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Effects of Green Manure Cover Crops on *Spodoptera litura* (Lepidoptera: Noctuidae) Populations

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ABSTRACT *Spodoptera litura* (F.) is an important pest of numerous agro-economic crops, including green manure cover crops. In Taiwan, sesbania (*Sesbanin roxburghii* Merr.), sunn hemp (*Crotalaria juncea* L.), and rapeseed (*Brassicae campestris* L. variety *chinensis*) are the most popular green manure crops; sesbania and sunn hemp are commonly planted in warm seasons, whereas rapeseed is grown in the winter. In this study, life-table data for *S. litura* reared on these three green manures were collected to evaluate their roles as refuges of this pest. The net reproductive rate, intrinsic rate of increase, and finite rate of increase of *S. litura* were the highest when reared on sesbania (1428.1 offspring, 0.2327 d^{-1}, 1.2621 d^{-1}), followed by sunn hemp (778.4 offspring, 0.2070 d^{-1}, 1.2300 d^{-1}) and rapeseed (737.6 offspring, 0.2040 d^{-1}, 1.2263 d^{-1}). The high growth rates on these green manure crops show that they can serve as potential breeding sites for *S. litura*. Population projection demonstrated the rapid growth of *S. litura* on sesbania, sunn hemp, and rapeseed as well. Because most growers have traditionally ignored pest management in green manure fields, the mass emergence of *S. litura* in these fields may cause unexpected infestations in nearby vegetable, corn, and peanut crops. This study shows that the use of green manures as sources of nutrients should be critically reassessed and an area-wide pest management program should be instituted by taking the population of *S. litura* in green manure fields into consideration.

KEY WORDS *Spodoptera litura*, two-sex life table, sesbania, sunn hemp, rapeseed

The tobacco cutworm, *Spodoptera litura* (F.) (Lepidoptera: Noctuidae), is a generalist herbivore and one of the most important pests in Taiwan and many other countries. The economic importance of *S. litura* is owing to its high increase rate and wide host spectrum, encompassing a large assortment of agricultural crops, including vegetables, green manures, and horticultural plants, as well as miscellaneous wild plants and weeds, totally covering >300 species (Chen and Hsiao 1984, Qin et al. 2004, Ahmad et al. 2007, Tojo et al. 2008, Fei et al. 2010, Xue et al. 2010, Zhou et al. 2010, Ahmad et al. 2013). For polyphagous pests, the continuous presence of diverse host plant species within their migration range plays a major role in their outbreak and makes management more complicated (Lu and Xu 1998, Liu et al. 2004). Although substantial time, effort, and funds have been invested in Taiwan over the past few decades to control *S. litura*, periodic outbreaks remain a serious problem. This is especially true in peanut production areas surrounded by green manure fields during early June and late October (Jiang et al. 2010).

Like growers worldwide, farmers in Taiwan have long used leguminous green manures as cover crops to aid nitrogen-fixation, to supplement minor elements, and to prevent weed growth (Dreyfus et al. 1985, Marutani 2003). Plants of the genera *Sesbania* and *Crotalaria* are commonly planted as green manures during the warm seasons in Taiwan, and many other tropical and subtropical areas (Dreyfus et al. 1985, Chaudhury et al. 1993, Marutani 2003, Selvi et al. 2005). In Taiwan, >200,000 hectares of green manures are planted annually (Jiang et al. 2010). Although some of these green manure crops are hosts of a number of pest species, they are, however, usually not subject to pest control strategies owing to their low economical value in Taiwan. Sesbania (*Sesbanin roxburghii* Merr.) and sunn hemp (*Crotalaria juncea* L.) are two major green manure crops planted during the hot season, whereas rapeseed (*Brassicae campestris* L. variety *chinensis*) is another common green manure crop that is planted in the rice-producing areas during the winter (November–February) after the rice harvest (AFA 2013). The entire sesbania, sunn hemp, and rapeseed crops will be tilled into the soil after the 50–60, 70–90, and 60–80 d, respectively, post-sowing and serve as sources of nutrients such as N, P, and K elements to reduce dependence on chemical fertilizers (AFA 2013). Because these three green manure crops are hosts of many pest species, including *S. litura*, they often become breeding sites for pests before they are incorporated into the soil.

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To comprehensively understand the role of green manures in the proliferation of *S. litura*, it is essential to elucidate the development, survival, and fecundity, or, in short, the demography, of the species on each manure crop. This information, however, has been limited to date. In this study, we collected the life-table data of *S. litura* on sesbania, sunn hemp, and rapeseed, and analyzed them by using the age-stage, two-sex life table. Furthermore, we demonstrated the growth potential of *S. litura* on these three green manures by using population projections. These data will be useful to the selection of green manure species, scheduling plowing times, and construction of integrated pest management (IPM) programs.

Materials and Methods

Artificial Diet. The artificial diet was modified from Tuan et al. (1997). The diet was prepared as follows: Step 1: 300 g kidney bean powder, 110 g wheat germ, 120 g yeast powder, and 1,100 ml distilled water were thoroughly mixed using a blender. Then, 75 g agar was dissolved in 1,100 ml boiling distilled water and allowed to cool to 70°C. These two parts were then thoroughly mixed. Step 2: 1.2 g L-cysteine, 12 g L-ascorbic acid, 75 g agar, and 0.75 g streptomycin were dissolved in 100 ml distilled water in a 500-ml beaker. Step 3: 3 g sorbic acid and 3.5 g methyl-p-hydroxbenzoate were dissolved in 30 ml of 95% ethanol in a 100-ml beaker. Step 4: The aforementioned three parts were then thoroughly mixed using a blender. Finally, the homogenized diet was poured into a plastic container and allowed to cool and formed into diet cake.

Rearing of *S. litura* (F.). The colony of *S. litura* was initially started from 10+ egg masses collected from taro (*Colocasia esculenta* (L.) Schott) fields in and around Wufeng County, Taichung, central Taiwan, in May 2010. The colony was maintained in a walk-in growth chamber set to 25 ± 1°C, 60 ± 10% RH, and a photoperiod of 12:12 (L: D) h. Larvae were reared on the artificial diet. The first through the third instars were mass-reared. Beginning with the fourth instar, larvae were kept individually in 30-well plastic plates (plate size: 44 by 14 by 3 cm; well size: depth 3 cm, diameter 3.25 cm) until pupation. Newly emerged adults were paired in a plastic oviposition cylinder (13.5 cm in diameter and 18.5 cm in height) with leaves of respective host plants for oviposition and fed with a cotton ball soaked with 20% honey solution. Egg masses were collected daily and adults were transferred to a new container. After three generations, insects from the colony were used for the life-table study.

Plant Culture. Sesbania, sunn hemp, and rapeseed were grown outdoors and planted in a mixture consisting of sandy loam, loam, organic cultivating soil, and peat soil (Potgrond H, Klasmann-Deilmann GmbH, Geeste, Germany) in equal proportions. The fertilizer Compound-Fer 43 (N:P:K:Mg = 15:15:15:4, Taiwan Agricultural Biotechnology Co., Ltd.) was applied 1 month after sowing. No pesticides were applied during the experiment.

Life-Table Study and Analysis. Ten pairs of newly emerged adults were put into an oviposition cylinder. In all, 10–12 oviposition containers were set-up for collecting eggs for each host plant. Ten egg masses laid on the same day from different oviposition containers were collected for the life-table study of different treatments. Each egg mass was placed in a rearing container (7 cm in diameter and 15 cm in height) with fresh leaves of the host plant. The petiole of the leaf was inserted into a 50-ml glass flask filled with water. A paper towel liner was placed on the bottom of the oviposition container to absorb condensed water, and the top covered with a fine mesh net for ventilation. Egg masses were checked daily and 10 newly hatched larvae were randomly picked and then transferred to a new rearing container containing leaves. Because we noticed the egg hatch rate varies with female age, we used only hatched egg for the life-table study. The rearing of larvae was the same as described in the rearing section. The sixth instar was provided with extra peat soil for pupation. Newly emerged moths were paired and kept in individual rearing containers with a paper towel lining and supplied with host leaves for oviposition. A cotton ball soaked with 20% honey solution was added as adult food. Survival and fecundity data were recorded daily until the death of all individuals. Eggs laid at different times were kept separately until hatching to determine the hatch rate of eggs laid at different female ages. In a few cases, a moth died after pairing, and another young moth of the same sex was recruited from the mass-rearing colony to mate with the survived one. The data of the recruited individuals were excluded from the life-table analysis. Because we began the life-table study using only hatched eggs, we also used hatched eggs to determine age-specific female fecundity. The raw data were analyzed according to the age-stage, two-sex life table (Chi and Liu 1985, Chi 1988) by using the computer program TWOSEX-MSChart (Chi 2013a). The age-stage survival rate (s_{xj}; where x = age and j = stage), the age-stage fecundity (f_{xj}), the age-specific survival rate (l_x), and the age-specific fecundity (m_x), as well as the population parameters, the intrinsic rate of increase (r), the finite rate of increase (λ, $\lambda = e^r$), the net reproductive rate (R_0), and the mean generation time (T), were estimated in sequence. The intrinsic rate of increase was estimated by using the iterative bisection method from the Euler–Lotka formula:

$$\sum_{x=0}^{\infty} e^{-r(x+1)} l_x m_x = 1,$$

with the age indexed from zero (Goodman 1982). The net reproductive rate represents the mean number of offspring that an individual can produce during its lifetime and is calculated as

$$R_0 = \sum_{x=0}^{\infty} l_x m_x.$$

The mean generation time is defined as the period that a population needs to increase to R_0-fold of its size when time approaches infinity and the population

Table 1. Mean ± SE of developmental time, adult longevity, adult preoviposition period (APOP), total preoviposition period (TPOP), fecundity, and female proportion in cohort of *Spodoptera litura* fed on sesbania, sunn hemp, and rapeseed leaves

Stage	Developmental time/longevity (d) (mean ± SE)[a]					
	n	Sesbania	*n*	Sunn hemp	*n*	Rapeseed
Egg	70	3.0 ± 0.0c	75	3.2 ± 0.0b	73	4.0 ± 0.0a
L1–L3	70	7.1 ± 0.0a	75	5.0 ± 0.1c	73	6.2 ± 0.1b
L4	70	2.1 ± 0.0a	73	2.3 ± 0.1a	73	2.2 ± 0.1a
L5	70	2.5 ± 0.1b	69	3.0 ± 0.1a	72	2.4 ± 0.1b
L6	61	3.1 ± 0.2b	60	4.0 ± 0.2a	66	3.2 ± 0.2b
L7	1	3.0 ± 0.0	0	–	0	–
Total larval stage	61	14.4 ± 0.1a	60	14.3 ± 0.2a	66	14.0 ± 0.2a
Prepupa + pupa	55	11.4 ± 0.1a	55	11.4 ± 0.2a	59	11.4 ± 0.1a
Preadult	55	28.9 ± 0.2a	55	28.8 ± 0.3a	59	29.1 ± 1.5a
APOP	30	0.9 ± 0.4b	23	2.3 ± 0.3a	24	2.0 ± 0.3a
TPOP	30	29.3 ± 0.5a	23	30.3 ± 0.5a	24	30.8 ± 0.4a
Female longevity	33	15.5 ± 0.9a	25	13.2 ± 1.3ab	28	11.9 ± 1.2b
Male longevity	22	20.3 ± 1.1a	30	12.1 ± 0.9b	31	17.0 ± 1.6ab
Female proportion in cohort[b]	70	0.47 ± 0.06a	75	0.33 ± 0.05b	73	0.38 ± 0.06ab
Fecundity (eggs/♀)	33	3012.4 ± 354.7a	25	2327.0 ± 339.1b	28	1939.5 ± 287.3b

[a] Means followed by different letters in the same row are significantly different between treatments by using Tukey–Kramer test at 5% significance level.

[b] The standard errors of female proportions in cohort and fecundity were calculated by using the bootstrap procedure.

reaches a stable age-stage distribution, and is calculated as

$$T = \frac{\ln R_0}{r}.$$

Both the age-stage-specific reproduction value (v_{xj}) and age-stage life expectancy (e_{xj}) were calculated with the TWOSEX-MSChart (Chi 2013a). The program TWOSEX-MSChart is available at http://140.120.197.173/ecology/Download/TWOSEX-MSChart.rar. The standard errors were estimated by using the bootstrap technique (Efron and Tibshirani 1993, Huang and Chi 2012, 2013) with 10,000 bootstraps. Tukey–Kramer test (Dunnett 1980) was used in conjunction with an analysis of variance to detect the differences among treatments.

Population Projection. Based on the age-stage, two-sex life table (Chi and Liu 1985), the program TIMING-MSChart was used to project population growth (Chi 1990, 2013b). For this projection, we assumed an unlimited growth with an initial population of 10 pairs of *S. litura* newly emerged adults. The aforementioned program can be downloaded at http://140.120.197.173/ecology/Download/TIMING-MSChart.rar.

Results

S. litura could successfully complete development and produce numerous progeny when reared on sesbania, sunn hemp, and rapeseed (Table 1). Most larvae went through six instars, with a few individuals developing into the seventh instar and a single individual reared on sesbania completed the seventh instar. The mean duration of total preadult stages of *S. litura* ranged from 28.8 to 29.1 d on the three crops without significant differences among them. Both male and female adults lived the longest when reared on sesbania. When reared on sunn hemp and rapeseed, the adult preoviposition periods (APOPs) of *S. litura* were not significantly different (2.3 and 2.0 d, respectively) from each other. The APOP of *S. litura* reared on sesbania, however, had a significantly shorter APOP (0.9 d), which showed that females reared on sesbania mated with males and laid fertilized eggs earlier than females reared on sunn hemp and rapeseed. When the preoviposition period was determined from birth, i.e., total preoviposition period, there were no differences among treatments. The mean fecundity of *S. litura* reared on sesbania (3012.4 hatched eggs/female) was the highest among the three treatments, which is significantly different from that of females reared on sunn hemp (2327.0 hatched eggs/female) and rapeseed (1939.5 hatched eggs/female). The female proportion in the cohort reared on sesbania was 0.4748, which was significantly higher than that of females reared on sunn hemp (0.3300), but not different from those developing on rapeseed (0.3793; Table 1).

The age-stage-specific survival rate (s_{xj}) of *S. litura* represents the probability that a newly born individual can survive to age *x* and stage *j*. Because the age-stage, two-sex life table is capable of describing the stage differentiation, the initiation and termination of subsequent stages (i.e., larva to adult stages) can be observed in the survival curve for each stage; for example, the prepupa stage began at age 16 d and ended at age 32 d when reared on sesbania, while the first female adult emerged at age 27 d and the last female died at age 60 d. Because the development rate varied among individuals, there was obvious overlapping between stages (Fig. 1). The age-specific survival rate remained as high as 1.0 until age 18 d for larvae fed on sesbania, but the survival rate of larvae fed on sunn hemp declined to 0.81 at age 18 d (Fig. 2). When *S. litura* were reared on sesbania or sunn hemp, females began to produce eggs at age 27 d, which was 2 d earlier than those fed on rapeseed. The maximal age-specific fecundity (m_x) of *S. litura* fed on sesbania

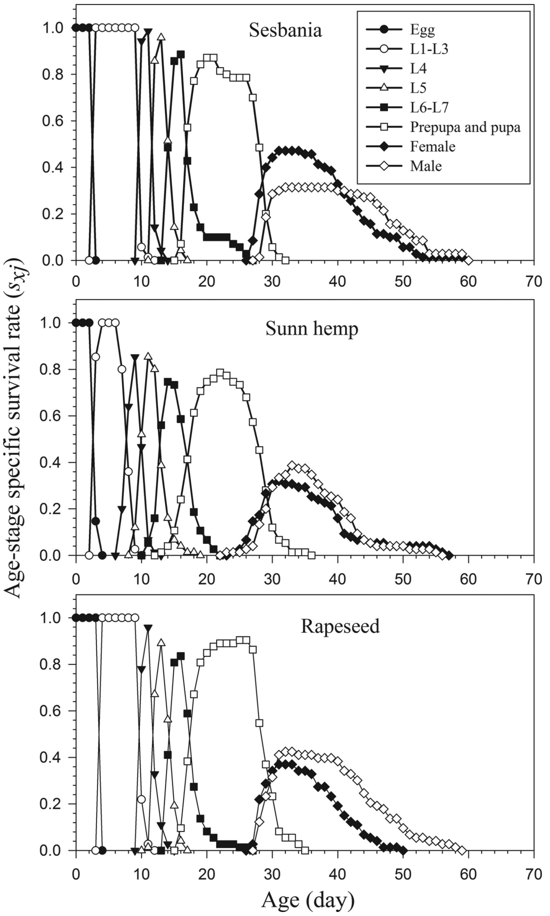

Fig. 1. Age-stage-specific survival rate (S_{xj}) of *Spodoptera litura* fed on sesbania, sunn hemp, and rapeseed.

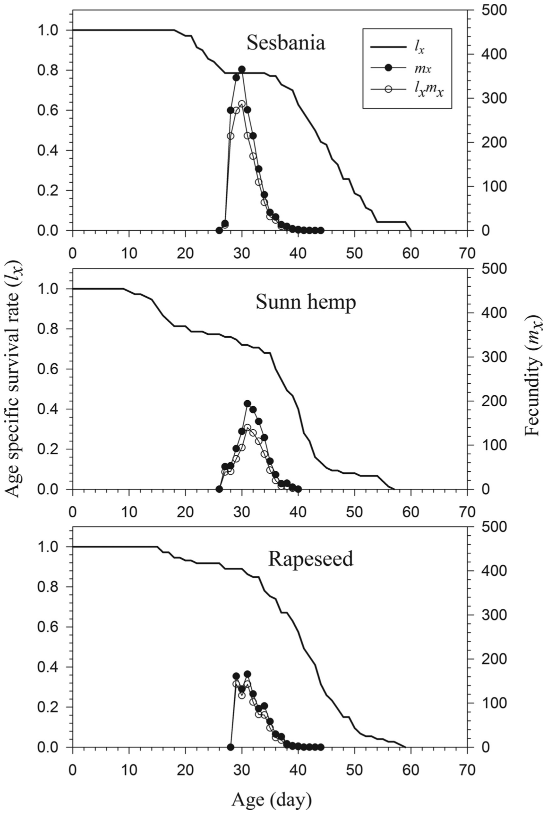

Fig. 2. Age-specific survival rate (l_x) and fecundity (m_x) of *Spodoptera litura* fed on sesbania, sunn hemp, and rapeseed.

occurred at age 30 d with 365.6 offspring, which was significantly higher than those fed on sunn hemp and rapeseed (Fig. 2). Both the age-specific fecundity and the age-specific hatch rate varied with female age and host plant species. The cohort reared on sesbania produced considerably more fertile eggs between age 28 and 42 d than those reared on sunn hemp and rapeseed. The majority of eggs were laid during the first 10 d after adult emergence (Fig. 3).

The age-stage life expectancy (e_{xj}) represents the length of time that an individual of age *x* and stage *j* is expected to survive. In general, the life expectancy of *S. litura* individuals fed on sesbania was longer than those fed on sunn hemp and rapeseed in all age and stage groups (Fig. 4; although the larvae that developed to the seventh instar had short life expectancies). The life expectancy of female adults reared on sesbania and rapeseed was shorter than that of male adults. The age-stage reproductive values (v_{xj}) of *S. litura* are shown in Fig. 5. The v_{xj} value represents the contribution of an individual at age *x* and stage *j* to the future population. When females emerged, the v_{xj} jumped to a high value of 1885.3, 564.3, and 921.8 on sesbania, sunn hemp, and rapeseed, respectively. The reproductive values for *S. litura* reared on sesbania were significantly higher than for those reared on sunn hemp and rapeseed.

The means and standard errors of life-table parameters estimated by bootstrap methods are shown in Table 2. The intrinsic rate of increase (r) and the finite rate of increase (λ) for the cohort reared on sesbania (0.2327 and 1.2621 d^{-1}, respectively) were significantly higher than for those reared on sunn hemp (0.2070 and 1.2300 d^{-1}, respectively) and rapeseed (0.2040 and 1.2263 d^{-1}, respectively). Similarly, the net reproductive rate (R_0) of the cohort fed on sesbania was 1,428.1 offspring, which was significantly higher than the R_0 of *S. litura* reared on sunn hemp (778.4) and rapeseed (737.6). The mean generation time of *S. litura* reared on sesbania (31.2 d) was significantly shorter than that of those reared on sunn hemp (32.1d) and rapeseed (32.3 d).

By using the life tables, the population growth was projected to reveal the stage structure of *S. litura* on these three green manure crops. Figure 6 shows the simulated population growth and stage structure of egg, larva, pupa, and adult stages, beginning with an initial population of 10 pairs of young adults. The growth of the *S. litura* population was very fast on all three crops. The predicted number of eggs reached

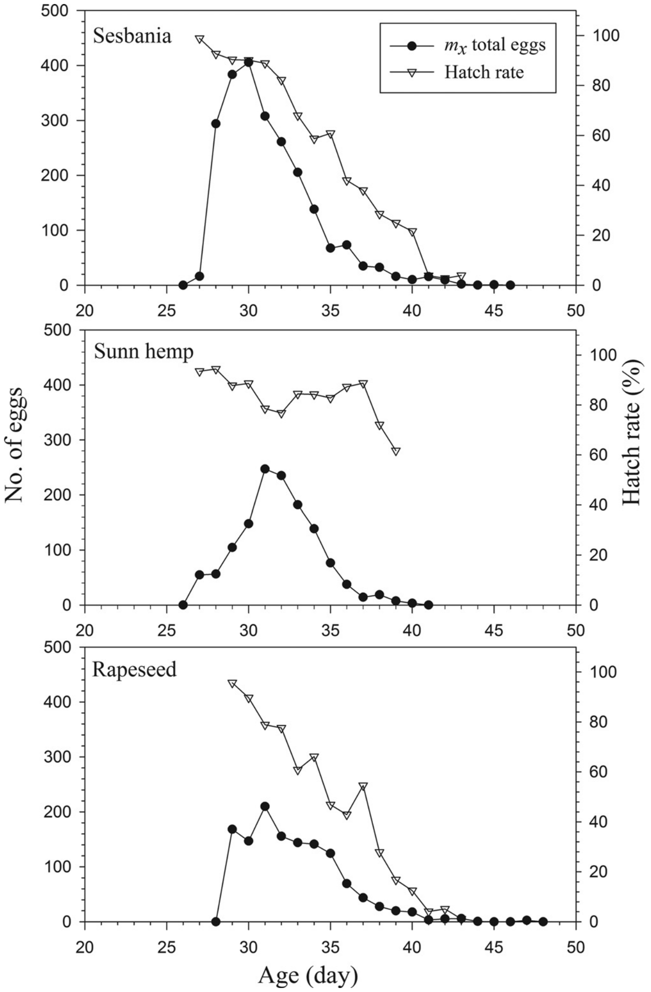

Fig. 3. Age-specific egg production, and hatch rate of *Spodoptera litura* fed on sesbania, sunn hemp, and rapeseed in laboratory at 25 ± 1°C, 60 ± 10% RH, and a photoperiod of 12:12 (L:D) h.

500 million on 32, 40, and 36 d on sesbania, sunn hemp, and rapeseed, respectively.

Discussion

The total larval developmental time of *S. litura* reared on sesbania, sunn hemp, or rapeseed ranged from 14.0 to 14.4 d. These times are shorter than those obtained by Shahout et al. (2011) when rearing *S. litura* on cabbage, cotton, soybean, cowpea, and sweet potato (15.6–19.6 d) at 27 ± 5°C. All of the developmental times reported by Chen and Hsiao (1984) when they reared *S. litura* on cauliflower (19 d), soybean (26 d), taro (18 d) at 25°C are longer than those for the three green manure crops observed in this study. The preadult survival rates on sesbania, sunn hemp, and rapeseed (78.6, 73.3 and 80.8%, respectively) are higher than those found by Xue et al. (2010) for *S. litura* reared on sweet potato (66.1%) and tobacco (49.2%) at 26°C and 60–80% RH.

Food and temperature not only affect insect survival and development rate, but also fecundity and adult longevity. In this study, females reared on sesbania had a very high fecundity (3,012 eggs/female), considerably higher than that found for females reared on sweet potato (≈2500 eggs/female) and cowpea (≈2100 eggs/female; Shahout et al. 2011). Adults in this study were longer lived (females, 15.5 d and males, 20.3 d) than those reported by Xue et al. (2010) reared on Chinese cabbage, cowpea, sweet potato, and tobacco (ranged from 6.6 to 8.8 d). Shahout et al. (2011) also reported a short longevity for individuals reared on cowpea (5.64 d) at 27 ± 5°C.

To compare growth potential, the intrinsic rate of increase, finite rate, and net reproductive rate are usually used to show the host suitability and environmental conditions (Greenberg et al. 2001, Liu et al. 2004, Jha et al. 2012, Mehrkhou et al. 2012). Owing to the higher proportion of fertile females, fecundity, and hatch rate, the intrinsic rate of increase, finite rate, and

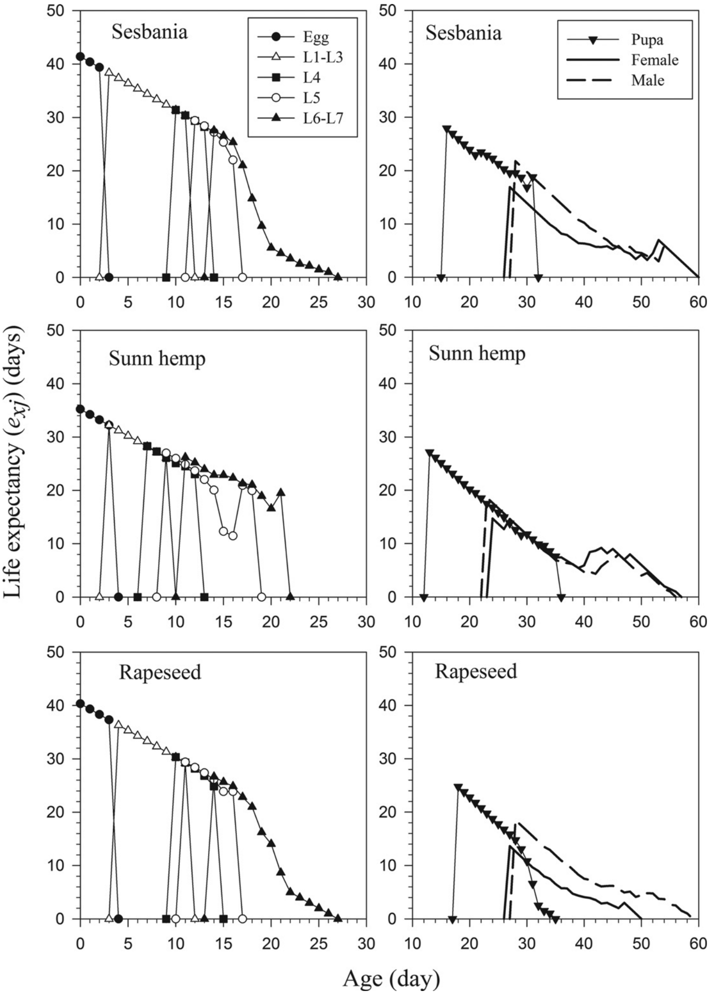

Fig. 4. Life expectancy (e_{xj}) of *Spodoptera litura* fed on sesbania, sunn hemp, and rapeseed.

net reproductive rate of *S. litura* reared on sesbania are significantly higher than of those reared on sunn hemp and rapeseed (Table 2). Ou-Yang (1994) reported the net reproductive rate as 1,078 and 1,011 offspring in two replicates reared on artificial diet based on the age-stage, two-sex life table. That the intrinsic rate of increase in the study by Ou-Yang (1994) was lower than this study may be due to ignoring the hatch rate in that study.

The relationship between the net reproductive rate R_0 and the mean female fecundity F was proven by Chi (1988) for the two-sex life table as

$$R_0 = F\left(\frac{N_f}{N}\right),$$

where N is the total number of eggs used for the life-table study at the beginning and N_f is the number of female adults that emerged. Thus,

$$\left(\frac{N_f}{N}\right)$$

is exactly the female proportion of the cohort (Table 1). All of our results for *S. litura* on the three green manure crops are consistent with this proven relationship. Because the cohort reared on sesbania had a high proportion of females and high fecundity, the net reproductive rate was significantly higher than for those reared on sunn hemp and rapeseed. As Huang and Chi (2012) demonstrated, when life-table raw data are analyzed using the traditional female age-specific life table, this solid relationship would not be observed.

All population parameters, i.e., the net reproductive rate (R_0), intrinsic rate of increase (r), finite rate of increase (λ), age-stage-specific reproductive value (v_{xj}), and the age-stage-specific life expectancy (e_{xj}), demonstrated that *S. litura* is well-adapted to these three green manure crops, with sesbania being the best host plant of the three. The differences in population parameters may be owing to variations in host plant nutrients, especially the effects of nitrogen content and protein quality on the fecundity of herbivores

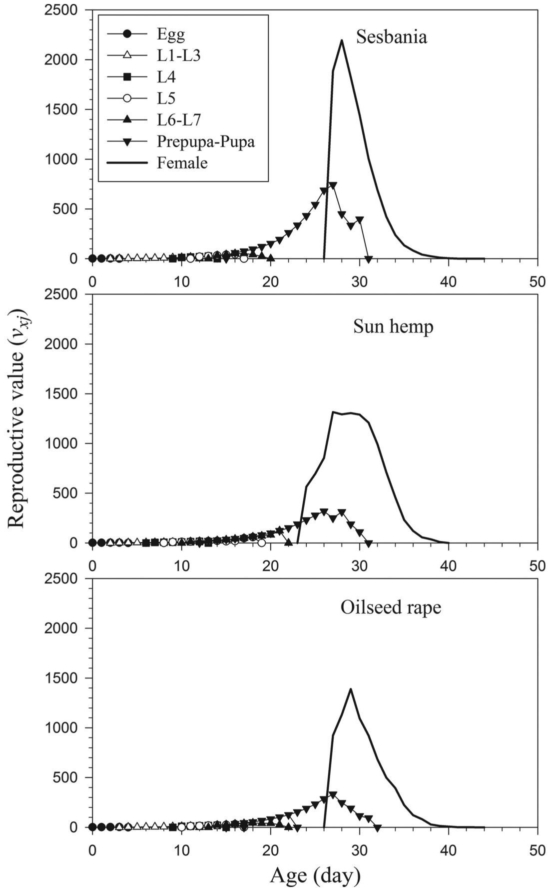

Fig. 5. Reproductive value (v_{xj}) of *Spodoptera litura* fed on sesbania, sunn hemp, and rapeseed.

(Awmack and Leather 2002, Blanco et al. 2006, Lee 2007, Hwang et al. 2008). The fitness of *S. litura* on these three widely planted green manure crops may, at least partially, explain the frequent outbreak of this polyphagous herbivore in Taiwan (Jiang et al. 2010, AFA 2013). Because green manures are not intended to be economical crops in Taiwan, pesticides are seldom used by growers. Because of this, *S. litura* can readily find suitable alternative host plants to maintain a viable population to successfully reinfest the crop fields the following growing season (Chen and Hsiao 1984, Jiang et al. 2010). Because farmers generally own small fields in Taiwan (<5,000 m^2; TNDAIS 2010), different crops are very often planted by different farmers in neighboring fields, thereby making area-wide control impractical. Monitoring data in southern Taiwan showed that there were peaks of *S. litura* populations in peanut-producing fields surrounded by sesbania fields (TARI 2013). By using the age-stage, two-sex life table, we demonstrated that *S. litura* can successfully survive and reproduce using these three green manure crops. Furthermore, population projections predicted the periodic emergence of adults. Our results partially explain the frequent emergence of *S. litura* in crop fields that are recorded using pheromone traps.

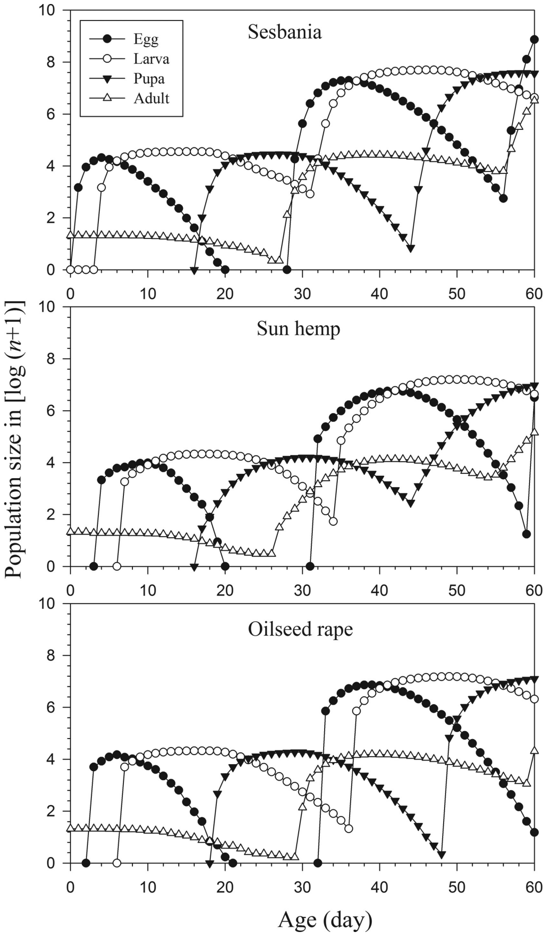

Fig. 6. Simulated population growth of *Spodoptera litura* fed on sesbania, sunn hemp, and rapeseed.

Table 2. Population parameters of *Spodoptera litura* fed on sesbania, sunn hemp, and rapeseed leaves with the 10,000 bootstraps

Host plants	Population parameter (means ± SE)^a			
	Intrinsic rate of increase r	Finite rate of increase λ	Net reproduction rate R_0 (offspring)	Mean generation time T (d)
Sesbania	0.2327 ± 0.0060a	1.2621 ± 0.0076a	1428.1 ± 243.7a	31.2 ± 0.2b
Sunn hemp	0.2070 ± 0.0080b	1.2300 ± 0.0098b	778.4 ± 168.0b	32.1 ± 0.5a
Rapeseed	0.2040 ± 0.0074b	1.2263 ± 0.0091b	737.6 ± 154.6b	32.3 ± 0.3a

^{a} Means in the same column followed by different letters are significantly different by using Tukey–Kramer test.

Because the age-stage, two-sex life table is capable of describing the stage differentiation, population projection based on life table revealed the details of population growth and the stage structure (Fig. 6). Population projection is an important and promising tool for successfully planning pest control programs and timing procedures in pest management (Chi 1990). Because pupae of *S. litura* survive without feeding, and adults are capable of surviving on only water and honeydew, combined with the long life expectancy of both pupae and adults (Fig. 4), we recommend that fields of green manure crops should be plowed under or cleaned up at least 30 d before planting vegetables or peanuts in nearby fields. To be effective, however, it is essential that this practice be carried out based on an area-wide pest management program.

Based on life-table study, we detected the rapid development, high survival rate, and high fecundity of *S. litura* on these three green manure crops and demonstrated that although sesbania, sunn hemp, and rapeseed are effective green manure crops for nitrogen fixation, they, unfortunately, also serve as excellent hosts for *S. litura* populations as well. The contradictory role of these green manures should be taken into consideration when planning an IPM strategy for this pest. An outbreak of *S. litura* occurred in Madou District, Tainan City, in November 2007, with a density of 2 million larvae per hectare followed by a mass migration of armyworms to neighboring farms (Jiang et al. 2010). We demonstrated the possibility of additional mass emergences of *S. litura* by using population projection.

With the increasing popularity of organic farming and sustainable agriculture, the use of green manure crops will, without doubt, be an increasingly important component in future agronomic management practices. Planting alternate green manure crops outside the host range of *S. litura* is an option; Meagher et al. (2004) suggested that using cowpeas and/or sunn hemp can potentially reduce populations of *Spodoptera frugiperda* (J. E. Smith). Although microbial and biological control are additional options for organic farming (Tuan et al. 1999), most small growers cannot afford the higher costs. Based on this study, we suggest the following strategies as part of the IPM of *S. litura* on green manure crops: (1) using sex-pheromone traps to monitor the density and to trap a percentage of *S. litura* males to reduce offspring numbers, (2) appropriately timed plowing to kill larvae and pupae before the moth eclosion, (3) cooperation among farmers to adjust the planting time of green manures and economic crops to avoid the overlapping period, and (4) planting green manure plant species that are not used as host plants by *S. litura.* Details of these strategies must, however, be founded on further and careful calculation based on life-table analysis and computer simulation. As Huang and Chi (2013) demonstrated, variability and differences often occur between life tables collected in the laboratory and under field conditions, and more studies will be needed before a successful and economical pest management strategy based on population ecology can be achieved.

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