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Research Article
Population Dynamics of Abundant Three Terrestrial Snail Species in Horticultural Fields at Beheira and Giza Governorate, Egypt

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Abstract

Background and Objective: Studying the population dynamic of the invasive terrestrial snails as agricultural pests, is essential for designing pest control program to reduce the economic losses to commercial field crops, vegetables and fruits. The population dynamic had been estimated for the three terrestrial snails *Theba pisana* (Müller, 1774) (Helicidae), *Eobania vermiculata* (Müller, 1774) (Helicidae) and *Monacha obstructa* (Pfeiffer, 1842) (Hygromiidae) on orange, apple and mango trees in horticultural fields in two locations. These locations are Nobaria City, Beheira Governorate and Mansouria Village, Giza Governorate. This study carried out during the two consecutive activity seasons September, 2018/August, 2019 and September, 2019/August, 2020. **Materials and Methods:** The population dynamic, incidence and infestation level of terrestrial snails had been recorded on economic host plants such as fruit trees and other field crops and vegetables. The correlations between climatic factors and the population density of land snails were interpreted by statistical analysis for the two seasons. **Results:** The population density of terrestrial snails increased gradually after winter to reach its maximum density during spring, while the lowest density was recorded in August. The incidence and infestation level of terrestrial snails varied according to the host plant, climatic factors and locality. *Eobania vermiculata* were the dominant land snail species in Beheira, while *Monacha obstructa* infested the majority of the examined fruit trees in Giza. **Conclusion:** Determining the activity and inactivity periods of land snails through the two seasons and their population dynamic will assist in designing effective control management program to decrease the number of pest and the economic losses of agricultural products.

Key words: Infestation, *Eobania vermiculata*, *Monacha obstructa*, population dynamic, population density, survey, *Theba pisana*

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Terrestrial snails consider one of the serious and dangerous agricultural pests that were introduced to Egypt as they become major agricultural and horticultural pest-infested diverse varieties of commercial crops, fruits, vegetables and ornamental plants. Terrestrial snails cause severe harm to host plants with high economic damages[1-4]. The terrestrial snails occurred in high population in the Delta region of Egypt[5-7] as well as in upper Egypt Governorate such as Fayoum[8,9], Assuit[10,11] and Sohag Governorate[12-14], where the climatic conditions high-temperature degrees and low level of humidity as hard climatic conditions for snails surviving. The three land snail species were reported in multiple governorates such as Alexandria[15], Beheira[16], Sharkia[17], Gharbia[18], Kafr El-Sheikh[19], Monufia, Qalubia, Dakahlia, Damietta and Ismailia[5], Giza[7] as well as in the Coastal region of Nile Delta.

Terrestrial snails reported on different field crops and vegetation, which are capable of spreading to new areas due to their tolerances against unfavourable climatic conditions such as hot and dry conditions[20]. Snails have high fecundity and adaptability to live in new habitats. They can ensure their survival and successful reproduction under heat and drought stress[20].

Temperature and relative humidity are the main factors that determine snails' activity and influence their occurrence[21]. The land snails become a widespread pest due to human activities, transport from infested regions to new areas[13]. Afterwards, this pest adapted to the new environment where several preferable host plants are present[13].

Numerous of previous studies discussed the population dynamic of many terrestrial snails in several governorates on infested economic field crops[15,22].

This study aimed to obtain necessary data on population dynamic and the density of common land snail species. In addition to record the activity and inactivity periods of land snails during the two seasons. Furthermore, understand the correlation between the population dynamic and the main climatic factors such as temperature and relative humidity. This work will support the growers in designing effective pest control management programs.

MATERIALS AND METHODS

Study area: The population density of terrestrial snails, which were distributed in two locations, was carried out on orange, apple and mango trees as host plants during September, 2018/August, 2019 and September, 2019/August, 2020. These locations are Nobaria City in Beheira Governorate and Mansoura Village in Giza Governorate. Their incidence and level of infestation were recorded on other vegetables, field crops and fruit trees.

Collecting samples: The terrestrial snail samples were observed and counted on the tree trunk one time every month. Ten fruit trees were selected randomly for the snails counting. The counting was in the early hours of the morning for estimating the population dynamic. For recording the level of infestation, the quadrate technique (50×50 cm^2) in fields was used every month for vegetables and ornamental plants[23]. The snails on host plants' leaves and soil surface around a tree trunk in quadrate were recorded[24]. The snail species were identified according to Ali and Ramdane[6].

Correlation between population dynamic and climatic factors: The monthly average temperature degree and relative humidity of the two locations were obtained from Central Climate Laboratory. The correlations between temperature and relative humidity as climatic factors and population density of the three land snails were interpreted for statistical analysis (SAS/ACCESS® 9.4 Interface to ADABAS, https://documentation.sas.com/doc/en/pgmsascdc/9.4_3.5/acadbas/titlepage.htm) with $p \leq 0.05$ during the two growing seasons.

RESULTS

The population dynamic of the three terrestrial snails had been recorded on three fruit trees orange, apple and mango in Nobaria City, Beheira Governorate and Mansoura Village, Giza Governorate during two activity seasons 2018/2019 and 2019/2020. The species are *Theba pisana* (Helicidae) and *Eobania vermiculata* (Helicidae) found in Nobaria City, Beheira Governorate. The species *E. vermiculata* and *Monacha obstructa* (Hygromiidae) were reported in Mansouria Village, Giza Governorate, where *M. obstructa* prefers to infest the leafy vegetables.

The incidence of snails had been evaluated according to their level of infestation on each host plant, climatic factors and locality. The listed host plants are categorized into three groups heavy, moderate and low infestation in Table 1. *Eobania vermiculata* was the common species spread in Beheira and Giza Governorates.

Table 1: Incidence and infestation level of the common three terrestrial snails on different field crops during the activity season started from September, 2018/August, 2019 and September, 2019/August, 2020

Location (city or village, governorate)	Terrestrial gastropod species	Host plant and level of infestation
Nobaria City, Beheira Governorate	*Theba pisana*	Orange (+++), mango (+++), apple (+++), apricot (+), potato (+), onion (+)
	Eobania vermiculata	Orange (+++), mango (+++), apple (+++), apricot (++), potato (+), onion (+)
Mansoria Village, Giza Governorate	*Monacha obstructa*	Egyptian clover (+++), cucumber (+++), eggplant (++), paper (++), wheat (++), broad bean (++), cabbage (++), lettuce (++), apple (++), orange (+), mango (+), olive (+), grape (+), pear (+), onion (+), mint (+), basil (+), palm tree (+)
	Eobania vermiculata	Orange (+++), mango (+++), apple (++), olive (+), grape (+++), pear (+++), paper (++), Egyptian clover (++), cabbage (++), lettuce (++), palm tree (++), eggplant (+), mint (+), basil (+), pomegranate (+)

(+): Low infestation (less than 15 snails/ 50×50 cm^2), (++): Moderate infestation (between 15-30 snails/ 50×50 cm^2) and (+++): Heavy infestation (more than 30 snails/ 50×50 cm^2)

The most susceptible fruit tree to infestation by *Theba pisana* and *Eobania vermiculata* are orange, mango and apple trees in Nobaria City in Beheira Governorate. The infestation was recorded in 50×50 cm^2 by more than 30 individual snails per one meter square, which were identified as heavy infestations (+++).

The fruit trees that are most affected are coming are apricot, potato and onion, where the number of snails was less than 15 individuals in 50×50 cm^2 and classified as a low infestation (+).

The same degree of infestation was reported by *Eobania vermiculata* on the same trees in Mansoria Village, Giza Governorate as well, which also recorded more than 30 individual snails in 50×50 cm^2 as heavy infestation (+++).

The number of infested crops and host plants was more in Mansoria Village, Giza Governorate, where the spread of *Monacha obstructa* and *Eobania vermiculata* increased and reported many times on other crops.

Green succulent and leafy vegetables were the most susceptible host plants for infestation by *Monacha obstructa*. The preferred host plants for *M. obstructa* were Egyptian clover and cucumber. The recorded number of individual snails was more than 30 individual snails in 50×50 cm^2 as heavy infestation (+++), while the other leafy vegetables recorded between 15-30 individual snails in 50×50 cm^2 as moderate infestation (++) such as eggplant, paper, wheat, broad bean, cabbage, lettuce and apple as fruit trees.

Monacha obstructa occurred on several host plants however, there was no high infestation as it was recorded by less than 15 individual snails in 50×50 cm^2 as low infestation (+).

At the same location, *Eobania vermiculata* was recorded as moderate infestation (++) on vegetables and leafy host plants, while the same species reported as low infestation (+) on fruits such as pomegranate trees and ornamental plants such as mint and basil.

The infested host plants had been surveyed in this study. These host plants are field crops such as Egyptian clover, *Trifolium alexandrinum* L. (Fabaceae), wheat *Triticum aestivum* L. (Poaceae), broad bean *Vicia faba* L. (Fabaceae), vegetable crops such as cabbage *Brassica oleracea* L. (Brassicaceae), onion *Allium cepa* L. (Amaryllidaceae), lettuce *Lactuca sativa* L. (Asteraceae), potato *Solanum tuberosum* L. (Solanaceae), eggplant *Solanum melongena* L. (Solanaceae), cucumber *Cucumis sativus* L. (Cucurbitaceae), bell pepper *Capsicum annuum* L. (Solanaceae), horticultural crops such as orange *Citrus sinensis* L. (Rutaceae), grape *Vitis vinifera* L. (Vitaceae), mango *Mangifera indica* L. (Anacardiaceae), apple *Malus domestica* Borkh. (Rosaceae), apricot *Prunus* sp. (Rosaceae), olive *Olea europaea* L. (Oleaceae), pear *Pyrus* sp. (Rosaceae), pomegranate *Punica granatum* L. (Lythraceae) and date palm *Phoenix dactylifera* L. (Arecaceae) as well as ornamental and herbal plants such as peppermint *Mentha* sp. (Lamiaceae) and basil *Ocimum basilicum* L. (Lamiaceae).

Population dynamic of *Eobania vermiculata* in Nobaria City, Beheira Governorate: The monthly population dynamic of *Eobania vermiculata* showed noticeable differences in species distribution and degree of infestation on host fruit trees such as orange, apple and mango according to temperatures degree and relative humidity level.

In season September, 2018/August, 2019, the highest monthly population numbers of *E. vermiculata* were recorded in March and April (Table 2). The monthly density of snail numbers on infested orange, apple and mango trees recorded 107.4, 98.5 and 78.1 individuals per 10 trees in March, while the monthly density recorded 106.1, 95.4 and 76.9 individuals per 10 trees on the same trees in April, respectively (Table 2). The lowest monthly density of snails was recorded in August, where the number of individuals averaged 10.8, 9.7 and 14.5 individuals per 10 trees of orange, apple and mango trees, respectively (Table 2). Orange trees were the most susceptible host plant to infestation. The total number of snails for the season recorded 619.5 snails on orange trees, 549.3 snails, on apple trees and then 446.2 snails on orange trees (Table 2), which showed a difference in the total number of snails on each type of tree.

Table 2: Population dynamics of *Eobania vermiculata* that infested three fruit trees orange, apple and mango trees during two consecutive seasons 2018/2019 and 2019/2020

	Average number of snails (individuals)/10 trees									
	Orange		Apple		Mango		Temperature (°C)		R.H (%)	
Months	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2018/2019
September, 2018	21.6	28.8	8.3	10.2	11.0	16.1	27.3	26.7	47.1	47.6
October	30.4	29.5	9.0	12.1	19.2	20.4	24.0	24.7	50.8	53.5
November	36.9	42.0	17.8	19.8	30.9	22.0	19.7	20.9	55.9	51.8
December	41.1	47.9	30.9	36.4	37.6	29.8	15.2	15.5	63.3	63.7
January, 2019	50.1	59.0	51.5	51.8	50.2	31.9	11.6	12.9	50.1	67.4
February	71.9	65.5	64.2	68.9	15.9	36.5	13.2	13.7	53.1	63.8
March	107.4	92.0	98.5	85.3	78.1	50.1	15.4	15.9	51.5	56.6
April	106.1	88.9	95.4	84.2	76.9	51.2	18.9	18.5	43.0	53.7
May	78.3	71.3	77.9	63.0	52.8	43.3	25.3	22.8	29.2	46.9
June	43.0	39.7	56.0	32.0	33.0	26.1	27.9	26.1	38.0	37.1
July	21.9	33.4	30.1	19.1	26.1	10.4	29.1	28.3	38.7	38.7
August	10.8	21.2	9.7	10.5	14.5	9.2	29.1	28.9	39.8	41.3
Total	619.5	619.2	549.3	493.3	446.2	347.0				
Average	51.6	51.6	45.8	41.1	37.2	28.9				

Regarding season September, 2019/August, 2020, the highest monthly population numbers of *E. vermiculata* were reported in March and April (Table 2). *E. vermiculata* numbers recorded 92, 85.3 and 50.1 individuals per 10 trees on infested orange, apple and mango in March, respectively, while it recorded 88.9, 84.2 and 51.2 individuals per 10 trees on the same trees in April, respectively (Table 2). August was the unfavourable month in terms of weather conditions and were reported with the lowest monthly density of snail numbers. The monthly density averaged 21.2, 10.5 and 9.2 individuals per 10 trees on orange, apple and mango trees, respectively.

In this season, orange trees were the most susceptible host plant to infestation. The total snail numbers recorded 619.2 snails on orange, 493.3 snails on apple trees and then 347 snails on orange trees (Table 2).

Eobania vermiculata survives over a wide range of temperatures. Snail activity is influenced by the change of temperature degrees, where the temperature is one of the most main factors along with humidity that affect land snail activity. Table 3 revealed that temperature and relative humidity showed the variable effect on the population density of *E. vermiculata* on three types of fruit trees.

The total number of snails was higher in the first season compared to the total number of snails in the second season on the three types of trees. Table 3 showed that the temperature has a non-significant effect on the *E. vermiculata* activity, its spread on the three types of fruit trees during the growing season 2018/2019, while it shows a significant effect on *E. vermiculata* number during the growing season 2019/2020, on the three fruit trees due to increase in temperature degrees. The temperature showed an insignificant negative effect on the total number of *E. vermiculata* on orange, apple and mango trees by -0.54, -0.44 and -0.44 in season 2018/2019, respectively.

This insignificant negative effect was observed on orange, apple and mango with a linear regression coefficient of -0.10, -0.09 and -0.12 individually.

In season 2019/2020, the temperature showed a significant negative effect on the total number of *E. vermiculata* by -0.69, -0.71 and a significant positive effect of 0.71 on orange, apple and mango trees, respectively.

The linear regression coefficient on the same fruit trees showed -0.19, -0.14 and -0.28 individually.

There was variation in temperature degrees in the second season, resulting in a decrease in the total number of snails due to a rise in temperatures in few months in the second season compared to the first season.

The effect of relative humidity was reported on the population density of this *E. vermiculata*.

It showed an insignificant negative effect on the total number of snails by -0.03, -0.2 and -0.07 on orange, apple and mango trees in season 2018/2019, respectively. While in 2019/2020, it showed an insignificant positive effect by the same correlation coefficient value of 0.46 on the three fruit tree types. This insignificant negative effect was observed on the same fruit trees with a linear regression coefficient of -0.007, -0.06 and -0.03 in season 2018/2019 individually, while in 2019/2020, the linear regression coefficient on the same fruit trees showed 0.46, 0.46 and 0.48 individually.

Table 3: Correlation between climatic factors temperature degree, relative humidity and population density of *Eobania vermiculata* during two consecutive seasons 2018/2019 and 2019/2020

	Temperature (°C)						Relative humidity (%)					
	2018/2019			2019/2020			2018/2019			2019/2020		
Host plant	r	b	p-value	r	b	p-value	r	b	p-value	r	b	p-value
Orange	-0.54	-0.10	0.6^{ns}	-0.69	-0.19	0.01*	-0.03	-0.007	0.9^{ns}	0.46	0.46	0.1^{ns}
Apple	-0.44	-0.09	0.1^{ns}	-0.71	-0.14	0.01*	-0.2	-0.06	0.4^{ns}	0.46	0.46	0.1^{ns}
Mango	-0.44	-0.12	0.1^{ns}	0.71	-0.28	0.01*	-0.07	-0.03	0.3^{ns}	0.46	0.48	0.1^{ns}

$p \leq 0.05$, r: Simple correlation, b: Liner regression coefficient, ns: Non-significance, *Significant and **Highly significant

Table 4: Population dynamics of *Theba pisana* that infested three fruit trees orange, apple and mango trees during two consecutive seasons 2018/2019 and 2019/2020

	Average number of snails (individuals)/10 trees									
	Orange		Apple		Mango		Temperature (°C)		R.H (%)	
Months	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2018/2019
September, 2018	11.9	12.8	10.0	12.0	23.1	8.7	27.3	26.7	47.1	47.6
October	20.4	16.7	11.0	18.0	28.6	20.0	24.0	24.7	50.8	53.5
November	26.5	18.0	16.2	20.0	30.9	23.6	19.7	20.9	55.9	51.8
December	32.0	23.2	20.9	21.0	31.6	29.7	15.2	15.5	63.3	63.7
January, 2019	36.3	25.0	27.0	23.9	33.4	35.9	11.7	12.9	50.1	67.4
February	41.0	34.1	31.8	28.1	38.1	41.7	13.2	13.7	53.1	63.8
March	61.1	45.2	46.7	55.1	50.2	62.8	15.4	15.9	51.5	56.6
April	55.9	44.2	43.0	52.0	46.3	61.3	18.9	18.5	43.0	53.7
May	42.1	23.9	38.1	41.6	31.2	36.3	25.3	22.8	29.2	46.9
June	21.8	16.8	14.1	27.3	15.0	19.0	27.9	26.1	38.0	37.1
July	16.2	12.0	10.2	13.5	6.9	5.2	29.1	28.3	38.7	38.7
August	9.7	7.9	8.9	5.6	4.3	2.1	29.1	28.9	39.8	41.3
Total	374.9	263.1	277.9	318.1	311.0	346.1				
Average	31.2	21.9	23.2	26.5	25.9	28.8				

The relative humidity showed an insignificant effect on *E. vermiculata* number during the two growing seasons. This may be due to the low level of humidity that was recorded during the two-season and no fluctuations in humidity in Nobaria City. Usually, the snail species show a tendency to be more active in high humidity levels, which is clear in the snail populations in natural field conditions.

Population dynamics of *Theba pisana* in Nobaria City, Beheira Governorate: During season September, 2018/ August, 2019, March and April are the most suitable months for increasing the number of snails and infestations, where the temperature degree and relative humidity are the most optimum conditions for snail's activity.

The highest monthly density number of *Theba pisana* recorded 61.1, 46.7 and 50.2 individuals per 10 trees on orange, apple and mango trees in March, respectively, while it recorded 55.9, 43 and 46.3 individuals per 10 trees on the same trees in April, respectively (Table 4). In August, the lowest number of *T. pisana* was recorded 9.7, 8.9 and 4.3 individuals per 10 trees on orange, apple and mango trees individually (Table 4).

In season September, 2018/August, 2019, the total snail numbers recorded 374.9 snails on oranges, 311 snails on mango trees then 277.9 snails on apple trees (Table 4).

The monthly density of *Theba pisana* recorded 45.2, 55.1 and 62.8 individuals per 10 trees on orange, apple and mango trees in March, respectively, while it recorded 44.2, 52 and 61.3 individuals per 10 trees on the same trees in April, respectively (Table 4). The lowest density number of snails was recorded at 7.9, 5.6 and 2.1 individuals per 10 trees on orange, apple and mango trees in August, respectively.

The climatic condition was different where the highest total snail numbers recorded 346.1 on mango trees, 318.1 snails on apple trees then 263.1 snails on orange trees (Table 4).

Table 5 represent the correlations between the climatic factors, temperature and relative humidity and population density of *Theba pisana.* These factors showed variable effects on the population density of *T. pisana* on orange, apple and mango trees.

The temperature has a direct and effective influence on snails' activity. Temperatures degree showed a significant effect on number of *Theba pisana* on orange and apple trees, which recorded large numbers of total snails on these trees, plus this effect became highly significant on individual's snail number on mango tree during September, 2018/August, 2019.

Table 5: Correlation between climatic factors temperature degree, relative humidity and population density of *Theba pisana* during two consecutive seasons 2018/2019 and 2019/2020

	Temperature (°C)						Relative humidity (%)					
	2018/2019			2019/2020			2018/2019			2019/2020		
Host plant	r	b	p-value	r	b	p-value	r	b	p-value	r	b	p-value
Orange	-0.68	-0.27	0.01*	-0.74	0.005	0.005**	0.12	0.69	0.7^{ns}	0.55	0.55	0.06^{ns}
Apple	-0.60	0.24	0.03*	-0.51	0.08	0.08^{ns}	-0.021	-0.01	0.9^{ns}	0.26	0.26	0.4^{ns}
Mango	-0.78	0.36	0.002**	-0.77	0.41	0.003**	0.41	0.27	0.1^{ns}	0.18	0.58	0.04*

$p \leq 0.05$, r: Simple correlation, b: Liner regression coefficient, ns: Non-significance, *Significant and **Highly significant

As temperature decreases, the snail activity increases in the field. The temperature showed a significant negative effect on the total number *Theba pisana* in season September, 2018/August, 2019 by -0.68 and -0.60 on orange and apple trees, respectively and highly significant by -0.78 on mango trees. In season September, 2019/August, 2020, the temperature showed a highly significant negative effect on the total number of this species by -0.74 and -0.77 on orange and mango trees, respectively, it showed an insignificant negative effect of -0.51 on apple trees. Furthermore, this significant negative effect was obtained on the same fruit trees orange, apple and mango with a linear regression coefficient of -0.27, 0.24 and 0.36 in season 2018/2019 individually, while in season 2019/2020 the linear regression coefficient recorded 0.005, 0.08 and 0.41 on the same fruit trees individually.

Higher humidity is associated with the greater activity of snails. The effect of relative humidity was stated on the population density of *T. pisana*. It showed an insignificant negative and positive effect on the total number of snails by 0.12, -0.021 and 0.41 on orange, apple and mango trees in season September, 2018/August, 2019 individually. While in 2019/2020, the effect of relative humidity showed an insignificant positive effect of 0.55 and 0.26 on orange and apple trees individually and a significant effect of 0.18 on mango trees.

This insignificant negative effect was observed on the same fruit trees with a linear regression coefficient of 0.69, -0.01 and 0.27 in season 2018/2019 individually, while in 2019/2020, the linear regression coefficient on the same fruit trees showed 0.55, 0.26 and 0.58 individually.

This may be due to the lack of moisture and short duration of humidity during the seasons, which did not affect significantly snails' activity.

Population dynamics of *Monacha obstructa* in Mansoria Village, Giza Governorate: During season September, 2018/August, 2019, the highest monthly number of snails was recorded in spring (March and April). The monthly density of *Monacha obstructa* recorded 28.1, 27.3 and 26.7 individuals per 10 trees on orange, apple and mango trees in March, respectively, while it recorded 21.6, 24.9 and 26.1 individuals per 10 trees on the same trees in April, respectively (Table 6).

The lowest monthly density of snail number was in August recorded 3.2, 5.8 and 2.1 individuals per 10 trees on orange, apple and mango trees, respectively (Table 6).

The total snail number of *Monacha obstructa* recorded 172.9 snails on apple trees followed by 160.8 snails on mango trees then 151 snails on orange trees (Table 6).

In season September, 2019/August, 2020, the highest monthly density number of *M. obstructa* was recorded in spring months. In March, it recorded 27.4, 21.9 and 32.7 individuals per 10 trees on orange, apple and mango trees, respectively, while it recorded 26.9, 20.5 and 31.9 individuals per 10 trees on the same fruit trees in April individually.

The lowest monthly density of snail number was recorded in August recorded 5.9, 4.1 and 4.8 individuals per 10 trees on orange, apple and mango trees, respectively (Table 6). The total snail numbers recorded 213.6 snails on mango trees as the highest number of individuals per season followed by 181.5 snails on orange trees and then 122.2 snails on apple trees (Table 6).

There are significant differences in snail activity at different levels of adaptation to temperature and relative humidity. The interaction between these factors is significant in the population density of *M. obstructa* on orange, apple and mango trees.

The temperature presented a significant negative effect (-0.66), insignificant negative effect (-0.35) and highly significant negative effect (-0.82) on the total number of *Monacha obstructa* in season September, 2018/August, 2019 on orange, apple and mango trees individually.

In season September, 2019/August, 2020, the temperature showed different levels of significance as well. It showed a highly significant negative effect (-0.80), insignificant negative effect (-0.53) and significant negative effect (-0.65) on orange, apple and mango trees individually.

Table 6: Population dynamics of *Monacha obstructa* that infested three fruit trees orange, apple and mango trees during two consecutive seasons 2018/2019 and 2019/2020

	Average number of snails (individuals)/10 trees									
	Orange		Apple		Mango		Temperature (°C)		R.H (%)	
Inspection date	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2018/2019
September, 2018	5.3	7.1	3.2	1.3	6.6	7.5	28.1	27.6	44.4	45.4
October	7.8	8.5	5.3	3.2	9.1	9.6	24.1	24.8	49.7	50.0
November	9.4	10.6	7.6	6.0	13.2	14.1	19.5	20.7	55.1	48.0
December	13.2	16.4	11.1	8.7	15.1	17.5	14.3	14.4	63.7	64.6
January, 2019	15.1	20.3	14.7	10.4	18.2	20.6	11.7	11.9	48.7	66.2
February	16.9	25.1	20.2	14.3	21.9	25.4	13.4	13.5	50.1	62.7
March	28.1	27.4	27.3	21.9	26.7	32.7	15.7	16.4	47.9	54.6
April	21.6	26.9	24.9	20.5	26.1	31.9	19.8	19.2	39.2	49.9
May	16.8	14.8	25.9	17.1	9.1	32.6	26.9	23.7	25.5	40.6
June	8.2	11.2	17.6	9.2	7.6	10.1	29.7	27.9	34.7	34.1
July	5.9	7.3	9.3	5.5	5.1	7.4	30.5	30.2	35.6	35.6
August	3.2	5.9	5.8	4.1	2.1	4.8	30.5	30.4	36.6	37.7
Total	151.5	181.5	172.9	122.2	160.8	213.6				
Average	12.6	15.1	14.4	10.2	13.4	17.8				

Table 7: Correlation between climatic factors temperature degree, relative humidity and population density of *Monacha obstructa* during two consecutive seasons 2018/2019 and 2019/2020

	Temperature (°C)						Relative humidity (%)					
	2018/2019			2019/2020			2018/2019			2019/2020		
Host plant	r	b	p-value	r	b	p-value	r	b	p-value	r	b	p-value
Orange	-0.66	-0.63	0.02*	-0.80	-0.66	0.001**	0.11	0.15	0.7^{ns}	0.63	0.88	0.02*
Apple	-0.35	-0.29	0.2^{ns}	-0.53	-0.52	0.07^{ns}	-0.29	-0.36	0.3^{ns}	0.27	0.44	0.3^{ns}
Mango	-0.82	-0.71	0.001**	-0.65	-0.41	0.02*	0.38	0.48	0.2^{ns}	0.43	0.44	0.1^{ns}

$p \leq 0.05$, r: Simple correlation, b: Liner regression coefficient, ns: Non-significance, *Significant and **Highly significant

The linear regression coefficient was recorded as -0.63, -0.29 and -0.71 in season September, 2018/August, 2019 individually. While in season September, 2019/August, 2020, the linear regression coefficient was recorded as -0.66, -0.52 and -0.41 on the same fruit trees individually.

There was a highly significant effect on the individuals' number of *M. obstructa* on mango trees during 2018/2019 and the same on orange trees during September, 2019/ August, 2020 (Table 7). Nonetheless, it recorded an insignificant effect on snail individuals' number on apple trees for both seasons in Table 7.

Effect of relative humidity was reported on the population density of *M. obstructa*. It showed an insignificant positive and negative effect on the total number of snails by 0.11, -0.29 and 0.38 on orange, apple and mango trees in season September, 2018/August, 2019, respectively. While in September, 2019/ August, 2020, it showed a significant positive effect (0.63) on orange trees and an insignificant negative effect of 0.27 and 0.43 on apple and mango trees, respectively. This insignificant positive and negative effect was observed on the same fruit trees with a linear regression coefficient of 0.15, -0.36 and 0.48 in season 2018/2019 individually, while in 2019/2020, the linear regression coefficient on the same fruit trees showed 0.88, 0.44 and 0.44 individually.

Population dynamics of *Eobania vermiculata* in Mansoria Village, Giza Governorate: During season September, 2018/August, 2019, the highest monthly number of snails was recorded in March and April. The highest monthly number of *E. vermiculata* recorded 62.5, 58.2 and 50.2 individuals number per 10 trees on the fruit trees orange, apple, mango in March, while it recorded 61.8, 40.1 and 39.5 individuals per 10 trees on the same trees in April, respectively (Table 8). The lowest number of snails recorded in August recorded 7.6, 9.3 and 5.2 individuals per 10 trees on the same trees, respectively (Table 8). The total snail numbers of *E. vermiculata* recorded 392.8 snails on orange trees followed by apple trees with 346.5 snails then mango trees with 309.4 snails (Table 8).

Regarding season September, 2019/August, 2020, the highest monthly number of the snail of *E. vermiculata* recorded 70.4, 60.1 and 60.7 individuals per 10 trees on orange, apple and mango trees in March, respectively, while it recorded 68.6, 54.8 and 48.8 individuals per 10 trees on the same trees in April, respectively (Table 8). The lowest monthly density was August recorded 8.8, 6.8 and 5.8 individuals per 10 trees on orange, apple and mango trees, respectively.

Table 8: Population dynamics of *Eobania vermiculata* that infested three fruit trees orange, apple and mango trees during two consecutive seasons 2018/2019 and 2019/2020

	Average number of snails (individuals)/10 trees									
	Orange		Apple		Mango		Temperature (°C)		R.H (%)	
Inspection date	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2018/2019
September, 2018	10.9	12.7	11.4	9.6	8.6	11.9	28.1	27.6	44.4	45.4
October	21.5	16.8	23.3	18.7	9.8	13.4	24.1	24.8	49.7	50.0
November	29.3	24.1	26.8	25.8	21.8	20.3	19.5	20.7	55.1	48.0
December	34.2	38.0	29.5	28.4	27.1	31.8	14.3	14.4	63.7	64.6
January, 2019	39.6	40.6	35.7	34.1	31.4	37.1	11.7	11.9	48.7	66.2
February	41.2	46.1	39.8	38.9	36.6	40.5	13.4	13.5	50.1	62.7
March	62.5	70.4	58.2	60.1	50.2	60.7	15.7	16.4	47.9	54.6
April	61.8	68.6	40.1	54.8	39.5	48.8	19.8	19.2	39.2	49.9
May	44.1	48.2	38.6	38.3	42.5	37.3	26.9	23.7	25.5	40.6
June	23.4	30.3	21.4	19.7	26.4	26.8	29.7	27.9	34.7	34.1
July	16.7	11.1	12.9	15.2	10.3	11.8	30.5	30.2	35.6	35.6
August	7.6	8.8	9.3	6.8	5.2	5.8	30.5	30.4	36.6	37.7
Total	392.8	369.6	346.5	340.8	309.4	346.2				
Average	32.7	30.8	28.9	28.4	25.8	28.9				

Table 9: Correlation between climatic factors temperature degree, relative humidity and population density of *Eobania vermiculata* during two consecutive seasons 2018/2019 and 2019/2020

	Temperature (°C)						Relative humidity (%)					
	2018/2019			2019/2020			2018/2019			2019/2020		
Host plant	r	b	p-value	r	b	p-value	r	b	p-value	r	b	p-value
Orange	-0.65	-0.26	0.02*	-0.68	-0.21	0.01*	0.085	0.05	0.7^{ns}	0.45	0.24	0.1^{ns}
Apple	-0.71	-0.35	0.009**	-0.69	-0.27	0.01*	0.17	0.12	0.6^{ns}	0.47	0.31	0.1^{ns}
Mango	-0.59	-0.28	0.04*	-0.73	0.29	0.007**	-0.016	-0.01	0.9^{ns}	0.51	0.34	0.09^{ns}

$p \leq 0.05$, r: Simple correlation, b: Liner regression coefficient, ns: Non-significance, *Significant and **Highly significant

The total snail numbers recorded 369.6 snails on orange trees followed by mango trees 346.2 snails then apple trees 340.8 snails (Table 8).

Table 9 showed the pattern of activity of *E. vermiculata* in the two seasons. The temperature degree showed a significant effect on *E. vermiculata* individuals during 2018/2019.

It was significant on the population density of *E. vermiculata* on orange and mango trees, besides a highly significant effect on snails' population density on apple trees (Table 9).

In season September, 2018/August, 2019, the temperature showed a significant negative effect on the total number of *E. vermiculata* by -0.65 and -0.59 on orange and mango trees, respectively and also a highly significant negative effect of -0.71 on apple trees.

During season September, 2019/August, 2020, the temperature degrees showed a significant negative effect on the total number of *E. vermiculata* by -0.68 and -0.69 on orange and apple trees, respectively and a highly significant positive effect of -0.73 on mango trees.

This significant negative effect was obtained on the same fruit trees with a linear regression coefficient of -0.26, 0.35 and 0.28 in season 2018/2019 individually, while in season September, 2019/August, 2020 the linear regression coefficient was recorded -0.21, -0.27 and 0.29 on the same fruit trees individually.

The noticeable decrease in temperatures contributed to the increase in snails on these trees. Here, it shows the importance of temperature on the activity of this species.

Relative humidity showed a non-significant effect on the number of *E. vermiculata* during the two consecutive seasons (Table 9) which may be due to the general lack of humidity in this location.

The effect of relative humidity was reported on the population density of this snail species.

It showed an insignificant positive and negative effect on the total number of snails by 0.085, 0.17 and -0.016 on orange, apple and mango trees in season 2018/2019, respectively. While, in 2019/2020, it showed an insignificant positive effect of 0.45, 0.47 and 0.51 on the three fruit tree types.

This insignificant positive and negative effect was observed on the same fruit trees with a linear regression coefficient of 0.05, 0.12 and -0.01 in season September, 2018/August, 2019 individually, while in September, 2019/August, 2020, the linear regression coefficient on the same fruit trees showed 0.24, 0.31 and 0.34 individually.

DISCUSSION

The population density of the three terrestrial snail species is increasing gradually after the winter months to reach the maximum density during spring, particularly in March and April, while the lowest monthly density was recorded in August for the two seasons (September, 2018 till August, 2019) and (September, 2019 till August, 2020). These snail species were observed on other field crops, vegetables and ornamental plants in the same governorates recording their level of infestation, which varied according to the host plant type, climatic factors and locality. *Eobania vermiculata* were the dominant species on host plants compared to *Theba pisana* since it was recorded in all surveyed localities in Beheira Governorate, while the majority of the examined fruit trees were infested with *Monacha obstructa* followed by *Eobania vermiculata* in Giza Governorate.

Recently, many growers are aware of the dangers caused by land snails as an agricultural pest on major economic field crops, fruit trees, vegetables and ornamental plants as well as gardens specifically in governorates of the Delta region. These three species of snails have received adequate attention in studying due to their economic importance. The populations of terrestrial snails had increased then their damage has been steadily spreading and pronounced in orchards. The land snails *E. vermiculata*, *T. pisana* and *M. obstructa* were the dominant species recorded on citrus, fruit orchards and ornamental plants in Alexandria and Beheira Governorates during two spring seasons in 2011 and 2012[16].

The seasonal fluctuations of three economic land snails were estimated. The snails were *Monacha* sp., *Theba pisana* and *Eobania vermiculata* that infested three fruit trees orange, apple and grape trees through the 2 years 2011/2012 and 2012/2013 at fruit orchards of Shebin El-Kom Centre, Monufia Governorate[25]. The highest occurrence of snail species was *E. vermiculata* at 39%, while the lowest occurrence of snail species was *T. pisana* with 28.5%. The highest infested host plant was orange, while the grape was the least infested fruit tree. The highest monthly density of snails was recorded in spring, while the lowest monthly density was in autumn and winter[25]. These findings are in agreement with the data of this research.

Eobania vermiculata represent a potentially serious threat that harms agriculture, natural ecosystems and global trade[26]. This species is established in dense populations and repeatedly increasing.

Eobania vermiculata occurs in varieties of habitats i.e., dry vegetation, hedgerows, gardens, vineyards and agricultural fields and often in coastal areas[27,28]. The active periods of *E. vermiculata* are mainly started in autumn[29] or at the beginning of the rainy periods.

Eobania vermiculata and *Monacha* sp., were reported in North western coast in different localities. The two species were reported throughout the year with low numbers in January and February. The population density increased gradually after winter months. The density reaches the maximum values during summer months[30]. The highest numbers of the two species were recorded during the spring season. *Eobania vermiculata* was noticed on tree trunks in high numbers compared with the snail number on soil surface[30].

Eobania vermiculata was an abundant species with a relatively high number of ornamental plants in the Kafr El-Sheikh district, Kafr El-Sheikh Governorate during the period from March, 2015 to February, 2016 at a nursery of ornamental plants[31].

The initial infestation of *E. vermiculata* in March was a relatively low population density on some ornamental plants, however, the snail's number increased gradually during April, which is in agreement with these findings in this research.

A slight decrease in population was observed in May, while the maximum increase of snail population returned to increase in June and the number of snails reached its peak[31].

Later, the population density of *E. vermiculata* severely decrease during July, then gradually through August, September, October and November[31].

Monacha sp., consider as a major agricultural pest species on the examined crops with heavy infestation in the localities understudy in Ismailia and Sharkia Governorate[32,33]. *Monacha* sp., was reported on field crops i.e., broad bean, Egyptian clover, maize, onion, wheat and vegetables i.e., cabbage, cucumber, eggplant, pepper, squash, strawberry, tomato, watermelon, potato and kidney bean[33].

The influence of climatic change on the population density of land snail *Monacha* sp., had been determined on fruit trees lemon and guava trees in Damietta Governorate during the two seasons 2011/2012 and 2012/2013[34].

The population density of *Monacha* sp., recorded the highest number and active in spring months then followed by autumn. The lowest population density recorded in winter seasons[35]. These data on the snail activity seasons are in agreement with the results that had been reported in this research.

The population dynamic of *Monacha* sp. and *Theba pisana* had been studied on leafy vegetables such as Egyptian clover, lettuce and cabbage for two growing seasons in 2015 and 2016 in Kafr El-Sheikh Governorate[35]. These results are in agreement with the population density of these two species that reach their maximum density in spring especially in April due to the appropriate climatic conditions of temperature and humidity during this season which confirm the results of this study.

A significant decreasing of snails' number on the infested trees was observed in August due to the high temperature and discontinuing their movement plus entering the aestivation period to avoid losing their body water during periods of drought[9].

Generally, the highest population densities of terrestrial snail *Monacha obstructa* were reported in March and April on field crops and leafy plantations[9]. The highest population density of terrestrial snails was recorded in spring due to the optimum climatic conditions for the snail's activity on fruit. The population dynamic of this study provide clear view of the snails' behavior and their dispersal in fruit orchards in Beheira and Giza Governorate.

Subsequently, it should to plan local quarantine strategies and establish laws to prevent the dispersal of land snails all over plantations of infested localities to new areas. That will lead to design an effective integrated pest control program[34].

CONCLUSION

The population dynamic and monthly density of terrestrial snails are the mainstay and core to establish a successful pest control program against this agricultural pest. Hence, this research presents the essential database of terrestrial snails' population dynamic and the correlation with temperature and humidity as climatic factors on snails' population density throughout the year. The activity and inactivity periods of this pest have also been determined. These data will assist the growers in envisioning an ideal appropriate control program to reduce the infestation level or eliminate the pest number. The novelty of this data aids to understand the land snails' behavior under different climatic conditions in the two governorates.

SIGNIFICANCE STATEMENT

This study documented the monthly population dynamic of the common and dominant three terrestrial snail species on economic fruit trees in horticultural fields at Beheira and Giza Governorate, Egypt. The monthly density of snails correlated with the climatic factors such as temperature degrees and humidity levels, which can be beneficial for designing and implementing integrated pest control programs to reduce the number of attacking snails on host plants and to lower the infestation level. This ecological data will support the researchers to understand the land snails' behavior as agricultural pests. The population dynamic correlated with temperature degrees and humidity levels throughout the year.

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