J. Agr. Sci. Tech. (2021) Vol. 23(4): 853-863

Effect of Different Fertilizer Regimes on Life Table Parameters of *Tetranychus urticae* (Acari: Tetranychidae) on Resistant Bean Cultivar

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ABSTRACT

Cultural methods such as crop fertilization can affect susceptibility of plants to herbivores by altering plant tissue nutrient. In this study, the life table parameters of the two-spotted spider mite (TSSM), *Tetranychus urticae* Koch were determined under different chemical fertilizer regimes on resistant bean cultivar (var. Parastoo) under laboratory conditions at 25±1°C, 60±5% RH and a photoperiod of 16:8 (L:D) hour. Treatments included 30, 60, and 100% of the recommended level of urea, ammonium nitrate, and potassium sulfate fertilizers. According to the obtained results, the longest preadult development time was related to individuals reared on the fertilized bean with potassium sulfate 60%, while the shortest period was related to those on 30% ammonium nitrate and 60%urea. The mean fecundity of the individuals reared on fertilized beans with different concentrations of ammonium nitrate (especially 60% ammonium nitrate) were significantly higher than the other fertilizers. The highest and lowest values of intrinsic rate of increase (*r*) were obtained on beans fertilized with 60% ammonium nitrate and 100%potassium sulfate, respectively. In addition, the values of net Reproductive rate (R_0) and the Gross Reproductive Rate (*GRR*) of TSSM reared on bean fertilized with 60% ammonium nitrate were significantly higher than the other fertilizer treatments. Our findings may provide important information in the design of a comprehensive program for integrated soil fertility management and subsequently integrated management of TSSM in bean fields.

Keywords: Nitrogen fertilizer, Potassium fertilizer, Two-spotted spider mite, Urea fertilizer.

INTRODUCTION

Two-Spotted Spider Mite (TSSM), *Tetranychus urticae* Koch (Acari: Tetranychidae) is one of the most important cosmopolitan pests that have a vast range of host plants (Luczynski *et al*., 1990; Farazmand *et al*., 2012 Khanamani *et al*., 2017a,b; Riahi *et al*., 2017; Alipour *et al*., 2019). This mite causes considerable damage to many outdoor and greenhouse crops such as bean (*Phaseolus vulgaris* Duch) (Chaudhri and Akbar, 1985; Ahmadi *et al*., 2006). This pest feeds using a piercing-sucking process that damages plant cells and tissues, reduces photosynthetic area, and leads to defoliation, leaf burning, and even plant death and reduces transpiration (Gorman *et al*., 2001).

Regarding the high rate of fecundity and a short development time of TSSM, its management is extremely difficult and, therefore, multiple applications are required (Fathipour *et al*., 2006). In addition, control

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[DOR: 20.1001.1.16807073.2021.23.4.7.6]

of this spider mite is difficult because of its high ability to develop resistance to chemicals (Cranham and Helle, 1985; Ganjisaffar *et al.*, 2011). To overcome the problems of resistance development in TSSM, the search for more durable crop protection solutions based on IPM systems is necessary (Sedaratian *et al*., 2009; Khanamani *et al*., 2015).

Fertilizer management is one of the important components of an integrated pest management program that affects pest population density, herbivores damage, efficiency of natural enemies, and amount of pesticide applications in agricultural ecosystems (Fathipour and Sedaratian, 2013). Fertilizers can affect the balance of nutritional elements in plants in different ways, and play a very important role in terms of reducing or increasing resistance to insect and mite pests. Cultural practices such as irrigation and fertilization can influence the feeding and reproductive rate of spider mites, and ultimately, their population density (Chen *et al*., 2007). Generally, spider mites are responsive to changes in leaf nutritional quality. Results of previous studies on how mites respond to plant nutrition imply that crop damages from mite feeding can be mitigated by adjusting fertilizer applications (Sudoi *et al*., 2001; Chen *et al*., 2007).

Changing the quality of host plant under different fertilization levels can influence the mite population dynamics as well as associated yield losses. Fertilizer application would change the proportion of nutrient composition in plant tissues and, consequently, their nutritive value helps in the management of sucking pests (Wooldridge and Harrison, 1968). It is now well recognized that host plant quality can affect several life history characteristics of their herbivores by impairing growth, lowering resistance to diseases, and reducing fecundity (Price *et al*., 1980).

The life table parameters are powerful tools for analyzing and understanding the impact of an external factor such as host plant quality (under different fertilization levels) on the growth, survival rate, reproduction and intrinsic rate of increase of an arthropod population. In this study, we aimed to evaluate the effect of different inorganic fertilizer levels on bio-ecological fitness and life table of the two-spotted spider mite.

MATERIALS AND METHODS

Plant Cultivation

The seeds of resistant bean cultivar (*Phaseolus vulgaris* var. Parastoo) to *T. urticae* (Ahmadi *et al*., 2006) were obtained from Agriculture and Natural Resources Research Center of Bam, Kerman Province, Iran. The seeds were planted in 2-liter pots, containing 2 kg soil. The cultivated pots were placed in a growth chamber at 25±1°C, 60±5% humidity and a photoperiod of 16:8 (L: D) hours.

Culture of Mite

The initial population of TSSM was obtained from a *Tetranychus urticae* colony stablished on *Phaseolus vulgaris* in the research greenhouse of the College of Agriculture, Shahid Bahonar University of Kerman, Iran. Offspring of this colony were reared on leaves of bean treatments under greenhouse conditions [at 25±5°C, 60±10% humidity and a photoperiod of 16:8 (L: D) hours] for two generations before the experiments.

Fertilizer Treatment

In this study, the effects of applying 30, 60, and 100% of the recommended level of nitrogen fertilization using ammonium nitrate (0.057, 0.114 and 0.17 g), urea (0.6, 3.92 and 1.96 g), and potassium fertilization (0.0348, 0.067, and 0.0116 g potassium sulfate) were investigated. As soon as the seedlings reached to the stage of 3 to 4 leaves, all the plants were irrigated at the same time and fertilizers were added to the irrigation water. The first application of fertilizer was at four-leaf stage, and the second one was carried out one week later. All fertilizers were used in soil.

Leaf Disc

The leaf discs taken from leaves of each treatment were used to determine the life table parameters of TSSM under different fertilizer regime (Naher *et al*., 2006; Khanamani *et al*., 2013). The leaves of each treatment in the beginning of plant reproductive stage were cut into 2.50 cm diameter leaf discs. In the next step, cut leaves were placed on agarose bed in smaller Petri dishes, with the underside facing upward. The leaf discs were changed with new ones every four days.

Demographic Parameters

All experiments were carried out under laboratory conditions at 25±1°C, 60±5% relative humidity and a photoperiod of 16:8 (L:D) hours. At the beginning of the experiments, to obtain the synchronized eggs of TSSM, 15 pairs of both sexes of TSSM were transferred from the colony of the related treatment onto a leaf disc of the same treatment. After 12 hours, the laid eggs of these females were individually transferred to the experimental units up to 70 replicates per treatment. These experimental units were checked twice a day (at 07:30 am and 07:30 pm) in immature stages and the duration and mortality of different immature stages were recorded using a stereomicroscope. After emergence of adults, females were coupled with the males obtained in the same experiment. They were kept together up to the end of the study. During mature stage, the daily observations (once a day at 08 am) were conducted under a stereomicroscope to determine longevity, fecundity, and mortality of adult females and males until the death of all individuals.

Estimating Age-Stage, Two-Sex Life Table Parameters

The life history raw data of all individuals were analyzed according to the age-stage, two-sex life table theory (Chi and Liu 1985; Chi 1988).

Statistical Analysis

Data analysis and population parameters were calculated by using the TWOSEX-MSChart program (Chi, 2018). The variances and standard errors of the population parameters were estimated by using the bootstrap procedure (Efron and Tibshirani, 1993; Huang and Chi, 2013). In addition, the two-sex life table bootstrap-values of the TSSM on different fertilizer treatments were compared using the paired bootstrap test based on confidence interval (Bahari *et al*., 2018). Differences of duration of different life stages and fecundity of the TSSM on different fertilizer treatments were analyzed using one-way ANOVA (SPSS 16). In addition, the Excel software was used to draw figures.

RESULTS

Biological Parameters

Fertilizer effects on duration of different life stages (days) and fecundity (offspring) of TSSM are shown in Table 1. There was significant difference among durations of different life stages of TSSM reared on beans fertilized with various fertilizers.

Duration of total developmental time of TSSM indicated significant differences on tested fertilizers, and the longest period was related to TSSM reared on bean fertilized with 60% potassium sulfate and the shortest

[DOR: 20.1001.1.16807073.2021.23.4.7.6]

Table 1. Fertilizer effects on duration of different life stages (days) and fecundity (offspring) (± SE) of *Tetranychus urticae* on bean. [a]

Parameters	Fertilizers								
	Ammonium nitrate 30%	Ammonium nitrate 60%	Ammonium nitrate 100%	Urea 30%	Urea 60%	Urea 100%	Potassium sulfate 30%	Potassium sulfate 60%	Potassium sulfate 100%
Egg	5.94 ± 0.2^{c}	5.91 ± 0.12^{c}	6.25 ± 0.13^{bc}	6.28 ± 0.18^{abc}	6.15 ± 0.24^{c}	6.24 ± 0.16^{abc}	6.33 ± 0.45^{abc}	6.4 ± 0.25^{ab}	6.50 ± 0.27^{a}
Larva	2.18 ± 0.12^{c}	2.09 ± 0.11^{c}	2.05 ± 0.06^{c}	2.4 ± 0.09^{bc}	2.25 ± 0.07^{c}	2.44 ± 0.1^{bc}	3 ± 0.23^{ab}	3.37 ± 0.31^{a}	3.15 ± 0.19^{a}
Protochrysalis	1.76 ± 0.09^{c}	1.69 ± 0.07^{c}	1.92 ± 0.07^{c}	2.08 ± 0.07^{abc}	1.92 ± 0.08^{bc}	2.13 ± 0.11^{abc}	2.5 ± 0.31^{a}	2.5 ± 0.16^{a}	2.38 ± 0.21^{bc}
Protonymph	1.93 ± 0.1^{b}	2.13 ± 0.1^{ab}	2.06 ± 0.1^{b}	2.35 ± 0.09^{ab}	2.02 ± 0.08^{b}	2.14 ± 0.09^{ab}	2.47 ± 0.33^{ab}	2.74 ± 0.21^{a}	2.4 ± 0.16^{ab}
Deutochrysalis	2.02 ± 0.08^{a}	2.22 ± 0.09^{a}	1.81 ± 0.1^{a}	2.05 ± 0.07^{a}	1.9 ± 0.1^{a}	1.73 ± 0.11^{a}	1.83 ± 0.14^{a}	2.12 ± 0.16^{a}	2.13 ± 0.19^{a}
Deutonymph	2.11 ± 0.09^{b}	2.28 ± 0.09^{ab}	2.15 ± 0.08^{b}	2.35 ± 0.08^{ab}	1.94 ± 0.1^{b}	2 ± 0.11^{b}	2 ± 0.11^{b}	2.68 ± 0.15^{a}	2.26 ± 0.11^{ab}
Teleiochrysalis	1.88 ± 0.07^{bc}	2.2 ± 0.09^{b}	1.92 ± 0.08^{bc}	2.17 ± 0.06^{b}	1.87 ± 0.07^{bc}	1.62 ± 0.09^{c}	2.16 ± 0.14^{b}	3.1 ± 0.16^{a}	2.33 ± 0.12^{b}
Total immature stages	17.56 ± 0.29^{e}	18.44 ± 0.28^{de}	18.28 ± 0.24^{de}	19.69 ± 0.27^{cd}	18.11 ± 0.27^{e}	18.25 ± 0.28^{de}	20.30 ± 0.77^{bc}	22.98 ± 0.52^{a}	21.16 ± 0.33^{ab}
APOP [b]	2.31 ± 0.17^{a}	2.38 ± 0.17^{a}	2.25 ± 0.14^{a}	2.13 ± 0.14^{a}	2 ± 0.13^{a}	2 ± 0.16^{a}	2.25 ± 0.13^{a}	2.33 ± 0.28^{a}	2.11 ± 0.26^{a}
Adult longevity (Male)	7.18 ± 0.9^{ab}	10 ± 0.8^{a}	6.66 ± 0.74^{ab}	7.66 ± 0.47^{ab}	7.7 ± 0.59^{ab}	6 ± 0.48^{b}	5.5 ± 0.56^{b}	4.83 ± 1.19^{b}	4.83 ± 0.4^{b}
Adult longevity (Female)	8.68 ± 0.52^{b}	10.71 ± 0.48^{a}	8.17 ± 0.4^{bc}	7.28 ± 0.41^{c}	7.24 ± 0.38^{c}	5.81 ± 0.35^{e}	6.16 ± 0.56^{de}	9.46 ± 1.12^{ab}	5.66 ± 0.23^{e}
Total life span	25.3 ± 0.42^{cd}	28.1 ± 0.68^{b}	25.8 ± 0.22^{cd}	27.12 ± 0.57^{bc}	26.1 ± 0.33^{c}	24.27 ± 0.18^{d}	26.4 ± 0.60^{c}	30.25 ± 0.38^{a}	26.99 ± 0.27^{c}
Fecundity (F) (Offspring)	6.21 ± 0.75^{d}	15.37 ± 1.81^{a}	9.03 ± 0.86^{b}	4.84 ± 0.48^{e}	4.79 ± 0.39^{e}	2.86 ± 0.31^{f}	2.91 ± 0.41^{c}	7.61 ± 1.88^{cd}	2.66 ± 0.28^{f}

[a] (a-f) Means within the same row followed by the same letters are not significantly different ($P< 0.05$, Tukey). [b] APOP: Adult Pre-Ovipositional Period.

period was related to those on 30% ammonium nitrate and 60% urea.The tested fertilizers did not affect the adult pre-ovipositional period (APOP), which is the duration from adult emergence to the first oviposition of TSSM (Table 1). However, the mean fecundity (eggs female^{-1}) of TSSM reared on beans fertilized with different concentrations of ammonium nitrate (especially 60% ammonium nitrate) were significantly higher than those reared on the other fertilizers.

The male and female longevity of adult TSSM was significantly different on tested fertilizers. On 60% ammonium nitrate, TSSM males and females were generally found to have the highest longevity, whereas the shortest longevity for both sexes was on 100%potassium sulfate.

Two-Sex Life Table Parameters

Fertilizer effects on age-stage, two-sex life table parameters of TSSM are shown in Table 2. Based on the age-stage, two-sex life table, the cohort reared on bean fertilized with 60% ammonium nitrate had the highest r value, and that on fertilized bean with 100% potassium sulfate had the lowest r value. Also, the highest and lowest values of finite rate of increase (λ) were obtained on beans fertilized with 60% ammonium nitrate and 100% potassium sulfate, respectively. In addition, the values of the net Reproductive rate (R_0) and Gross Reproductive Rate (*GRR*) of TSSM reared on bean fertilized with 60% ammonium nitrate were significantly higher than the other fertilizer treatments. However, our results revealed that the mean generation Time (T) of TSSM on the examined fertilizers was not significantly different.

Mortality and Fecundity Curves

The age-stage specific survival rates (s_{xj}) of TSSM reared on beans fertilized with various fertilizers (Figure 1) show the probability that a newborn will survive to age x and develop to stage j. These curves also show the survivorship and stage differentiation as well as the variable developmental rate. The age specific survivorship (l_x) shows the probability that a newborn individual will survive to age x and is calculated by pooling all individuals of both sex (Figure 2). According to these results, the preadult mortality of TSSM was lower on beans fertilized with different concentrations of ammonium nitrate, whereas, it was higher on beans fertilized with different concentrations of potassium sulfate.

The age-stage specific fecundity (f_{xj}) and age specific fecundity (m_x) of TSSM reared on beans fertilized with various fertilizers

Table 2. Fertilizer effects on age-stage, two-sex life table parameters (Means±SE) of *Tetranychus urticae* on bean. [a]

Fertilizer	*GRR* (eggs individual^{-1})	R_0 (eggs individual^{-1})	r (d^{-1})	λ (d^{-1}0	T (d)
Ammonium nitrate 30%	8.23±0.92^{b}	3.43±0.58^{bc}	0.051±0.006^{bc}	1.053±0.006^{bc}	23.56±0.29^{a}
Ammonium nitrate 60%	16.29±1.98^{a}	8.93±1.41^{a}	0.089±0.007^{a}	1.093±0.007^{a}	24.31±0.31^{a}
Ammonium nitrate 100%	9.76±1.24^{b}	4.51±0.73^{b}	0.065±0.006^{b}	1.067±0.006^{b}	22.77±0.24^{a}
Urea 30%	5.32±0.78^{c}	2.15±0.38^{cd}	0.030±0.006^{d}	1.031±0.006^{d}	24.40±0.45^{a}
Urea 60%	5.40±0.69^{c}	2.40±0.37^{cd}	0.037±0.005^{cd}	1.038±0.006^{cd}	22.80±0.25^{a}
Urea 100%	3.11±0.40^{c}	1.10±0.21^{d}	0.004±0.009^{e}	1.004±0.009^{e}	23.03±5.03^{a}
Potassium sulfate 30%	4.29±0.59^{c}	1.09±0.16^{d}	0.002±0.005^{e}	1.002±0.005^{e}	25.75±6.22^{a}
Potassium sulfate 60%	9.44±2.21^{b}	1.93±0.46^{cd}	0.021±0.007^{d}	1.021±0.008^{d}	27.85±2.61^{a}
Potassium sulfate 100%	2.53±0.25^{c}	1.044±0.14^{d}	0.001±0.0004^{e}	1.001±0.004^{e}	26.70±6.44^{a}

[a] (a-e) Means within the same column followed by the same letters are not significantly different (P< 0.05, paired bootstrap test).

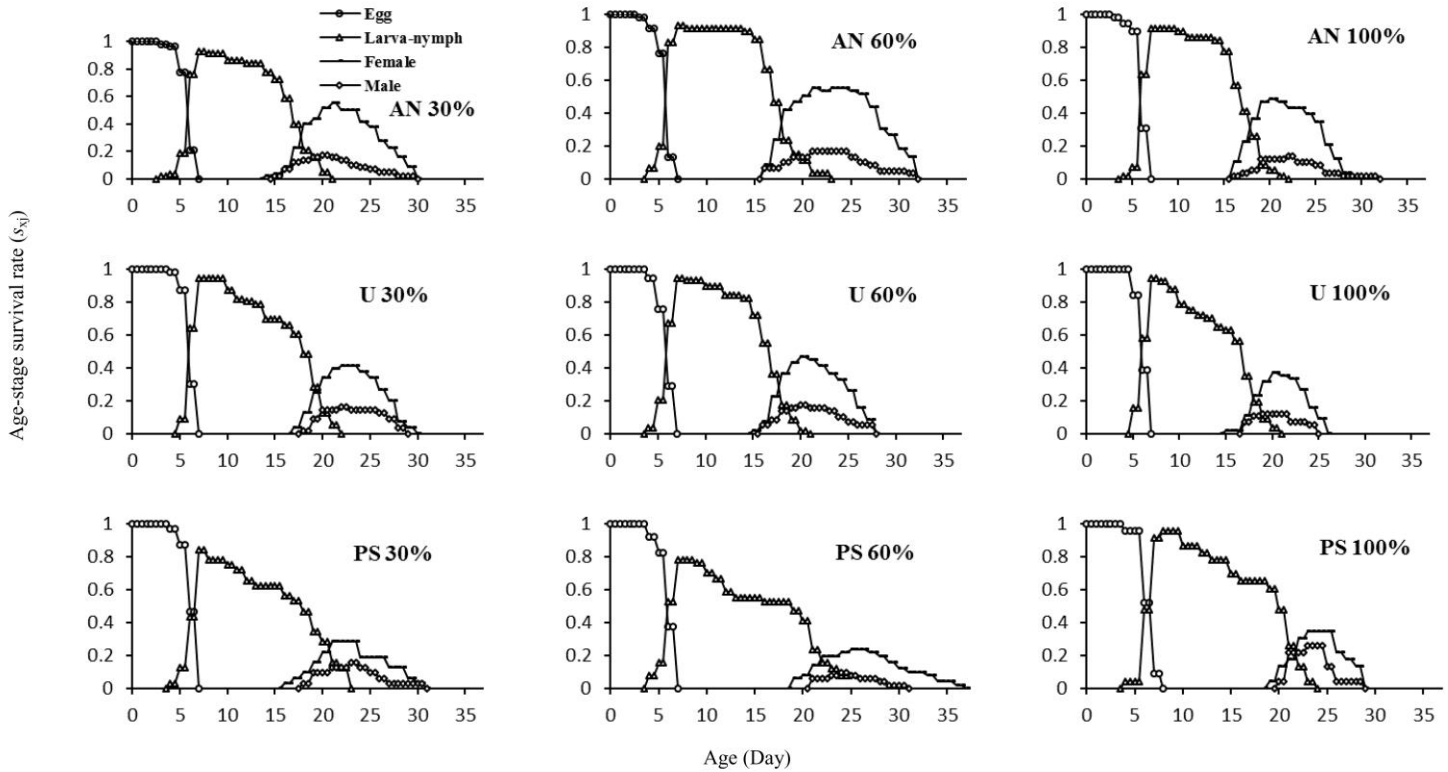

Figure 1. Fertilizer effects on age-stage survival rate (s_{xj}) of *Tetranychus urticae* on bean. (AN: Ammonium Nitrate; U: Urea, PS: Potassium Sulfate).

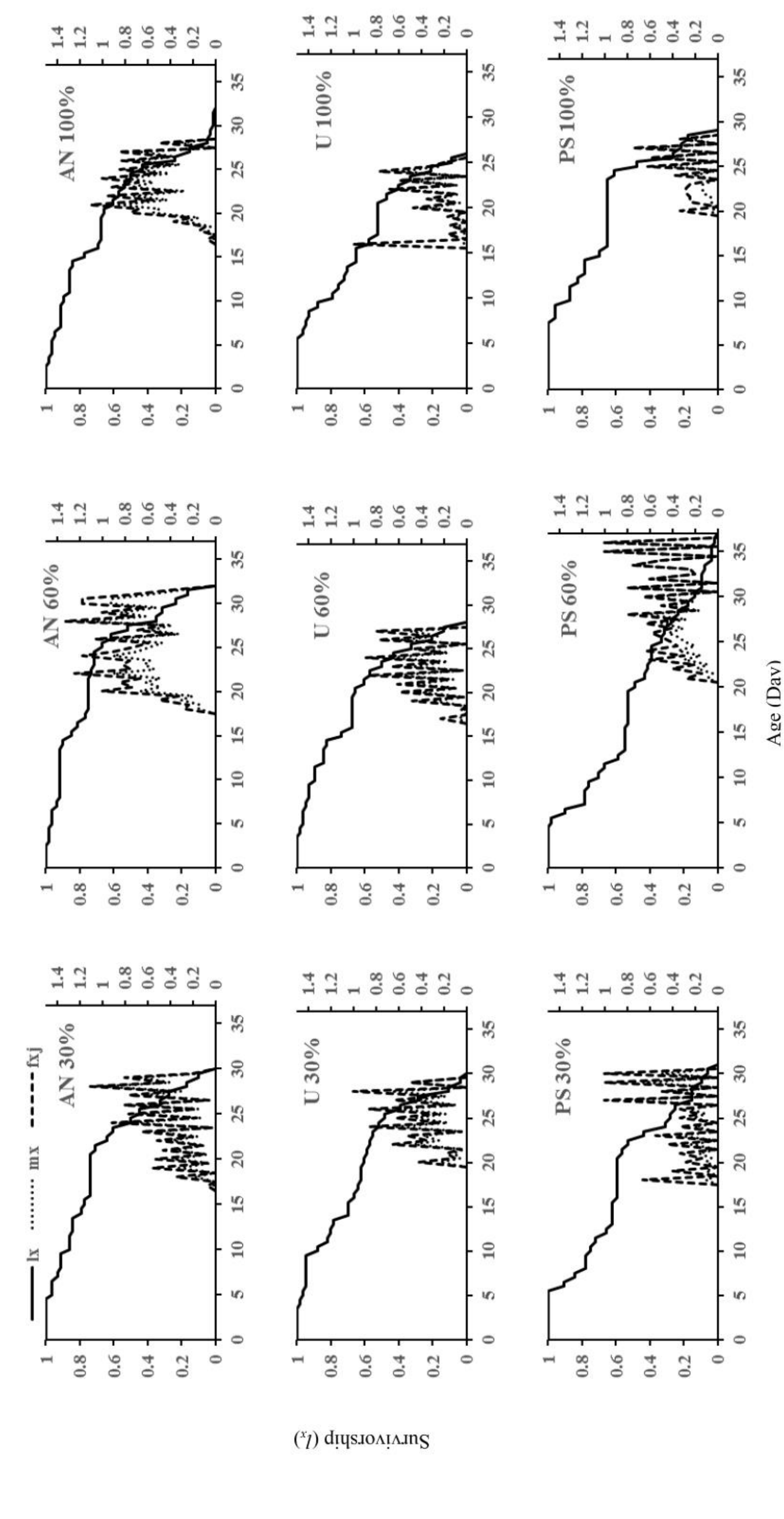

Figure 2. Fertilizer effects on age-specific survivorship (l_x), age-specific fecundity (m_x), and age-stage specific fecundity (f_{xj}) of *Tetranychus urticae* on bean. (AN: Ammonium Nitrate; U: Urea, PS: Potassium Sulfate).

are shown in Figure 2, indicating that TSSM could successfully reproduce on different tested fertilizers. However, daily fecundity of TSSM reared on beans fertilized with different concentrations of ammonium nitrate (especially 60% ammonium nitrate) were higher than the other fertilizers.

DISCUSSION

One of the most important aspects in plant production is proper supply of nutrients during the growing period (Rahbar *et al*., 2018). Chemical fertilizers can dramatically influence the balance of nutritional elements in plants (Khodayari *et al*., 2018), and it is likely that their excessive use will create nutrient imbalances, which in turn, reduce resistance to insect pests (Altieri and Nicholls, 2003). In this study, to evaluate the effect of different inorganic fertilizer levels on bio-ecological fitness of the two-spotted spider mite, life table studies were performed.

The obtained results indicated that different inorganic fertilizer levels have different significant effects on bio-ecological parameters of the two-spotted spider mite. The cohorts reared on bean fertilized with different concentrations of ammonium nitrate (especially 60% ammonium nitrate) had a greater reproductive potential because they had the highest *r*-value and shortest development time, showing that this fertilizer is presumably a more suitable nutrient than the other ones. Previous studies have found a positive correlation between high soil nitrogen concentration and density of *Tetranychus* spp. (Suski and Badowska, 1975; Wermelinger *et al*., 1985). Chow *et al.* (2009) analyzed two-spotted spider mite density after fertilizing roses with standard vs. reduced amounts of nitrogen, and found mites and their eggs were twice as dense on roses fertilized with 100% (150 ppm) compared to lower nitrogen concentrations (33% N or 50 ppm and 50% N 75 ppm).

Plant resistance is linked directly to the physiology of the plant, and any factor that affects the physiology of the plant may lead to changes in resistance to insect pest. The obvious morphological responses of crops to fertilizers, such as changes in growth rates, accelerated or delayed maturity, size of plant parts, and thickness and hardness of epicuticle also influence the success of many pest species in utilizing the host (Altieri and Nicholls, 2003). In this study, TSSM had the lowest *r*-value on bean fertilized with different concentrations of potassium sulfate (especially 100%potassium sulfate) and it was the least favorable fertilizer evaluated in the current study. Moreover, longer developmental time and lower reproductive performance of TSSM were observed on different concentrations of potassium sulfate. Khodayari *et al*. (2018) demonstrated that fertilizing with potassium could improve plant health and vigor, while conferring resistance against a wide range of diseases.

In conclusion, although soil fertility management is needed to support optimal crop development, it also modifies the resources available to pest organisms by altering plant-quality, which, in turn, can affect insect abundance and subsequent levels of herbivore damage. Our findings may provide important information in the design of a comprehensive program for integrated soil fertility management and subsequently integrated management of TSSM in bean fields. Our findings may provide a relatively reliable result regarding interactions between bean and TSSM under application of different soil fertilizers at microcosm scale. However, to achieve more practical results, semi-field and field experiments should be conducted in future research programs.

ACKNOWLEDGEMENTS

The support of this research by the Department of Entomology, Shahid Bahonar

[DOR: 20.1001.1.16807073.2021.23.4.7.6]

University of Kerman, Iran, is greatly appreciated.

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تاثیر رژیم‌های مختلف کودی بر پارامترهای زیستی کنه‌ی *Tetranychus urticae* (*Acari: Tetranychidae*) روی رقم مقاوم لوبیا

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چکیده

روش‌های کنترل زراعی مانند کوددهی محصول می‌تواند حساسیت گیاه به گیاه‌خوار را با تغییر مغذی بافت گیاهی تغییر دهد. در این پژوهش، پارامترهای جدول زندگی کنه تارتن دو لکه‌ای، *Tetranychus urticae*، تحت رژیم‌های کودی شیمیایی مختلف روی رقم مقاوم گیاه لوبیا (رقم پرستو) در شرایط آزمایشگاهی در دمای ۱±۲۵درجه، رطوبت نسبی ۵±۶۰ درصد و طول دوره روشنایی به تاریکی ۱۶ به ۸ ساعت، تعیین گردید. تیمارهای کودی شامل سه سطح (۳۰، ۶۰، و ۱۰۰ درصد از سطح توصیه شده) از کودهای اوره، نیرات آمونیم و سولفات پتاسیم بودند. بر اساس نتایج به دست آمده، کوتاه‌ترین و طولانی‌ترین طول دوره قبل از بلوغ، به ترتیب مربوط به افراد پرورش یافته روی لوبیای تیمار شده با رژیم‌های کودی نیترات آمونیم ۳۰٪، اوره ۶۰٪، و سولفات پتاسیم ۶۰٪ بود. میانگین باروی افراد پرورش یافته روی لوبیای تیمار شده با غلظت‌های مختلف کود نیترات آمونیم (خصوصا ۶۰٪) به طور معنی‌داری بیشتر از سایر تیمارهای کودی بود. بیشترین و کمترین مقدار نرخ ذاتی افزایش جمعیت (r)، به ترتیب مربوط به افراد پرورش یافته روی لوبیای تیمار شده با رژیم‌های کودی نیترات آمونیم ۶۰٪، و سولفات پتاسیم ۱۰۰٪ بود. علاوه بر این، مقادیر نرخ خالص تولید مثلی (R_0) و نرخ ناخالص تولید مثلی (GRR) کنه‌های تارتن پرورش یافته روی لوبیای تیمار شده با کود نیترات آمونیم ۶۰٪ به طور معنی‌داری بیشتر از سایر تیمارهای کودی بود. نتایج به دست آمده در این پژوهش ممکن است اطلاعات مفیدی برای طراحی یک برنامه جامع در مدیریت تلفیقی کوددهی خاک و نهایتا مدیریت تلفیقی کنه تارتن در مزارع لوبیا فراهم آورد.

[DOR: 20.1001.1.16807073.2021.23.4.7.6]