IPPC Model Analysis Summary – Sept. 25, 2017 vers. 1.0

Cotton or common cutworm (Spodoptera litura) Phenology (degree-day) Model

By Len Coop for use at Oregon State University's Integrated Plant Protection Center website http://uspest.org

Developed for APHIS PPQ CAPS program — Pest status: high risk of US invasion; polyphagous pest throughout Asia especially on cotton, soybean and vegetables; known long-distance migratory behavior

Model abbrev: sli

note significant data used in final model in salmon background

note points added to force x-intercept method in yellow



Parameter	**Celsius**	**Fahrenheit**	
Lower Threshold:	**10.56**	**51**	
Upper Threshold:	**40**	**104**	**(nominal based on good survival all stages at 35C)**
Start Date:	**Jan. 1st (nominal based on no true diapause; evidence of overwintering in larval or pupal stages)**		
Calculation type:	**single sine (UC Davis default)**		
Region of Known use:	**Developed for use in the continental U.S.**		
Validation status:	**1st version based solely on analysis of sources below; more evidence of 1st spring flight would be helpful**		

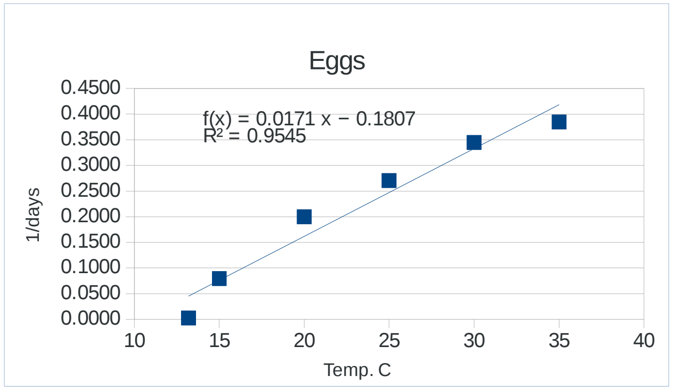
Event	**DDs10.56 (C)**	**DDs51 (F)**	**notes**
First flight of springtime adults in pheromone traps	**120**	**216**	**← based on flight trapping data several locations in Japan**
First oviposition spring adults	**174**	**314**	**← assume female emerg., mating, ovarian devel., host location, OV all in 54 DD**
Peak oviposition spring adults	**193**	**347**	**(so a rather conservative value)**
Peak spring or 1st generation larvae	**393**	**707**	
First flight 1st generation adults	**688**	**1239**	**← using 1st flight in spring + avg generation time (Egg to 25% OV)**
Peak flight 1st generation adults	**761**	**1370**	
Peak 2nd generation larvae	**961**	**1729**	
Peak flight 2nd generation adults; expect overlapping generations	**1329**	**2393**	
Peak 3rd generation larvae	**1529**	**2752**	
Peak flight 3rd generation adults	**1897**	**3415**	
Peak 4th generation larvae	**2097**	**3775**	
Peak flight 4th generation adults	**2466**	**4438**	
Peak flight 5th generation adults	**3034**	**5461**	
Peak flight 6th generation adults	**3602**	**6483**	

Sources and analyses:

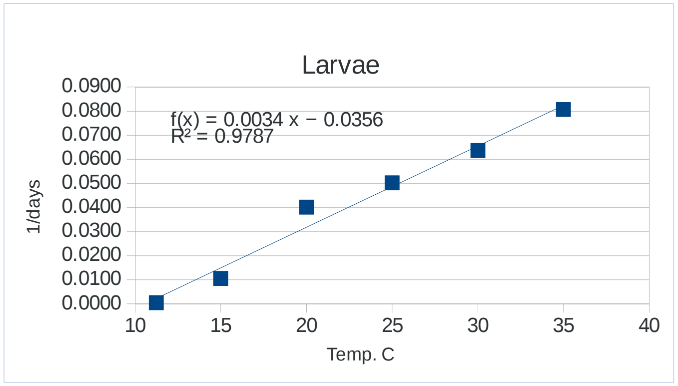
1. Ranga Rao, G.V., J.A. Wightman, and D.V. Ranga Rao. 1989. Threshold Temperatures and Thermal Requirements for the development of Spodoptera litura (Lepidoptera: Noctuidae). Environ. Entomol. 18:548-551.

-Reared in lab in Patancheru, India, using leaves of groundnut (peanut), Arachis hypogaea L. Relative Humidity was 75%

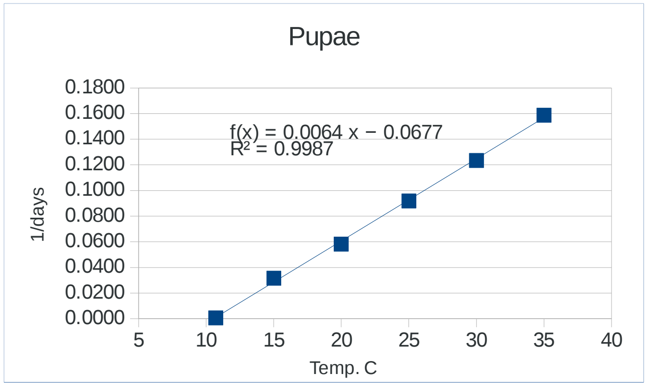
Table 1.	**Eggs**	Temp. C	1/days	Days
		13.19	0.0025	400
		15	0.0794	12.6
		20	0.2000	5
		25	0.2703	3.7
		30	0.3448	2.9
		35	0.3846	2.6
		37	0.3704	2.7
		Slope=b	0.0171	
		intercept=a	-0.1807	
	Tlow	X-interc -a/b	10.5549	
	DD-req	1/slope	58.41	
		RSQ	0.9545	



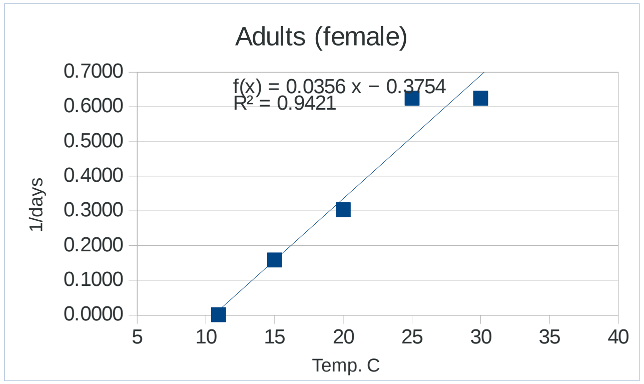
	Larvae	Temp. C	1/days	Days
		11.237	0.0005	2000
		15	0.0106	94.5
		20	0.0402	24.9
		25	0.0503	19.9
		30	0.0637	15.7
		35	0.0806	12.4
		37	0.0641	15.6
		Slope=b	0.0034	
		intercept=a	-0.0356	
	Tlow	X-interc -a/b	10.5559	
	DD-req	1/slope	296.55	
		RSQ	0.9787	



	Pupae	Temp. C	1/days	Days
		10.701	0.0005	2000
		15	0.0316	31.6
		20	0.0581	17.2
		25	0.0917	10.9
		30	0.1235	8.1
		35	0.1587	6.3
		37	0.1370	7.3
		Slope=b	0.0064	
		intercept=a	-0.0677	
	Tlow	X-interc -a/b	10.5554	
	DD-req	1/slope	155.90	
		RSQ	0.9987	



Pre-OV	Temp. C	1/days	Days
	10.933	0.0010	1000
	15	0.1587	6.3
	20	0.3030	3.3
	25	0.6250	1.6
	30	0.6250	1.6
	35		
	37		
	Slope=b	0.0356	
	intercept=a	-0.3754	
Tlow	X-interc -a/b	10.5552	
DD-req	1/slope	28.12	
	RSQ	0.9421	

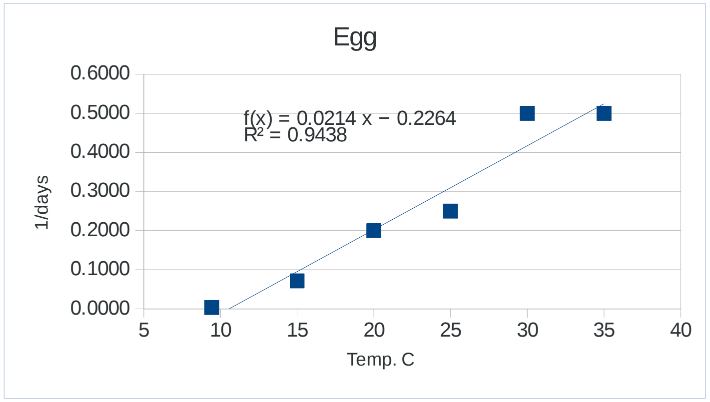


Notes: No indication of summer/warm temperature induced aestivation. 2. Upper temperature threshold around 40C

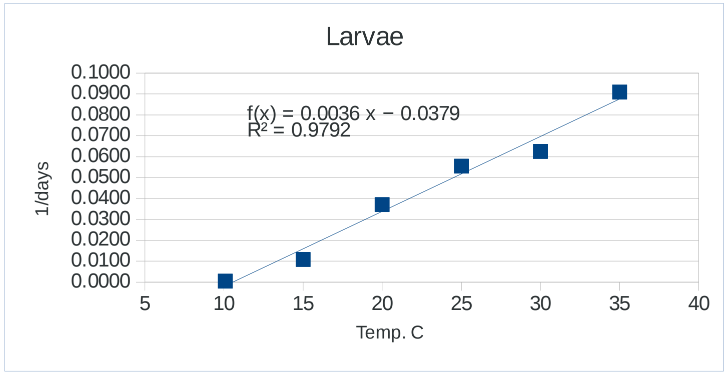
3. Instar relative percent of full larval period were (1-6th instars:) 14%, 11%, 12%, 13%, 15%, and 35%

2. Fand, B., N.T. Sul, S.K. Bal, P.S. Minhas. 2015. Temperature impacts the development and survival of common cutworm (Spodoptera litura): Simulation and visualization of potential population growth in India under warmer temperatures through life cycle modeling and spatial mapping. PlosOne. https://doi.org/10.1371/journal.pone.0124682

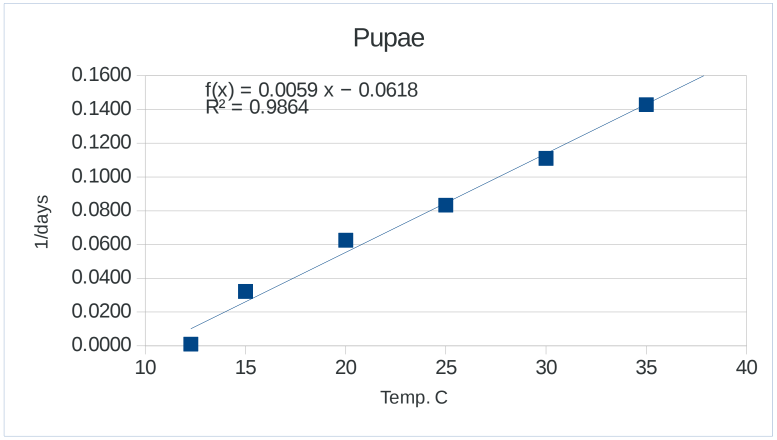
Table 1.	Eggs	Temp. C	1/days	Days
		9.439	0.0033	300
		15	0.0714	14
		20	0.2000	5
		25	0.2500	4
		30	0.5000	2
		35	0.5000	2
		Slope=b	0.0214	
		intercept=a	-0.2264	
	Tlow	X-interc -a/b	10.5560	
	DD-req	1/slope	46.63	
		RSQ	0.9438	



Larvae	Temp. C	1/days	Days
	10.088	0.0005	2000
	15	0.0108	93
	20	0.0370	27
	25	0.0556	18
	30	0.0625	16
	35	0.0909	11
	Slope=b	0.0036	
	intercept=a	-0.0379	
Tlow	X-interc -a/b	10.5565	
DD-req	1/slope	278.90	
	RSQ	0.9792	



Pupae	Temp. C	1/days	Days
	12.274	0.0010	1000
	15	0.0323	31
	20	0.0625	16
	25	0.0833	12
	30	0.1111	9
	35	0.1429	7
	38		10
	Slope=b	0.0059	
	intercept=a	-0.0618	
Tlow	X-interc -a/b	10.5566	
DD-req	1/slope	170.73	
	RSQ	0.9864	



Female adult	Temp. C	1/days	Days
	12.959	0.0010	1000
	15	0.0345	29
	20	0.0769	13
	25	0.1250	8
	30	0.1333	7.5
	35	0.1667	6
	38		6
	Slope=b	0.0072	
	intercept=a	-0.0760	
Tlow	X-interc -a/b	10.5552	
DD-req	1/slope	138.87	
	RSQ	0.9541	

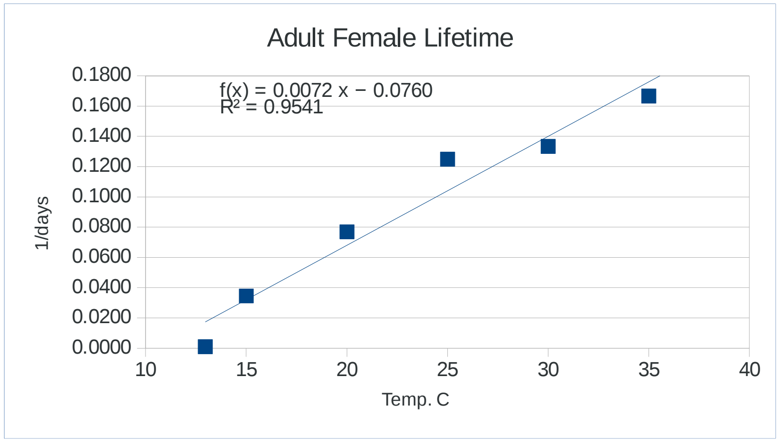
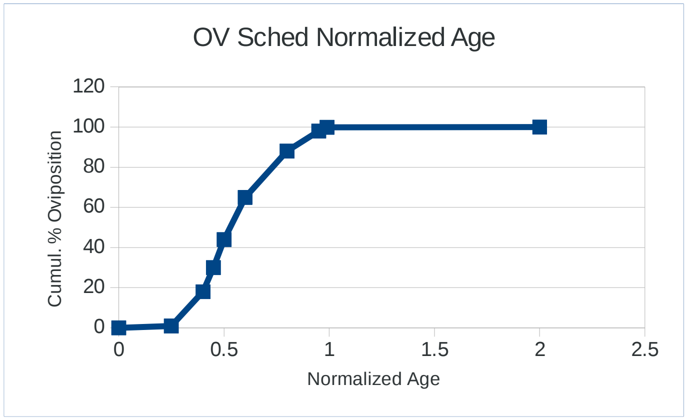


Fig. 5 **Oviposition Schedule**

Oviposition vs. normalized female age (0-1)

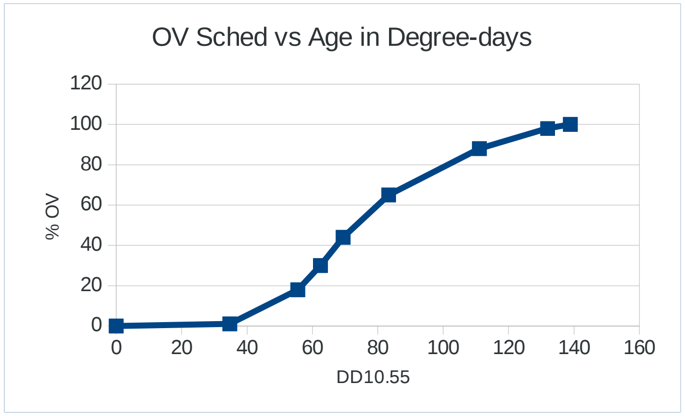
age	Cum % OV
0	0
0.25	1
0.4	18
0.45	30
0.5	44
0.6	65
0.8	88
0.95	98
0.99	99.9
2	100



Convert normalized age to DD from adult female longevity above

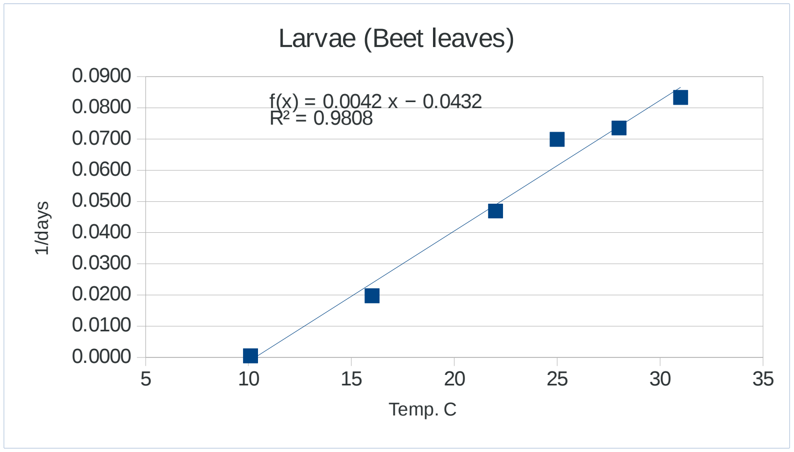
age	DD10.56	Cum % OV
0	0	0
0.25	35	1
0.4	56	18
0.45	62	30
0.5	69	44
0.6	83	65
0.8	111	88
0.95	132	98
1	139	99.99
2	138.87	100

Final OV	DD10.56	Cum % OV
Schedule	35	1
	60	25
	73	50
	95	75
	135	99

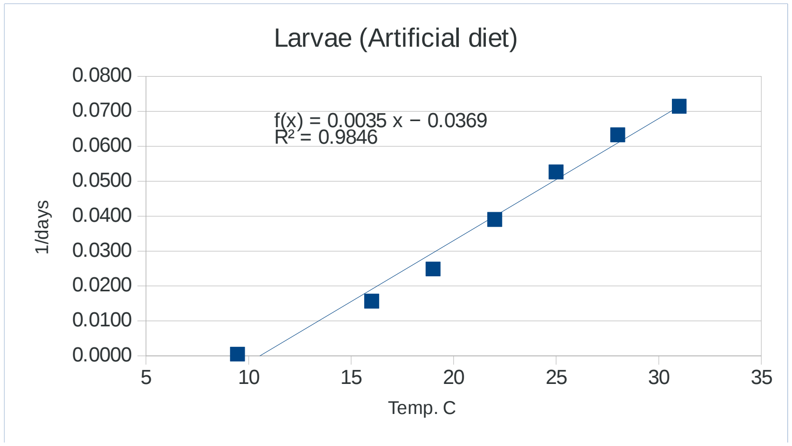


3. Miyashita, K. 1971. Effects of constant and alternating temperatures on the development of Spodoptera litura F. (Lepidoptera: Noctuidae). Appl . Ent. Zool. 6:105-111.

Table 4.	**Larvae**	Temp. C	1/days	Days
	Beet leaves	10.1	0.0005	2000
		16	0.0198	50.6
		19		
		22	0.0469	21.3
		25	0.0699	14.3
		28	0.0735	13.6
		31	0.0833	12
		Slope=b	0.0044	
		intercept=a	-0.0460	
	Tlow	X-interc -a/b	10.5554	
	DD-req	1/slope	229.38	
		RSQ	0.9787	



Larvae	Temp. C	1/days	Days
Artif. Diet	9.458	0.0005	2000
	16	0.0157	63.7
	19	0.0249	40.2
	22	0.0391	25.6
	25	0.0526	19
	28	0.0633	15.8
	31	0.0714	14
	Slope=b	0.0035	
	intercept=a	-0.0369	
Tlow	X-interc -a/b	10.5564	
DD-req	1/slope	286.24	
	RSQ	0.9774	



				Nominal rearing Temp				
Table 3.	**Prepupae**	Temp. C	DD	Temp=25	Tlow	Days	DD	
		Tlow=12.0	27.32	25	12	2.1015	27.32	← Solved for 2.1 days at 25C to accumulate 27.32 DD
		Tlow=10.56	30.4	25	10.556	2.1015	30.35	←-Converted value for Tlow=10.556

Notes: Larval period is treated separately from prepupal stage, which required 27.3 DD at Tlow=12.0C, approx. 30 DD at Tlow=10.56, so add this value for full larval development.

Total Larvae+Prepupae	
Beet leaves	260
Artif. Diet	317

From Table 3 use same conversion method to estimate DD requirements for other stages at Tlow=10.556

			Nominal rearing Temp				
Eggs	Temp. C	DD	Temp=25	Tlow	Days	DD	
	Tlow=10.1	63.69	25	10.1	4.2745	63.69	← Solved for 4.27 days at 25C to accumulate 63.69 DD
	Tlow=10.56		25	10.556	4.2745	61.74	←-Converted value for Tlow=10.556
Larvae	Temp. C	DD	Temp=25	Tlow	Days	DD	
	Tlow=10.6	227.27	25	10.6	15.7825	227.27	← Solved for 15.78 days at 25C to accumulate 227.27 DD
	Tlow=10.56		25	10.556	15.7825	227.96	←-Converted value for Tlow=10.556
Pupae	Temp. C	DD	Temp=25	Tlow	Days	DD	
	Tlow=9	185.19	25	9	11.5745	185.19	← Solved for 11.57 days at 25C to accumulate 185.19 DD
	Tlow=10.56		25	10.556	11.5745	167.18	←-Converted value for Tlow=10.556
Egg-adult	Temp. C	DD	Temp=25	Tlow	Days	DD	
	Tlow=10.3	526.32	25	10.3	35.804	526.32	← Solved for 35.8 days at 25C to accumulate 526.3 DD
	Tlow=10.56		25	10.556	35.804	517.15	←-Converted value for Tlow=10.556

		DD10.556
Check	Egg	61.74
(Beet lvs)	Larvae	228
	PrePupae	30.4
	Pupae	167.18
	Total	487
	Egg-adult	517.15

Notes: Egg-adult total (487) differs from Egg-adult DD (517) estimated from table 3; this difference is not unusual. Murata et al. (below) also derived 517 (526 base 10.3) DD from this same study. Also, development rate was more rapid at fluctuating temperatures than constant; a common finding. We typically ignore this difference to due other mitigating circumstances (limited food availability + microcomate differences)

4. Matsuura, H., and A. Naito. 1997. Studies on the cold-hardiness and overwintering of Spodoptera litura F. (Lepidoptera: Noctuidae) VI. Possible Overwintering areas predicted from Meteorological data in Japan. Appl. Entomol. Zool. 32:167-177.

Larvae: lower lethal temperature -5C
Note that the theory exists that adults migrate into Japan every year so OW survival not always important
-Used a Tlow=10C to detn that 0.9 DD/day required for OW survival

5. Murata M., T. Etoh, K. Itoyama and S. Tojo. 1998. Sudden occurrence of the common cutworm, Spodoptera litura (Lepidoptera: Noctuidae) in southern Japan during the typhoon season. Appl. Entomol. And Zool. 33:419-427.

-(page 420) Determined Pre-OV period to be 102 DD at Tlow=10.3C
-(page 420) Determined Egg-Adult period to be 526 DD at Tlow=10.3C (from Miyashita 1971)
-Male capture in pheromone traps often increased at the times of typhoons in late Aug and Sept.
-Male capture associated with moderate wind 2-5 mps (5-11miles per hour)
-Conclude appearance in Saga and Kogoshima not due to OW but to immigration

Pre-OV	Temp. C	DD	Temp=25	Tlow	Days	DD	
	Tlow=10.3	102	25	10.3	6.94	102.02	← Solved for 6.94 days at 25C to accumulate 102 DD
	Tlow=10.56		25	10.556	6.94	100.24	←-Converted value for Tlow=10.556
Egg-adult	Temp. C	DD	Temp=25	Tlow	Days	DD	
(verify from	Tlow=10.3	526	25	10.3	35.8	526.26	← Solved for 35.8 days at 25C to accumulate 526 DD
Miyashita 71)	Tlow=10.56		25	10.556	35.8	517.10	←-Converted value for Tlow=10.556
Generation T	Temp. C	DD	Temp=25	Tlow	Days	DD	
(verify from	Tlow=10.3	628	25	10.3	42.722	628.01	← Solved for 42.7 days at 25C to accumulate 628 DD
Miyashita 71)	Tlow=10.56		25	10.556	42.722	617.08	←-Converted value for Tlow=10.556

6. Tojo, S., M.Ryuda, T. Fukuda, T. Matsunaga, DR Choi, A. Otuka. 2013. Overseas migration of the common cutworm, Spodoptera litura (Lepidoptera: Noctuidae), from May to Mid-July in East Asia. Appl. Entomol. And Zool. 48:131-140.

-Spring to early summer male catch increases at locations 1000's of km apart plus coincidence of strong SW air currents suggest migration patterns in W. Japan, S. Korea, China, and Taiwan
-Source of populations were S. China and/or Taiwan

7. Ishida, S., and K. Miyashita. 1976. Effects of photoperiod and temperature on development and overwintering of Spodoptera litura F.: Lepid.: Noctuidae. Appl. Entomol.and Zool. 11:248-257.

-bean and wheat germ diet used for rearing
-Interpreted results to state that best OW stages are young larvae; and these can survive in glass and plastic covered houses.
-pheromone trap captures indicate flight as early as March in S. Japan, June-July in N. Japan (main island), none in Hokkaido (N. Island)
-traps records seem to indicate successful overwintering probably as larvae in these warmer (coastal) areas of S. Japan **(**main island and Kyushu**)**
-climate suitability in Japan is discussed; several survived temps down to -2C
-adults generally survived temps down to -2C; all stages killed by 1 day at -5 C
-data correlated with 0C isothermal line for monthly mean of daily Tmin in January
-not sensitive to photoperiod ranging from 10:14 to 16:8.

larvae+pupae	Temp. C	1/days	Days
	10.389	0.0005	2000
	20	0.0217	46
	25	0.0392	25.5
	Slope=b	0.0026	
	intercept=a	-0.0273	
Tlow	X-interc -a/b	10.5563	
DD-req	1/slope	385.97	
	RSQ	0.9847	

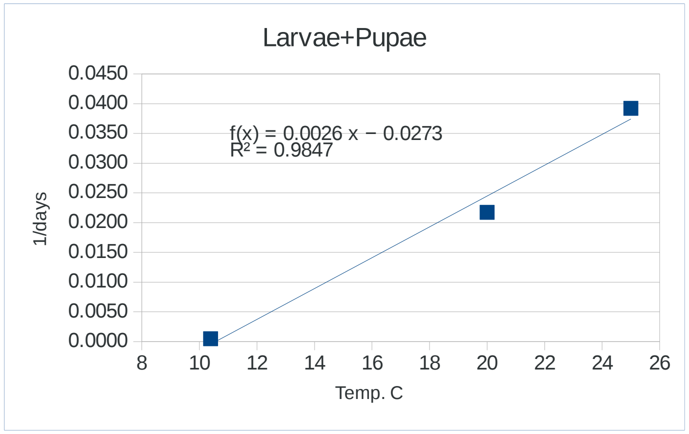


Fig. 2. First Flight for different regions of Japan:

Region	general location	Month
Kagoshima, Kagawa	Furthest S Island; coastal	March
Yamaguchi	Far S. Main island; coastal	March
Mie	S. Main Island; coastal	April
Fukui	SW Central Main Island; coa	May
Shizpoka	SE Main Island; coastal	March
Tateyama	SE Central Main Island; coa:	Feb
Nigata	N. Central Main Island	July
All locations	N. Main Island	July
Hokkaido	All locations	no capture

Notes:

-Notice lack of evidence of discrete generations; suggests migratory flight in addition to local population flight; either that or Rather widespread overwintering distribution

-Northern locations good certainty no OW (too cold during winter); but migration by later generations could occur?

7A. Considering Hokkaido climate-matches N. New England (states including Maine, New Hampshire, most of Vermont, most of upstate New York, etc.), little or no migration flight would be expected in this part of the U.S., or about 400 or so chill units below a chill stress threshold of -3 C.

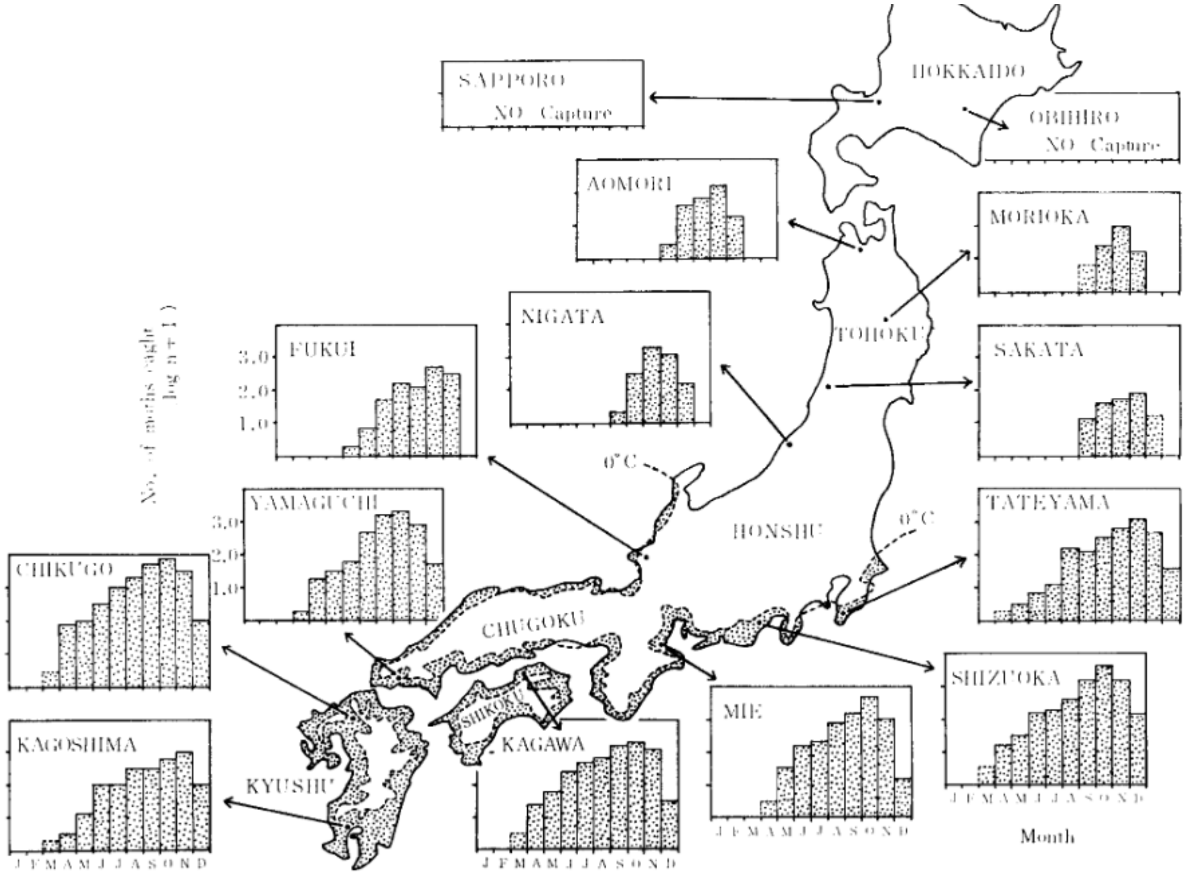


Fig. 2. Capture records of moths by sex pheromone traps. The 0°C isothermal line (dotted line) indicates the monthly mean of daily minimum temperature in January (after Climatic Atlas of Japan, Vol. 1 (1971), Japan Meteorological Agency).

7B. Rough Estimate of Degree-Days for first flight; weather data avail. for 3 locations

Single Sine (S1)	1st Flight estim. April			1st Flight estim. April			1st Flight estim. March		KAGOSHIMA	
Dds10.56	IZUMO13	IZUMO14	AVERAGE	KYOTO07	KYOTO10	AVERAGE	1994	1995	1996	AVERAGE
100	04/24/13	04/21/13	04/22/13	04/14/07	04/17/07	04/15/07	03/21/94	03/24/94	03/22/94	03/22/94
120	04/29/13	04/25/13	04/27/13	04/20/07	04/25/07	04/22/07	03/31/94	03/30/94	03/29/94	03/30/94
140	05/05/13	04/29/13	05/02/13	04/23/07	04/30/07	04/26/07	04/04/94	04/06/94	04/07/94	04/05/94
200	05/14/13	05/08/13	05/11/13	05/04/07	05/07/07	05/05/07	04/14/94	04/17/94	04/24/94	04/18/94
300	05/26/13	05/21/13	05/23/13	05/17/07	05/21/07	05/19/07	04/27/94	05/02/94	05/06/94	05/01/94
400	06/04/13	05/30/13	06/01/13	05/27/07	06/02/07	05/30/07	05/08/94	05/15/94	05/18/94	05/13/94
500	06/12/13	06/08/13	06/10/13	06/06/07	06/11/07	06/08/07	05/17/94	05/24/94	05/27/94	05/22/94

Notes: 10.56C is a relatively high threshold for a Noctuid; It seems flight could be a bit earlier than predicted by DDs; leading to the following hypotheses: OW as pupae or Migration produces 1st catch

Results from above indicate possible 1st adult flight after ca. 120 DD10.56; this would imply that this insect ends the winter in the early pupal stage ca. 45 DD into the stage

8. Tu, YG, KM Wu, FS Xue, and YH Lu. 2009. Laboratory evaluation of flight activity of the common cutworm, Spodoptera litura (Lepidoptera: Noctuidae) . Insect Science 17:53-59.

- Overwinter as pupae in S. China
- 2 day old females have strong flight capabilities; 6-day old not so much
- appears to support evidence that Pre-OV and OV periods are brief
- mating status did not seem to affect flight behavior; both mated and unmated females capable of long flights

9. Combined analysis from above studies

			Degree Days (Tlow=10.556C)								
Source:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**			
	RangaRao et	**Fand etal**	**Miyashita**	**Matsuura eta**	**Murata etal**	**Tojo etal**	**Ishida etal**	**Tu etal**			
	1989	**2015**	**1971**	**1997**	**1998**	**2013**	**1976**	**2009**		**Selected**	
Stage	**Peanut leaves**		**Beet leaves**	**Artif Diet**			**Artif Diet**		**Avg Value**	**Value C**	**Notes/Comments**
Eggs	58.41	46.63	61.74						55.6	56	DDs
Larvae incl. Prepupae	296.55	278.90	259.73	316.59					287.9	288	DDs
Pupae	155.90	170.73	167.18						164.6	165	DDs
Larvae+Pupae	452	450	427				385		428.5	453	DDs
Egg-adult	511	496	517		517				510.3	508	DDs
Pre-OV/1% OV	28.12	35			100				54.4	54	DDs
25% OV		60							60.0	60	DDs
50% OV		73							73.0	73	A relatively short OV period
75% OV		95							95.0	95	DDs
100% OV		138.87							138.9	139	DDs
Generation time Egg-Adult plus 25% OV										568	DDs
Larvae Lower Lethal Temp.				-2 to -5 C						-3 C	Lethal short-term temps in lab;
General lethal temps by region							-2 C			-2 C	Probably a good estimate
Adult lower lethal Temp.							-2 C			-2 C	for lethal longer-term threshold
Timing of migration					late Aug,Sep.	spring/early summer					outdoors
Chill Stress Threshold for DDRP										-3 C	Assume some thermal protection outdoors
Chill Stress Units preventing overwintering										25	based on OW success cited Ishida etal
Chill Stress Units restricting migration										425	consider trap results Ishida etal
Photoperiod sensitivity							none found			none found	
OW Stage							pupae	pupae		pupae	
1^{st} flight							120			120	
First OV following first flight: not known; assume a nominal value = Pre-OV period = 54 DD										174	
Peak OV OW adult (using DD to 50% OV lab data = 73 DD)										193	
Peak Spring or 1^{st} generation larvae (Peak OV + egg + 50% larvae)										393	
1^{st} flight 1^{st} generation (1^{st} flight OW gen + generation time)										688	
Peak flight 1^{st} generation										761	
Peak 2^{nd} generation larvae										961	
Peak flight 2^{nd} generation; assume some overlap of generations by this time										1329	
Peak 3^{rd} generation larvae										1529	
Peak flight 3^{rd} generation										1897	
Peak 4^{th} generation larvae										2097	
Peak flight 4^{th} generation										2466	
Peak flight 5^{th} generation										3034	
Peak flight 6^{th} generation										3602	