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The effect of irrigation regimes and n-fertilizer levels on developmental time and parameters of fecundity life table of *spodoptera exigua* (hubner) on sugar beet

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ABSTRACT

The beet armyworm, *Spodoptera exigua*, is one of the most important pests of sugar beet in Iran. The aim of this study was to determine the effect of water and nitrogen treatments of sugar beet plant on developmental time and fecundity life table parameters of the pest. An experiment was carried out under laboratory conditions (25±2°C, 70±5% R.H. and 12L: 12D) on larvae reared on sugar beet leaves collected from different treated plants. Treatments consisted of three irrigation regimes, irrigation after 70, 105, 140 mm of cumulative evaporation from class A pan, and also three N-fertilizer levels, 200, 150, 100 kg/ha net nitrogen. The results showed that the longest larval and pupal developmental time, the lowest pupal weight and the shortest adult longevity were observed in 70 mm cumulative evaporation treatment. Additionally, the longest pupal developmental time, the lowest pupal weight and the shortest adult longevity were in 100 kg/ha net nitrogen treatment. Larvae reared on leaves collected from 105 mm cumulative evaporation and 200 kg/ha net nitrogen treatment resulted in the highest intrinsic rate of increase (r_m), net reproductive rate (R_o), gross reproductive rate (G. R. R.), finite rate of increase (λ), the shortest mean generation time (T) and doubling time (t). This indicated that moderate drought stress and the highest amount of nitrogen fertilizer may increase the population density of the pest.

Key Words: Irrigation regimes, *Spodoptera exigua*, Sugar beet

INTRODUCTION

Sugar beet armyworm, *Spodoptera exigua*, is one of the most important pests of sugar beet in Iran. Larvae feed on leaves. In severe damage, total leaves are eaten by larvae and veins only remain, thus affecting the photosynthetic capacity of the crop with subsequent reduction of yield. Because of the relatively low nutritional value, high concentration of indigestible and a variety of repellant and toxic compounds plants are considered as suboptimal food sources for herbivores (Schoonhaven *et al*,1998). Herbivore performance is typically mediated by a few plant traits, such as leaf water content and nitrogen (N) concentration (With, 1984). Two main hypotheses addressed the impact of growing condition –based physiological changes in the host plant on insect herbivores. First, the plant stress hypothesis predicts that stressed plants will serve as better hosts for insect herbivores (White, 1984, Mattson and Haack, 1987). Plants under stress are more suitable for insect herbivores due to increased nutritional value (mainly free amino acids) (With, 1984). Contrariwise, the plant vigor hypothesis (Price, 1991) predicts that herbivorous insects will prefer. However experimental studies demonstrate that the effect of host plant stress is in many cases unpredictable and depend on the plant and

insect species and the levels of stress (Larsson, 1989). Quality and quantity of food consumed by herbivores affect the growth, survival and fecundity of individuals, and hence their populational improvement (Slansky, 1993). Particularly , those population parameters that express the potential capacity of growth: intrinsic growth rate, net reproductive rate and generation time are related to the suitability of the host plants consumed (Sauvion *et al*, 2005). Numerous ecological factors may alter plant quality for insect herbivores. Soil nutrients and water are two essential resources whose availability can have marked effects on plant growth, morphology, and chemistry, and both have been linked to insect herbivore performance. Soil nutrient additions are well known to increase plant biomass, and have also been shown to affect traits such as foliar nutrient. In general the addition of fertilizer to the soil has been shown to increase foliar N content (Crone and Jones, 1999) as well as often increasing insect growth (Mattson, 1980, Warring and Cobb, 1992). Most studies have shown that drought increases concentrations of N in plant tissues (Mattson and Haack, 1987). The objective of this research was to study the effects of three irrigation and fertilizer levels on N and water content of sugar beet leaves with subsequent differences in developmental time, pupal weight and fecundity life table parameters of sugar beet armyworm.

MATERIALS AND METHODS

Experimental set-up

All of the experiments carried out under laboratory conditions (25±2^{o}C, 70±5% R.H. and photoperiod 12L: 12D). The initial population of the sugar beet armyworm collected from a sugar beet farm at north east of Isfahan. Experiments were initiated after one generation rearing of *S. exigua* under laboratory conditions on lettuce leaves. Larvae and adults were placed in plexiglas cylindrical containers (Lengh:13.5cm and diameter: 27cm) and sealed with a net screen to prevent them from escaping. There was some streel soil in 5cm height at the bottom of larvae containers. Soil in containers were surveyed daily. The pupae were placed in other containers and they were checked daily for adults emergence. Newly emerged adults were placed in the container with paper bands to oviposition and a tube (length: 10cm and diameter: 1.5cm) of sugar solution(10%) to adults feeding. Paper bands were checked daily for newly deposited egg clusters. The egg clusters and their paper bands substrate were placed in plastic Petri dishes and covered with a perforated plastic lid. Eggs were checked daily for hatching. New larvae emerged from egg clusters were used for experiments. Newly emerged first instar larvae from egg clusters reared on freshly sugar beet leaves collected from different farm plot every second day. Farm experiment was conducted in a complete randomized block design with two factors and four replications. The main factor was three irrigation regims (irrigation after 70, 105 and 140 mm cumulative evaporation from class A pan) and the split factor was three fertilizer levels (200, 150 and 100 kg/ha net nitrogen). Farm experimental factors (irrigation and N fertilizer levels) were started from 4 months before the first of the laboratory experiment The laboratory experimental design was a randomized complete block in factorial arrangement with 10 replications.

Plant traits

We measured two plant traits which were lickly to influence armyworm feeding and growth: leaf water content and percentage leaf nitrogen (N) content, in the beginning and the end of experiment. These two traits were measured using leaves that had been excised from three plants in each replication of farm treatments. We bulked leaves of these three plants and

measured water and N content. Water content was determined by weighting the leaves before and after drying at 72 ^{o}C in oven. We calculated leaf water content using the following formula: $(W_w-W_d)/W_w$, where W_w is the wet weight and W_d is the dry weight of the leaves. Percentage leaf N content was calculated by weighting and grinding the leaves and analyzed for kjeldahl N.

Developmental time and pupal weight

Larval (from hatching to pupation) and pupal developmental duration (day), pupal weight (48h after pupation) (mg) and fecundity (total number of eggs/ female) were assessed on different treatments. Fecundity was estimated on one female maintained in a plastic containainer with at least one male containing paper bands for oviposition. We also determined adults longevity from the date that the adults emerged to died.

Parameters of fecundity life table

Parameters of fecundity life table as net reproductive rate (R_o), gross reproductive rate (G. R. R.) intrinsic rate of increase (r_m), fnite rate of increase (λ), mean generation time (T) and doubling time (t) were calculated for the treatments that adults emerged. In other treatments, mortality rate (random mortality or mortality by low nutritional quality of host plant) was high and no larvae became changed in to adult. These treatment were irrigation after 105 mm cumulative evaporation from class A pan and 200 kg/ha net nitrogen, irrigation after 105 mm cumulative evaporation from class A pan and 150 kg/ha net nitrogen, irrigation after 140 mm cumulative evaporation from class A pan and 200 kg/ha net nitrogen, irrigation after 140 mm cumulative evaporation from class A pan and 150 kg/ha net nitrogen, irrigation after 140 mm cumulative evaporation from class A pan and 100 kg/ha net nitrogen.

Calculating net reproductive rate ***(R_o):*** The net reproductive rate is defined as the mean number of daughters produced per cohort of female over their lifetime (Carey 1993). Net reproductive rate was calculated as: $(R_o) = \sum l_x m_x$

Where $l_x m_x$= net female maternity.

Calculating generation time (T). Generation time is average interval separating the births of one generation from the births of the next (Carey 1993). Generation time was calculated as:

$$T = \frac{\sum l_x m_x x}{\sum l_x m_x} = \frac{\sum l_x m_x x}{R_o}$$

Calculating the intrinsic rate of increase (r_m). Intrinsic rate of increase is the maximum exponentioal rate of increase by a population growing within defined physical conditions (Carey 1993) (**r_m=** $\sum_{x=0}^{\infty} e^{-r_m . x} l_x m_x = 1$**).** This equation was solved by iteration until both sides of the equation were equal to 1.

Calculating population increase at each time interval ***(λ).*** Population increase at each time interval is defined as the ratio of population sizes at each time step (Carey 1993) and was calculated as $\lambda = e^{r_m}$.

Calculating doubling time (t). Doubling time is the time needed for a population to double in size from a fixed point in time (Gotelli 1995). Doubling time was calculated as $t = \frac{\log_e(2)}{r_m}$.

Data analysis

We used a analysis of variance (ANOVA) to test for effects of irrigation and fertilizer on leaf water and nitrogen content. Data were analysed using the SAS software. Means were compaired with Duncan' multiple range test at the 5% level.

RESULTS

The effect of irrigation on developmental time and pupal weight

The effect of irrigation on larval (F=13.7, d.f.=2 P<0.0001) pupal (F=3.78, d.f.=2, P=0.0082) developmental time, pupal weight (F=26.58, d.f.=2, P<0.0001) and adult longevity (F=23.47, d.f.=2, P<0.0001) was significant. The longest larval developmental time (15.25±0.25a) was related to irrigation after 70 mm cumulative evaporation from class A pan treatment. The highest pupal weight (0.24±0.016a) and adult longevity (12±0.21a) were observed in 105 mm irrigation treatment and the lowest of these parameters were in 70 mm irrigation treatment (table 1).

Table 1. Effect of irrigation on developmental time, pupal weight and adult longevity of *S. exigua* under laboratory conditions.

Treatments	Larval developmental time (days)	Pupal developmental time (days)	Pupal weight (gram)	Adult longevity (days)
Irrigation 1 (1)	15.25±0.25a*	12.5±0.29a	0.19±0.002c	7.45±0.38c
Irrigation 2 (2)	12.70±0.14b	11±0.25ab	0.24±0.016a	12±0.21a
Irrigation 3 (3)	12.05±0.14c	10.33±0.31b	0.21±0.004b	9.14±0.2b
F	13.7	3.78	26.58	23.47
P	0.0001	0.0082	0.0001	0.0001

(1): Irrigation after 70 mm cumulative evaporation from class A pan.
(2): Irrigation after 105 mm cumulative evaporation from class A pan.
(3): Irrigation after 140 mm cumulative evaporation from class A pan
*Within columns means followed by the same letter are not significantly different (*P*= 0.05, Duncan's multiple range test).

The effect of N fertilizer on developmental time and pupal weight

There was significant effect of N fertilizer on pupal developmental time (F=3.78, d.f.=2, P=0.0082), pupal weight (F=26.58, d.f.=2, P<0.0001) and adult longevity (F=23.47, d.f.=2, P<0.0001). Pupal developmental time was only significantly defferent between 100 and 200 kg/ha net N treatments. Pupal developmental time was the highest in100 kg/ha net N

treatments (11.43±0.29a). In 200 and 150 kg/ha net N treatments the pupal weight was significantly higher than in 100 kg/ha net N treatment. Adult longevity in 200 kg/ha net N treatment (10.06±0.45a) significantly longer than other treatments (table 2).

Table 2. Effect of N fertilizer on developmental time, pupal weight and adult longevity of *S. exigua* under laboratory conditions.

Treatments	Larval developmental time (days)	Pupal developmental time (days)	Pupal weight (gram)	Adults longevity (days)
Fertilizer 1 (1)	12.66±0.28a*	10.5±0.33b	0.23±0.009a	10.06±0.45a
Fertilizer 2 (2)	12.5±0.29a	11.29±0.42ab	0.22±0.013a	9.67±0.55ab
Fertilizer 3 (3)	12.8±0.36a	11.43±0.29a	0.18±0.007b	9.27±0.7b
F	13.7	3.78	26.58	23.47
P	0.0001	0.0082	0.0001	0.0001

(1): 200 kg/ha net nitrogen.
(2): 150 kg/ha net nitrogen.
(3): 100 kg/ha net nitrogen.
*Within columns means followed by the same letter are not significantly different (*P*= 0.05, Duncan's multiple range test).

The effect of irrigation and N fertilizer on parameters of fecundity life table:

Net reproductive rate (R_o), gross reproductive rate (G. R. R.), intrinsic rate of increase (r_m), finite rate of increase (λ), mean generation time (T) and doubling time (t) are presented in table 3. The highest intrinsic rate of increase (r_m), net reproductive rate (R_o), gross reproductive rate (G. R. R.), finite rate of increase (λ), the shortest mean generation time (T) and doubling time (t) were observed in 105 mm irrigation and 200 kg/ha nitrogen treatments.

Table 3. The effect of irrigation and fertilization on fecundity life table parameters of *S. exigua* under laboratory conditions.

Treatment	Fecundity life table parameters					
	(R_o)	**(G.R.R)**	**(r_m)**	**(λ)**	**(T)** (days)	**(t)** (days)
1	245.6	937.3	0.186	1.2	27.04	3.7
2	132	792	0.179	1.98	27.81	3.87
3	126.5	658.5	0.174	1.19	28.87	3.98
4	104.33	656	0.16	1.17	29.5	4.33
5	101.4	547.5	0.15	1.16	32.55	4.6

1: Irrigation after 105 mm cumulative evaporation from class A pan and 200 kg/ha net nitrogen treatment.
2: Irrigation after 105 mm cumulative evaporation from class A pan and 150 kg/ha net nitrogen treatment.
3: Irrigation after 140 mm cumulative evaporation from class A pan and 200 kg/ha net nitrogen treatment.
4: Irrigation after 140 mm cumulative evaporation from class A pan and 150 kg/ha net nitrogen treatment.
5: Irrigation after 140 mm cumulative evaporation from class A pan and 100 kg/ha net nitrogen treatment.

The effect of irrigation on leaf water and N content

Significant differences were observed for effect of irrigation on leaf water ($F=44.7$, d.f.= 2, $P<0.0001$ and $F=158.54$, d.f.=2, $P<0.0001$) and N ($F=71$ d.f.=2, $P<0.0001$ and $F=32.61$, d.f.=2 $P<0.0001$) content at the first and the end of experiment respectively. At the first and the end of experiment in 70 and 105 mm irrigation treatments leaf water content was significantly higher than 140 mm irrigation treatment (table 3). Leaf N content in 105 and 140 mm irrigation treatments were higher than 70 mm irrigation treatment not only in the first but also in the end of experiment (table 4).

The effect of N fertilizer on leaf water and N content

There was not significant difference for the N fertilizer on leaf water content nither at the first nor at the end of experiment ($F=0.2$, d.f.=2, $P=0.817$ and $F=0.45$, d.f.=2, $P==0.644$). The effect of N fertilizer on leaf N content was significant at the first ($F=6.01$, d.f.=2, $P=0.01$) and at the end ($F=2.75$, d.f.=2, $P=0.0091$)of experiment. At the first of experiment in 200 and 150 kg/ha net N treatment, leaf N content was significantly higher than 100 kg/ha net N treatment. At the end of experiment leaf N content was only significantly different between 200 and 100 kg/ha net N treatments. The highest leaf N content was related to 200 kg/ha net N treatment (table 5).

Table 4. Effect of irrigation on leaf water and N content at the first and the end of experiment

Date of analysis	Treatments	Leaf water content	Leaf N content
First of experiment	Irrigation 1 (1)	86.7±0.4a*	16.02±0.7b
	Irrigation 2 (2)	81.5±2.1a	21.9±0.91a
	Irrigation 3 (3)	51.1±4.1b	20.99±0.67a
End of experiment	Irrigation 1 (1)	80.7±0.54a	16.73±0.97b
	Irrigation 2 (2)	79.3±1.9a	22.67±0.95a
	Irrigation 3 (3)	45.2±1.8b	23.6±0.81a

(1),(2) and(3) : Refer to subtitle of table 1

*Within columns means followed by the same letter are not significantly different (P= 0.05, Duncan's multiple range test).

Table 5. Effect of N fertilizer on leaf water and N content at the first and the end of experiment

Date of analysis	Treatments	Leaf water content	Leaf N content
First of experiment	Fertilizer 1 (1)	76.7±4.49a*	20.31±0.71a
	Fertilizer 2 (2)	72.14±3.1a	20.07±0.84a
	Fertilizer 3 (3)	70.5±4.08a	18.6±1.5b
End of experiment	Fertilizer 1 (1)	70.2±1.48a	22.09±0.92a
	Fertilizer 2 (2)	68.4±1.49a	20.97±1.74ab
	Fertilizer 3 (3)	66.5±3.2a	19.94±0.98b

(1),(2) and(3) : Refer to subtitle of table 2

*Within columns means followed by the same letter are not significantly different (*P*= 0.05, Duncan's multiple range test).

DISCUSSION

Our results showed that increased irrigation interval reduced larval and pupal developmental time. The shortest larval and pupal developmental time were observed in 140 mm irrigation treatment. Pupal weight and adult longevity increased when larval and pupal developmental time were shortend. More decreased larval and pupal developmental time adversely affected pupal weight and adult longevity. So that pupal weight and adult longevity were lower in 140 mm irrigation treatment than 105 mm irrigation treatment. Many studies have investigated effects of host plant quality on herbivorous insects developmental time; larval and pupal developmental time of insects that feeding on suitable host plants, shorten. We found that irrigation reduction, increases leaf nitrogen content. Leaf nitrogen content in 140m and then 105 mm irrigation treatments was greater than 70 mm irrigation treatment. This was consistent with previouse studies; drought generally increases concentration of nitrogen in plant tissues as well as often increasing insect growth. Unexpectedly, the highest pupal weight and adult longevity were observed in 105 mm irrigation treatment. Significant shortage of leaf water content in 140 mm irrigation treatment than 105 mm irrigation treatment has probably restricted the larvae growth in this treatment. It looks leaf water content other than leaf nitrogen content is a determining factor on insect growth. In 70 and 105 mm irrigation treatments increased water availability enhanced the ability of sugar beet to uptake and conserve water internally therby leaf water content across these treatments increased. Although plants under water stress are more suitable due to increased nutritional value (mainly free amino acids) but shortage of water could itself restrict insect performance (Schoonhoven et al. 1998). Insect larvae that feeding on these plants, encounter water deficit. Hence they consume their energy to continue their water balance. So thatwater deficit offset increased amino acids in host plant under water stress. Lower and Orians (2002) also reported that leaf beetle, *Plodiogdera versicolora*, performance on *Salix sericea* was related to nitrogen and water content of leaves. They observed that increasing of leaf nitrogen content lead to increase of pupal weight and plant nutritional quality. They also demonstrated that leaf

water content was positively correlated with developmental time of the leaf beetle. Showler and Moran (2003) showed that the survival of *S. exigua* larvae on cotton reduced because of leaf water content reduction. We also found that more increased nitrogen fertilizer application to sugar beet increases leaf nitrogen content a pattern which has also been observed in other studies (Lower&Orians 2003). So the lowest pupal developmental time, highest pupal weight and adult longevity were observed in 200 kg/ha net N treatment. This is in agreement with the results obtained by Faknath and Lalljee (2005) that found N fertilizer application to *Solanum tuberosum* increased leaf N content, so larval and pupal survival and pupal and adult body weight and length of *Lirriomyza trifolii* Burgess increased. Intrinsic rate of increase and mean generation time reflect the suitability of the host plant. The high nutritional quality of 105 mm irrigation and 200 kg/ha nitrogen treatment had positive effects on the capacity of population increase (higher R_o and r_m and lower T). This positive relationship between R_o and r_m of *S. exigua* on one hand and nutritional quality of the host plant on the other hand has also been observed for other insect pests and host plants (Tsai&Wang 1996, Yong&Hall, 1986). Tsai and Wang (1996) studied the R_o and r_m of *Bemisia argentifolii* on different solanaceous plants such as sweet potato, tomato, *Solanum* and cucumber. They reported the highest R_o, r_m and the shortest T and t of *B. argentifolii* were observed on *Solanum* so this host plant was introduced as a suitable host for this insect.

Conclusion

Quality and quantity of food consumed by herbivores affect the growth, survival and fecundity of individuals and hence their populational improvement (Slansky 1993). The understanding of the host plants range quality could allow predicting the possible expansion in different environmental conditions on crops. This study indicated that moderate drought stress and the highest amount of nitrogen fertilizer may increase the population density of *S. exigua* on sugar beet.

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