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Prediction of Number of Generations of *Spodoptera litura* Fab. on Peanut under Climate Change Scenarios

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Abstract

Investigations were made to predict the impact of increase in temperature on number of generations of *S. litura* on peanut for four locations of India *viz*., Dharwad (15° 28' N, 75° 2' E); Junagadh (21° 31' N, 70° 36' E); Ananthapur (14° 62' N, 77° 65' E) and Vridhachalam (11° 3' N, 79° 26' E) for baseline (1961-1990), present (1991-2005), near future (2021-2050) and distant future (2071-2098) climate change (A1B) scenarios. Higher accumulation of degree days making it possible one or two additional generations of *S. litura* was inferred for both near and distant-future climate change scenarios compared to baseline and present periods, at four locations. The mean generation time under baseline (41 days) and present (36 days) periods, lasted longer over the near future (35 days) and distant future (31 days) scenarios at Dharwad. It is also predicted that the completion of generation would be 5-6 days earlier during future climatic scenarios than the current period at other locations. The additional number of generations and the variations in the generation time of *S. litura* imply definitive and differential impacts, respectively of the projected increasing temperature in future periods.

Key words*: Degree days, generations, generation time, climate change scenario, Spodoptera litura*.

1. Introduction

The fourth assessment report of Inter Governmental Panel on climate change (IPCC 2007) observed that the annual average temperature of the earth is likely to increase by 1°C by 2025 and by 3°C towards the end of the century. It is further indicated that 'warming of climate system is now unequivocal'. Though climate change is global in its occurrence and consequences, it is the developing countries like India that face more adverse impacts as majority of the population depends on agriculture with excessive pressure on natural resources and because of poor coping mechanisms. Rising concentrations of temperature and atmospheric CO_2 have both been very significantly for the last three decades (Stern 2007) influencing all sectors of agriculture. Since climate is the direct input into the agriculture production process, the agricultural sector has been a natural focus for research. Within agriculture, how the climate change impacts insect pests and diseases is an important area that is engaging the biological scientists. Climate change projections made up to 2100 for India indicate an overall increase in temperature by 2-4°C with no substantial change in precipitation quantity (Krishnakumar et al. 2011). Last three decades witnessed saw a sharp rise in mean annual temperature in India **(**Venkateswarlu 2009**)**. Though most dryland crops tolerate high temperatures, rainfed crops grown during *rabi* are vulnerable to changes in minimum temperatures. Analysis of data for the period 1901-2005 by Indian Meteorological Department (IMD) suggests that annual mean temperature for the country as a whole has risen by 0.51°C over the period. It may be mentioned that annual mean temperature has been consistently above normal (base period: 1961-1990) since 1993. This warming is primarily due to rise in maximum temperature over a larger part of the data set across the country.

Peanut (*Arachis hypogaea* L.) also known as groundnut, earthnut and ground bean, is the world's fourth most important source of edible vegetable oil and third most important source of vegetable protein. Production is concentrated in Asia (50% of global area and 64% of global production) and Africa (46% of global area and 28% of global production), where the crop is grown mostly by smallholder farmers under rainfed conditions with limited inputs. China, India, Nigeria, USA and Myanmar are the major peanut growing countries. India is the second largest producer of peanut in the world with an average annual production of 5.51 million tons (http://faostat.fao.org) from an area of 5.47 million ha. Productivity levels of peanut in India is1007 kg/ha as against 1522 kg/ha of the globe and 3356 kg/ha of China. Elevated CO_2 was reported to cause significant increase in total biomass at final harvest of peanut crop but decreased final seed yield in selected cultivars (Bannayan et al. 2009). The crop is attacked by many species of insects which cause damage ranging from incidental feeding to near total plant destruction and yield loss (Wightman and Ranga Rao 1994). Amongst them, the tobacco armyworm, *Spodoptera litura* (Fab.) is a major pest which can cause yield losses of 35-55%. Larvae feed gregariously on leaves causing severe defoliation, leaving only midrib veins.

Insects are cold-blooded, ectothermic organisms with their body temperature controlled by atmospheric temperature. Climate change resulting in increased temperature could impact crop pests in several complex ways. The metabolism and development of insects is highly dependent on air temperatures and thus temperature is rated as key environmental factor influencing the development and survival of the insects (Hallmann and Denlinger 1998). Insect developmental rate and geographical distribution are highly responsive to change in external temperatures. Insect species diversity tends to decrease with higher latitude and altitude, implying that rising temperatures could result in more insect species attacking more crops in temperate climates. It is observed that the diversity of insect species and the intensity of their feeding have increased historically with increasing temperature (Bale et al. 2002). Another important aspect of insect development is their voltinism (the number of generations per year or crop season) that varies both between species and geographically within a given species. Effect of increasing temperature on insect voltinism is direct in the sense that the increase in surface temperatures would permit multivoltine species to increase the number of generations per year. However, the relationship between climate change and voltinism could be more complex. The objective of the present study is to quantify the impact of increase in temperature on number of generations of *S. litura* on peanut crop for four different climatic periods *viz*., baseline (1961-1990), present (1991-2005), near future (2021-2050) and distant future (2071-2098) for four major peanut growing locations of the country.

2. Materials and Methods

The work comprises of three components *viz.,* (i) obtaining historical data and climate projections on daily temperature from respective grid points, (ii) computation of growing degree days (GDD) for completion of life cycle of *S. litura* based on the threshold temperature and (iii) estimation of the possible number of generations during crop season for various scenarios of climate including the future projected climate by substituting the projections on the temperature using SRES A1B scenario.

2.1 Collection of historical temperature data

Historical daily temperature (maximum and minimum) for four study locations *viz*., Dharwad (15° 28' N, 75° 2' E); Junagadh (21° 31' N, 70° 36' E); Ananthapur (14° 62' N, 77° 65' E) and Vridhachalam (11° 3' N, 79° 26' E) were collected from a 1X1 degree grid database provided by IMD (Srivastava *et al*., 2008) for the period 1991-2005 being referred as a present (PR) period in this research.

2.2 Estimation of Growing Degree-days (GDD) required for the development of S. litura on Peanut

The standard GDD approach was followed to estimate the number of generations of *S. litura* occurring on peanut during a crop season. The maximum and minimum temperatures were transformed to heat units using the lower threshold temperature of (t_0) 10°C for *S. litura* on peanut. By using the minimum and maximum daily temperatures for the above mentioned four periods, the number of generations of *S. litura* was calculated using cumulative degree days for each generation of insect. The data on degree day units of *S. litura* were obtained from www.nappfast.org/databases/. The average development time needed for completion of the *S. litura* life cycle was calculated by using the standard formula (Elsaadany et al. 2000 and Richmond et al. 1983).

2.3 Future climate data

A number of global circulation models with their corresponding versions of downscaled projections at a relatively smaller spatial resolution are available and the projections vary from the parent GCM **(**Krishnakumar et al. 2011**)**. In this paper, we chose to use the projections obtained at a resolution of 50 x 50 km grid using the PRECIS where the daily data on maximum temperature, minimum temperature and rainfall are available for the period between 1961 and 2098. The output for the A1B emission scenario showing 'reasonable skill in simulating the monsoon climate over India' (Krishnakumar et al. 2011) was considered. A1B is 'the most appropriate scenario as it represents high technological development, with the infusion of renewable energy technologies following a sustainable growth trajectory' (MoEF 2012).The future temperature data thus obtained were classified into two categories *viz*., 'near future' (NF) consisting of 2021-2050 and distant future (DF) consisting of 2071-2098. The period between 1961 and 1990 was referred as the base line (BL) period. Accumulation of degree days was calculated considering the specific biological event called as "Biofix". In this case the pheromone trap 'first catch'was considered as a Biofix and the cumulative degree days for *S. litura* was estimated for the crop season covering 133 days of crop duration across four locations.

3. Statistical Analysis

The data on variation in number of generations of *S. litura* across four locations for the four periods *viz.,* baseline, present, near and distant future periods were analyzed the Kendall Family of Trends test (Helsel et al. 2006).The mean number of generations in base line, present, near future and distant future scenarios was compared using two-sample t-test assuming equal variances. The significance of mean values was defined at $p< 0.01$ and all statistical analysis were done using SPSS version 16.0.

4. Results

The findings on the possible number of generations during peanut crop season, time taken to complete a generation and the inter-generation variations therein are presented hereunder.

4.1 Variation in growing degree days (DD) and number of generations

Results on the variation in growing degree days and number of generations of *S. litura* are presented in Table 1. *S. litura* took 1575 and 1577 DD during the BL and PR periods at Dharwad, accommodating about three generations with a mean of 525 DD per generation (Table 1). The number of degree days increased to 2103 DD during near-future and to 2027 DD during the distant-future making it possible to complete one more generation compared to the current climatic conditions. At Junagadh, the degree days increased from 2028 DD for the BL period to 2099 DD for the PR climate. The higher number of degree days possible during both the near-future and distant-future was found to accommodate one additional generation during the crop season compared to three generations during the BL period. The possible increase in temperature in Ananthapur leading to two additional generations expected with higher degree days (3138 DD) accumulated for the distant-future compared to 2098 DD in the PR period was estimated. A noticeable increase in the number of generations was also observed at Vridhachalam wherein higher temperatures are projected to prevail during the coming decades resulting in accumulation of 3141 DD in NF and 3147 DD in DF scenarios. The number of generations possible increased to six during near and distant future climate scenarios resulting in two generations higher than current climatic periods.

(Insert Table 1 here)

The results on inter-generic variation in total and mean GDD of *S. litura* are presented in Table 2 showed a significant variation across all generations in NF and DF scenarios over current climate comprising of BL and PR periods at Dharwad. Similar trend was noticed for the other three remaining peanut growing locations.

(Insert Table 2 here)

The mean number of generations among four climate scenarios analyzed using t-test indicated that the variation was significant. Increased number of generations are expected during NF (p=< 0.01; t= 16.17) and DF (p=< 0.01; t= 25.17) scenarios at Ananthapur and NF (p=< 0.01; t= 10.86) and DF (p=< 0.01; t= 20.45) Vridhachalam locations. The predicted number of generations would be higher by one and the increased number of generations were predicted to be not significant in NF scenario at Dharwad (p=< 0.01; t= 1.47) and at Junagadh NF (p=< 0.01; t= 1.30). The increase in number of generations was found to be highly significant at Dharwad (p=< 0.01; t= 12.60) and at Junagadh (p=< 0.01; t= 8.09) during DF over present climatic conditions (Table 3).

(Insert Table 3 here)

Mann-Kendall test performed to evaluate the trend in the number of generations of *S. litura* during the crop season during different climate change scenarios indicated a very high positive value of Mann-Kendall statistic (S), at Junagadh denoting an increasing trend under the four climatic conditions being significant for NF (p= <0.01; tau C= 0.26) and DF (p= <0.01; tau C= 0.40) scenarios. Similar increasing trends were noticed at Dharwad for all four climate conditions. The temporal variation of *S. litura* at Vridhachalam was not significant during BL and PR periods whereas the trend was found to be significantly increasing in NF (p= <0.01; tau C= 0.40) and DF (p= <0.01; tau C= 0.30) climatic scenarios. Overall, it is expected that there would be an increase of one to two generations in the future climate change scenarios at all four locations (Table 4) growing peanut.

(Insert Table 4 here)

4.2 Variation in mean generation time

The increase in number of generations is obviously due to the reduction in the time taken to complete a generation for the insect made possible by the faster accumulation of required heat units. Variations in mean generation time of *S. litura* at four different climate scenarios are depicted in Figure 1. The average length of time taken to complete life cycle of *S. litura* at Dharwad was found to be 35 and 31 days during the near and distant-future compared to 41 and 36 days during the reference and current climatic periods, respectively. The completion of generation would be earlier than in the current climate by 5-6 days in both the scenarios. At Junagadh the generation time of *S. litura* was found to be 31 and 28 days in reference and present periods and it is expected that life cycle of pest would be reduced by 2-3 days during NF and DF future climatic scenarios. Mean generation time was in the range of 30-32 days for both the current climate periods and similar trend of advancement of life cycle completion (3-9 days) was predicted during future climate change scenarios at Ananthapur. The average life cycle of *S. litura* was found to be 25 and 26 days during reference period and present climatic conditions at Vridhachalam. The shortened life cycle of 23 and 21 days indicating the reduction of life cycle by 2 and 5 days was expected in NF and DF climatic scenarios, respectively. In all, the expected generation time of *S. litura* on peanut reduced at four locations for NF and DF future climatic scenarios with significant variations between latitudes of 11 and 21^{o}N.

(Insert Figure 1 here)

4.3 Inter-generic variation in generation time

Since temperature varies with season during any year, there was noticeable variation in the time taken to complete life cycle over generations. The findings on inter-generation variation in completing the life cycle (mean generation time) over different generations across four climatic conditions are depicted in Figure 2. Among three generations recorded at Dharwad, first generation was completed with an average of 40 days during both reference and present periods and the third generation was completed in 37 days. The results of NF and DF climate change scenarios at same centre indicated one additional generation with a reduced life cycle of 27-38 days of the pest would be possible. The generation time of 28-32 days was noticed among the four generations during both BL and PR climatic conditions at Junagadh. The similar reduction of life cycle for future climate change scenarios at this centre represented a shortened life cycle with 22-30 days. At Ananthapur, the average generation time varied from 30 to 31 days under both climatic conditions and accelerated development is expected with shortened life cycle during future climate change scenarios. Among five generations recorded, the insect cycle got completed in 25 and 26 days with respect to reference and present periods at Vridhachalam, and the number of days per generation in NF and DF climate change scenarios is expected to be shortened by 2 and 5 days, there by a significant advancement of completion of life cycle was predicted, resulting in more number of generations (6) compared to other locations.

(Insert Figure 2 here)

Maps of variation of number of generations of *S. litura* on groundnut at four locations of South India under BL-1961-1990; PR-1991-2005; NF-2021-2050 & DF- 2071-2098 were depicted in figure 3. It is predicted that the incidence of *S. litura* would increase under NF and DF climate change scenario at Ananthapur and Vridhachalam locations.

(Insert Figure 3 here)

5. Discussion

It is well known that effect of increasing temperatures on insect with a logical assumption that increase in surface temperature would permit/ allow multi-voltine species to increase the number of generations per year albeit the relationship between the climate change and voltinism could be complex. Prediction of developmental time or mean generation time of insect pests in relation to temperature can be an important tool for pest management (Roy et al. 2002). Insects develop more rapidly during periods of time with suitable warmer temperatures. Increased temperature will accelerate the development of insects possibly resulting in more cycles of generations per year (Awmack et al. 1997). Future climatic warming would affect temperate annual and multivoltine species in different ways at different magnitudes. Insects of Aphididae and some Lepidoptera, e.g. *Pieris brassicae*, which are multivoline in nature, undergo faster development time, probably allowing for additional generations within a year (Pollard and Yates 1993) at higher temperatures. Many of these species will expand their geographical ranges to higher latitudes and altitudes, as has already been observed in a number of common butterfly species (Parmesan et al. 1999). The occurrence of insect population varies from year to year and its dynamics can be predicted using the approach of Growing Degree-days (GDD) defined as the units combining time and temperature, used to measure the development of an organism from one point to another in its life cycle (Wilson and Barnett. 1983). GDD approach can be used to predict the insects' life cycle especially number of generations during the season by measuring the growth in terms of temperature over time and considers average daily temperatures which influence insect development. The present study was conducted using the standard GDD approach.

Predictions of *S. litura* development on peanut were attempted under current (BL and PR periods) and expected future climate change (near and distant future) scenarios. The accumulated thermal heat units expressed as degree days (DD), the number of generations and mean generation time of *S. litura* were estimated for four representative peanut growing locations in India. The influence of temperature on development and survival of *S. litura* would affect the population dynamics of pest and such influence can be estimated and quantified by calculating the number of generations. The highest number of generations (6) was predicted for Vridhachalam which was nearly two additional generations estimated for Dharwad of South India during future climatic scenarios. The longest mean generation time (43 days) recorded at Dharwad during current climatic condition was nearly twice that of observed at Vridhachalam (24 days).

Production of more number of generations annually with extreme temperatures in case of majority of insect species is well known and this phenomenon becomes regular with gradual warming (Lastuvka 2009) and our results add *S. litura* on peanut in India to the list as a case in point. The information on occurrence of additional generations with increase in temperature was well documented across various insect orders *viz*., lepidopterans - *N. cancticepes* (Yamamura 2006), *Plutella xylostella* (Kiritani 2006), *Cydia pomonella* (Kocsis and Hufnegal 2011; Marchioro and Foerster 2011; Hirschi et al. 2012), *Phthorimaea operculella* (Abolmaaty et al. 2011), Homopterans-Aphids (Yamamura 1998), Dipterans - *Bactocera zonata* (Tranka et al. 2007 ; Khalil et al. 2010), *Bactocera dorsalis* (Kriticos et al. 2007) and coleopterans - *Ips typographus* (Lange et al. 2006; Jonson et al. 2009 and Hlasny et al. 2011), *Tribolium confusum* (Estay et al. 2009). Climate change, especially increase in global mean temperature has proven effects on herbivore voltinism, number of life cycles that can be completed in a single season. Altermatt 2010 found that a substantial proportion of the 263 multivoltine lepidopteran species in his dataset exhibited an increased frequency of second and subsequent generations since 1980, with 44 species displaying a stable increase in the number of generations after 1980. Current investigations for locations from four different agro-ecological zones of the country have shown significant variation in developmental time, number of generations and thermal requirements of *S. litura* on peanut. While these results consider the effect of temperature only, other factors such as host plant response to changing climate, thermal adaptation and rainfall distribution may also influence the rate of insect development.

Conclusion

The predicted additional number of generations of *S. litura* on peanut across locations in India implies direct and definitive impact of projected increasing in temperature in the near and distant future climate change scenarios. Nevertheless peanut pest management can always account for the anticipated higher number of generations in the future.

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Annexure

Table 1: Mean Generation Time (GT) and Growing Degree Days (GDD) of *S. litura* on peanut under Climate Change Scenario (CCS)

Name of the location	Current Climate Period						Climate Change Scenario					
	BL			PR			NF			DF		
	Mean GT	Mean GDD	Tot GDD	Mean GT	Mean GDD	Tot GDD	Mean GT	Mean GDD	Tot GDD	Mean GT	Mean GDD	Tot GDD
Dharwad	41.01	524.93	1574.78	36.40	525.67	1577.01	34.67	525.82	2103.29	31.39	506.64	2026.58
Junagadh	31.04	507.05	2028.19	28.35	524.85	2099.40	27.69	522.95	2614.74	26.07	525.13	2625.63
Ananthapur	29.76	524.57	2098.28	31.68	524.44	2097.74	26.73	524.53	2622.64	23.40	522.93	3137.58
Vridhachalam	24.55	454.55	2272.77	26.27	523.23	2623.17	23.19	523.47	3137.85	21.30	524.58	3147.48

Table 2 Comparison of growing degree days (GDD) and generation time (GT) of *S. litura* on peanut under CCS

Name of the location	Gen No.	Current Climate Period				Climate Change Scenario			
		BL		PR		NF		DF	
		GT	GDD	GT	GDD	GT	GDD	GT	GDD
Dharwad	1	42.57	528.38	36.73	529.69	37.80	529.27	33.32	530.17
	2	42.07	523.73	37.00	522.95	37.67	523.96	33.64	522.83
	3	38.40	522.67	35.47	524.37	34.70	522.93	31.96	524.25
	4	-	-	-	-	28.50	527.13	26.64	449.33
Junagadh	1	30.57	531.26	27.47	531.34	27.47	529.76	25.39	533.95
	2	32.00	521.74	29.13	525.47	30.33	523.93	27.93	520.26
	3	31.57	522.94	29.00	520.62	29.37	522.52	27.39	523.53
	4	30.03	452.26	27.80	521.97	29.30	523.09	26.04	524.02
	5	-	-	-	-	22.00	515.44	23.61	523.88
Ananthapur	1	29.83	530.88	30.60	530.44	26.63	531.26	24.04	535.30
	2	30.27	522.14	31.67	522.07	27.67	524.73	24.54	522.83
	3	29.43	524.22	31.67	522.52	27.23	521.07	24.39	521.07
	4	29.50	521.04	32.80	522.71	26.13	523.08	23.71	520.12
	5	-	-	-	-	26.00	522.50	23.75	525.56
	6	-	-	-	-			20.00	512.69
Vridhachalam	1	23.97	531.51	25.20	533.98	22.10	534.25	20.82	537.23
	2	24.77	524.51	25.40	522.81	22.70	523.04	20.61	520.50
	3	25.30	523.75	25.67	520.60	23.60	523.75	21.21	521.94
	4	25.00	520.10	26.67	523.51	22.90	521.56	21.43	522.82
	5	23.73	172.90	28.42	522.27	23.83	521.79	21.14	523.51
	6	-	-	-	-	24.00	516.45	22.56	521.48

BL: Baseline; PR : Present; NF: Near Future; DF: Distant Future

Table 3 Number of generations (mean ± standard deviation) of *S. litura* across four peanut locations

Name of the location	Current Climate Period		Climate Change Scenario	
	BL	PR	NF	DF
Dharwad	3.30 ± 0.12 (11.43)**	3.69 ± 0.08	3.75 ± 0.13 (1.47) NS	4.25 ± 0.16 (12.60)**
Junagadh	4.28 ± 0.17 (8.86)**	4.70 ± 0.10	4.64 ± 0.17 (1.30)NS	5.10 ± 0.18 (8.09)**
Ananthapur	4.47 ± 0.18 (5.61)**	4.19 ± 0.09	4.94 ± 0.17 (16.17)**	5.53 ± 0.194 (25.17)**
Vridhachalam	5.22 ± 0.18 (3.25)**	5.06 ± 0.07	5.69 ± 0.22 (10.86)**	6.22 ± 0.21 (20.45)**

Figures in parentheses are't'- values
**** Indicate that the difference relative to the Present period is significant at p<0.01**

Table 4: Temporal trends in number of generations of *S. litura* across four peanut growing locations using Mann Kendall Test

Name of the location	Climate scenario	No. of Data points	Tau Correlation co-efficient	Mann Kendall statistic (s)	Normalized Test Statistic (Z)	Probability	Trend
Dharwad	BL	30	0.44	193	3.43	0.0006*	↑
	PR	15	0.27	29	1.39	0.16	NS
	NF	30	0.47	205	3.64	0.0003*	↑
	DF	28	0.45	171	3.36	0.0008*	↑
Junagadh	BL	30	0.16	69	1.21	0.22	NS
	PR	15	0.01	1	0.00	1.00	NS
	NF	30	0.26	111	1.96	0.05*	↑
	DF	28	0.40	152	2.98	0.03*	↑
Ananthapur	BL	30	0.22	97	1.71	0.08*	↑
	PR	15	0.40	42	2.03	0.04*	↑
	NF	30	0.31	144	2.55	0.01*	↑
	DF	28	0.36	135	2.65	0.008*	↑
Vridhachalam	BL	30	0.10	43	0.75	0.45	NS
	PR	15	0.28	29	1.39	0.16	NS
	NF	30	0.40	176	3.124	0.0018*	↑
	DF	28	0.30	113	2.22	0.02*	↑

***Significant at p=<0.05, NS- not significant,**
BL- Base line, PR- Present, NF- Near future & DF- Distant future

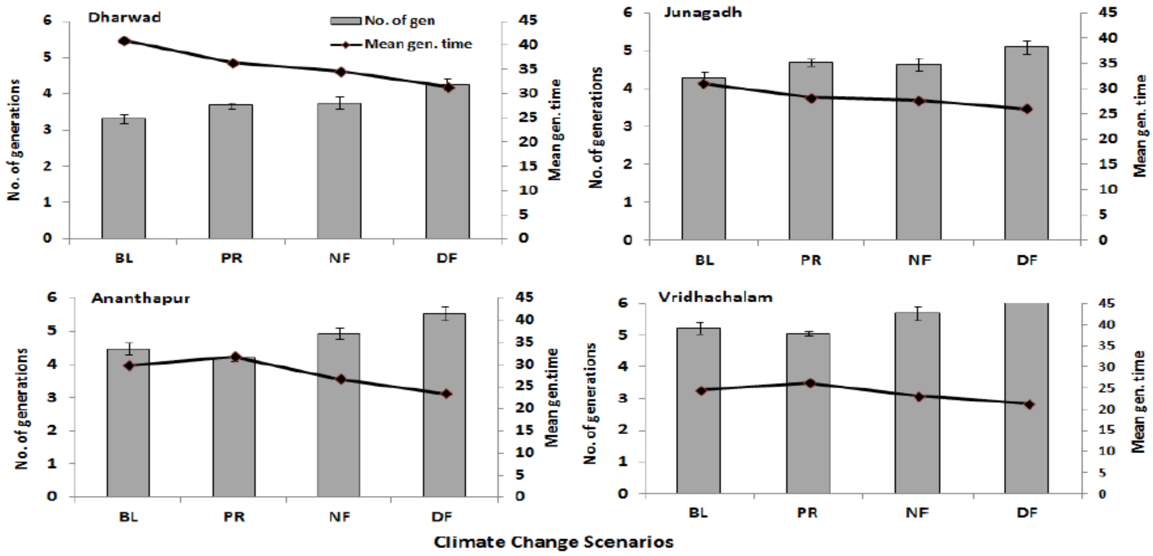

Figure 1: Variation in Mean Generation Time and Mean Number of Generations of *S. litura* on CCS

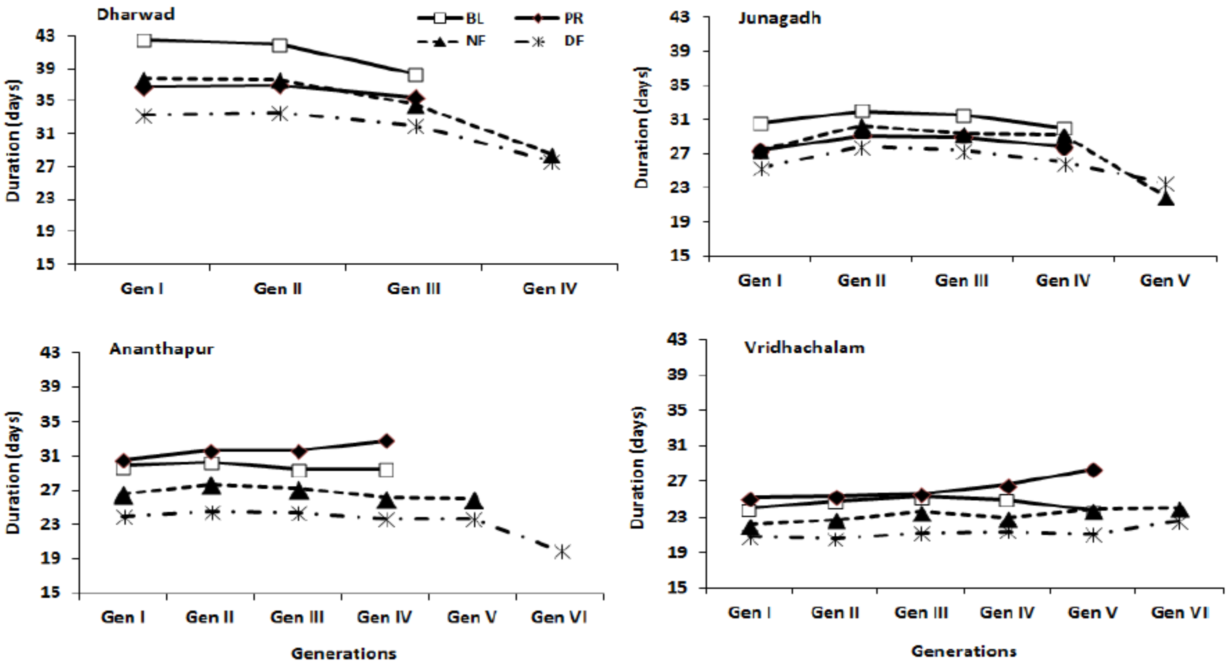

Figure 2: Prediction of Number of Generations of *S. litura* under CCS

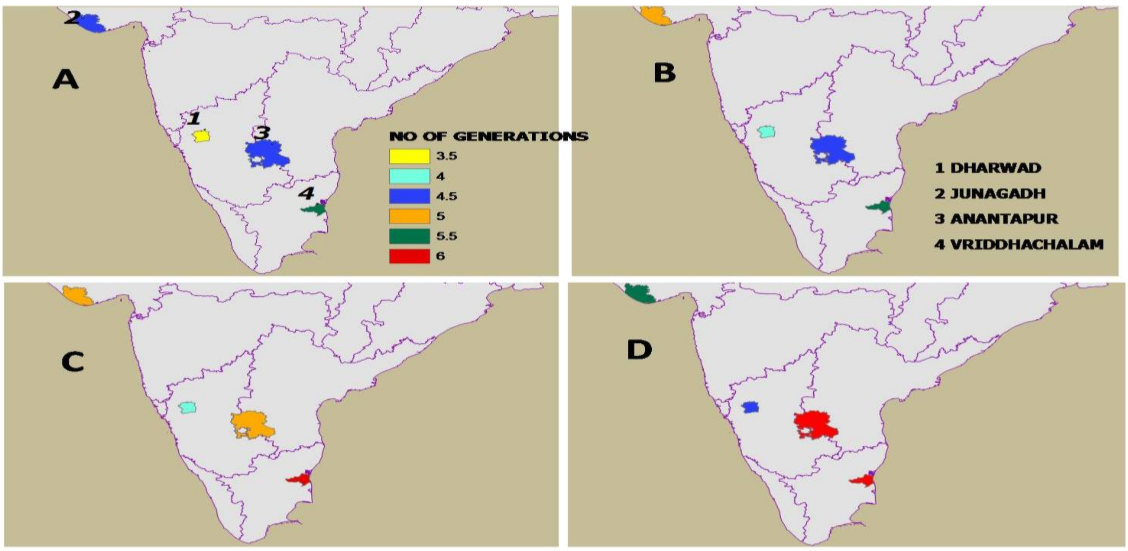

Fig 3 Maps of variation of number of generations of *S. litura* on groundnut at four locations of South India under A (BL-1961-1990); B (PR-1991-2005); C (NF-2021-2050); D (DF- 2071-2098)