Population Growth Parameters of *Tuta absoluta* (Lepidoptera: Gelechiidae) on Tomato Plant Using Organic Substrate and Biofertilizers

P. Mohamadi¹,², J. Razmjou¹, B. Naseri¹, and M. Hassanpour¹

¹Plant Protection Department, Faculty of Agricultural and Natural Resources, University of Mohaghegh Ardabili, Ardabil, Iran (p.mohamadi_uma@yahoo.com; razmjou@uma.ac.ir; b_naseri@uma.ac.ir; hassanpour@uma.ac.ir) and ²Corresponding author, e-mail: p.mohamadi_uma@yahoo.com

Subject Editor: Nicolas Desneux

Received 25 November 2016; Editorial decision 22 January 2017

Abstract

The tomato leafminer, *Tuta absoluta* (Meyrick) is a devastating pest associated with tomato. In this study, effects of tomato plants treated with vermicompost (20, 40, and 60%), humic fertilizer (2, 4 and 6 g/kg soil) and plant growth promoting rhizobacteria (*Pseudomonas fluorescens* and *Bacillus subtilis*) were investigated on the life table parameters of *T. absoluta* in a growth chamber at 25 ± 2 °C, 65 ± 5% RH, and 16:8 (L:D) h. Significant differences were found for the total developmental time, fecundity, and oviposition period of *T. absoluta* on the treatments tested. The net reproductive rate (*R₀*), intrinsic rate of natural increase (*rₚ*), finite rate of increase (*λ*), mean generation time (*T*), and doubling time (*DT*) of *T. absoluta* were significantly different among treatments tested. We found that in all vermicompost, humic fertilizer and plant growth promoting rhizobacteria treatments, values of *R₀*, *rₚ*, and *λ* were lower than control treatment. However, the lowest values of these parameters were obtained on 2 g/kg humic fertilizer and 40% vermicompost. Furthermore, *T. absoluta* had longest *T* and *DT* values on 2 g/kg humic fertilizer treatment. Data obtained showed that the addition of 2 g/kg humic fertilizer and 40% vermicompost to the growing soil reduced *T. absoluta* populations in tomato cultures. In addition, these levels of fertilizers improved growth parameters of tomato seedlings (plant height, wet weight, and dry weight) compared with other treatments. These results could be useful in improving the sustainable management of the moth.

Key words: vermicompost, humic fertilizer, plant growth promoting rhizobacteria, population decrease, tomato leafminer
health by using organic or biofertilizers can be other approach to manage the tomato leafminer. Soil fertility practices can affect physiological susceptibility of crop plants to insect pests by either affecting the resistance of individual plant to attack or by changing plant acceptability to certain herbivores (Chau and Heong 2005). Researches demonstrated that plants grown using organic amendments have high resistance to insect pests and diseases than plants grown with synthetic inorganic fertilizer amendments (Arancon et al. 2004). Some researchers indicated that vermicomposts may improve plant growth and yields (Atiyeh et al. 2000, Arancon et al. 2004) as well as enhance plant resistance against some diseases and pests (Arancon et al. 2004, Yardim et al. 2006, Razmjou et al. 2011, 2012). Vermicomposts improve plant growth through the increasing availability of nutrients and improving physicochemical and microbiological properties of soil (Arancon et al. 2007). There is scientific evidence of suppression of specific insect attacks by vermicomposts (Arancon et al. 2004, 2005, 2007; Edwards et al. 2010, Razmjou et al. 2011, 2012). Furthermore, it is recognized that humic substances have beneficial effects on physical, chemical, and microbiological properties of the soil and can improve physiological properties of plants (Nardi et al. 2002). These aspects are important because they constitute the most ubiquitous source of non-living organic material that nature knows. Effects of humic substances on the rates of growth of a variety of crops have been assessed in the greenhouse and some field crops (Varanini and Pinton 1995, Chunhua Liu et al. 1998, Arancon et al. 2003). Humic substances enhance the resistance of plants to environmental stress factors and insect attacks (Jackson 1993). However, there are few researches about humic substance application and its effect on populations of insect herbivores (Yildirim and Unay 2011). Several groups of soil-borne microbes such as plant growth promoting rhizobacteria (PGPR) can exert positive effects on plant growth and survival through the plant growth promotion and induced systemic resistance (ISR) (Bezemer and van Dam 2005). PGPR induce resistance in plants against diseases, and insects and nematode pests (Ramamoorthy et al. 2001). Some researches demonstrated that induced resistance in plants by PGPR strains reduced populations of insect herbivores (Bong and Sikorowski 1991, Zehnder et al. 1997). The models used for studying the effect of different conditions of host plants on insects are usually based on insect developmental rates (Martins et al. 2016). This study was conducted to investigate whether population growth attributes of T. absoluta affect by using organic and biofertilizers (vermicompost, humic fertilizer, and PGPR) in tomato plant and to evaluate effects of these fertilizers on growth parameters of tomato seedlings.

### Materials and Methods

The experiments were conducted during 2015 in the greenhouse and laboratory of Plant Protection department, Faculty of Agriculture, Miyaneh Azad University, East Azerbaijan province, Iran. The cattle manure vermicompost was obtained from AnooshSheAaraab Co. Ltd., Tehran, Iran. The chemical properties and nutrient composition of vermicompost used in this study are shown in Table 1. The trade humic composition named Perl Humus (containing 60% humic acid, 1% N, 0.2% P, and 0.3% K) was obtained from BazarğanKalka Company, Tehran, Iran. Also the powder formulation of PGPR (containing $10^7$ colony-forming units/g) used in this study were obtained from the Soil and Water Research Institute of Karaj, Iran.

#### Host plant

The seeds of greenhouse tomato, Lycopersicon esculentum Mill. c.v. Urbana 9090 were planted in plastic pots (8 cm diameter × 10 cm height) filled with sandy loam soil. The plants were kept in a greenhouse at 19–28°C, 50–60% RH, and a natural photoperiod of 16:8 (L:D) h before using in experiments. Tomato seedlings at the six- to eight-leaf stage were used for experiments.

#### Rearing of T. absoluta

The laboratory colonies of T. absoluta were started from larvae collected from a commercial tomato plantation located at Miyaneh, East Azerbaijan province, Iran. The pest was reared in the laboratory on tomato seedlings. The larvae were added with tomato seedlings in cages. Pupae were collected from leaves and soil of tomato plants and were housed in plastic cages (8 × 6 × 4 cm³) until the emergence of adults (Atowa et al. 2013). When at least five pair of adults had emerged, they were put in clear plastic cage (20 × 20 × 30 cm³) prepared with one tomato seedling as oviposition substrates. To feed the adult moths, a piece of cotton saturated in a 10% sugar solution was placed in each cage. The eggs on the tomato seedling were reared until pupation. T. absoluta remained in laboratory for at least three generations before start the experiments (one generation on treated plants) (Reda and Hatem 2012).

#### Experiments

To study the effects of vermicompost, humic fertilizer, and PGPR on development and fecundity of T. absoluta, the experiments were conducted in a growth chamber at 25 ± 2°C, 65 ± 5% RH, and a photoperiod of 16:8 (L:D) h by using a randomized complete block design. Tomato seedlings individually grown in plastic pots were used in the experiments. Nine treatments were compared: tomato grown in the soil amended with (i) 20, (ii) 40, and (iii) 60% vermicompost; tomato grown in the soil containing (iv) 2, (v) 4, and (vi) 6 g/kg humic fertilizer; tomato grown with PGPR (seed treatment with powder formulation) (vii) Pseudomonas fluorescens, and (viii) Bacillus subtilis; and (ix) control.

#### Evaluation of development period and survival of T. absoluta

To evaluate the survival and pre-adult period of T. absoluta on tomato plants treated with different fertilizer treatments, one tomato seedling of each treatment was exposed to the five pair of adults in a clear plastic cage (20 × 20 × 30 cm³ with a mesh lid to allow ventilation) for 24 h. Newly laid eggs on the tomato seedlings were collected by fine brush and each egg was placed on an individual treated tomato leaf (the petiol of which was then maintained in moist cotton wool) in a plastic box (8 × 6 × 4 cm³ with a mesh lid to allow air movement) and maintained in growth chamber. The experiment was replicated 100 times giving 100 eggs per each

### Table 1. Chemical properties and nutrient measurement of vermicompost used in the experiments

| PH  | EC (ds/m) | N (%) | P (%) | K (%) | Ca (%) | Mg (%) | Fe (mg/kg) | Mn (mg/kg) | Cu (mg/kg) | Zn (mg/kg) | Pb (mg/kg) | C/N | OM (%) | OC (%) |
|-----|-----------|-------|-------|-------|--------|--------|------------|------------|------------|------------|------------|-----|-------|-------|
| 7.64| 1.12      | 1.55  | 0.4   | 0.4   | 2.73   | 0.95   | 5000       | 275        | 20         | 110        | 19          | 21.25 | 56.8  | 32.9   |

Analysis of vermicompost samples was conducted by Soil and Water Research Institute of Karaj, Iran.
treatment. The hatch rate and incubation period were recorded daily. Once eggs had hatched, fresh tomato leaves were added as required to feed the larvae. The hatched larvae were monitored daily for molting, survivorship, and duration of the larval period until pupation. Pupae were monitored daily until the adult emergence. We used at least 20 tomato seedlings for each treatment in this experiment.

Evaluation of adult longevity and fecundity of *T. absoluta*

For each treatment, newly emerged adults of *T. absoluta* were paired and placed in individual clear plastic box (8 × 6 × 4 cm³ with a hole in the lid covered with mesh cloth) containing fresh tomato leaf (the petiol of which was maintained in moist cotton wool) for subsequent mating and oviposition. To feed the adult moths, a piece of cotton saturated in a 10% sugar solution was placed in each box. The boxes were checked daily during which the number of eggs laid by each female were recorded. Observations continued until the death of the last *T. absoluta*. By monitoring the boxes, pre-oviposition period, oviposition period, post-oviposition period, adult longevity, and fecundity of *T. absoluta* were determined. This experiment was replicated 20 times giving 20 pairs of adult moths per each treatment.

Determination of life table parameters of *T. absoluta*

Intrinsic rate of increase \( r_m \) of *T. absoluta* were calculated according to the equation given by Birch (1948) as follows:

\[
e^{-rT}l_xm_x = 1,
\]

where \( x \) is age in days; \( r \) is an intrinsic rate of natural increase; \( l_x \) is age-specific mortality; \( m_x \) is age-specific number of female offspring.

Moreover, the net reproductive rate \( R_0 = \sum l_xm_x \) mean generation time \( T = \ln R_0/r \), doubling time \( DT \), and finite rate of increase \( \lambda = e^r \) for *T. absoluta* were calculated (Birch 1948; Carey 1993).

Growth parameters of tomato seedlings

We also tested effects of vermicompost, humic fertilizer, and PGPR on growth parameters including plant height, wet weight, and dry weight of tomato seedlings. We measured and recorded growth parameters of 12 tomato seedlings per each treatment in this experiment.

Statistical analysis

Normality of data was tested by Kolmogorov–Smirnov method. All data of survivorship, duration of immature stages, oviposition period, pre- and post-oviposition period, adult longevity, and fecundity of *T. absoluta* were evaluated for each treatment by one-way analysis of variance (ANOVA) using SPSS ver.16.0 (SPSS 2007) statistical software. When differences among treatments were significant, comparison among means were conducted using Tukey’s test with the SPSS ver.16.0 (SPSS 2007) statistical software.

Plant growth parameters including plant height, wet weight, and dry weight were tested for each treatment by one-way analysis of variance (ANOVA) using SPSS ver.16.0 (SPSS 2007) statistical software. Comparison among means were conducted using Tukey’s test at \( z = 0.05 \).

Results

Effect of fertilizer treatment on *T. absoluta* juvenile development and survival

The effects of plants grown with different fertilizer treatments on the development of *T. absoluta* were listed in Table 2. There were significant differences for the egg incubation period \( F = 5.948; df = 8, 775; P = 0.000 \). The longest values of this parameter was recorded for *T. absoluta* eggs on the plants grown in the soil contained 2 and 4 g/kg humic fertilizer and the shortest value was observed on control. Fertilizer treatments significantly influenced hatch rates of *T. absoluta*. Eggs from the control treatment had higher (92%) hatch rates than that at 40% vermicompost concentration (84%). There were no significant differences for the first \( (F = 0.324; df = 8, 761; P = 0.957) \), second \( (F = 1.257; df = 8, 754; P = 0.263) \), and fourth \( (F = 2.368; df = 8, 660; P = 0.016) \) larval instars of *T. absoluta* on various treatments. However, significant differences were observed for the third \( (F = 5.283; df = 8, 695; P = 0.000) \) and total developmental time of larvae \( (F = 3.219; df = 8, 660; P = 0.001) \) of *T. absoluta* on different fertilizer treatments. The third larval instar of *T. absoluta* was longest on 20% vermicompost rate and shortest on 4 g/kg humic fertilizer. Moreover, the longest and shortest total developmental time of larvae were observed on 20% vermicompost rate and *P. fluorescens* treatment, respectively. There were no significant differences for pupal period \( (F = 2.102; df = 8, 621; P = 0.034) \) of *T. absoluta* on different treatments, however significant differences were found for duration of *T. absoluta* life cycle \( (F = 6.204; df = 8, 621; P = 0.000) \) on fertilizer treatments tested. The longest and shortest duration of life cycle were on 2 g/kg humic fertilizer and control, respectively.

Effect of fertilizer treatment on *T. absoluta* adult longevity and fecundity

Pre-oviposition \( (F = 0.424; df = 8, 171; P = 0.906) \) and post-oviposition period \( (F = 0.829; df = 8, 171; P = 0.578) \) of the *T. absoluta* did not differ significantly among treatments, but oviposition period \( (F = 2.665; df = 8, 171; P = 0.009) \) significantly differed among treatments. The longest and shortest oviposition period were observed for adults on control and 4 g/kg humic fertilizer respectively. No significant effect on adult longevity \( (F = 2.013; df = 8, 171; P = 0.048) \) was recorded. Significant effect was observed on *T. absoluta* total fecundity \( (F = 6.144; df = 8, 171; P = 0.000) \), however the mean daily fecundity of *T. absoluta* was not significantly different among treatments \( (F = 0.987; df = 8, 171; P = 0.448) \) (Table 3). The highest mean number of eggs laid per female was observed for control treatment; whereas moths reared on plants grown in soil that contained 2 g/kg humic fertilizer produced the lowest number of eggs per female (Table 3).

Life table parameters

The influence of different fertilizer treatments on the stable population growth parameters of *T. absoluta* is presented in Table 4. Significant effects on population growth parameters of *T. absoluta* were recorded: net reproductive rate \( (R_0) \ (F = 31.345; df = 8, 171; P = 0.000) \), intrinsic rate of natural increase \( (r_m) \ (F = 17.238; df = 8,
Effect of fertilizer treatment on plant growth parameters

There was a significant variation for all growth parameters of tomato seedlings including plant height ($F = 8.766; df = 8, 99, P = 0.000$), wet weight ($F = 8.907; df = 8, 99, P = 0.000$), and dry weight ($F = 7.267; df = 8, 99, P = 0.000$) among fertilizer treatments. Tomato seedlings treated with 2 g/kg humic fertilizer and 40% vermicompost had the highest values of plant height (24.96 ± 0.298 and 24.87 ± 0.231 cm, respectively), wet weight (5.97 ± 0.148 and 5.88 ± 0.109 g, respectively) and dry weight (0.88 ± 0.030 and 0.87 ± 0.022 g respectively) compared with other fertilizer treatments (Table 5).

Discussion

In this study, different fertilizer treatments clearly affected the developmental time and fecundity of *T. absoluta*. The moths reared on the plants treated with 2 g/kg humic fertilizer and 40% vermicompost concentration, had the longest developmental time and the lowest total fecundity; while the shortest developmental time and highest total fecundity were observed for control treatment. Consequently, the life table parameters of *T. absoluta* were affected by different fertilizer treatments. The lowest values of $r_m$, $R_0$, and $\lambda$ of *T. absoluta* were observed on plants that were treated with 2 g/kg humic fertilizer and 40% vermicompost; however the highest values of these traits were found on control treatment. Also the longest $T$ and $DT$ values were found on plants treated with 2 g/kg humic fertilizer. The $r_m$ is a useful index for evaluating the pest performance on different conditions of host plants and reflect many factors including survival and fecundity of the pest, as well as generation time (Southwood and Henderson 2000). The $r_m$ values of *T. absoluta* in the current study ranged from 0.120 to 0.143 female/female/day on 2 g/kg humic fertilizer and control treatment, respectively. The $r_m$ value of moth decreased even more on plants grown in pots with 2 g/kg humic fertilizer and 40% vermicompost compared with other fertilizer treatments. Reduction of $r_m$ value was less on other vermicompost and humic fertilizer rates as well as on PGPR treatments. The exact reason for these differences remain unknown but according to the substantial variation in chemical composition among the soil and the fertilizers were used, it is leasable that the best overall nutrient balance for the plants was reached with 2 g/kg humic fertilizer and 40% vermicompost amendments since these levels of fertilizers improved growth parameters of tomato plants (plant height, wet weight, and dry weight) compared with other treatments. The result certainly suggests that there is an optimal level of humic fertilizer and vermicompost addition that allows for strong suppression of moth populations without suppressing plant growth. The use of organic amendments to soil can supply a more balanced source of nutrition for plant growth, since the organic matter gradually is degraded by microorganisms and the available nutrients of these materials are released with lower mineralization (Patrquin et al. 1995, Zink and Allen 1998). According to results of this study, population growth of *T. absoluta* decreased on plants grown in the
Table 3. Comparative adult longevity and fecundity (mean ± SE) of T. absoluta on tomato plants treated with different fertilizer treatments

| Mean daily fecundity (eggs/female/day) | Mean total fecundity (eggs/female) | Adult Longevity | Post-oviposition period | Oviposition period | Pre-oviposition period | Treatment |
|--------------------------------------|-----------------------------------|-----------------|-------------------------|-------------------|----------------------|-----------|
| 7.98 ± 0.62a                         | 64.80 ± 0.74a                     | 11.90 ± 0.32a   | 1.00 ± 0.13a            | 8.65 ± 0.39a      | 2.25 ± 0.10a         | Control   |
| 7.22 ± 0.22a                         | 58.25 ± 2.09abc                   | 10.55 ± 0.34a   | 1.05 ± 0.15a            | 8.15 ± 0.30ab     | 2.35 ± 0.15a         | Vermicompost (20%) |
| 8.71 ± 0.72a                         | 52.10 ± 2.28c                     | 10.05 ± 0.52a   | 1.40 ± 0.17a            | 6.60 ± 0.44b      | 2.05 ± 0.18a         | Vermicompost (40%) |
| 7.42 ± 0.42a                         | 54.30 ± 1.78bc                    | 10.70 ± 0.48a   | 1.00 ± 0.16a            | 7.65 ± 0.41ab     | 2.05 ± 0.15a         | Vermicompost (60%) |
| 7.32 ± 0.57a                         | 51.60 ± 1.80c                     | 10.50 ± 0.49a   | 0.85 ± 0.20a            | 7.55 ± 0.41ab     | 2.10 ± 0.14a         | Humic substances (2 g/kg) |
| 7.68 ± 0.46a                         | 54.30 ± 1.35bc                    | 10.55 ± 0.51a   | 1.00 ± 0.21a            | 7.50 ± 0.39ab     | 2.05 ± 0.17a         | Humic substances (4 g/kg) |
| 8.13 ± 0.64a                         | 56.45 ± 1.28bc                    | 10.85 ± 0.53a   | 1.20 ± 0.22a            | 7.55 ± 0.44ab     | 2.10 ± 0.16a         | Humic substances (6 g/kg) |
| 8.58 ± 0.54a                         | 56.95 ± 1.50bc                    | 10.25 ± 0.42a   | 1.15 ± 0.13a            | 7.00 ± 0.32ab     | 2.10 ± 0.18a         | B. subtilis |
| 7.61 ± 0.52a                         | 59.85 ± 1.65ab                    | 11.55 ± 0.39a   | 1.15 ± 0.17a            | 8.30 ± 0.38ab     | 2.10 ± 0.18a         | P. fluorescens |

For each parameter, differences among treatments were determined by Tukey’s test. Within columns, means followed by different letters are significantly different (P < 0.01).

Table 4. Life table parameters (mean ± SE) of T. absoluta on tomato plants treated with different fertilizer treatments

| ji(d⁻¹) | DT(d) | T(d) | rₘ(d⁻¹) | Rₓ(♀♂) | Treatment |
|---------|-------|------|---------|--------|-----------|
| 1.15 ± 0.001a | 4.85 ± 0.044e | 24.53 ± 0.183ab | 0.143 ± 0.001a | 33.27 ± 0.379a | Control |
| 1.14 ± 0.002bc | 5.241 ± 0.084cd | 24.99 ± 0.232ab | 0.132 ± 0.002bc | 27.21 ± 0.977bc | Vermicompost (20%) |
| 1.13 ± 0.002de | 5.36 ± 0.098ab | 24.45 ± 0.227ab | 0.125 ± 0.002de | 20.98 ± 0.920de | Vermicompost (40%) |
| 1.14 ± 0.001cd | 5.45 ± 0.053bc | 24.77 ± 0.182ab | 0.127 ± 0.001cd | 23.26 ± 0.763de | Vermicompost (60%) |
| 1.13 ± 0.001e | 5.78 ± 0.064a | 25.06 ± 0.156a | 0.120 ± 0.001e | 20.14 ± 0.704e | Humic substances (2 g/kg) |
| 1.14 ± 0.001cd | 5.45 ± 0.043bc | 24.61 ± 0.159ab | 0.127 ± 0.001cd | 22.85 ± 0.567de | Humic substances (4 g/kg) |
| 1.14 ± 0.002bc | 5.20 ± 0.056cd | 23.91 ± 0.200b | 0.133 ± 0.001bc | 24.15 ± 0.348cd | Humic substances (6 g/kg) |
| 1.14 ± 0.002bcd | 5.31 ± 0.083bcd | 24.36 ± 0.280b | 0.130 ± 0.002bcd | 23.97 ± 0.630d | B. subtilis |
| 1.14 ± 0.002b | 5.12 ± 0.051de | 24.47 ± 0.151ab | 0.135 ± 0.001b | 27.52 ± 0.760b | P. fluorescens |

For each parameter, differences among treatments were determined by Tukey’s test. Based on jackknife estimates of each parameter, within columns, means followed by different letters are significantly different (P < 0.01).

Table 5. Growth parameters (mean ± SE) of tomato seedlings treated with different fertilizer treatments

| Dry weight (g) | Wet weight (g) | Plant height (cm) | Treatment |
|----------------|---------------|-------------------|-----------|
| 0.67 ± 0.033d | 4.71 ± 0.154d | 22.42 ± 0.319c | Control |
| 0.77 ± 0.022bcd | 5.37 ± 0.125bc | 23.79 ± 0.257ab | Vermicompost (20%) |
| 0.87 ± 0.022ab | 5.88 ± 0.109ab | 24.87 ± 0.231a | Vermicompost (40%) |
| 0.80 ± 0.025abc | 5.56 ± 0.129abc | 24.21 ± 0.278ab | Vermicompost (60%) |
| 0.88 ± 0.030a | 5.97 ± 0.148a | 24.96 ± 0.298a | Humic substances (2 g/kg) |
| 0.81 ± 0.023abc | 5.58 ± 0.104abc | 24.29 ± 0.234ab | Humic substances (4 g/kg) |
| 0.79 ± 0.031abc | 5.51 ± 0.160abc | 24.04 ± 0.322ab | Humic substances (6 g/kg) |
| 0.80 ± 0.017abc | 5.57 ± 0.099abc | 24.17 ± 0.207ab | B. subtilis |
| 0.70 ± 0.025cd | 5.05 ± 0.132cd | 23.12 ± 0.269bc | P. fluorescens |

For each parameter, differences among treatments were determined by Tukey’s test. Within columns, means followed by different letters are significantly different (P < 0.01).

Soil amended with vermicompost. Similar results obtained by Arancon et al. (2005) that reported the decreased populations of green peach aphid (Myzus persicae Sulz) and mealy bugs (Pseudococcus spp.) on tomatoes and peppers as well as caterpillars of Pieris brassicae L. on cabbage by vermicomposts. Also Yardim et al. (2006) reported the significant decrease of tomato hornworm (Manduca quinquemaculata (Haworth)) and cucumber beetles (Acalymma vittatum Fabr. and Diabrotica undecimpunctata Howardi Barber) populations through the vermicompost applications. Moreover, Razmjou et al. (2012) showed the high potential of vermicomposts for reducing Aphis gossypii populations in cucumber cultures. This study indicated that promoting the growth of host plants through the soil fertility with vermicompost, affects the population growth parameters of T. absoluta. The beneficial effects of vermicompost amendment may be due to an increase in microbial populations and activities in the soils or to the vermicompost’s content of humic acid (Muscolo et al. 1993). The organic matter in vermicomposts can usually affect plant morphology and physiology that could provide plants with more resistance to pest attacks or made the plants less susceptible to the pests (Patriquin et al. 1995, Zink and Allen 1998). In this study, application of humic fertilizer could enhance tomato resistance to T. absoluta. It may be related to the promoted growth and nutrient uptake of plant due to addition of humic substances. The beneficial effects of humic substances reported here are in agreement with previous reports. Yildirim and Unay (2011) reported the promoted growth of tomato plants treated with humic substances and the negative effect of humic substances on Liriomyza trifolii (Burgess) population on these plants. Other
studies revealed positive effects of humic substance on plant growth and mineral uptake of plant (Chen and Aviad 1990, David et al. 1994, Chunchua Liu et al. 1998, Asik et al. 2009). However, the effectiveness of humic substances on plants changes due to the levels of treatment, growing media, and origin of humic substances (Chen and Aviad 1990, Arancon et al. 2006). We did not deal with the functional basis of moth population growth differences among plants grown with different fertilizer treatments. Arancon et al. (2007) suggested that possible mechanisms of suppression include: the form of nitrogen available in the leaf tissues, the effects of vermicomposts on micronutrient availability, and the possible production of phylloclads, by the plants after applications of vermicomposts, making the tissues unpalatable. In addition to, PGPR-treated plants in our study influenced population growth parameters of T. absoluta compared with control treatment. Reduced populations of T. absoluta on PGPR treated plants could be related to the promoted plant growth and ISR. According to Ramamourthy et al. (2001), seed treatment with PGPR causes cell wall structural modifications and biochemical/physiological changes leading to the synthesis of proteins and chemicals involved in plant defense mechanisms. Other studies have provided evidence that PGPR affects population growth of insects. *Pseudomonas maltophilia* affected the growth of larval stage of *Helicoepera zea* (Boddie) and caused 60% reduction in adult emergence (Bong and Sikorowski 1991). Also PGPR strains significantly reduced cucumber beetles (*D. undecimpunctata howardi* and *A. vittatum*) populations (Zehnder et al. 1997). These findings will be helpful to induce resistance in tomato against *T. absoluta* especially through amending the soil with optimal level of humic fertilizer and vermicompost. These results could be help the implementation of efficient control programs when planning integrated management strategy of this pest.

**Acknowledgments**

We would like to thank Madadi for his valuable helps to providing the materials needed for this experiment.

**Funding**

This study was supported by the Miyaneh Azad University, East Azerbaijan, Iran, which provided some places and facilities for our study and University of Mohaghegh Ardabili, Ardabil, Iran.

**References Cited**

Abbes, K., A. Biondi, A. Kurtulus, M. Ricupero, A. Russo, G. Siscaro, B. Chermiti, and L. Zappala. 2015. Combined non-target effects of insecticide and high temperature on the parasitoid *Bracon mircigrans*. PLoS One. 10: e0138411.

Arancon, N.Q., S. Lee, C.A. Edwards, and R.M. Atiyeh. 2003. Effects of humic acids derived from cattle, food and paper-waste vermicomposts on growth of greenhouse plants. Pedobiologia. 47: 741–744.

Arancon, N.Q., C.A. Edwards, P. Bierman, C. Welch, and J.D. Metzger. 2004. Influence of vermicompost on field strawberries. 1. Effect on growth and yields. Bioresour. Technol. 93: 145–153.

Arancon, N.Q., P.A. Galvis, and C.A. Edwards. 2005. Suppression of insect pest populations and damage to plants by vermicomposts. Bioresour. Technol. 96: 1137–1142.

Arancon, N.Q., C.A. Edwards, S. Lee, and R. Byrne. 2006. Effects of humic acids from vermicomposts on plant growth. Eur. J. Soil Biol. 42: 65–69.

Arancon, N.Q., C.A. Edwards, E.N. Yaridom, T. Oliver, R.J. Byrnem, and G. Keeney. 2007. Suppression of two spotted spider mite (*Tetranychus urticae*) mealy bugs (*Pseudococcus sp.*) and aphid (*Myzus persicae*) populations and damage by vermicomposts. Crop Prot. 26: 29–39.

Asik, B.B., M.A. Turan, H. Celik, and A.V. Katkat. 2009. Effects of humic substances on plant growth and mineral nutrients uptake of wheat (*Triticum durum cv. Salihli*) under conditions of salinity. Asian J. Crop Sci. 1: 87–95.

Atiyeh, R.M., S. Subler, C.A. Edwards, G. Bachman, J.D. Metzger, and W. Shuster. 2000. Effects of vermicomposts and composts on plant growth in horticultural container media and soil. Pedobiologia. 44: 579–590.

Attwood, W.A., N.A. Omar, L.M.A. Ebadah, A.E. Wahab, T.E. Moawad, S.M. Hanaa, and E. Sadek. 2015. Life table parameters of the tomato leaf miner, *Tuta absoluta* (Meyrick) and potato tuber moth *Phthorimaea operculella* Zeller (Lepidoptera: Gelechiidae) on tomato plants in Egypt. Agric. Sci. Res. J. 5: 1–5.

Banihammer, V., and A. Cheraghian. 2011. The current status of *Tuta absoluta* in Iran and initial control strategies, pp. 20–23. In International symposium on management of *Tuta absoluta* (tomato borer) Proceeding. 16–18 November, Agadir, Morocco.

Bezemer, T.M., and N.M. van Dam. 2005. Linking aboveground and belowground interactions via induced plant defenses. Trends Ecol. Evol. 20: 617–624.

Biondi, A., N. Desneux, G. Siscaro, and L. Zappala. 2012. Using organic-certified rather than synthetic pesticides may not be safer for biological control agents: selectivity and side effects of 14 pesticides on the predator *Orius laevigatus*. Chemosphere. 87: 803–812.

Biondi, A., L. Zappala, N. Desneux, A. Aprao, G. Siscaro, C. Rapisarda, T. Martin, and G. Tropea Garzia. 2015. Potential toxicity of *a*-cypermethrin-treated nets on *Tuta absoluta* (Lepidoptera: Gelechiidae). J. Econ. Entomol. 108: 1191–1197.

Biondi, A., L. Zappala, J.D. Stark, and N. Desneux. 2013. Do biopesticides affect the demographic traits of a parasitoid wasp and its biocontrol services through sublethal effects?. PLoS One. 8: e76548.

Birch, L.C. 1948. The intrinsic rate of increase of an insect population. J. Anim. Ecol. 17: 15–26.

Bong, C.F.J., and P.P. Sikorowski. 1991. Effects of cytoplasmic polyhedrosis virus and bacterial contamination on growth and development of the corn earworm, *Helicoepera zea*. J. Invertebr. Pathol. 57: 406–412.

Campos, M.R., A.R.S. Rodrigues, W.M. Silva, T.B.M. Silva, V.R.F. Silva, R.N.C. Guedes, and H.A.A. Siqueira. 2014a. Spinosad and the tomato borer *Tuta absoluta*: a bioinsecticide, an invasive pest threat, and high insecticide resistance. PLoS One. 9: e103235.

Campos, M.R., T.B.M. Silva, W.M. Silva, J.E. Silva, and H.A.A. Siqueira. 2014b. Susceptibility of *Tuta absoluta* (Lepidoptera: Gelechiidae) Brazilian populations to ryanodine receptor modulators. Pest Manag. Sci. 71: 537–544.

Campos, M.R., T.B.M. Silva, W.M. Silva, J.E. Silva, and H.A.A. Siqueira. 2015. Spinosyn resistance in the tomato borer *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). J. Pest. Sci. 88: 405–412.

Carey, J.R. 1993. Applied demography for biologists, with special emphasis on insects, p. 206. Oxford University Press, UK.

Chailleux, A., A. Biondi, P. Han, E. Tabone, and N. Desneux. 2013. Suitability of the pest-plant system *Tuta absoluta* (Lepidoptera: Gelechiidae)—tomato for *Trichogramma* (Hymenoptera: Trichogrammatidae) parasitoids and insights for biological control. J. Econ. Entomol. 106: 2310–2321.

Chailleux, A., N. Desneux, J. Sequrct, H.D.T. Khanh, P. Maignet, and E. Tabone. 2012. Assessing European egg parasitoids as a mean of controlling the invasive South American tomato pinworm *Tuta absoluta*. PLoS One. 7: e48068.

Chau, I.M., and K.L. Heong. 2005. Effects of organic fertilizers on insect pest and disease of rice. Omonrice. 13: 26–33.

Chen, Y., and T. Aviad. 1990. Effects of humic substances on plant growth, pp. 161–186. In P. MacCarthy, C.E. Clapp, R.L. Malcolm, and P.R. Bloom (eds.), Humic substances in soil and crop sciences: selected readings. American Society of Agronomy, Madison, WI.

Chunchua Liu, R.J., J. Cooper, and D.C. Bowman. 1998. Humic acid application affects photosynthesis, root development, and nutrient content of creeping bentgrass. J. Hortic. Sci. 33: 1023–1025.
Cocco, A., S. Deliperi, and G. Delrio. 2013. Control of Tuta absoluta (Meyrick) (Lepidoptera: Gelechiidae) in greenhouse tomato crops using the mating disruption technique. J. Appl. Entomol. 137: 16–28.

Colomo, M.V., D.C. Berta, and M.J. Chocobar. 2002. El complejo de himenópteros parasitoides que atacan a la “polilla del tomate” Tuta absoluta (Lepidoptera: Gelechiidae) en la Argentina. Acta Zool. Lilloana. 46: 81–92.

David, P.P., P.V. Nelson, and D.C. Sanders. 1994. A humic acid improves growth of tomato seedlings in solution culture. J. Plant Nutr. 17: 173–184.

Desneux, N., E. Wajnberg, K.A.G. Wyckhuys, G. Burgio, S. Arpaia, C.A. El complejo de Colomo, M.V., D.C. Berta, and M.J. Chocobar. 2002

Maia, A.H.N., A.J.B. Luiz, and C. Campanhola. 2000. Statistical influence on associated fertility life table parameters using jackknife technique, computational aspects. J. Econ. Entomol. 93: 511–518.

Martins, J.C., M.C. Piccano, L. Bacci, R.N.C. Guedes, P.A. Santana, Jr., D.O. Ferreira, and M. Chediak. 2016. Life table determination of thermal requirements of the tomato borer Tuta absoluta. J. Pest Sci. 89: 897–908.

Meyer, J.S., C.G. Igersoll, L.L. MacDonald, and M.S. Boyce. 1986. Estimating uncertainty in population growth rates, Jackknife vs. Bootstrap techniques. Ecology. 67: 1156–1166.

Muscolo, A., M. Felcim, G. Concheri, and S. Nardi. 1993. Effect of earthworm humic substances on esterase and prooxidase activity during growth of leaf explants of Nicotiana plumbaginifolia. Biol. Fert. Soils. 15: 127–131.

Nardi, S., D. Pizzeghello, A. Muscolo, and A. Vianello. 2002. Physiological effects of humic substances on higher plants. Soil Biol. Biochem. 34: 1527–1536.

Patriquin, D.G., D. Baines, and A. Abboud. 1995. Diseases, pests and soil fertility, pp. 161–74. In H.F. Cook and H.C. Lee (eds.), Soil management in sustainable agriculture. Wye College Press, Wye, UK.

Ramanouroth, V., R. Viswanathan, T. Raguchander, V. Prakasham, and R. Samiyappan. 2001. Induction of systemic resistance by plant growth promoting rhizobacteria in crop plants against pests and diseases. Crop Prot. 20: 3–11.

Razmjou, J., M. Mohammadi, and M. Hassanpour. 2011. Effect of vermicompost and cucumber cultivar on population growth attributes of the melon aphid (Hemiptera: Aphididae). J. Econ. Entomol. 104: 1379–1383.

Razmjou, J., C. Vorburger, M. Mohammadi, and M. Hassanpour. 2012. Induction of vermicompost and cucumber cultivar on population growth of Aphis gossypii Glover. J. Appl. Entomol. 136: 568–575.

Reda, A.M.A., and A.E. Hatem. 2012. Biological and eradication parameters of the tomato leaf miner, Tuta absoluta (Meyrick) (Lepidoptera: Gelechiidae) affected by two biopesticides. Bol. San. Veg. Plagas. 38: 321–333.

Roditakis, E., V. Vasakis, M. Grispou, M. Stavrakaki, R. Nauen, M. Gravouil, and A. Bassi. 2015. First report of Tuta absoluta resistance to diadie insecticides. J. Pest. Sci. 88: 9–16.

Salehi, Z., F. Yarahmadi, A. Rasheki, and N. Z. Sohani. 2016. Functional responses of Ornis albipennis Reuter (Hemiptera, Anthocoridae) to Tuta absoluta Meyrick (Lepidoptera, Gelechiidae) on two tomato cultivars with different leaf morphological characteristics. Entomol. Gen. 36: 127–136.

SAS Institute. 2001. SAS release 8.2. SAS Institute, Cary, NC.

Sohrabi, F., H. Nooryazdan, B. Gharati, and Z. Saeidi. 2016. Evaluation of ten tomato cultivars for resistance against tomato leaf miner, Tuta absoluta (Meyrick) (Lepidoptera: Gelechiidae) under field infestation conditions. Entomol. Gen. 36: 163–175.

Southwood, R., and P.A. Henderson. 2000. Ecological methods, 561 pp. 3rd ed. Blackwell Science, Oxford, USA.

SPSS. 2007. SPSS base 16.0 user’s guide. SPSS Incorporation, Chicago.

Sylla, S., T. Brévault, K. Diarra, P. Bearez, and N. Desneux. 2016. Life-history traits of Macrolophon pygmaeus with different prey foods. PLoS One. 11: e0166610.

Tropea Garzia, G., G. Siscaro, A. Biondi, and L. Zappala. 2012. Tuta absolu-

Tuta absoluta, a South American pest of tomato now in the EPPO region: biology, distribution and damage. Bull. OEPP/EPPO Bull. 42: 205–210.

Varanini, Z., and R. Pintor. 1995. Humic substances and plant nutrition, pp. 97–117. In U. Lüttge (ed), Progress in botany, vol. 56, Springer, Berlin.

Yildirim, E.M., and A. Unay. 2011. Effects of different fertilizations on Lirionympha trifolii (Diptera: Agromyzidae) in tomato. Afr. J. Agric. Res. 6: 4104–4107.

Zappala, L., A. Biondi, A. Alma, I.J. Al-Jboory, J. Arno, A. Bayram, A. Chailloux, A. El-Arnaouty, D. Gerling, Y. Guenaooui, et al. 2013. Natural enemies of the South American moth, Tuta absoluta, in Europe, North Africa and Middle East, and their potential use in pest control strategies. J. Pest. Sci. 86: 635–647.

Zehnder, G., J. Kloepper, C. Yao, and G. Wei. 1997. Induction of resistance in cucumber against cucumber beetles (Coleoptera: Chrysomelidae) by plant growth-promoting rhizobacteria. J. Econ. Entomol. 90: 391–396.

Zink, T.A., and M.F. Allen. 1998. The effect of organic amendments on the restoration of a disturbed coastal sage scrub habitat. Restor. Ecol. 6: 52–58.