633.844 : 632.93 (540)

CALIBRATION AND VALIDATION OF THERMAL-TIME BASED MODELS FOR FOREWARNING OF APHID PEST IN RAPESEED-MUSTARD CROP IN INDIA

1. Rapeseed-Mustard (*Brassica* spp.) group of crops contributes nearly 25-30% of the total oilseed production in the country. Though India occupies a major position in the acreage and production of mustard in the world, the average yield per hectare is low as compared to other countries where mustard is grown. One major reason for this low yield is mustard aphid infestation (*Lipaphis erysimi* Kaltenbach) which causes reduction in yield. Tracking the economic threshold level (ETL) of the pest is an essential task in Indian scenario, where there has been an unprecedented use of pesticides. The outbreak of these pests is highly dependent upon weather variables and stage of the crop. Two thermal time based models developed earlier, which gave predictions on the severity and timing of severity of the pest, were studied. These models were either developed for one particular location or without calibrating for other stations. Therefore attempts were made to calibrate and validate these thermal time based models developed by Agromet Advisory Service Division (Tharranum *et al*., 2017a and Tharranum *et al*., 2017b) and by Chakravarty and Gautam (2002), for specific stations using real-time weather dataand local varieties of rapeseed-mustard.

2. *Field trials* : Based on field experiments conducted under All India Coordinated Research Project for Rapeseed-Mustard (AICRP-RM), outlined by the Directorate of Rapeseed-Mustard Research (DRMR-ICAR), for 12 consecutive *rabi* seasons from 2003-04 to 2014-15, rapeseed-mustard varieties cultivated at 13 DRMR cooperating stations, *viz.*, Bharatpur, SK Nagar, Hisar, Sriganganagar, Kanpur, Dholi, Berhampore, Faizabad, Morena, Pantnagar, Ludhiana, Shillongani and Alwar across India. Selection of cooperating centres of study was based on the area of crop and importance of aphid as a serious pest problem in rapeseed and mustard crop across the country.

Varieties under study and period of study : The varieties considered for the study belonged to *Brassica juncea* species (Table 1). Most of these were medium

TABLE 1

***Brassica juncea* varieties and seasons considered for station-wise calibration**

S. No.	Station	Variety	Duration (days)	Seasons for calibration
1.	Bharatpur	Rajat (PCR-7)	130	2003-04, 2004-05, 2006-07, 2007-08, 2008-09, 2009-10, 2010-11, 2011-12, 2012-13, 2013-14
2.	SK Nagar	GDM-4	112	2011-12, 2012-13, 2013-14
3.	Hisar	RH-30	130-135	2003-04, 2008-09, 2009-10, 2010-11, 2011-12, 2012-13, 2013-14, 2014-15
4.	Sriganganagar	Laxmi	145	2008-09, 2011-12, 2013-14
5.	Kanpur	Urvashi	125	2004-05, 2006-07, 2008-09, 2011-12, 2012-13, 2013-14
6.	Dholi	Rajendra Sufalam	130	2009-10, 2010-11, 2013-14
7.	Berhampore	Varuna (T-59)	125-130	2004-05, 2006-07, 2007-08, 2008-09, 2009-10, 2013-14
8.	Faizabad	Narendra Rai (NDR-8501)	125	2004-05, 2006-07
9.	Morena	Jawahar Mustard-3 (JMM-915)	130-132	2006-07, 2007-08, 2008-09, 2009-10, 2010-11
10.	Pantnagar	Varuna (T-59)	125-130	2003-04, 2004-05, 2007-08, 2009-10, 2010-11, 2011-12, 2013-14, 2014-15
11.	Ludhiana	PBR-91	150-151	2006-07, 2007-08, 2008-09, 2009-10, 2010-11, 2011-12, 2012-13, 2013-14
12.	Shillongani	*B.juncea* var.(not mentioned)		2012-13, 2013-14
13.	Alwar	Aravalli (RN-393)	136	2004-05, 2006-07, 2007-08, 2008-09, 2012-13

duration varieties. The seasons under study considered for calibration are also mentioned in Table 1. The uniformity in duration and species are maintained because of the fact that the appearance, attainment of peak, decrease and dispersal of the aphid population are dependent on crop phenological events (Rao *et al*., 2014; Dhaliwal *et al*., 2006; Chakravarty and Gautam, 2002) and severity of mustard aphids were highly dependent on species (Prasad and Phadke, 1989).

Aphid pest data : The weekly population dynamics of aphids on crops sown on optimum date recommended for that location, spanning 42 to 15 SMW of *rabi* seasons shown in Table 1, were considered for station-wise calibration. The pest population data was also categorised quantitatively as low (0-10), moderate (11-30), high (31-60) and severe (>60 average no. of aphids/ 10 cm apex of central twig of 5 plants). The high and severe levels depicted the severity of the pest infestation above economic threshold level (ETL).While economic injury level (EIL) refers to the lowest population density which will cause economic damage, ETL refers to the population density at which control measures should be initiated to prevent the increasing pest population from reaching EIL (Stern *et al*., 1959). The data excluded those weeks where moderate to heavy rainfall (7.6-35.5mm and 64.5-124.4mm, respectively, IMD) during crop seasons were observed. All the data relied on natural population dynamics of the average aphid infesting the 10 cm tip of central twig over timely sown crop in each station. No pest protection measures were taken against aphid pest in the study area. For real-time validation, weekly aphid pest population data was collected from Agromet Field Units (AMFUs), for three consecutive *rabi* seasons 2016-17, 2017-18 and 2018-19.

3. *Real time weather data* : The daily weather data comprising of maximum, minimum temperatures and rainfall were obtained from agromet observatories in corresponding AMFUs from 1984 to 2019 to compute the Growing degree days (GDD) of these seasons and calibrate them for model-II (Chakravarty and Gautam, 2002), even though aphid data is taken from 2003-04 onwards. This is because long term weather data is required for stable computation of inter-seasonal variability of GDD for station-wise calibration. The weather data under this study were from fourteen stations covered by DRMR (mentioned in Table 1). In addition to it, weather data from AMFUs of Dantewada, Majhian, Kalyani, Kharagpur, Ballowal, Bathinda, Sonitpur, Anand, Jammu, Gossaigaon, Udaipur, Tikamgarh, Kalimpong and Varanasi were also analysed.

4. *Weather data analysis*: Derived weather parameters, *viz*., growing degree days (GDD) or thermal time or heat units (°C.day) for all the seasons were computed, using the formula:

Accumulated GDD (°C.day)

$$= \sum_{a}^{b} \left[\left(T\max + T\min \right) / 2 \right] - T_{base} \quad \text{(Nuttonson, 1955)}$$

where, ‘a’ and ‘b’ were starting and ending days respectively and T_{base} is the base temperature.

The base temperature (T_{base}) was taken as 3.04 °C for mustard aphid *L. erysimi* (Godoy and Cividanes, 2001).

Forewarning models under study: The forewarning models which were studied are given below. The models were also validated for three seasons (2016-17, 2017-18 and 2018-19) on real-time basis.

Model-I : A model (Tharranum *et al*., 2017a and Tharranum *et al*., 2017b) was developed by Agromet Advisory Services, using thermal time as an index for computation of aphid infestation level. The model used previous week’s aphid infestation level, as input to predict the current week’s aphid count. Station-wise calibration was done for this model for all the 13 stations for the years shown in the Table 1. Coefficients were obtained by regressing the observed pest population in the calibration seasons in the *Brassica juncea* varieties against model-I predicted population by large number of iterations.

The model-I used:

$Y_{(i)} = Y_{(i\text{-}1)}$ *(exp{[a+(b/D)]*D});

where, ‘a’ and ‘b’ are coefficients, a = 0.00045 and b = 0.225 (Tharranum *et al*., 2019).

$Y_{(i)}$ = Aphid population of the i^{th} week /10 cm shoot apex;

$Y_{(i\text{-}1)}$ = Previous week’s aphid population;

D = GDD (°C.day) accumulated from the start of 51 SMW to the end of i^{th} week, *i.e*., the period between 51 SMW to 8 SMW (10 weeks’ duration between 24 December and 25 February). The duration was fixed here, because in most of the stations and seasons, the onset and reaching of peak aphid infestation levels happened between these two limits of time.

Thermal time based model-II : The thermal time based thumb rule (model-II) by Chakravarty and Gautam (2002, 2004) which states that ‘Aphid population may be more in a year when the degree day accumulation from 1st to 25th January is slower and *vice versa*’, was considered because of its simplicity in predicting the severity of pest population. The methodology of this model lies in inter-seasonal comparison of GDD between 1 and 25 January for many seasons including current season with real-time. If the rate of GDD accumulation is higher, the current season shall predict a least infestation and *vice versa*. The aphid infestation (average no. of aphids/ 10 cm apex of central twig of 5 plants) was categorised into four depending upon severity: low, moderate, high and severe. If the current season GDD falls among the plotted lines having higher GDDs of multi-seasons, the season may be predicted as having low infestation after two weeks. If it falls among the plotted lines having GDDs of multi-seasons, the season may have severe infestation after two weeks. Similarly, position of GDD of the current year among previous years may give an outlook on infestation level after few weeks.

At some stations, it was found that the onset and attaining of the peak population was earlier than January. Hence, station-wise calibration of data was carried to find out exactly the date from which GDD must be started to accumulate in order to predict the severity of infestation precisely at every location. At fourteen stations, the thumb rule of Model-II was analysed. These fourteen stations were: New Delhi, Kharagpur, SK Nagar, Anand, Jammu, Gossaigaon, Tikamgarh, Kalimpong, Morena, Ludhiana, Udaipur, Varanasi, Majhian and Sonitpur. These AMFUs consistently provided the qualitative and quantitative pest status every week of three consecutive *rabi* seasons of 2016-17, 2017-18 and 2018-19. Hence, were selected for calibration of model-II. The growing degree days were computed from 1st October to 31st March, for all the *rabi* seasons between 1984-85 to 2012-13 (29 seasons). The day when the difference between inter-seasonal maximum and minimum thermal time reached peak was culled out and GDD of 20 surrounding days were computed from that day onwards and taken as standard for comparison, for outlook on the aphid infestation severity, for that particular station. This was made possible by computing standard deviation of GDD from October 1st onwards. A graph was made using standard deviation on vertical axis and days on horizontal axis. The final criterion of deciding the days for GDD computation was those surrounding peak of the standard deviation. This duration was station-specific and was found that it varied for all stations. It encompassed mostly 19-20 days surrounding the peak achieved. This critical duration was very important to ascertain the aphid pest severity of season. This duration was considered to be the standard and critical one for inter-seasonal GDD variability computation, which would reflect the pest status two weeks later. Thereafter, validation of this station-specific duration was made for three seasons on real-time observations.

5. *Station-wise calibration of Model-I* : The station-wise calibration coefficients obtained were presented in the Table 2. The correlation between observed and predicted aphid pest data during station wise calibration varied between: 0.59** for Sriganganagar and 0.99** for Faizabad station. The calibration study also reveals that

TABLE 2

Station-wise calibration of model-I

S. No.	Station	a	b	R^2	*r* (correlation coefficient between observed and predicted)	*N*
1.	Bharatpur	0.0007	0.235	0.71	0.84**	96
2.	SK Nagar	-0.0007	0.805	0.83	0.92**	31
3.	Hisar	-0.0007	1.377	0.83	0.91**	68
4.	Sriganganagar	-0.0006	0.963	0.33	0.59**	30
5.	Kanpur	-0.0034	2.743	0.71	0.84**	60
6.	Dholi	-0.0001	0.199	0.76	0.88**	31
7.	Berhampore	-0.0013	1.092	0.49	0.73**	55
8.	Faizabad	-0.0014	1.363	0.99	0.99**	22
9.	Morena	-0.0009	0.504	0.53	0.75**	47
10.	Pantnagar	-0.0052	2.861	0.74	0.87**	65
11.	Ludhiana	0.0015	-0.662	0.93	0.97**	64
12.	Shillongani	-0.005	3.246	0.72	0.86**	23
13.	Alwar	0.003	-2.548	0.60	0.79**	47

**statistically highly significant at $P < 0.01$

most of the stations have negative 'a' coefficients as against positive coefficient before calibration.

Real-time validation of Model-I according to station-wise calibrated coefficients : The real-time validation according to the calibrated station-wise coefficients was done with the information received from AMFUs falling under the same NARP (National Agricultural Research Project) Agro-Climatic zones for the three *rabi* seasons : 2016-17, 2017-18 and 2018-19. It was observed that the predictions made without station-wise calibration has huge mean difference with observations in the paired *t*-test, even though these differences were non-significant. The regression analysis showed that coefficient of determination is higher for the predictions made using station-wise calibrated coefficients (R^2 = 0.81) than predictions made without using station-wise calibrated coefficients (R^2 = 0.76) (Table 3) (Fig. 1).

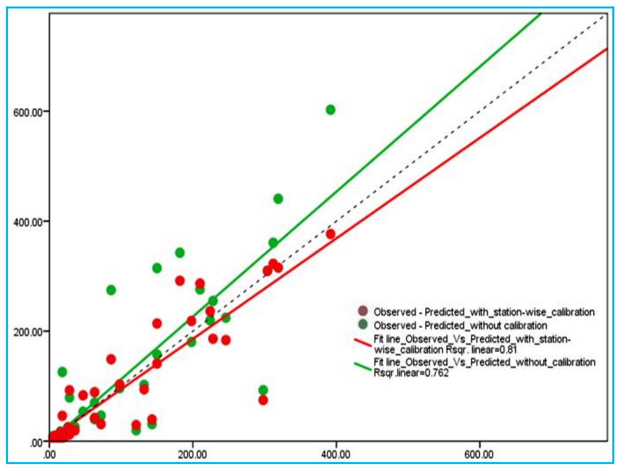

Fig. 1. Regression analysis between real-time observed and predicted aphid infestation with and without station-wise calibrations

Station-wise calibration of Model-II: The inter-seasonal variability comparison of GDD, between many seasons and the current season, gives an outlook on the pest severity for the real-time weather. This critical duration was found to be as early as 20 October-8 November for Gossaigaon and as late as 7-26 January and 8-27 January for New Delhi and Majhian, respectively. Most of the stations have their critical duration before January and it coincides with 50% flowering stage, which is the most vulnerable phase of the crop cultivated there. Only in Sonitpur AMFU, even though the peak difference between maximum and minimum thermal time of all seasons' occurred between 27th December and 15th January, a very early peak difference of 5th to 24th December was taken up for computation of GDD. This was done because the real time observations showed that the aphid-build up at Sonitpur was much earlier and severe.

Real-time validation of Model-II according to station-wise calibration: The duration as recommended on calibration were considered and GDD was computed for all seasons for validation and comparison was made with real time observations. Real time validation of the three seasons showed that six out of ten, six out of eight and four out of six stations in 2016-17, 2017-18 and 2018-19, respectively, stood correctly predicted (Table 4). Therefore, 66.67 per cent correctness of predictions were achieved, in the pooled data, if the thumb rule is modified

TABLE 3

Statistics showing comparison between predictions made without and with station-wise calibrations

Paired - *t* test values for significance of differences between observed and predicted						
Pairs	Mean difference	SD (d)	SE (m)	Computed *t*-value	df	Sig. (2-tailed)
Observed - Predicted without station-wise calibration	-11.49	70.23	10.13	-1.134	47	N.S
Observed - Predicted with station-wise calibration	4.75	48.84	7.05	0.675	47	N.S
Regression analysis between observed and predicted						
Pairs	Equation	r	R^2			
Observed - Predicted without station-wise calibration	Observed = 0.67 * predicted + 22.31	.87**	0.76			
Observed - Predicted with station-wise calibration	Observed = 0.89 * predicted + 14.62	.90**	0.81			

**statistically highly significant at P < 0.01

TABLE 4

Real time validation of Model-II in the *rabi* seasons 2016-17, 2017-18 and 2018-19

S. No.	Station	1st peak difference observed (after 1st October)	Aphid Severity 2 or 3 weeks after								
			2016-17			2017-18			2018-19		
			Observed	Predicted	Validation	Observed	Predicted	Validation	Observed	Predicted	Validation
1.	New Delhi	8 January	Low	Moderate	x	Low	Low	✓	Moderate	Moderate	✓
2.	Kharagpur	13 December	Severe	Moderate	x	Severe	High	x	Severe	Severe	✓
3.	SK Nagar	21 December	Low	Low	✓	Severe	Severe	✓	-	-	-
4.	Anand	11 December	High	High	✓	-	-	-	-	-	-
5.	Jammu	3 November	Moderate	Moderate	✓	-	-	-	-	-	-
6.	Gossaigaon	20 October	Low	-	-	Moderate	Moderate	✓	Low	Low	✓
7.	Tikamgarh	20 November	Severe	Severe	✓	-	-	-	-	-	-
8.	Kalimpong	1 January	Severe	Severe	✓	-	-	-	Low	Moderate	x
9.	Morena	21 December	Low	Low	✓	-	-	-	-	-	-
10.	Ludhiana	23 December	-	-	-	Moderate	Moderate	✓	-	-	-
11.	Udaipur	8 December	-	-	-	Severe	Severe	✓	Severe	Severe	✓
12.	Varanasi	21 November	-	-	-	-	-	-	Low	Moderate	x
13.	Majhian	8 January	Severe	Low	x	Severe	Severe	✓	-	-	-
14.	Sonitpur	5 December	Severe	Moderate	x	Severe	Moderate	x	-	-	-

according to the peak difference in maximum and minimum growing degree days in the 29 seasons' data. Without calibration, the model gave correct predictions in six out of thirteen, six out of nine and two out of six stations in 2016-17, 2017-18 and 2018-19 *rabi* seasons, respectively (Tharranum *et al*., 2019), which accounted for 48.67 per cent correctness in predictions made.

6. The model-I was effective in determining the ETL of the pest (high and severe categories of the pest), where it became necessary for a pesticide application, without which significant crop losses would incur and would impact severely on economy of crop cultivation. The model-I was purely GDD-based, hence simple and effective in prediction with two weeks lead time. It was calibrated for multi-locations using data from AMFUs all over mustard zones (14 stations). Upon real-time validation using three *rabi* seasons' data, the coefficient of determination was found to be higher for the predictions made using station-wise calibrated coefficients (R^2 = 0.81). Earlier developed models like thermal-time based thumb rule (model-II) by Chakravarty and Gautam,

2002, was calibrated for many stations and validated on real-time; The model-II which predicted qualitative outlook on pest severity could achieve 66.67 per cent correctness of predictions upon real-time validation. These weather-based pest forewarning models cannot fulfil aphid pest related forewarning requirements when taken up singly. In combination, these models can effectively be formulated in construction of decision support system which will cater the important aspects of aphid pest life cycle. These are quantity of pest each week, maximum severity of pest in the season and time of occurrence of peak population, which will be forewarned by: models I and II, in combination. The dynamic thermal time based models are already in use under GKMS project under IMD, MoES, on experimental basis and decision support system is being constructed by AASD, for real-time forewarning using medium and extended range forecast weather. It would enable decision makers to know the timing of pest population crossing ETL in advance and this can be operationalized spatially to forewarn against the aphid pest population in future under GKMS scheme. Currently, dynamic pest weather calendar of Rapeseed-Mustard crop is being developed at IMD on the basis of the study.

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