.18	26.00±0.33	19.54±0.73
	12	1.69±0.02	24.50	12.27±0.80	20.80±0.44	27.33±0.42	20.13±0.75
Average		1.90±0.01	14.78	8.66±0.07	15.46±0.10	20.67±0.11	14.93±0.50

The average production of okra fruits per plot of unsprayed plants was 2.17 and 2.23 kg/plot (area of 10.5 m^2) throughout the first and second seasons of the investigation, respectively.

Table 2: Multiple regression analysis for explain the relationship between *P. solenopsis* total counts and the okra productivity over the two seasons (2021 and 2022).

Season	Tested counts	Simple correlation and regression values				Partial correlation and regression values			Analysis variance			
		r	b	S.E	t-test	P. reg.	S.E	t-test	F values	MR	R^2	E.V.%
2021	Average no. of mealybugs/leaf at 9 weeks after planting	-0.94	-0.07	0.01	-9.07 **	0.02	0.04	0.39	40.85 **	0.97	0.94	93.87
	Average no. of mealybugs/leaf at 15 weeks after planting	-0.94	-0.04	0.005	-8.90 **	-0.01	0.02	-0.48				
	Average no. of mealybugs/leaf at 20 weeks after planting	-0.97	0.04	0.003	-12.19 **	-0.04	0.02	-2.33 *				
2022	Average no. of mealybugs/leaf at 9 weeks after planting	-0.96	-0.08	0.007	-10.87**	0.09	0.04	2.27 *	108.90 **	0.99	0.98	97.60
	Average no. of mealybugs/leaf at 15 weeks after planting	-0.98	-0.05	0.003	-13.90 **	-0.07	0.02	-3.32 *				
	Average no. of mealybugs/leaf at 20 weeks after planting	-0.97	-0.04	0.003	-12.35 **	-0.03	0.01	-2.69 *				

r = Simple correlation; b = Simple regression; P. reg. = Partial regression; MR = Multiple correlation; R^2= Coefficient of determination; E.V% = Explained variance; S.E = Standard error; * Significant at $p \leq 0.05$; ** Highly significant at $p \leq 0.01$.

Table 3: Gradual decrease in okra fruits productivity in relation to of in three peaks of activity 2021 and 2022 seasons.

Season	Inspected plots	Yield (kg)	Peak of activity at 9 weeks after planting		Peak of activity at 15 weeks after planting		Peak of activity at 20 weeks after planting		General average	
			No. of mealybugs / leaf	Expected yield	No. of mealybugs / leaf	Expected yield	No. of mealybugs / leaf	Expected yield	No. of mealybugs / leaf	Expected yield
2021	1	2.09	6.00	2.40	13.13	2.52	17.70	2.64	12.28	2.53
	2	2.02	6.17	2.40	13.97	2.52	18.83	2.63	12.99	2.53
	3	2.00	6.60	2.40	14.23	2.51	19.07	2.63	13.30	2.53
	4	1.95	7.60	2.39	15.13	2.51	19.33	2.63	14.02	2.52
	5	1.92	7.77	2.39	16.47	2.51	20.17	2.63	14.80	2.52
	6	1.86	8.10	2.39	17.03	2.50	21.07	2.62	15.40	2.52
	7	1.82	8.20	2.39	17.23	2.50	22.20	2.62	15.88	2.52
	8	1.74	8.63	2.39	18.63	2.50	23.63	2.61	16.97	2.51
	9	1.71	9.83	2.38	19.17	2.49	25.33	2.61	18.11	2.51
	10	1.69	10.50	2.37	19.50	2.49	27.00	2.60	19.00	2.50
	11	1.65	11.27	2.37	22.63	2.48	28.43	2.59	20.78	2.49
	12	1.63	12.80	2.36	24.97	2.47	29.17	2.59	22.31	2.49
2022	1	2.16	5.97	2.51	10.50	2.57	15.83	2.68	10.77	2.59
	2	2.09	6.17	2.50	10.93	2.57	16.93	2.67	11.34	2.58
	3	2.07	6.53	2.50	12.27	2.57	17.17	2.67	11.99	2.58
	4	2.02	7.10	2.50	13.20	2.56	17.50	2.67	12.60	2.58

	5	1.99	8.00	2.49	14.67	2.56	18.33	2.67	13.67	2.57
	6	1.93	8.40	2.49	15.17	2.55	19.17	2.66	14.24	2.57
	7	1.89	8.77	2.49	15.33	2.55	20.13	2.66	14.74	2.57
	8	1.80	9.27	2.48	16.83	2.55	21.67	2.65	15.92	2.56
	9	1.77	9.43	2.48	17.47	2.54	23.00	2.65	16.63	2.56
	10	1.75	10.10	2.48	17.67	2.54	25.00	2.64	17.59	2.55
	11	1.71	11.97	2.46	20.67	2.53	26.00	2.64	19.54	2.54
	12	1.69	12.27	2.46	20.80	2.53	27.33	2.63	20.13	2.54

Table 4: Gradual increase in yield loss with the population density increase of the total population of *P. oleae* during three peaks of the seasonal activity during the two successive seasons.

Season	Inspected plots	% Yield reduction	Peak of activity at 9 weeks after planting		Peak of activity at 15 weeks after planting		Peak of activity at 20 weeks after planting		General average	
			No. of mealybugs / leaf	% Estimated reduction	No. of mealybugs / leaf	% Estimated reduction	No. of mealybugs / leaf	% Estimated reduction	No. of mealybugs / leaf	% Estimated reduction
2021	1	3.72	6.00	-10.69	13.13	-16.01	17.70	-21.31	12.28	-16.53
	2	7.14	6.17	-10.64	13.97	-15.85	18.83	-21.11	12.99	-16.38
	3	7.81	6.60	-10.50	14.23	-15.80	19.07	-21.07	13.30	-16.32
	4	10.35	7.60	-10.17	15.13	-15.62	19.33	-21.02	14.02	-16.17
	5	11.57	7.77	-10.12	16.47	-15.37	20.17	-20.88	14.80	-16.01
	6	14.37	8.10	-10.01	17.03	-15.26	21.07	-20.72	15.40	-15.89
	7	16.00	8.20	-9.98	17.23	-15.22	22.20	-20.52	15.88	-15.79
	8	20.09	8.63	-9.84	18.63	-14.95	23.63	-20.27	16.97	-15.57
	9	21.46	9.83	-9.45	19.17	-14.85	25.33	-19.97	18.11	-15.34
	10	22.07	10.50	-9.24	19.50	-14.79	27.00	-19.68	19.00	-15.16
	11	24.03	11.27	-8.99	22.63	-14.19	28.43	-19.43	20.78	-14.79
	12	24.96	12.80	-8.49	24.97	-13.74	29.17	-19.30	22.31	-14.48
2022	1	3.13	5.97	-12.17	10.50	-15.18	15.83	-19.71	10.77	-15.79
	2	6.57	6.17	-12.10	10.93	-15.09	16.93	-19.51	11.34	-15.66
	3	7.25	6.53	-11.98	12.27	-14.81	17.17	-19.47	11.99	-15.53
	4	9.80	7.10	-11.79	13.20	-14.62	17.50	-19.41	12.60	-15.40
	5	11.03	8.00	-11.49	14.67	-14.31	18.33	-19.26	13.67	-15.17
	6	13.84	8.40	-11.35	15.17	-14.21	19.17	-19.11	14.24	-15.05
	7	15.49	8.77	-11.23	15.33	-14.17	20.13	-18.93	14.74	-14.94
	8	19.61	9.27	-11.06	16.83	-13.86	21.67	-18.66	15.92	-14.69
	9	20.98	9.43	-11.01	17.47	-13.73	23.00	-18.42	16.63	-14.54
	10	21.59	10.10	-10.79	17.67	-13.69	25.00	-18.06	17.59	-14.33
	11	23.57	11.97	-10.16	20.67	-13.06	26.00	-17.87	19.54	-13.92
	12	24.50	12.27	-10.06	20.80	-13.04	27.33	-17.63	20.13	-13.79

Table 5: Estimated values (increase or decrease) in okra productivity and its decrease with increasing numbers of *P. solenopsis* over the three peaks of the populations in 2021 and 2022 seasons.

Season	No. of insects / leaf	Estimated yield			% Yield reduction		
		Peak of activity at 9 weeks after planting	Peak of activity at 15 weeks after planting	Peak of activity at 20 weeks after planting	Peak of activity at 9 weeks after planting	Peak of activity at 15 weeks after planting	Peak of activity at 20 weeks after planting
2021	1	2.44	2.57	2.70	-12.3	-18.3	-24.2
	4	2.42	2.56	2.69	-11.3	-17.8	-23.7
	7	2.40	2.54	2.68	-10.4	-17.2	-23.2
	10	2.38	2.53	2.66	-9.4	-16.6	-22.7
	13	2.36	2.52	2.65	-8.4	-16.0	-22.1
	16	2.33	2.51	2.64	-7.5	-15.5	-21.6
	19	2.31	2.49	2.63	-6.5	-14.9	-21.1
	22	2.29	2.48	2.62	-5.5	-14.3	-20.6
	25	2.27	2.47	2.61	-4.5	-13.7	-20.0
	28	2.25	2.46	2.60	-3.6	-13.2	-19.5
	31	2.23	2.44	2.58	-2.6	-12.6	-19.0
Mean	160	2.33	2.51	2.64	-7.45	-15.46	-21.61
2022	1	2.54	2.62	2.74	-13.8	-17.2	-22.4
	4	2.52	2.60	2.72	-12.8	-16.5	-21.9
	7	2.50	2.59	2.71	-11.8	-15.9	-21.3
	10	2.48	2.58	2.70	-10.8	-15.3	-20.8
	13	2.45	2.56	2.69	-9.8	-14.7	-20.2
	16	2.43	2.55	2.68	-8.8	-14.0	-19.7
	19	2.41	2.54	2.66	-7.8	-13.4	-19.1
	22	2.39	2.52	2.65	-6.8	-12.8	-18.6

	25	2.36	2.51	2.64	-5.8	-12.2	-18.1
	28	2.34	2.49	x2.63	-4.8	-11.5	-17.5
	31	2.32	2.48	2.62	-3.8	-10.9	-17.0
Mean	160	2.43	2.55	2.68	-8.82	-14.03	-19.68

2021 Season

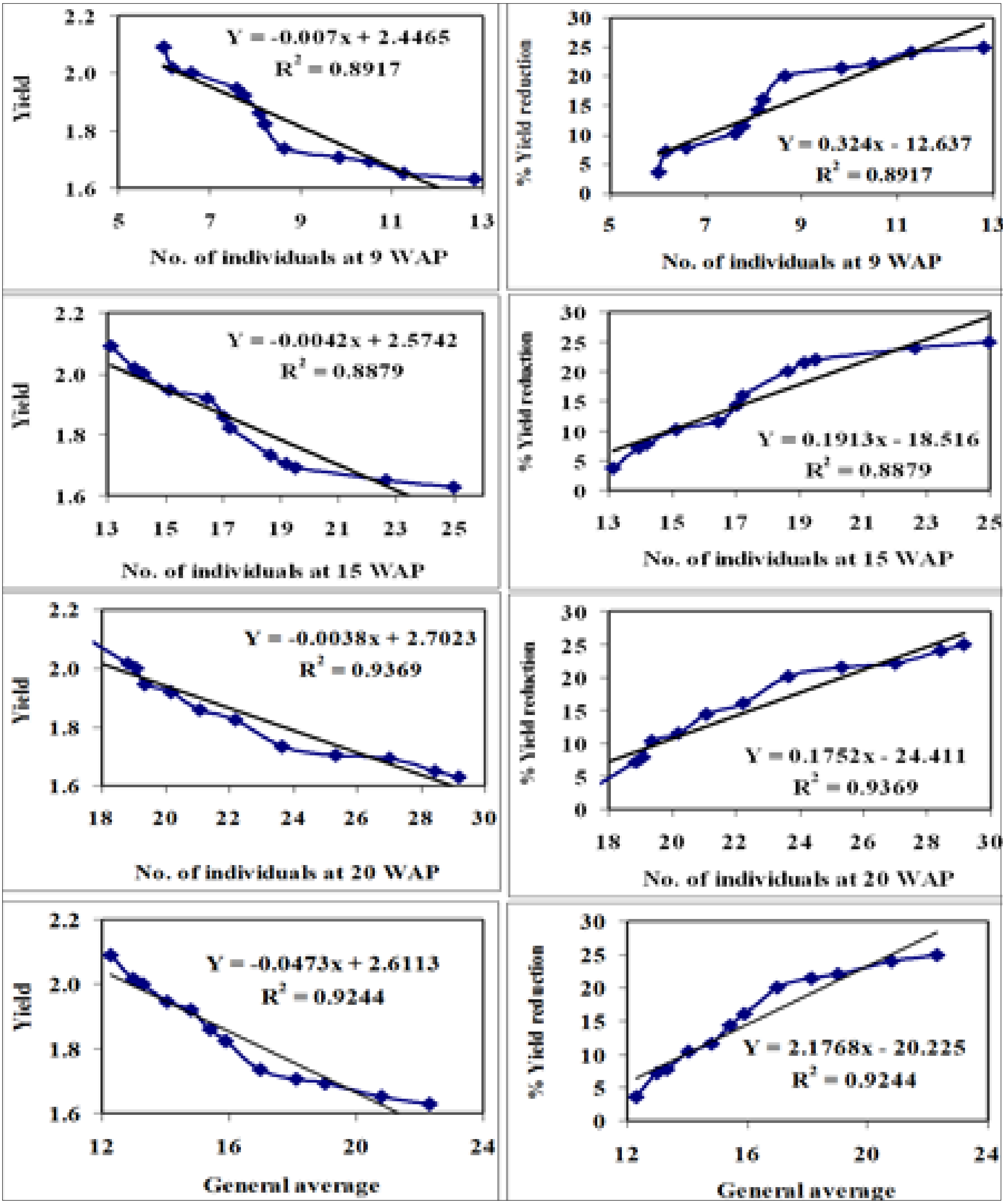

Fig 2: Relationship between the population estimates of *P. solenopsis* and okra productivity and yield reduction in 2021 season

2022 Season

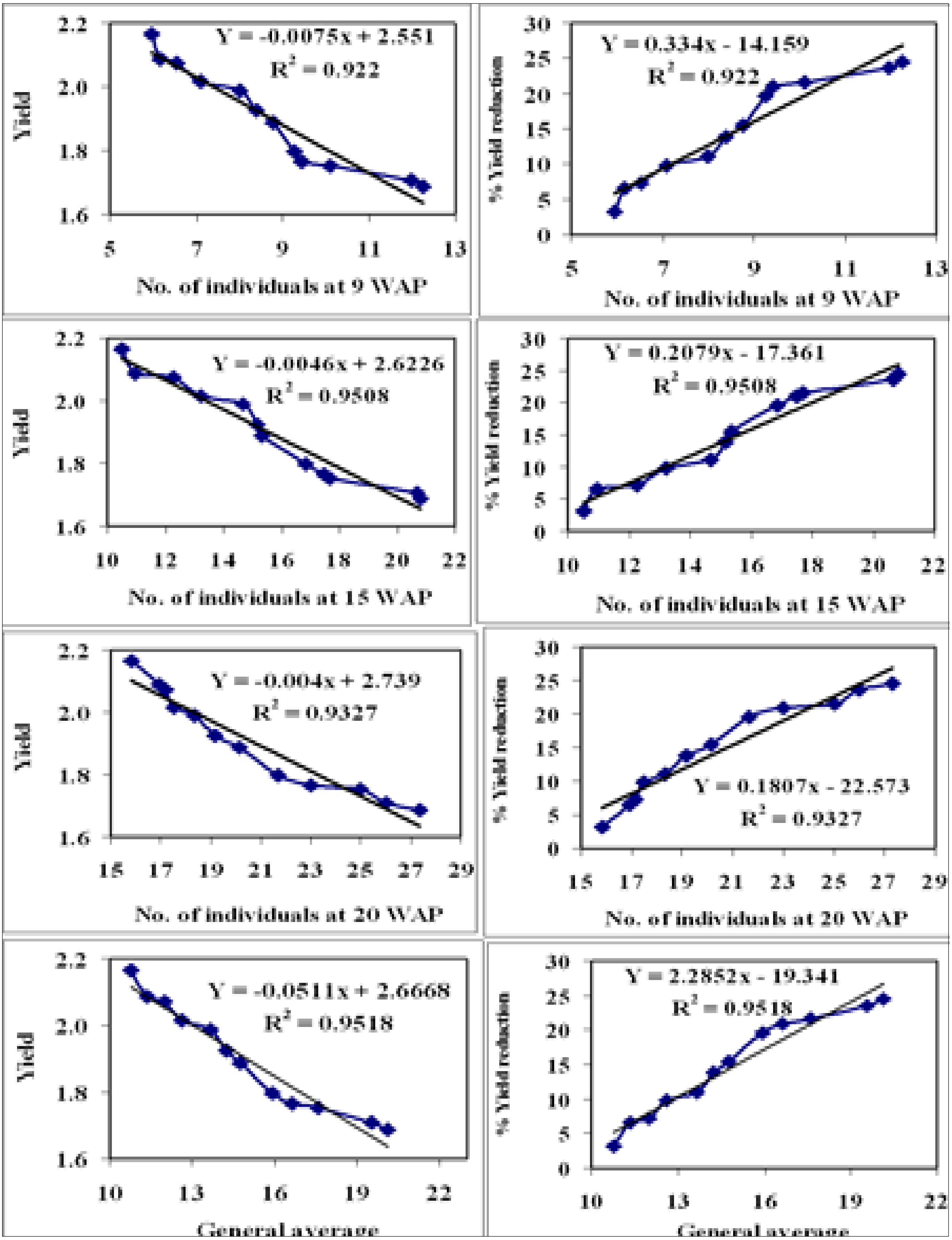

Fig 3: Relationship between the population estimates of *P. solenopsis* and okra productivity and yield reduction in 2022 season

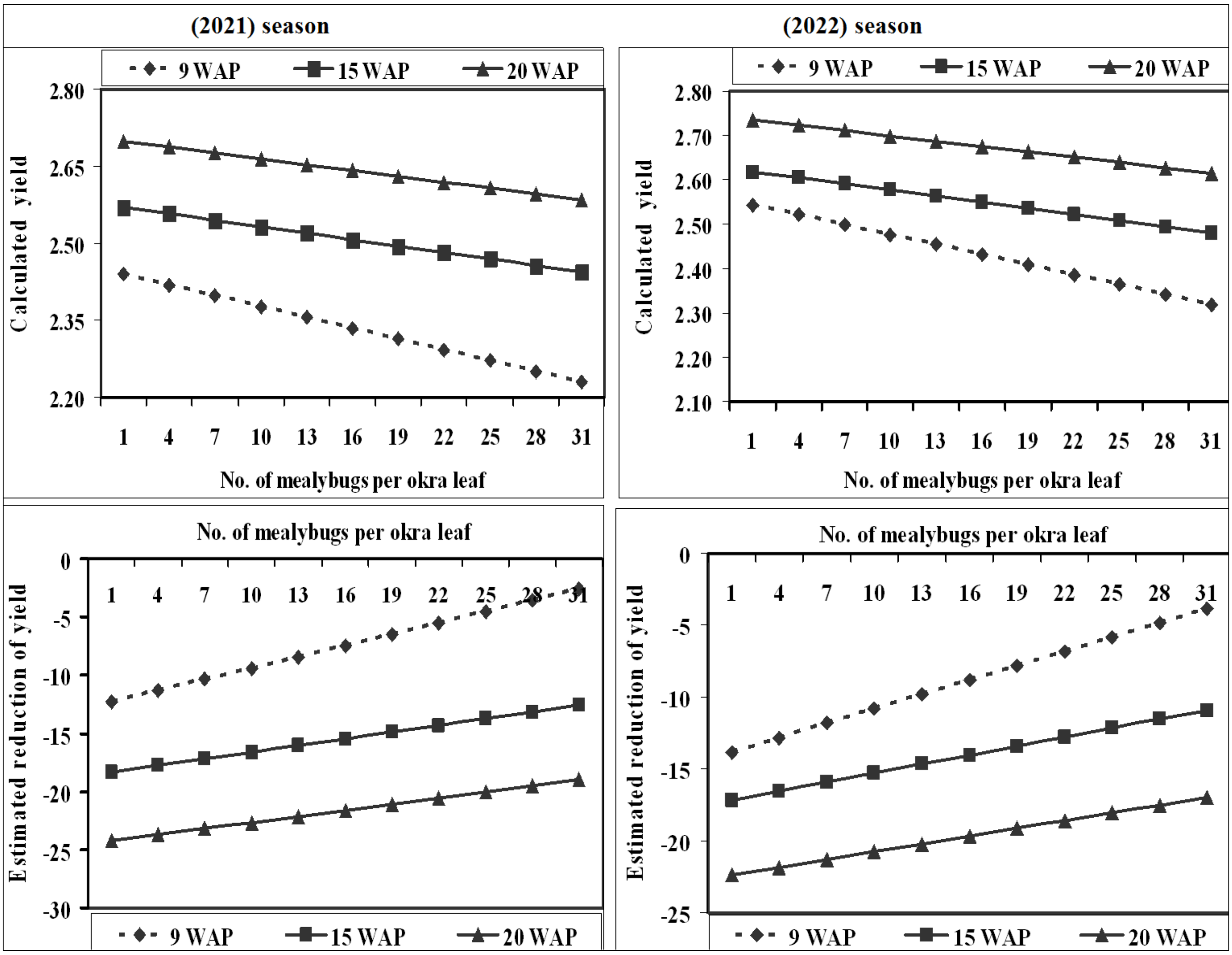

Fig 4: Estimated values (increase or decrease) in okra productivity and its decrease with increasing numbers of *P. solenopsis* over the three peaks of the populations in 2021 and 2022 seasons.

Conclusion and Recommendation

After studying the data for the two-season period, it becomes clear that the increasing numbers of *P. solenopsis* individuals led to a gradual decrease in okra fruit production, resulting in a greater percentage of production decline at all peaks of pest activity. The degree of infestation, severity of infestation, and susceptibility of the host plant to invasion are known to be among the most important of several factors that contribute to decreased okra fruit production.

Significance statement

This work can help evaluate the relationship between total populations of *P. solenopsis* at different activity peaks and okra productivity.

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Author Contributions

MMSB designed the experiment, data collection, wrote the paper and performing data analysis. LHYM and EAS revising the first draft of the manuscript and revising the final manuscript and Interpretation of the results. All authors agreed the final manuscript.

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Ethics Approvals: Not applicable in this paper.

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