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Simulation of rice brown planthopper [*Nilaparvata lugens* (Stal)] damage for determining economic injury levels

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This study presents InfoCrop-rice model to simulate damage mechanism of brown planthopper (BPH), *Nilaparvata lugens* (Stal.) on two rice cultivars (Pusa Basmati 1 and ADT-38). Simulated yield and total dry matter (TDM) in various treatments over two experiments were proximal to observed yields ($R^2 = 0.969$; RMSE = 5.49%) and TDM ($R^2 = 0.940$; RMSE = 4.45%), respectively. Simulated yield and TDM losses were also proximal to respective observed losses of yield ($R^2 = 0.801$; RMSE = 18.47%) and TDM ($R^2 = 0.843$; RMSE = 20. 73%), indicating proper validation of damage mechanism of BPH. Validated model simulated economic injury levels (EILs) of BPH at different rice growth stages with two control expenditures, incurred on two applications with each of monocrotophos 36 WSC @ 500 g a.i./ha and buprofezin 25 SC @ 100 g a.i./ha and three market prices of Pusa Basmati 1 and ADT-38 apiece. EIL exhibited a negative relationship with market value of produce but had a positive with control measure expenditure. Simulated EILs were comparable to earlier established empirical thresholds.

Keywords: Brown planthopper, Damage mechanism, Economic injury level, Rice, Simulation model

Introduction

In India during 2008-09[1], rice (*Oryza sativa* L.) was grown on an area of 45.35 million hectares with a production of 99.15 million tonnes. However, rice productivity in India is lower compared to China and Sri Lanka[2], may be due to several biotic and abiotic stresses. Brown planthopper (BPH), *Nilaparvata lugens* (Stal.), is the most important insect pest on rice. BPH outbreak during 2008 in northern India resulted in heavy yield losses[3]. Use of economic thresholds of pests facilitates judicious pesticide application, thereby reducing environmental pollution as well as likelihood of pesticide resistance development in pests[4]. Empirical economic thresholds, developed for rice planthoppers[5], are location specific[6] and a better approach involves use of crop simulation models coupled with pest damage mechanisms[7,8], which may be defined as plant physiological processes affected by pest injury[9,10]. Simulation models in agriculture take into consideration the physiological basis of pest damage that empirical models do not, making them useful in establishing location and weather-specific economic thresholds and increasing efficiency of field experiments substantially[8,11,12]. This study validates InfoCrop-rice model for BPH damage and simulates economic injury levels (EILs) for its management.

Experimental Section

Model Description

InfoCrop-rice model[10] was used to simulate BPH damage on rice. It is a generic crop growth model that can simulate effects of weather, soil, agronomic management, nitrogen, water and major pests on crop growth and yield. BPH was classified as assimilate sapper because it sucked sap from plant stems and leaf sheaths. Extent of yield loss due to pest depended upon its population and crop growth stage. Effect on crop growth and yield was simulated by reducing weights of green leaves (RWLVG) and stem reserves (RWIR) based on pest's sucking rate from leaf sheaths (SUCKLV) and stems (SUCKST) as

$$RWLVG = GCROP \times FSH \times FLV - SUCKLV \qquad \ldots(1)$$

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GCROP, FSH and FLV refer to net assimilates available for plant growth (kg/ha/day), fraction of GCROP allocated to shoot and fraction of FSH allocated to leaves respectively. Allocation of assimilates increased leaf weight while leaf death due to senescence and BPH sucking reduced it. Rate of change in RWIR weight is given as

RWIR = GCROP x FSH x FST x FSTRT- SUCKST …(2)

FST refers to fraction of FSH allocated to stems while FSTRT represents mobilisable fraction of stem weight. Assimilates sucked by BPHs were deducted from weight of stem reserves and not from stem weight because a part of these reserves are often available for current growth in rice.

BPH sucking rate from leaf sheaths and stems is given as

SUCKLV= SUCKRT*PPOSK*SKINWT*FRPPOLV …(3)

SUCKST= SUCKRT*PPOSK*SKINWT*FRPOST …(4)

Daily rate of assimilate sucking from plant parts (SUCKLV, SUCKST) depended upon sucking rate per unit insect weight per day (SUCKRT), weight of one insect (SKINWT), BPH population/ha (PPOSK) and fraction of pest population on plant stems (FRPOST) and leaf sheaths (FRPOLV). SKINWT (2.0 mg) was derived as an average value based on weights of 3rd-5th instar nymphs of BPH[13,14]. Since BPH population in experiments comprised of nymphs and adults of BPH, value of SUCKRT was derived as an average value (1.340E-6 kg/mg insect wt/day), based on data on sucking rates of BPH nymph (6.8E-7 kg/mg insect wt/day) and BPH adult (1.99E-6 kg/mg insect wt/day)[15,16]. Likewise, sucking rate of BPH was determined to be 1.3736E-6 kg/mg insect weight/day[17]. FRPOST (0.3) and FRPOLV (0.7) were used as parameters because BPHs fed on basal portion of rice plant as: plant stems, 70%; and leaf bases, 30%. BPHs along with carbohydrates also drained plants of their nitrogen (amino acid). Their effect on crop nitrogen (N) was modelled by reducing rate of available N in leaves (NLV) and stems (NST) depending upon N sucking rate (SUKNLV and SUKNST) of BPHs on respective plant parts. NLV depended upon initial N content of leaves (NLVI), rate of N availability to leaves (NALV) and SUKNLV. Similarly, NST depended on rate of N availability to stems (NAST) and SUKNST as

NLV= NLVI*NALV-SUKNLV …(5)

SUKNLV=SUKNRT*PPOSK*SKINWT*FRPOLV …(6)

NST=NSAT-SUKNST …(7)

SUKNST=SUKNRT*PPOSK*SKINWT*FRPOST …(8)

N sucking rate per unit insect weight per day (SUKNRT) was required as an input in the model. Amount of N sapped by pests was estimated at 2% of carbohydrate amount removed from plants; SUKNRT was used as a parameter with its value being 2% of SUCKRT[18].

Model Calibration and Validation

Two field experiments, one at New Delhi (28.66°N, 77.15°E) during *kharif* 2009 (experiment 1) and another at Aduthurai (11.02°N, 79.53°E) during *rabi* 2009-10 (experiment 2) were undertaken to quantify BPH damage mechanism on rice. Experiment 1, which was conducted with Pusa Basmati 1 rice, comprised of nine insecticidal treatments along with an untreated control (Table 1), while experiment 2 with ADT-38 rice had six insecticidal treatments along with an untreated control (Table 2). Both experiments had three replications in a randomized block design. Monocrotophos 36 WSC @ 500 g a.i./ha in experiment 1 and buprofezin 25 SC @ 100 g a.i/ha in experiment 2 were applied at different frequency and interval to create differential BPH population. BPH counts were recorded on five randomly selected hills in each plot at weekly intervals from 50 days after transplanting (DAT) until crop maturity. Counts were subjected to a square root transformation before statistical analysis. At harvest, total fresh biomass of each plot excluding roots was weighed and a sample (500 g) was oven dried at 70°C for 72 h to determine total dry matter (TDM) as

TDM (kg) =weight of oven dried sample (g)/500g x fresh biomass weight (kg)

Similarly, a grain sample (100 g) from each plot was oven dried and yield was obtained as

Yield (kg) = Weight of oven dried sample (g)/100 g x fresh grain weight (kg)

Table 1—Mean brown planthopper population on rice variety Pusa Basmati 1 with different insecticide treatments of the field experiment during *kharif* 2009

Treatment number	Insecticidal application at DAT*	Mean planthopper population/hill** at DAT							Yield kg/ha
		64	74	79	84	89	94	104	
T_1	60	0^{c}	2.2^{c}	9.3^{cd}	11.8^{c}	7.5^{b}	2^{bc}	0^{b}	4277.7^{c}
		(1.0)	(1.8)	(3.2)	(3.5)	(2.9)	(1.7)	(1.0)	
T_2	70	5.9^{ab}	1.3^{cd}	2.5^{e}	10.7^{c}	8.1^{b}	3.3^{ab}	0^{b}	4122.2^{cd}
		(2.6)	(1.5)	(1.8)	(3.4)	(3.0)	(2.0)	(1.0)	
T_3	80	6.4^{a}	10.3^{b}	13.2^{bc}	1.4^{d}	1^{d}	0^{d}	0^{b}	3752.7^{de}
		(2.7)	(3.3)	(3.7)	(1.5)	(1.3)	(1.0)	(1.0)	
T_4	90	6.4^{a}	9.6^{b}	15^{b}	17.2^{b}	7.3^{b}	0^{d}	0^{b}	3675.0^{e}
		(2.7)	(3.2)	(3.9)	(4.2)	(2.8)	(1.0)	(1.0)	
T_5	100	5.8^{ab}	14.4^{a}	17^{ab}	18.7^{b}	4.9^{c}	0^{d}	0^{b}	3577.7^{e}
		(2.6)	(3.9)	(4.2)	(4.4)	(2.3)	(1.0)	(1.0)	
T_6	60 & 80	0^{c}	2^{cd}	8.5^{d}	0.6^{de}	5.9^{bc}	1.3^{c}	0^{b}	4958.3^{ab}
		(1.0)	(1.7)	(3.0)	(1.2)	(2.6)	(1.5)	(1.0)	
T_7	70 & 90	5.1^{b}	1^{de}	2.1^{e}	12.2^{c}	5.8^{bc}	0^{d}	0^{b}	4705.5^{b}
		(2.4)	(1.3)	(1.7)	(3.6)	(2.6)	(1.0)	(1.0)	
T_8	80 & 100 DAT	5.5^{ab}	15.3^{a}	20.3^{a}	0.7^{de}	0^{d}	0^{d}	0^{b}	3791.6^{de}
		(2.5)	(4.0)	(4.6)	(1.2)	(1.0)	(1.0)	(1.0)	
T_9	60, 80 & 100	0^{c}	0^{e}	7.0^{d}	0^{e}	0.3^{d}	0^{d}	0^{b}	5152.7^{a}
	(Complete protection)	(1.0)	(1.0)	(2.8)	(1.0)	(1.1)	(1.0)	(1.0)	
T_{10}	Untreated control	6.6^{a}	14.4^{a}	19.4^{a}	22.7^{a}	15.8^{a}	4.5^{a}	1.7^{a}	3538.8^{e}
		(2.7)	(3.8)	(4.5)	(4.8)	(4.0)	(2.3)	(1.6)	
S.E.m±		(0.12)	(0.23)	(0.27)	(0.18)	(0.22)	(0.18)	(0.04)	183.9
C.D. (P<0.05)		(0.27)	(0.48)	(0.57)	(0.39)	(0.47)	(0.38)	(0.08)	

*DAT= Days after transplanting; ( ) = Values in parentheses are square root transformed values; ** Mean planthopper populations with same superscript do not differ significantly

Table 2—Mean brown planthopper population on rice variety ADT-38 in different insecticide treatments of the field experiment during *rabi* 2009-2010

Treatment number	Insecticidal application at DAT*	Mean planthopper population/hill** at DAT					Yield kg/ha
		64	74	84	89	94	
T_1	60	0^{b}	1.5^{d}	6.6^{b}	3.9^{b}	1.1^{bc}	2879.1^{b}
		(1.0)	(1.5)	(2.7)	(2.2)	(1.4)	
T_2	70	1.3^{a}	1.6^{d}	5.5^{b}	3.7^{bc}	1.0^{bc}	2733.3^{b}
		(1.51)	(1.6)	(2.5)	(2.1)	(1.4)	
T_3	80	1.2^{a}	6.2^{b}	2.7^{c}	2.6^{cd}	1.4^{b}	2624.0^{bc}
		(1.48)	(2.6)	(1.9)	(1.9)	(1.5)	
T_4	90	1.2^{a}	8.6^{a}	13.5^{a}	8.4^{a}	0^{d}	2296.0^{cd}
		(1.49)	(3.0)	(3.8)	(3.0)	(1.0)	
T_5	60 & 80	0^{b}	3.9^{c}	2.2^{c}	2.3^{d}	0.9^{bc}	3280.0^{a}
		(1.0)	(2.2)	(1.8)	(1.8)	(1.3)	
T_6	70 & 90	1.1^{a}	1.7^{d}	7.1^{b}	3.4^{bcd}	0.6^{cd}	2806.2^{b}
		(1.45)	(1.6)	(2.8)	(2.0)	(1.2)	
T_7	Untreated control	1.1^{a}	7.7^{a}	14.1^{a}	8.6^{a}	2.7^{a}	2223.1^{d}
		(1.46)	(2.9)	(3.8)	(3.1)	(1.9)	
S.Em±		(0.04)	(0.12)	(0.14)	(0.12)	(0.12)	165.5
C.D. (P<0.05)		(0.09)	(0.28)	(0.31)	(0.26)	(0.26)	358.5

*DAT= Days after transplanting; ( ) = Values in parentheses are square root transformed values; ** Mean planthopper populations with same superscript do not differ significantly

Yield (dry wt basis) and TDM/plot were converted to yield and TDM on hectare basis. Loss in yield and TDM loss was also calculated for different treatments as

Yield or TDM loss (%) = (A - B)/A x 100

where, A refers to yield/TDM of completely protected crop and B to yield/TDM of infested crop.

InfoCrop model was calibrated for crop phenology, TDM, yield and BPH damage mechanism. Crop phenology was calibrated by matching simulated flowering time and physiological maturity time with their corresponding observed values in field experiments by adjusting required thermal time for flowering (TTVG) and physiological maturity (TTGF), respectively. Model was calibrated for rice growth and yield with TDM and yield data of completely protected crop; T_9 in experiment 1 (Table 1) and T_5 in experiment 2 (Table 2). Crop in these treatments was kept free of BPHs by regular pesticide application at 20-day interval. Values obtained of various model parameters and coefficients during calibration process for Pusa Basmati 1 and ADT-38, respectively, were found as follows: TTGERM, 50, 50 DM; TTGF, 480, 450 DD; TTVG, 1400, 1300 DD; RGRPOT, 0.009, 0.009 growth rate/day; SLAVAR, 0.0025, 0.0025 m^2/kg; RUEMAX, 2.5, 2.6 kg/ MJ/day; KDFMAX, 0.6, 0.6; GNOCF, 50000, 50000 grains/kg; GFRVAR, 0.70, 0.70 mg/ day; POTGWT, 22, 22 mg; SKINWT, 2, 2 mg; SUKNRT, 4.02E-8, 4.02E-8 kg/ mg insect/day; and SUCKRT, 2.01E-6, 2.01E-6 kg/mg insect/ day. Model was also calibrated for rice BPH damage mechanism with yield and BPH population data of untreated control; T_{10} in experiment 1 and T_7 in experiment 2. Values were calibrated as: sap sucking rate (SUCKRT) of BPHs, 2.01E-6 kg/mg insect weight/ day; N sucking rate (SUKNRT) of BPHs, 4.02E-8 kg/ mg insect weight/day; and weight of an insect (SKINWT), 2.0 mg. Yield, TDM and BPH population data of rest of the treatments (T_1-T_8 at New Delhi, and T_1-T_4 & T_6 at Aduthurai) were used for validation of rice BPH damage mechanism.

Simulation of Economic Injury Levels (EILs)

Validated InfoCrop model was run from no infestation to pest incidence up to 20 hoppers/hill at 2-insect intervals with New Delhi weather of 2009 and Aduthurai weather of 2009-10 at each of 30, 40, 50, 60, 70 and 80 DAT. EIL was calculated by comparing monetary yield loss due to BPH injury with control expenditure because EIL signifies minimum population density that causes economic damage, which is the amount of damage where monetary yield loss is at least equal to pest control expenditure. EIL was calculated with respect to expenditure incurred on optimum number of pesticide applications required for BPH population suppression and market price of produce. EILs were determined with three market prices of Pusa Basmati 1 (15, 20 and 25 Rs/kg) and ADT-38 (10, 15 and 20 Rs/kg) that prevailed at Delhi market and Tamil Nadu market, respectively and with control expenditure involved in two sprays each of monocrotophos 36 WSC @ 500 g a.i./ha and buprofezin 25 SC @ 100 g a.i/ha. An average price of Rs 20 was used to calculate EILs on Pusa Basmati 1 and ADT-38, respectively.

Results and Discussion

Model Calibration

BPH population was low in the beginning of crop season but increased significantly during 60 to 80 DAT. Application of monocrotophos 36 WSC @ 500 g a.i./ha in experiment 1 (Table 1) and that of buprofezin 25 SC @ 100 g a.i/ha in experiment 2 (Table 2) at different frequency and intervals created differential population levels. In both experiments, untreated control had highest BPH population that resulted in lowest yield among various treatments. On the other hand, lowest BPH population in experiments was observed in completely protected crop, T_9 and T_5 in experiment 1 and 2 that received three and two sprays of insecticides, respectively at regular intervals and had highest yield. Therefore, variation in population levels in different treatments led to variability in crop yield.

Among two insecticidal applications in experiment 1, yields with two sprays at 60 & 80 DAT (T_6) and 70 & 90 DAT (T_7) were significantly higher than that with two sprays at 80 & 100 DAT (T_8). Between treatments T_6 and T_7, yield in former did not differ significantly from that with three insecticidal applications (T_9) while latter had significantly lower yield than T_9. Thus two sprays of monocrotophos at 60 & 80 DAT (T_6) proved to be optimum against BPH on Pusa Basmati 1 at New Delhi.

In experiment 2, two insecticidal applications at 60 & 80 DAT (T_5) recorded significantly higher yield than two sprays at 70 & 90 DAT (T_6). Besides, yield in T_5 was also significantly higher than single spray treatments (T_1, T_2 and T_3), while T_6 had yield at par with these treatments. Therefore, two sprays of buprofezin at 60 &

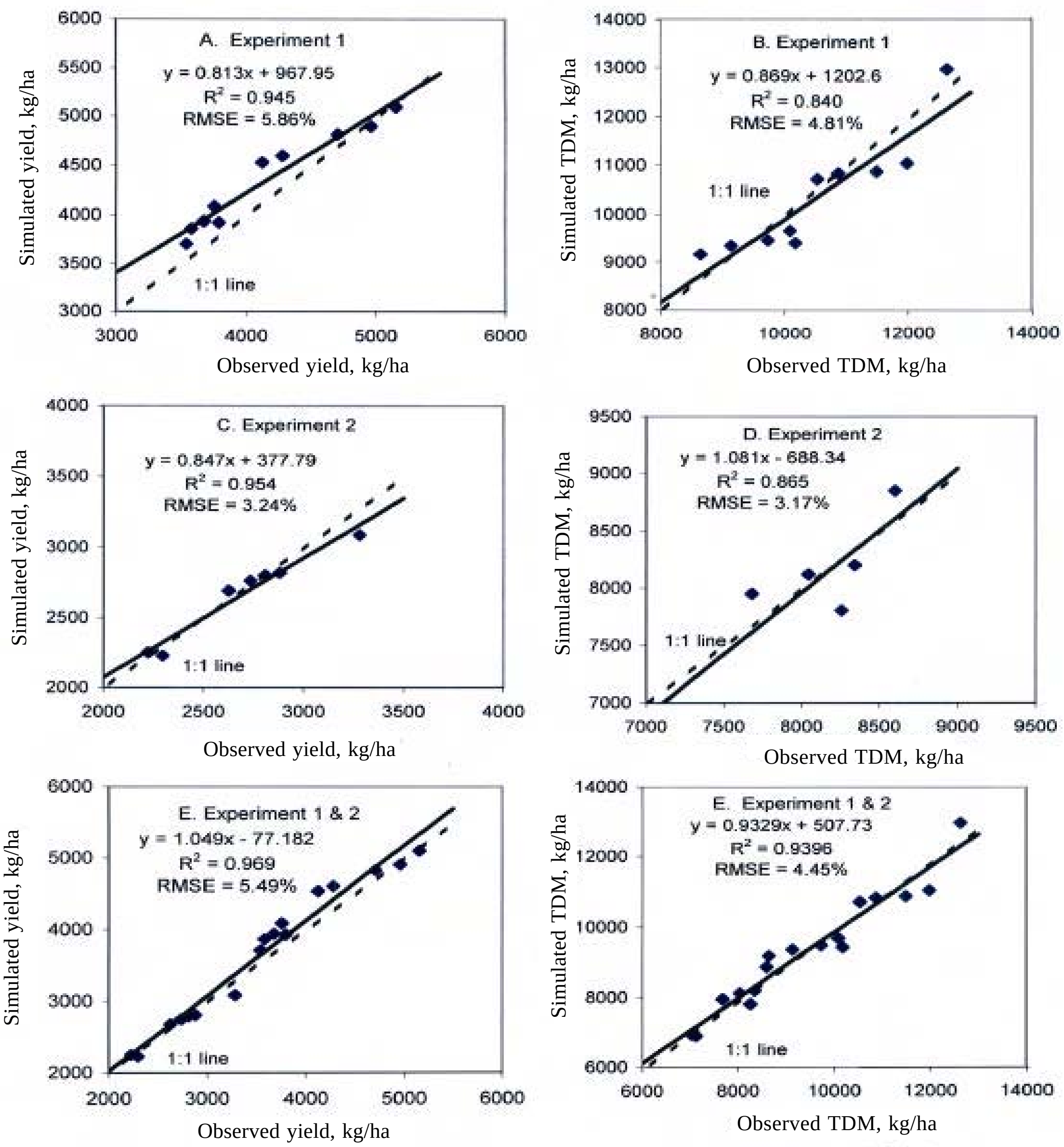

Fig. 1—Relation between observed and simulated yield and total dry matter (TDM) of rice cv Pusa Basmati 1 in New Delhi (Experiment 1) and ADT-38 in Aduthurai (Experiment 2)

80 DAT (T_5) were considered to be optimum for protecting ADT-38 crop against BPH. Two sprays with either of the insecticides were found to be optimum against BPHs earlier too[18]. Thus proper timing of pesticide application can greatly help in reducing frequency of pesticide use. Appropriate timing of pesticide application can only be known through regular pest surveillance, which would be useful only if executed through development of decision support tools like EILs.

InfoCrop was calibrated for crop phenology, growth and yield as well as for pest damage at both locations. In experiment 1, simulated and observed days to 50% flowering were 67 and 66, respectively while simulated days to physiological maturity were 103 compared to 108 observed days. Simulated weight of storage organ (WSO: yield on dry wt basis) and TDM in completely protected crop (T_9), used for model calibration for uninfested crop, showed only 1.2 and 2.7% variation from their observed value, respectively. Simulated WSO in untreated control (T_{10}), used for model calibration for BPH damage, differed by 4.7% from observed WSO while simulated TDM varied by 6.0% over observed TDM.

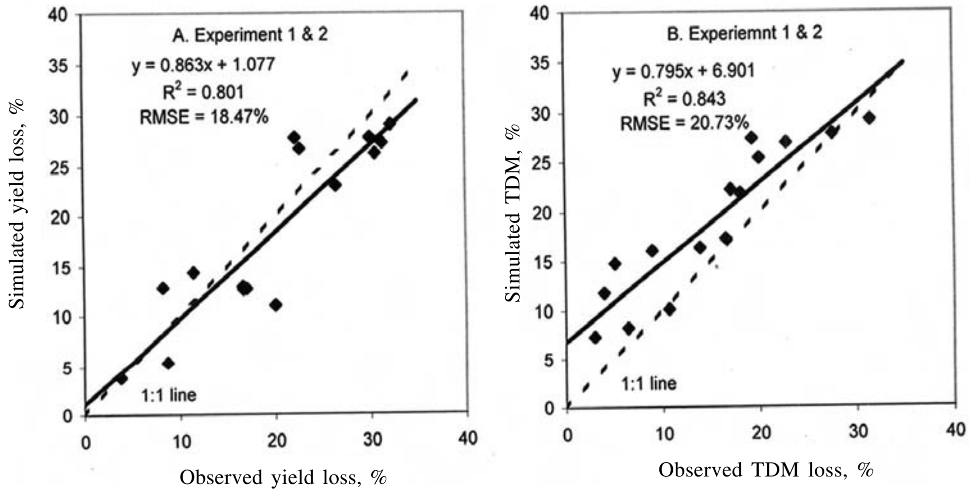

Fig. 2—Relation between observed and simulated yield loss and total dry matter (TDM) loss due to brown planthopper injury in Pusa Basmati 1 in New Delhi (Experiment 1) and ADT-38 in Aduthurai (Experiment 2)

In experiment 2, simulated and observed days to 50% flowering were 76 and 74, respectively while simulated days to physiological maturity were 108 compared to 112 observed days. Simulated WSO and TDM in completely protected crop (T_5), used for model calibration for uninfested crop, differed only by 6.0 and 2.9%, respectively from their observed values. Similarly, simulated WSO in untreated control (T_7), used for model calibration for BPH damage, differed only by 1.2% while simulated TDM departed by 1.6% from observed TDM. Model was, therefore, assumed to be calibrated satisfactorily for phenology, growth and yield as well as BPH damage mechanism on Pusa Basmati 1 and ADT-38 rice.

Model Validation

In experiment 1, simulated and observed yield (Fig. 1A: R^2 = 0.945; RMSE = 5.86%) as well as simulated and observed TDM (Fig. 1B: R^2 = 0.840; RMSE = 4.81%) of treatments (T_1-T_8), used for model validation, were close to each other. In experiment 2, simulated and observed yield (Fig. 1C: R^2 = 0.954; RMSE = 3.24%), and simulated and observed TDM (Fig. 1D: R^2 = 0.865; RMSE = 3.17%) in treatments, T_1-T_4 and T_6, used for BPH damage validation, were similar, differing only by 0.7-6.0 % and 1.75-7.78%, respectively. Similarly, pooled analysis of yield (Fig. 1E: R^2 = 0.969; RMSE = 5.49%) as well as TDM (Fig. 1F: R^2 = 0.940; RMSE = 4.45%) reflected precision between their observed and simulated values in various treatments. Simulated and observed losses of yield (Fig. 2A: R^2 = 0.801; RMSE = 18.47%) and TDM (Fig. 2B: R^2 = 0.840; RMSE = 20.73%) were also identical. InfoCrop-rice was thus deemed to be validated satisfactorily for BPH damage both under New Delhi and Aduthurai environments. InfoCrop-rice, simulated effect of BPH on yield and biomass of Pusa Basmati 1 and ADT-38 appropriately under New Delhi and Aduthurai environments, respectively. The model could, therefore, be used to account for BPH effect on rice growth and yield under varying environments.

Determination of Economic Injury Levels (EILs)

Expenditure on two sprays of monocrotophos 36 WSC @ 500g a.i./ha/spray was estimated as Rs 1694 based on: i) insecticide cost (Rs 834) for 2.78 l @ Rs 300/l; ii) labour charges (Rs 800) for two mandays/spray/ha @200/ manday; and iii) sprayer hire charges (Rs 60) @15/ sprayer/day. Likewise, expenditure on two sprays of buprofezin 25 SC @ 100 g a.i./ha/spray was determined to be Rs 1900 depending on: i) insecticide cost (Rs 1040) for 0.8 l @ Rs 1300/l; ii) labour charges (Rs 800) for two man days/spray/ha @200/manday; and iii) sprayer hire charges (Rs 60) @15/sprayer/day.

EIL of BPH on Pusa Basmati 1 at New Delhi ranged between 2-18 BPHs/hill while that on ADT-38 at Aduthurai varied from 3-15 BPHs/hill. EIL changed with crop age (Fig. 3A, 3B, 3C, 3D), market produce of crop produce (Fig. 3A, 3B) and control expenditure (Fig. 3C, 3D). These were lower during initial crop growth stages

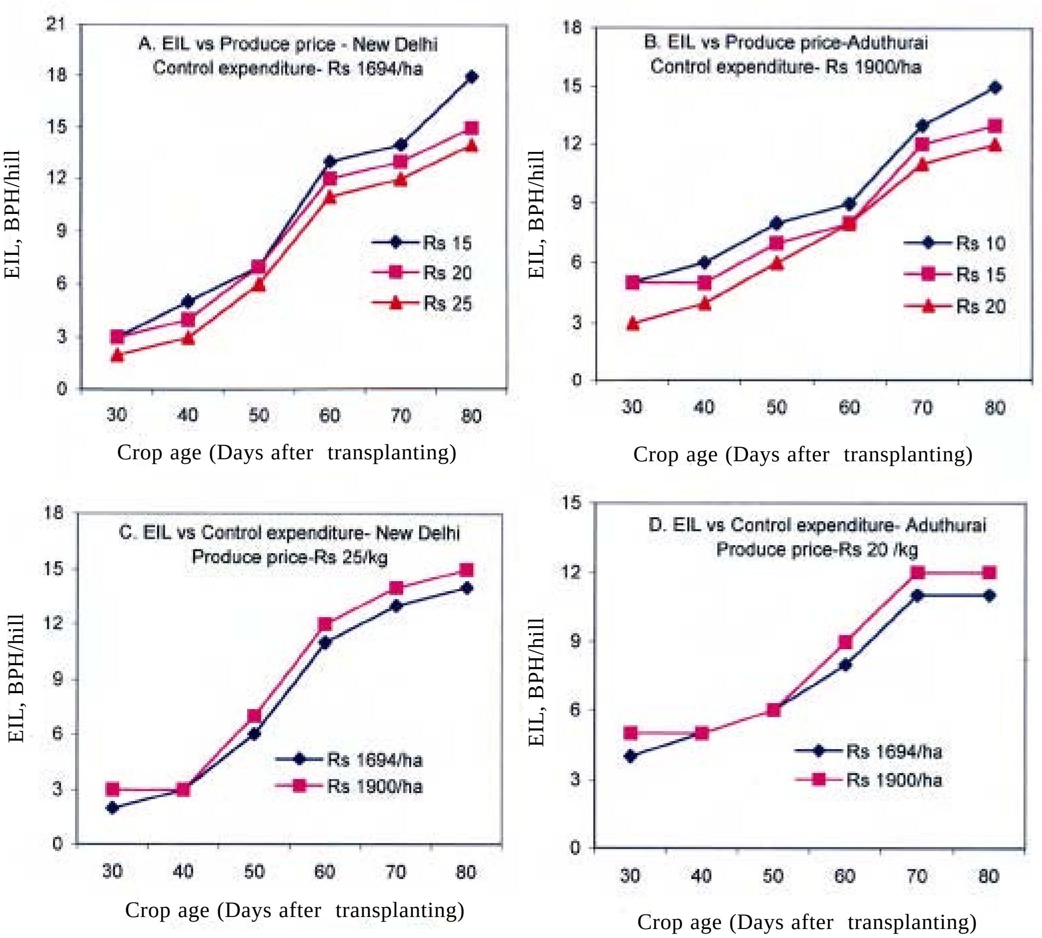

Fig. 3—Economic injury levels of brown planthopper simulated with different produce prices and control expenditures at various crop stages

and continuously increased until crop maturity. EILs were highest during 60 to 80 DAT with two sprays of buprofezin as well as monocrotophos while these were lowest during 30 to 40 DAT, showing that crop was highly susceptible at these stages and fewer insects could inflict higher economic damage. EIL tended to be positively related to control expenditure because greater yield loss was required to justify higher cost of control measures and vice-versa. On the other hand, EIL had negative relation with market value of produce as even fewer BPHs could cause economic loss at higher market price of produce. EILs of BPH have been found to vary from 5 to 20 insects at various crop growth stages across India[2]. Simulated EILs were thus observed to be comparable to empirical EILs established earlier. Simulated EILs at New Delhi and Aduthurai were more or less comparable suggesting similar trend of crop-pest interactions at both locations. EIL is a highly dynamic entity that may differ among geographic locations, plant growth stages, control expenditures and market prices[19]. Empirical EILs, being location-specific, need to be developed for each location, however, crop simulation models can be readily adapted to determine location-specific EILs[11,12]. Simulation models have been used for simulating EILs of *Cnaphalocrosis medinalis*[20], *Scirpophaga incertulas*[21] and plant hoppers[14] on rice.

This study indicated that crop response to BPH pressure varied with crop growth stage and use of blanket EIL may not thus be appropriate. In absence of location-specific EILs, use of blanket thresholds is not technically sound[6].

Conclusions

Infocrop-rice model simulated BPH damage at New Delhi and Aduthurai appropriately. EILs of BPH, simulated for various combinations of produce market price and control expenditure, were comparable to earlier established EILs across the country. It could have not been otherwise so easy to manipulate BPH population in field experiments due to limitation of number of treatments and other constraints. Therefore, InfoCrop proved to be a valuable tool in exploring effect of a large number of BPH population scenarios on crop growth and yield, thereby enhancing efficiency of field research.

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