

tillers declined afterward because of tiller death and remained constant after flowering. The crop cycle was shorter in PS6 and PS7 than in PS2. The maximum leaf dry weight and the maximum number of tillers were much smaller in PS7 than in PS2 and PS6. This is probably because of the crop establishment method in PS7 (using old transplanted seedlings), which favored the growth of a small number of big tillers. The maximum dry weight of stems was observed in PS2 and was attributed to the longer crop cycle in this PS, which allowed the stem to grow for a long time. The final yield was largest in PS7, followed by PS6 and PS2. The lower fertilization in PS2 than in the two other PSs explains the poorer performance of this PS.

The table gives simulated and observed grain yields for the 15 (PS × injury) combinations addressed in the experiment. Yield loss ranged from 0.3% to 24%. An acceptance interval of ± 10% of the observed grain yield was defined to assess simulated yield outputs. The model simulated yields within this acceptance interval in all cases. It can thus be assumed that the model accounted well for the effects of different injuries manipulated in this experiment.

Results show that the simulation model adequately describes PSs and re-

**Simulated and observed grain yield (g m<sup>-2</sup>) in the experiment done at CNRRI in 1998.**

Treatment <sup>a</sup>	PS2 <sup>b</sup>		PS6 <sup>b</sup>		PS7 <sup>b</sup>	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
CTRL	422	418	579	568	787	787
WH	420	408	-	-	-	-
SHB	393	402	519	517	689	711
WEED	319	331	523	550	669	686
COMBI	361	343	509	493	611	670

<sup>a</sup>CTRL = control, WH = white heads, SHB = sheath blight, WEED = weeds, COMBI = combination of the three injuries.

<sup>b</sup>PS2 = reference production situation, PS6 and PS7 = production situations that prevail in Zhejiang Province.

flects fairly well the damage caused by sheath blight, weeds, and whiteheads, alone or in combination. Previous evaluations of the model yielded similar conclusions under different sets of PSs (Willoquet et al 1998, 1999a,b, 2000). This study shows that the model behaves fairly well under other rice production environments, such as those found in Zhejiang Province.

The simple model structure and the approach used to calibrate and test it can be used by different research teams to address specific (PS × injuries) combinations. The model is flexible enough to address other injuries, such as those caused by brown planthopper, bacterial leaf blight, or defoliators. It can thus be used for scenario analyses that may help in prioritizing research for rice pest management.

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## Analysis of spatial structure and distribution of brown planthopper at a macro-scale level

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Brown planthopper (BPH) is a migrant insect pest and is observed to complete about seven to eight generations in Guangdong Province of China (Bao et al 1996). Its spatial structure and distribution are complex and difficult to predict at a macro-scale level. Early studies tried to

describe distribution using classical statistics, neglecting the spatial location of samples and their interdependence. To capture these spatial relations, we have adapted a geostatistical modeling approach to predict the density distribution of BPH.

In this study, BPH density was considered as a typical regionalized variable, and the semivariogram—a function describing the relationship between distance and sample values—was used as a tool to analyze its spatial structure (Journel 1984). The Kriging interpolation technique,

which estimates spatial values by taking a weighted linear average of available samples (Krige and Magri 1982), was applied to estimate BPH density distribution. Data on BPH density in 82 plots in the province in 1997 were used for analysis. The geographic information system (GIS) software, IDRISI, was employed to assemble and collate data. Analytical procedures were as follows: (1) the region was divided into grid cells ( $2 \times 2$  km) and digitized, (2) the semivariogram was developed, (3) spatial structure and anisotropy (directional semivariogram) were analyzed, (4) Kriging interpolation was used to estimate BPH density for each unknown grid cell, and (5) a scenario of BPH spatial structure and distribution was generated with GIS.

Results indicated that the BPH population aggregated at a macro-scale level and clump diameter ranged from 70 to 400 km in immigration generations and from 198 to 205 km in other generations. The spatial structure of BPH in the early rice-growing season was more stable than

in the late rice season, and a significant anisotropy appeared from east to west.

BPH density and its distribution areas increased with generation. In the first generation of the early rice-growing season, the density in most areas was less than 1 BPH hill<sup>-1</sup>, but in the second generation, the population increased to 5 BPH hill<sup>-1</sup> and was distributed over 3 million ha in the Leizhou Peninsula and Pearl River Delta. In the third generation, areas with a density of 5–10 BPH hill<sup>-1</sup> expanded to 11 million ha, mainly located in the central and northern parts of the province (see figure, a-c).

A similar situation occurred in the late rice-growing season, when BPH immigrated back to the province. Densities of 5–8 BPH hill<sup>-1</sup> were observed in the Pearl Delta over 180,000 ha. As the population developed into the sixth generation, however, areas with more than 20 BPH hill<sup>-1</sup> reached 3 million ha, covering the southwest part of the province (see figure, d-e).

The technique of regionalized variable, semivariogram, and Kriging interpolation performed well in predicting the spatial distribution of BPH density, as shown by comparisons with data collected in fields different from those sampled to obtain input data for the GIS analysis. The technique appeared to be useful for macro-scale-level forecasting of insect density. A spatio-temporal model may be one type of modification of this technique to further improve the prediction level.

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