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Simulation of economic injury levels for leaf folder (*Cnaphalocrocis medinalis* Guenee) on rice (*Oryza sativa* L.)

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Leaf folder incidence on rice (Pusa Sugandha 3) was 1.2-20.5% folded leaves with highest infestation between 45-55 days after transplanting (DAT). Two spray applications with endosulfan 35 EC at 50 and 70 DAT were found optimum for preventing yield loss (26%) due to pest. Leaf folder damage was calibrated and validated through a generic crop growth model, InfoCrop. Validated model was used for simulating economic injury levels (EILs) of the pest. Simulated EIL was found to be 9, 11 and 12% folded leaves at 50 DAT and 12, 15 and 14% at 70 DAT during 2003, 2004 and 2005, respectively. Simulation models could account for changes in weather, inputs and crop-pest interactions, and therefore, could be potential tools for formulating site specific EILs for pests.

Keywords: Economic injury level, Leaf folder, Rice, Simulation model

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Introduction

Though India ranks first[1] in area under rice (*Oryza sativa* L.), rice productivity under irrigated ecosystem for India is less (4.2 tons/ha) as compared to China (6.1 tonnes/ha) and Egypt (8.3 tonnes/ha). Leaf folder (*Cnaphalocrocis medinalis* Guenee) infestation leads to high (60-70%) leaf damage[2,3] inflicting significant rice yield losses (80%)[4-6]. Thus, there is a need to rationalize pesticide use to ensure least disruption of rice ecosystem. Economic injury levels (EILs) play a significant role in rationalizing pesticide use on crops, thereby avoiding farmers' expenditure and averting environmental contamination[7]. EILs developed through empirical relations are location specific[8]. Simulation models based on crop physiological and ecological processes incorporate effects of weather changes, soil, management practices, crop genotype and pest situations, which can be used to determine location specific EILs for pesticide use[9].

Present study demonstrates simulated and validated EILs for rice leaf folder through InfoCrop-rice model.

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Materials and Methods

Field Experiment

Field experiment was conducted during *kharif* season in 2003 with rice variety Pusa Sugandh-3 at Indian Agricultural Research Institute (IARI), New Delhi. Nursery was raised at 35 kg/ha of seed rate and sowing was done in plot (2 m x 2 m) at a depth of 4 cm. Seedlings (25-days old) were transplanted (3 seedlings at one hill) with plant to plant and row to row spacing of 15 cm x 15 cm.

Experiment was conducted in a randomized block design with 10 pesticide treatments [endosulfan 35 EC, 500 g active ingredient (a.i.)/ha/spray] replicated thrice at various intervals and frequencies in different plots (Table 1). Pesticide was sprayed on leaves using a pneumatic sprayer. Infestation of leaf folder was recorded from 25 days after transplanting (DAT) onwards at 10 days interval. Number of folded leaves and total number of leaves were counted on randomly selected five hills in each plot and pest infestation (%) was worked out. Harvesting and threshing were done manually. Total fresh biomass of each plot was weighed and sample (500 g) was oven dried at 70°C for 24 h to work out total dry matter (TDM). Likewise, fresh and

Table 1 — Leaf folder incidence on Pusa Sugandh 3 rice during *Kharif* 2003 and economics of different insecticidal treatments

Treatment (Endosulfan spray)	Folded leaves, % Days after transplanting (DAT) 25	35	45	55	65	75	Total dry matter kg/ha	Yield kg/ha	Benefit-cost ratio
T1- 30 DAT	4.0(11.5)	2.6(9.1)	11.7(20.0)	19.2(26.0)	10.7(19.1)	11.3(19.7)	9405	3904	0.4
T2- 40 DAT	2.5(9.0)	3.4 (10.7)	12.4(20.6)	13.7(21.7)	11.4(19.7)	10.3(18.7)	9793	4100	2.7
T3- 50 DAT	4.5(12.2)	2.8(9.5)	15.3(23.0)	12.0(20.2)	9.8(18.2)	13.1(21.2)	9983	4325	5.4
T4-60 DAT	2.7(9.4)	3.3(10.5)	16.0(23.5)	15.0(22.7)	8.0(16.5)	8.9(17.3)	9840	3925	0.7
T5-70 DAT	1.2(6.2	3.4 (10.6)	20.5(26.9)	18.5(25.5)	6.2(14.4)	8.9(17.3)	9825	4000	1.6
T6-80 DAT	2.3 (8.7)	3.3 (10.5)	16.5(23.4)	16.6(24.0)	10.1(18.5)	11.5(19.9)	9231	4108	2.8
T7-30 & 50 DAT	4.2(11.7)	6.3 (14.6)	17.7(24.8)	13.2(21.3)	9.8 (18.2)	8.1 (16.6)	10101	4415	6.4
T8-50 & 70 DAT	2.7(9.4)	2.5(9.1)	12.8(20.9)	11.3 (14.7)	9.7(14.8)	12.4(20.6)	11729	4881	11.9
T9-60 & 80 DAT	3.5(10.7)	4.1(11.7)	18.7(25.3)	16.6(24.0)	8.3(16.7)	12.5(20.6)	9940	4131	3.1
T10- Untreated check	1.8(7.7)	4.0(11.4)	19.4(26.1)	20.0(26.9)	10.8(19.1)	14.2(22.1)	9413	3867	-
S.Em ±	0.86	0.65	0.40	0.52	0.70	0.80	64.6	254.4	-
C.V., %	15.5	10.5	2.9	3.9	6.9	7.1	1.1	10.6	-
C.D. at 5%	1.8	1.4	0.84	1.1	1.5	1.7	135.7	534.5	-

Figures in parentheses are angular transformed values [angle=Arc sin (percentage)^{½}]

dry yields were also recorded. Data on pest infestation, TDM and yield were analyzed statistically.

Benefit-cost analysis was carried out by using prevailing market price of paddy, Pusa Sugandh 3 (Rs 700 /qtl), while control expenditure was calculated based on pesticide cost (Rs 260/l), labour charges (Rs 104/manday) and hire charges for sprayer (Rs 10/day).

Leaf folder Damage Mechanisms

Effect of leaf folder damage on rice biomass and yield was simulated through InfoCrop[10], a generic crop growth model that can simulate effects of weather, soil, agronomic procedures, nitrogen, water and major pests on crop growth and yield. Leaf folder acts as a tissue consumer by feeding on leaves as well as assimilates rate reducer by affecting radiation use efficiency of the crop[11]. These damage mechanisms of leaf folder are described as follows:

$$LALOSS = LAI*LFOLDR*0.5$$

$$RLAI = LAII+GLAI–DLAI–LALOSS$$

$$DLV = WLVG*DLAI/(LAI+LFOLDR*0.5)$$

$$RWLVG = GCROP*FSH*FLV–DLV$$

$$RUE = RUEMAX* (1.0 – LFOLDR*0.25)$$

where LAII, initial leaf area index; LAI, leaf area index; LALOSS, leaf area loss due to leaf folder; GLAI, leaf area growth rate; RLAI, rate of change in leaf area; DLAI, leaf area death rate; LFOLDR, leaf folder incidence rate per day; DLV, dead leaf weight; WLVG, green leaf weight; RWLVG, rate of change in green leaf weight; GCROP, daily rate of net photosynthesis; FSH, fraction of assimilates partitioned to shoot; FLV, fraction of assimilates partitioned to leaves; RUE, radiation use efficiency; RUEMAX, maximum radiation use efficiency for the crop.

Effect of leaf folder was simulated by reducing RLAI and increasing DLV by 50% of its infestation rate as it damaged leaves partially. RUE of the crop was reduced to 25% of its incidence level. Percentage of damaged leaves was used as an input in the model[12].

Calibration and Validation of Simulation Model

InfoCrop was calibrated for TDM, yield and leaf folder damage mechanisms with data of the experiment conducted during rainy season 2003. Crop phenology was calibrated by adjusting simulated thermal time for flowering (TTVG) and thermal time for physiological maturity (TTGF) in relation with their observed counterparts. Flowering and physiological maturity in the field occurred on 265 and 302 day of the year (DOY), respectively. The model was run with Delhi weather data of 2003 and the crop management data of the field experiment.

TDM and yield data of treatment T8 was used for model calibration, as maximum yield and lowest leaf folder incidence (LFI) was recorded in this treatment. The data used in model calibration were seed rate (SEEDRT), sowing depth (SOWDEP), thermal time for germination (TTGM), thermal time for flowering (TTVG), thermal time for grain filling (TTGF), specific leaf area of plant (SLAVAR), radiation use efficiency (RUEMAX), potential grain weight (POTGWT), number of grains per kg dry matter during grain formation stage (GNOCF), relative leaf growth rate during exponential phase (RGRPOT) and weather data (solar radiation, max. and min. temp., rainfall). Treatment T1 data was used for calibration of leaf folder damage mechanisms. Total LFI observed at 10 days interval in the field was converted in to incidence rate per day as an input to the model. Data of remaining treatments was used for validation of crop-pest interaction. Simulated (%) and observed reductions in TDM and yield were calculated. Observed and simulated TDM and yield in different treatments were validated by paired data set of t-test. Model was also validated for leaf folder damage mechanisms with another data set comprising yield of Pusa 169 rice under different levels leaf folder intensity[13].

Economic Injury Levels

EILs were simulated using weather data of Delhi for 2003, 2004 and 2005. Prevailing market prices during 2003, 2004 and 2005 were, respectively: Pusa Sugandh 3, Rs 700, Rs 750 and Rs 800 per quintal; endosulfan 35 EC, Rs 260, Rs 280 and Rs 300; and labour charges, Rs 104, Rs 108 and Rs 110/manday. Validated InfoCrop model was run from no infestation (healthy crop) to incidence up to 15%, with 1% incidence interval. Pest infestation as incidence rate per day for a period of 10 days prior to EIL determining crop age was input to the model. EIL was determined at 50 and 70 DAT as two pesticide applications at these stages were observed to be most effective against the pest. Monetary return was worked out for each run. Pest incidence level at which value of yield loss equaled control expenditure was considered as EIL.

Results and Discussion

Leaf Folder Incidence (LFI) and Rice Yield

Cumulative LFI in different treatments including control was 1.2-20.5 % folded leaves (Table 1). Highest incidence of the pest was recorded between 45-55 DAT, which coincided with panicle emergence stage of the crop. High infestation of leaf folder was found during tillering and panicle emergence stage of the crop[14]. Paddy yield was maximum (4881 kg/ha) in T8 treatment (spray at 50 & 70 DAT) and minimum (3867 kg/ha) in untreated control (Table 1). The yield with two sprays at 50 & 70 DAT (T8) and two sprays at 30 & 50 DAT (T7)) was significantly higher than control. Yield in different treatments could be related to cumulative pest incidence.

Single spray at 50 DAT (T3) proved as effective as two sprays at 30 and 50 DAT (T7) and more effective than other single spray treatments as well as two sprays at 60 & 80 DAT (T9). The crop was found to be most prone to leaf folder attack at 50 DAT and its protection at this stage prevented crop losses to a great extent. Another spray at 70 DAT further supplemented the effect of first spray and increased crop yield (26%) over control. The expenditure on single pesticide application was Rs 597 while it was Rs 1198 in case of two sprays. Benefit-cost ratio in various treatments varied (0.4-11.9) (Table 1) with highest recorded by two sprays at 50 & 70 DAT (T8) followed by two sprays at 30 & 50 DAT (T7) and single spray at 50 DAT (T3). The pesticide application against leaf folder at 50 and 70 DAT thus proved most profitable.

Calibration and Validation of Simulation Model

Observed and simulated TDM with two sprays at 50 & 70 DAT (T8), used for calibration, was 11729 and 11487 kg/ha while corresponding yield was 4881 and

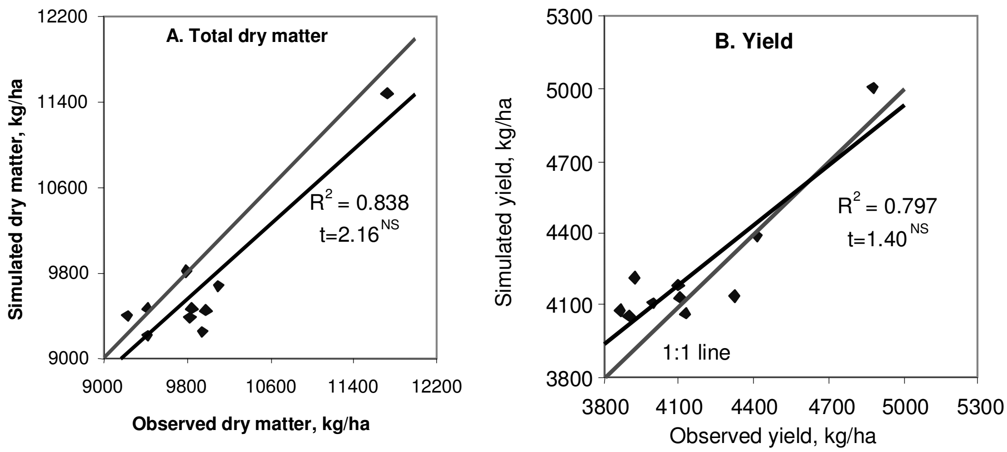

Fig. 1 — Relation between observed and simulated dry matter and yield of Pusa Sugandh 3 rice under different rice leaf folder incidence levels during rainy season 2003

Observed reduction, % Observed reduction, %

Fig. 2 — Observed and simulated reduction in dry matter and yield in Pusa Sugandh 3 rice under different leaf folder incidence levels during rainy season 2003

5003 kg/ha. Model underestimated TDM (2.1%) and overestimated yield (2.5%), thereby indicating almost accurate simulation. Observed and simulated TDM with single spray at 30 DAT (T1), used for calibrating pest damage mechanisms, was 9450 and 9472 kg/ha respectively, whereas corresponding yield was 3904 and 4056 kg/ha. Model overestimated TDM (0.71%) and yield (3.89%), indicating leaf folder damage mechanisms were also simulated properly. Values of different parameters derived during simulation were: TTGERM, 60; TTVG 1050; and TTGF, 600 degree days (DD). Respective values of RGRPOT, GFRVAR and SLAVAR were 0.011/day, 0.64 mg/day and 0.0025 m^2/kg. Likewise, RUEMAX, KDFMAX, POTGWT and GNOCF were found to be 0.25 g/MJ/day, 0.8, 24 mg and 60000 grains/kg dry matter, respectively.

Pest incidence, TDM and yield data of rest of the treatments were used for model validation. Variations in different parameters (Fig. 1) were found as follows: Observed TDM, 9231-10101; simulated TDM, 9225-9709 kg/ha; observed yield, 3867-4415 kg/ha; and simulated yield, 4067-4350 kg/ha. Simulated TDM differed (0.2-7.01%) from the observed TDM, while simulated yield varied (0.55-7.39%) over the observed yield. Marginal differences between observed and simulated yields as well as TDM in different treatments validated the model simulation [paired t test at 5%, 9 degrees of freedom (df)].

Observed reduction in yield due to LFI varied (9.5-20.8%) in different treatments, while simulated yield reduction ranged between 12.2% and 18.9%, respectively (Fig. 2B). In different treatments (Fig. 2A),

Table 2 — Economic injury levels of leaf folder on Pusa Sugandh 3 rice as simulated with InfoCrop model during 2003-2005

	2003 (control expenditure = Rs 1198)			2004 (control expenditure = Rs 1270)			2005 (control expenditure Rs 1335)		
Leaf folder incidence %	Yield kg/ha	Yield loss kg/ha	Value of yield loss Rs 7/kg	Yield kg/ha	Yield loss kg/ha	Value of yield loss Rs 7.50/kg	Yield kg/ha	Yield loss kg/ha	Value of yield loss Rs 8/kg
				50 days after transplanting					
Healthy crop	5003	-	-	5294	-	-	5474	-	-
2	4965	38	266	5265	29	217	5440	34	272
4	4928	75	525	5236	58	435	5407	67	536
5	4910	93	651	5221	73	547	5391	83	664
6	4890	113	791	5206	88	660	5374	100	800
7	4871	132	924	5192	102	765	5358	116	928
8	4860	143	1001	5177	117	877	5341	133	1064
9	4831	172	1204	5162	132	990	5325	149	1192
10	4809	194	1350	5147	147	1102	5307	167	1336
12	4767	236	1652	5118	176	1320	5275	199	1592
14	4723	280	1960	5088	206	1545	5242	232	1856
				70 days after transplanting					
2	4975	28	196	5272	22	165	5450	24	192
4	4948	55	385	5250	44	330	5426	48	384
5	4934	69	483	5239	55	413	5414	60	480
6	4919	84	588	5228	66	495	5402	72	576
7	4905	98	686	5217	77	578	5391	83	664
8	4896	107	749	5206	88	660	5379	95	760
9	4876	127	889	5195	99	743	5367	107	856
10	4862	141	987	5184	110	825	5355	119	952
12	4831	171	1197	5162	132	990	5331	143	1144
14	4803	200	1400	5140	154	1155	5307	167	1336
16	4776	227	1589	5118	176	1320	5282	192	1536

reduction in TDM varied as follows: observed, 13.9-21.3%; and simulated, 15.7-19.7%. There were not significant differences in observed and simulated reductions in TDM and yield in different treatments (paired t test at 5%, 9 df). Validation of the model with another dataset[13] showed variations in simulated yield (5171-5887 kg/ha) compared with observed yield (4881-5960 kg/ha) under various leaf folder treatments (Fig 3). Marginal differences between observed and simulated yields revealed proximity between observed and simulated yield data (paired t test at 5%, 7 df).

Validation with two sets of experimental data thus showed that InfoCrop could simulate the effect of leaf folder damage in rice satisfactorily.

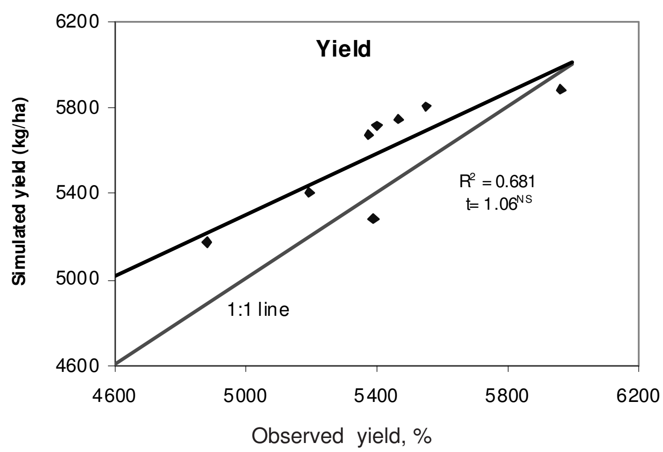

Fig. 3 — Relation between observed and simulated yield of Pusa 169 rice under different leaf folder incidence levels during rainy season 1998

Economic Injury Levels

During 2003, expenditure on optimum number of sprays (two sprays) was worked out to be Rs 1198/ha (endosulfan 35 EC for two sprays at 500 g a.i./ha/spray, Rs. 742; labour charges @ Rs. 104/manday, Rs 416; sprayer hire charges @ Rs 10/day, Rs 40). Depending upon cost of control and market price of Pusa Sugandh 3 (Rs 700/q), GT was determined 171 kg /ha. Likewise, GT was 169 kg/ha based on control expenditure of Rs 1270/ha and market price of Pusa Sugandh 3 of Rs 750 during 2004. On other hand, it was 166 kg/ha during 2005 as market price of Pusa Sugandh 3 and control expenditure were Rs 800 and Rs 1335, respectively.

During 2003, at 50 DAT with 8% pest incidence, monetary yield loss (Rs 1001) was less than the expenditure on control measures (Rs 1198), while with 9% incidence level monetary yield loss of Rs 1204/ was found, which exceeded control expenditure (Table 2). EIL (8.5%) was thus determined by averaging these two incidence levels. Similarly, at 70 DAT, EIL (12%) was obtained. EILs found at 50 and 70 DAT for 2004 and 2005 were, respectively: 2004, 11 and 15%: and 2005, 10 and 14%. EILs were worked out at 50 and 70 DAT because two applications with the pesticide at these stages were found to be most effective and profitable in the field study. EILs varied during different years because of weather variability, which affected crop-pest interactions and yield. Simulated yield of uninfested crop was: 2003, 5003; 2004, 5294; and 2005, 5474 kg/ha. Further, prevailing market price of Pusa Sugandh 3, endosulfan 35 EC and labour charges were also different during three years. EIL is a highly dynamic entity, which may differ among geographic locations, plant growth stages, control expenditures and market prices[8]. EIL was lower at 50 DAT compared to 70 DAT in all years. In general, EIL for foliage feeders increases with advancing crop age due to enhanced tolerance of the crop to pest stress. Hence simulated EILs were logical. Traditionally, EILs have been worked out empirically through regression analysis. Empirical EIL for the leaf folder was found to be 5.5% at late tillering stage (45-55 DAT)[15], while EIL for the leaf folder was reported[13] as 6-8% folded leaves on Pusa 169 rice at panicle emergence stage (55-65 DAT) during two years. However, these empirical relations are limited in their scope and application since these equations are data-specific and insensitive to variable cropping and pest conditions[16]. Such empirical equations are simple models reflecting pest effects on crops but cannot be used under variation of weather, crop cultivar, soil type and agronomical procedures[17].

On the other hand, current simulation models are based on crop physiological and ecological processes with variations in pest damage mechanisms, changes in weather, soil and agronomical procedures[18].

Conclusions

Simulated EILs were found comparable to empirical EILs, reflecting the dynamic nature and adaptability of InfoCrop in simulating the leaf folder damage in rice. Crop-pest simulation models can thus be used for deriving site-specific EILs based on agronomic procedures, weather and pest data, thereby overcoming limitations of empirical models for estimating EILs.

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