धान के तना बेधक के कारण उपज हानि का प्रतिरूपण और कृषि–पारिस्थितिक आंचलीकरण

MODELLING YIELD LOSS DUE TO RICE STEM BORER AND AGRO-ECOLOGICAL ZONATION

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MODELLING YIELD LOSS DUE TO RICE STEM BORER AND AGRO-ECOLOGICAL ZONATION

By

REJI G.

A Thesis
Submitted to the Faculty of Post-Graduate School,
Indian Agricultural Research Institute, New Delhi
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DOCTOR OF PHILOSOPHY

IN

ENTOMOLOGY

2007

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This is to certify that the thesis entitled "Modelling yield loss due to rice stem borer and agro-ecological zonation" submitted to the Post-Graduate School, Indian Agricultural Research Institute, New Delhi, in partial fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** in **ENTOMOLOGY**, embodies the results of *bona-fide* research work carried out by **REJI G. (Roll No. 8990),** under my guidance and supervision. No part of the thesis has been submitted for any other degree or diploma.

He has duly acknowledged all the assistance and help received during the course of investigation.

New Delhi
February 2, 2007

(SUBHASH CHANDER)
Chairman,
Advisory Committee

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(REJI G.)

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1. INTRODUCTION

Rice is the most important staple food crop for more than two thirds of the population in India. With area of 44.6 million hectares and production of about 90 metric tons, India ranks second only to China (Mishra, 2005). However, the productivity of rice under irrigated ecosystems in India is 4.2 tons/ha as compared to 6.1 and 8.3 tons/ha in China and Egypt, respectively (Siddiq, 2000).Intensification of agriculture has aggravated the problems of biotic constraints like insects, diseases and weeds. The crop is mostly grown under warm and humid climate, which is also conducive to many pests and diseases (Mathur *et al.*, 1999). It is estimated that insect pests cause on an average up to 50 per cent loss in rice production (Balasubramanian *et al.,* 1973).

Over 800 insect species have been identified damaging either standing or stored rice (Grist and Lever, 1969). Pradhan (1971) described pests as a major bottleneck to a break through in rice production similar to that witnessed in wheat, following the introduction of high yielding varieties. By mid seventies, a total of 221 species of insects feeding on rice were reported from India (Arora and Dhaliwal, 1996). These pests inflict serious damage from seedling stage to maturity and a few act as vector of virus disease also. The insect pest complex of rice crop has undergone a tremendous change during the last three decades. Species like leaf folder, brown plant hopper, white backed plant hopper, green leaf hopper, whorl maggot, thrips, case worm, and army worm that were minor pests earlier have started appearing in epidemic form (Dale, 1994).

Among the insect pests of rice, stem borers are the most destructive ones. The yellow stem borer, *Scirpophaga incertulas* is the dominant stem borer species distributed throughout the rice growing tracts in the country (Nair, 1995). It is also an important pest of deep water rice in India, Bangladesh, Thailand and Myanmar (Rockwood *et al.*, 1984). Apart from this, striped borer, *Chilo suppressalis;* dark headed borer, *Chilo polychrysus;* pink borer, *Sesamia inferens* and white borer, *Scirpophaga innotata* damage rice crop in the country. The yellow stem borer is the most predominant stem borer species in Tamil Nadu followed by the pink stem borer

and dark-headed borer (Ragini *et al.*, 2001). The larvae of these moths bore through the rice stem, feeding on the internal tissues. The symptoms of attack are manifested in the form of 'deadheart' during vegetative stages and 'white earhead' during the reproductive stage. The yellow stem borer causes damage to rice crop from early tillering through maximum tillering to flowering. It has been observed to inflict 18-25% damage to rice crop in Punjab (Inaytullah *et al.*, 1989) and about 40% damage in Orissa (Senapati *et al.*, 1990). Rice variety Pusa Basmati-1 is highly susceptible to the yellow stem borer with about 25-30% incidence having been recorded in Haryana.

India suffers a monetary loss of Rs. 30,000 crores annually on account of pest damage to agricultural commodities (Sehgal, 2001). Crop yield can be enhanced substantially by curtailing pest loss to certain extent. There is a need for precise quantification of yield losses in different regions in relation to the spatial and temporal incidence of yield reducing factors. Data on such yield losses are necessary when agricultural systems are undergoing rapid and important transformations, as in India today (Savary *et al.*, 1997). Information on yield losses would be useful in research prioritization and for formulation of effective pest management strategies.

Empirical approaches like regression analysis have been used for establishing yield-infestation relationships between pest incidence and crop damage. These relations can be made use for the assessment of crop losses. In this approach yield is regressed upon pest incidence at various crop growth stages. Pest is considered to inflict economic loss only when regression coefficient of yield-infestation relation is significant. It is a two-step approach in which pest incidence is related to crop yield without considering the pest effects on plant physiological processes.

Several pests may infest the crop simultaneously or in sequence during the crop season. Multiple pests can be handled through crop loss profile methodology using multiple regressions (Pinstrup *et al.*, 1976; Chiarappa, 1980). This approach quantifies the contribution of each constraint to the total yield loss. With this approach several pest constraints, environmental variables and cropping practices can be considered simultaneously. This may also be considered an endeavour to include the concept of production situation. The production situation refers to crop management and environment variables that result in to a given yield of the system

(Penning de Vries, 1982). Statistical techniques such as principal components, canonical correlation and multiple regression analyses have been applied to analyze complex, multivariate data generated by surveys (Stynes, 1980). In fact several statistical methods are available, which can be exploited based on nature of data and objective of study (Madden, 1983). However, such relationships exhibit spatial and temporal variability and hence, cannot be extrapolated without the risk of error. In order to improve the accuracy, these relationships need to be developed for each location individually, which is generally not feasible.

The mechanistic approach of crop loss assessment involves the concept of damage mechanisms. These are plant physiological processes affected by pest injury. The pest damage mechanisms can be coupled with crop growth simulation models. These continuous dynamic models are based on state variable-rate variable approach. They simulate all the physiological processes in the crop plant. Simulation models can account for spatial and temporal changes in weather, soil, genotype, management and pest incidence.

The assessment of crop losses with mechanistic approach is a three-step approach taking in to consideration, the pest incidence, damage mechanism of the pest and the crop yield. The crop-pest model is first run for healthy crop to obtain attainable yield. The model is then run with pest incidence to assess the actual yield. The difference between attainable yield and actual yield is the yield loss due to pest. Models which are properly calibrated and validated can be a useful tool in pest management. They can be used to establish decision support tools like economic injury levels.

Outbreak of crop pests may lead to severe losses to farmers in certain years. If the changes in pest population can be predicted well in time, they can be managed in a better way. The intensity of pest damage varies in different agro-ecological zones due to variability in weather parameters. This necessitates the study of pest biology in relation to weather. Yellow stem borer light trap catches have shown positive relation with maximum temperature, relative humidity, rainfall and wind speed, while these were negatively related to minimum temperature and daily sunshine hours (Padhi and Saha, 2004). The moth catches during the period of maximum activity were correlated with maximum and minimum temperature to the tune of 36°cand and 26.8°c, respectively (Pandya *et al.*, 1989). The maximum temperature of 34°c or above with relative humidity below 70% is a useful predictor of stem

borer mortality (Suwongwan and Catling, 1987). Attempts were made by various workers to develop forewarning models of rice stem borer based on light trap catches and weather factors (Prasad *et al.* 2003; Samui *et al.*, 2004). The data on weather and pest infestation in a particular area over a period of time can be used to develop pest weather modules. These modules describe the range of weather variables favourable for severe infestation by the pest. The severity of pest infestation at a particular location can be predicted using the module by inputting the weather data.

Geographical Information System (GIS) refers to a system of hardware and software for collection, analysis, storage and retrieval of georeferenced data. GIS can be used for agro-ecological zonation of crop pests, which includes carving out areas of equal epidemic potential based on the pest-weather modules. This will help to identify the hotspots of pest infestation and also the probability of outbreaks in different parts of the country. Delineation of pest hotspots would also help in locating sites for pest resistance breeding programmes. The concept of pest zoning is applicable generally for large area pest management. Knowledge of pest incidence in different zones would allow strategic decisions within each zone with respect to selection of crop cultivars. Probable life of resistant cultivars can also be presumed. This would help extension workers in the selection of appropriate management options in different zones (Yuen and Teng, 1990).

Although stem borers are a major impediment to increase in rice productivity in India, not much work has been done to understand the stem borer damage mechanism. A mechanistic approach is needed in the assessment of crop losses due to rice stem borer. The influence of meteorological factors on stem borer incidence and the severity of crop damage have not been elucidated on a countrywide basis. The hotspots of pest infestation are also not well documented.

Keeping in view the above facts, the proposed study was undertaken with the following objectives:

1. Quantification of rice stem borer damage mechanisms
2. Simulation of rice stem borer damage mechanisms
3. Formulation of decision support tools for rice stem borer management
4. Establishment of pest - weather modules for rice stem borer
5. Agro-ecological zonation for rice stem borer

2. REVIEW OF LITERATURE

The literature relevant to the present study has been reviewed under the following heads.

2.1 Simulation models in pest management

2.2 Pest damage mechanisms

2.3 Rice stem borer – species composition and damage

2.4 Modelling yield loss due to rice stem borer

2.5 Economic injury levels for rice stem borer

2.6 Influence of weather on rice stem borer infestation

2.7 Geographical information systems in pest management

2.1 Simulation models in pest management

A model is a schematic representation of a system. In the real world the appearance of biological systems changes and these are called continuous dynamic systems and their models are often known as dynamic. Analysis of dynamic systems is based on the assumption that the state of the system at any particular time can be expressed quantitatively and that changes in the system can be described in mathematical terms (de Wit and Goudriaan, 1974). This leads to formulation of state-determined models in which state variables, driving variables, rate variables and auxiliary variables are distinguished. State variables quantify the current state of the system, such as amount of biomass, the leaf surface area, the N content of a part of the system etc. Driving variables such as meteorological variables characterize the influence of the environment. The formulation of the relations between all the variables is called the structure of a model. Simulation is the scientific study of building and utilizing explanatory models. Models are called explanatory when their behaviour is based on the underlying processes of the system.

In eco-physiological crop models i.e. crop simulation models, two types can be distinguished based on the level of detail in which they simulate dry matter accumulation. The first type involves models that simulate daily dry matter

production based on leaf photosynthesis and respiration using detailed routines for light absorption at different heights in the canopy and for different times during the day e.g. SUCROS (Simple Universal Crop Growth Simulator) models. These models are generic models that have been parameterized for many crops like wheat, potato and maize (Spitters *et al.*, 1989); MACROS models (Penning de Vries *et al.*, 1989); the ORYZA models (rice) that were derived from SUCROS and MACROS by Kropff *et al.* (1994); and the GRO models for crops like soybean, peanut and other leguminous crops (Jones *et al.*, 1998). In these models, the total daily rate of canopy CO_2 assimilation is calculated from the daily incoming radiation, temperature and leaf area index. Photosynthesis profile is in the canopy is obtained on the basis of light profile in the canopy and the photosynthesis characteristics of single leaves. Integration over the leaf area index of the canopy and over the day gives the daily CO_2 assimilation rate. The net daily growth rate in kilograms of dry matter per hectare per day is obtained after subtracting the respiration requirements.

The second type involves models that use a radiation use efficiency (grams of dry matter per joule of radiation absorbed) approach to estimate dry matter accumulation directly from the daily absorbed radiation by the canopy, e.g. the CERES (Crop Estimation through Resources and Environment synthesis) models. In CERES-rice, the growth sub model simulates plant mass accumulation, expansion growth, assimilate partitioning ands senescence. Potential mass accumulation is dependent on absorption of photosynthetically active radiation, the radiation use efficiency (RUE), leaf area index (LAI), and light extinction coefficient as affected by row spacing (Singh *et al.*, 1991).

Economic injury levels for bean leaf beetle (BLB) infesting soybean have been simulated using coupled models (Nordh *et al.*, 1988). The model was run from no pest to populations that result in no crop yield. The simulated crop-yield/insect density relationship was translated into an economic relationship by attaching a price to the crop yield. Net return was determined by subtracting cost of production from gross return. The EIL was then established by first subtracting the cost of control from the net return of simulation run without pest stress and secondly by finding pest density that produced a similar return. Because EIL is that minimum population density at which value of crop protected from pest damage is at least equal to cost of control. Similarly simplified pest models or simplified decision rules from crop-pest

models with economic values assigned to their outputs have been used for managing sugarbeet, *Cercospora* leafspot (Shane *et al.*, 1985), sweet corn common rust (Teng, 1987), wheat diseases (Zadoks, 1984, 1989), rice blast (Surin *et al.*, 1991). Detailed simulation models have been used to design strategies for insecticide use (Heong, 1990) and to predict disease epidemics (Teng *et al.*, 1978).

Models can also be used for analysing the risk associated with the introduction of exotic pests into ecosystems in which they did not exist earlier. Yang *et al.* (1991) showed the possibility of the approach with a soybean rust model, SOYRUST, which when run with continental USA weather data predicted potential areas for epidemics. When model disease estimates were further linked to soybean crop model, the potential losses attributable to rust epidemics were determined. Risk analysis for foreign pests requires the availability of as much information as possible on the organism and its interaction with the environment. Obviously the foreign pests that are under quarantine cannot be tested in the field directly to obtain direct measures of their capacity to cause damage under given environmental conditions. Therefore models are very useful to evaluate situations where actual field work on the pest is not possible because of concern for potential hazards, and simulation appears to be the ideal tool for exploring the options (Teng, 1991).

Graf *et al.* (1992) developed a simulation model for the population dynamics of rice leaf-folders and their interactions with rice crop. The model represented a synthesis of experimental results on leaf folder biology and behaviour. The host-plant on the one hand was assumed to affect the leaf folder survival, migration and growth rates, while leaf folders on the other hand influenced plant growth and development by feeding and folding of leaves. In a preliminary test with independent field and laboratory data, the model predicted the leaf-folder population dynamics and the resulting leaf area losses in rice in a satisfactory manner. The model suggested that economic injury levels were generally underestimated. It stressed the influence of adult migration and natural enemies on leaf folder population dynamics.

Jingyuan (1997) investigated the life cycle parameters of cotton aphid, *Aphis gossypii* and *Coccinella septumpunctata* as influenced by temperature in China and developed a simulation model of the temporal dynamics of the predator-prey system in cotton monoculture. The model was tested and evaluated at three levels of

complexity: laboratory, field cage and open field. At each level, processes were added to the model based on discrepancies between 'original model' behaviour and observations and additional experimentation. Processes included in the model at the laboratory level were temperature dependent development, survival and reproduction of both insects and prey density, prey size-group and temperature dependant predation.

Safranyik *et al.* (1999) developed an interactive simulation model of mountain pine beetle, *Dendroctonus penderosae* population dynamics. The model was composed of four main parts- a forest stand submodel, beetle management sub-model, and an input-output interface. The interface allows for interactive manipulation of tree, site and insect variables in order to assess effects on the course of an infestation evaluated by graphical or tabular output of results. In simulated runs, the model generally gave qualitatively accurate descriptions of the course of infestation in terms of the relative effects of tree and site factors and management.

Butturini *et al.* (2000) described a simulation model of the phenology of plum fruit moth, *Cydia funebrana*. To stimulate the stochastic process, a time-distributed delay model was used. The model was validated in northern Italy and there was good correlation between the oviposition activity forecast by the model with that actually observed in the orchards.

Morgan (2000) developed a simulation model to investigate the inter-relationship of factors influencing the population dynamics of bird cherry oat aphid *Rhopalosiphum padi* in barley during autumn and winter. The model-incorporated algorithms describing alate immigration, development and survival of adults and nymphs, fecundity and morph determination in newly born nymphs. It was observed that increasing daily temperature by only 1°C, more than doubled the peak aphid abundance. The model identified our understanding of the mechanisms of aphid mortality as a limiting factor in the accurate prediction of *R. padi* outbreaks in the field.

Otto and Homes (2000) devised a simulation model for the population dynamics of the onion fly, *Delia antiqua*. The model was based on an extended Leslie model, which used daily mean air and soil temperatures and calculated the

population matrix for developmental stages of *D. antiqua*. The simulation could be used to optimize the timing of control measures against a specific life stage of *D. antiqua*.

Hao *et al.* (2000) formulated a simulation model on the developmental and survival rate of brown plant hopper (*Nilaparvata lugens*) nymphs in different growth stages of rice. The model was based on the data from the experimental population researches.

Benigno *et al.* (1987) simulated the population dynamics of the leaf folder, based on its biology. Monthly rates of egg predation and parasitism as well as larval parasitism were included in the simulation. Daily leaf consumption rates of healthy and parasitised larvae were also considered to simulate leaf damage throughout the crop season. Yield loss was estimated based on per cent leaf damage at 65 and 75 DAT.

Fabeller *et al.* (1994) simulated rice leaf folder feeding effects on yield using MACROS model. The leaf area damaged by larvae was higher on plants at 40 days after sowing (DAS) than on plants at 60 and 80 DAS. Leaf consumption in terms of actual damaged area was incorporated in to the model. Simulation run were made for each larval density and crop age. The model predicted 3.12 and 30% leaf area reduction on plants at 80, 60 and 90 DAS. Watanabe (1999) observed the feeding effects of rice leaf folder on flag leaf gas exchange of rice plant at flowering. No difference was observed in the reduction of net photosynthesis and stomatal conduction among the cultivars.

He and Wang (1999), developed the model for simulating the dynamics of *Cnaphalocrocis medinalis* and its predators including spiders, carabids, stapylinidae and coocinellidae using data obtained from both laboratory and field studies in Sihui, China. The results of the simulation agreed well with real data collected in rice fields.

Willocquet (1999) tested the yield loss simulation model for rice pests under different production systems of South Asia and South East. The model simulated attainable growth and yield adequately in contrasting production systems

2.2 Pest damage mechanisms

Crop growth can be simulated at three levels of production i.e. potential production, attainable production and actual production. Potential production is determined by plant genotype and climatologically factors and there are no constrains of nutrients, water and pests. Plant genotype and climatologically factors are called yield-determining factors. Potential production gets reduced to attainable production level due to limitation of nutrients and water. No pest constraint is considered at this production level. Nutrients and irrigation are called yield-limiting factors. When in addition to nutrient and water constraints, there is pest (insect, disease, weed, other harmful organism) attack also then yield gets reduced from attainable level to actual yield level. The pests are known as yield reducing factors. Inclusion of different factors in model depends upon the level of production, we want to simulate.

The plant physiological processes affected by pests are called damage mechanisms. Different categories of damage mechanisms can be distinguished (Rabbinge *et al.*, 1994) like competition for resources, plant killing, reduction of assimilation rate, tissue necrosis and interception of light, tissue consumption, assimilate consumption, hampering of water uptake etc. Accordingly the pests are broadly categorized as resource stealers, stand reducers that remove plants or their parts, assimilation rate reducers that effect photosynthetic reactions, assimilate sappers which suck carbohydrates and tissue consumers that effect plant foliage. One pest can affect the crop through more than one damage mechanisms.

Germination reducers damage seeds in the soil before germination. Pests like mole cricket and seed maggots are included in this category.

Stand reducers are insects or diseases that kill plants in the canopy, e.g. stem borer (Rubia and Penning de Vries, 1990), cutworms, termites, damping off and wilts etc. The severity of loss due to these pests depends upon number and distribution of lost plants, compensation ability of remaining plants and development stage of the crop. Rice and wheat can compensate such effects during the tillering stage of the crop whereas crops like beets or maize compensate less effectively. Other crops like beets or maize compensate for open spots in the canopy less effectively. This damage mechanism is simulated by reducing rates of leaf area,

leaf weight, stem weight, stem area, grain number and storage organ weight of the crop.

Assimilation rate reducers affect the photosynthetic capacity of green tissue. They may affect the photosynthesis rate at light saturation or the light use efficiency. Photosynthesis rate may be affected by reducing number of chloroplasts per unit leaf area, altering the chloroplast ultrastructure and components of the electron transport chain or causing malfunctioning of stomatal guard cells. Diseases such as powdery mildew, blight, rust and virus diseases belong to this category. Some insects may also act as assimilation rate reducers as they accelerate leaf senescence. The effect of assimilation rate reducers is accounted for by reducing radiation use efficiency (RUE) of the crop.

Assimilate sappers are sucking pests like aphids, plant hoppers, whiteflies, mites, thrips and bugs etc. which suck assimilates from plant and as a result less carbohydrates remain available for plant growth. Their effect on plants is simulated by reducing the rate of available assimilates for plant growth. These pests may suck sap from all plant parts or any of the plant parts.

Tissue consumers are pests which feed on different plant parts like roots, leaves, stems and storage organs, etc. However most evident among them are leaf consumers that reduce the capacity of the crop to capture light and to photosynthesize. Defoliating beetles, grasshoppers, leaf folders, leaf miners, node borers, grain feeders and foliar diseases like leaf blights, blast, sheath blights etc can be grouped in this category. Their effect can be simulated by reducing rate of leaf area, leaf weight increase, stem area, stem weight or storage organ weight depending upon their nature of damage.

These categories have to be seen as a broad framework. Defining the category for a pest is difficult because some pests affect the crop in several ways. Coupling points for damage mechanisms in crop growth models are located at the level of resource capture (light, water, nutrients), at the process level (photosynthesis, respiration, translocation) or at the state variable level (leaf area, stem weight, leaf weight) (Aggarwal *et al.* 2004).

2.3 Rice stem borer – species composition and damage

The yellow stem borer *Scirpophaga incertulas* is the dominant stem borer species in India. It is a monophagous pest which is distributed throughout the rice growing tracts in the country. Apart from this, striped borer *Chilo suppressalis*, dark headed borer *Chilo polychrysus*, pink borer *Sesamia inferens* and white borer *Scirpophaga innotata* damage rice crop in the country(Nair, 1995).

Scirpophaga incertulas is an important pest of deepwater rice in India, Bangladesh, Thailand, and Burma. The yield losses result from erosion of the plant stand during the flooding period, a reduction in panicle weight and the production of whiteheads. High population densities develop in deepwater varieties mainly because of their long growth period, the suitability of the elongating stem for penetration and feeding by the larvae and the general adaptability of this pest to an aquatic environment (Rockwood *et al.*, 1984).

A survey was conducted in Killikulam, Tamil Nadu, to evaluate the seasonal occurrence and relative abundance of 3 rice stem borer species, viz. the yellow stem borer (YSB), *Scirpophaga incertulas;* the pink stem borer (PSB), *Sesamia inferens;* and the dark-headed borer (DHB), *Chilo polychrysus*. The YSB was the most predominant species while the PSB was the second most predominant whereas DSB was least abundant. Screening of commercial rice cultivars viz. ASD 19, ADT 39 and IR 20 revealed that these cultivars had more infestation by YSB and PSB than by DHB. YSB infestation was predominant from early tillering to maximum tillering stage, and decreased gradually with increasing PSB infestation from the flowering stage. (Ragini *et al*, 2001).

Field studies were conducted in Bhubaneswar, Orissa, to study the composition of different borer species in semi-deep water conditions, population conditions and off-season behaviour. The yellow stem borer produced two broods, with the first peak during the last week of September and second peak during the second week of November which coincided with the dough stage of rice. *S. incertulas* was the dominant species until the first week of October when the stripe stem borer (*Chilo supressalis*) and pink stem borer (*Sesamia inferens*) contributed to the total larval population, which was greatest during the second and third weeks of December respectively (Tripathy *et al*, 1997).

It was found in tests with potted rice plants in the greenhouse in India that most larvae of *Scirpophaga incertulas* (Wlk.) entered the plant through a hole they made themselves, usually through the middle part of the leaf sheath, the time taken averaging 50 minutes. . Most larvae were in the third, fourth and growing sheaths for the first day after entry, and later moved to the first sheath; and most were found in the middle and basal part of the plant. Larvae of *Chilo polychrysus* (Meyr.) entered mainly through the growing shoot, taking 20 minutes. They remained in the upper portion of the leaf sheath until the sixth day after their entry, and later moved to the middle part of the plant. Most were either in the central whorl or midrib of the growing leaf for the first two days, and later moved to any other leaf sheaths. For both species, the presence of only two larvae was sufficient to cause a dead heart at the vegetative stage of the plant (Yadava *et al*, 1975).

Feeding by larvae of *Scirpophaga incertulas* (Wlk.) on young panicles of rice was observed in the laboratory and field at Cuttack in Orissa. The available literature indicated feeding by this species to be only on the vegetative parts of the rice plant, but during these studies some entry holes were observed and the larvae fed on the spikelets from within. In other cases, they fed on the spikelet from outside, consuming the developing caryopsis beneath the leaf-sheath. Usually the top few spikelets of a panicle were healthy and damage was concentrated on those towards the base. Considerable grain loss was caused by this type of feeding (Chaturvedi and Mathur, 1979).

The incidence of stem borers in Punjab, India, was surveyed by examining samples of rice stubble taken at harvest. Overall tiller infestation ranged from 18 to 25%. The species recorded were *Scirpophaga incertulas, S. innotata, Sesamia inferens* and *S. uniformis* (Inayatullah *et al.*, 1989).

Datta *et al.*, (1985) studied infestation by *Scirpophaga incertulas* at different internodes of deep-water rice plants. At harvest, damage was low in the 13th internode but substantially higher in the last 3. Infestation increased with decreasing water level

Scirpophaga incertulas was found to be the most predominant pest species (95.2%) in rice in Punjab, followed by *S. innotata* (3.5%) and *Sesamia inferens* (1.3%). The extent of damage on cv. Basmati 385 varied from 80-97% while on cv. PR111 it ranged from 46-54% (Sharma *et al*, 1996).

In field studies conducted during the *Ahu* and *Sali* seasons of 1990 and 1991 at Titabar, Assam, the incidence of *S. incertulas* varied considerably between seasons and years. In the *Ahu* crop, pest incidence was higher in the vegetative stage with a peak level of damage (9-12.5% dead hearts) whereas in the reproductive stage, damage was very low (0.4-0.6% white ear heads). During *Sali*, pest incidence was low in the early crop stage, but damage later increased to a maximum of 8.72% deadhearts. (Bora *et al*, 1995).

Islam (1990) identified four mechanisms of crop loss due to *S. incertulas,* deadhearts at the vegetative stage, loss of damaged but apparently healthy stems in flood water, white-heads at the reproductive stage, and the effect of late season stem damage on panicles. A great proportion of damaged stems were not visible and damage symptoms were found to be an unreliable indicator for the assessment of borer activities in the field, and did not represent the actual yield loss. Stem damage had a negative influence on the stem density, with reduced panicle density and grain yield. Stem borer damage also seemed to reduce the elongation ability of the rice stem causing them to rot. Late season stem damage reduced the number of filled grains, mean grain weight and panicle weight and increased grain sterility. These effects were related to severity and position of damage. The average estimated yield loss due to *S. incertulas* was about 17%, which took place during the last 11 weeks (from flood peak to crop maturity) of the deepwater rice season (32 weeks).

Catling *et al* (1987) assessed yield losses due to stem borer in deepwater rice in Bangladesh and Thailand using 5 different methods. Because of the long stems and special growing conditions of the crop, the only 3 reliable methods were, pot experiments in metal containers, exposure of potted plants in the field and use of floating exclusion cages in the field. Yields were reduced by 27-34% and 1% yield loss was associated with 2% damaged stems at harvest. Yield loss was mainly due to a loss of bearing stems and lighter panicles borne by compensatory nodal tillers. A tentative damage threshold of 10% damaged stems at the booting-flowering stage and 20% damaged stems at plant maturity was proposed.

Field surveys in rice-fields in China, showed that considerable numbers of 3rd to 5th instar larvae of *Scirpophaga incertulas* (Wlk.) at various stages of development were causing undetected damage to the stalks of rice plants. The affected plants appeared normal at the maturation stage, when compared with those showing

dead-hearts or white heads, but 7.3-21.5% of the seeds were unfilled at harvest, and the 1000-seed weight was lower than normal by 1.4-2.25 g (Chen *et al,* 1982).

Studies on the effects of infestation by larvae of *Scirpophaga incertulas* (Wlk.) on deepwater rice showed that larval passage through the septum did not disrupt conduction or reduce growth above an infested internode and feeding in the internodes seldom penetrated into the parenchyma as far as the inner ring of vascular bundles. No evidence was seen of an interruption of xylem flow to the apex in any infested stems. Larval feeding early in the season causing damage to the internode tissue at the base of the plant prompted the production of aquatic roots that enabled the plant to tolerate the larvae. In a few instances, deadhearts were caused by small 1st or 2nd instar larvae that had bored between the flag-leaf sheath and the stem to enter just above the top node (Taylor, 1984).

Senapati *et al.* (1990) conducted field surveys in Orissa, to determine the incidence of stem borers on deepwater rice cultivars. *Scirpophaga incertulas* was the most abundant species found at the grain ripening stage (66.67-100%) followed by *Sesamia inferens* (0-22.22%) and *Chilo suppressalis* (0-11.11%). Only larvae of *S. incertulas* were recorded from the vegetative stage. More than 40% of rice stems were consistently damaged with a yield loss ratio (stem infestation: yield loss) of 1:1.

Five deep water rice varieties were used to study effect of damaged stem length, particularly yellow stem borer, on the yield per panicle and its contributing characters, the number of grains per panicle and percent chaffiness. Chaffiness was found to be positively correlated and the other two parameters were negatively correlated with length of damage in all test varieties. Position of damage in the stem was found to be more important than total length of damage in causing yield loss (Tripathy *et al*, 1996).

According to Taylor (1996) the role played by *S. incertulas* in the life cycle of deep water rice is controversial. The major question is whether or not larval feeding in the elongated stems is damaging and if so, although no visible symptoms can be observed, this leads to loss of yield. Examination of evidence from entomological and agronomic studies, especially in Bangladesh and Thailand, showed that there was little or no correlation between early or mid-season borer infestation and yield and that stem

density always declined from a pre-flood maximum, irrespective of borer infestation. Late-season infestations, however, could lead to serious crop loss.

Field and greenhouse experiments were conducted to investigate the effect of *S. incertulas* injury on the physiology and yield response of irrigated rice. The compensation mechanisms investigated included increased tillering, increased percentage of productive tillers, and increased grain weight. Assimilates were translocated from stem borer-injured tillers to healthy tillers. The photosynthesis rate of green leaves in stem borer-injured tillers increased. The results indicated that all these mechanisms could be employed by rice plants in response to stem borer injury. The implications for rice pest management include breeding for cultivars tolerant to stem borer injury, nitrogen fertilization to encourage plant compensation and an increase in the economic threshold for stem borers (Rubia *et al.*, 1996).

Damage to rice by the stem-boring larvae of *Chilo suppressalis* (Wlk.) and *Tryporyza incertulas* (Wlk.) was evaluated by initially assessing the infestation level by a suitable sampling technique and subsequently relating larval incidence to yield loss. Relations between yield and percentage incidence were exponential. The data indicated that for accurate assessment of yield loss, dead hearts and white heads should be counted once (Gomez and Bernardo, 1974).

2.4 Modelling yield loss due to rice stem borer

Khosla, (1977) suggested three methods to assess rice crop losses due to pests and diseases: (a) a multiple regression study using actual pest and disease incidence in the crop, (b) calculating an index based on incidence of major pests and diseases and (c) adopting chemical protection measures to control pests and diseases. The formulae were simplified as far as possible and applied to data from the pilot sample survey in the West Godavari district of Andhra Pradesh. The estimated losses by methods (a) and (b) were 19.21 and 20.35%, with standard error of 9.58 and 5.36%, respectively. The percentage of avoidable loss calculated by method (c) was 4.68% with standard error of 1.17%.

Rubia *et al.* (1990) simulated reduction in rice yield caused by stem borer in irrigated IR 64. The computer simulations predicted that up to 20% deadhearts at the vegetative stage would cause no significant decrease in grain yield, while damage at

the grain filling stage (whiteheads) would cause an almost proportionate yield reduction.

Damage caused by *S. incertulas* to rice was simulated in field trials conducted in Nagaland and equations describing yield loss were determined. The relationship between stem damage (%) and loss in yield (%) was 1:1.5. It was concluded that 5% damage to the crop represented the economic threshold level above which control measures became necessary (Bakthavatsalam, 1991).

Chen *et al.* (1992) simulated the effects of damage by the pyralids, *Chilo suppressalis* and *Scirpophaga incertulas*, rice plant density and nitrogen fertilizer treatments on yields.

Zhang *et al.* (1991) used marginal analysis method to develop a system model for determining the optimum time and concentration of insecticide application to control *Scirpophaga incertulas* in rice. The system model consisted of 4 submodels: a population dynamics model; a yield loss forecasting model; an insecticide degradation model; and an insecticide efficiency model. A weighted factor reflecting rice susceptibility to damage by *S. incertulas* was also introduced. The optimum time and concentration of insecticide application could be obtained by maximization.

Zhang *et al.* (1995) considered different control methods for *S. incertulas*, based on an improved population simulation model and a yield loss rate forecasting model for rice. It was concluded that the system model could provide an optimal decision strategy to effectively control the pest population, including cultural, biological and chemical control.

Modelling yield loss in indica rice in farmers' fields due to multiple pests has shown that among the insect pests, *S. incertulas* alone could explain 69% of the yield variation in dwarf and 62% in tall varieties. (Gangwar *et al.*,1986).

The yield loss simulation (YLS) model and the MACROS L1Q.CSM model were used to simulate the effect of stem borer damage by detillering at 5, 15, 30 and 60% at vegetative, panicle initiation and grain filling stages, on yield of rice variety Ratna. The predicted reduction in yield due to detillering at grain filling stage varied from 10.93 to 62.5% and 2.59 to 57.2% with the YLS and the MACROS, respectively, compared with the observed reduction of 4.8 to 56.1%. The simulated and observed

pest effects on crop yield during grain filling stage were comparable (Chander *et al*, 2002).

Muralidharan and Pasalu (2006) used databases created from insecticide control experiments undr the All India Coordinated Rice Improvement Project from 1965 to 1992 to empirical estimates of yield losses caused by stem borers. Each unit percent damage due to white earhead damage had a much greater impact on rice yield in irrigated ecosystem that did damage due to dead heart. White earhead damage occurred late in the season and resulted in direct loss of yielding panicle and thus compensation was possible.

2.5 Economic injury levels for rice stem borer

Rao *et al.* (1990) estimated economic injury thresholds for *Scirpophaga incertulas* on the basis of pest incidence and protection costs under rice field conditions. The economic injury thresholds ranged from 5.7 to 12% deadhearts and 9.4 to 14.7% white earheads.

Pandya *et al* (1994) estimated losses due to rice stem borer in Gujarat and reported that the influence of white earheads was much greater than that of deadhearts on yield and crop losses ranged from 1.98 to 2.1 and 1.74 to 2.47% per unit damage, respectively.

S. incertulas caused damage during both vegetative and reproductive stages in 6 rice cutivars. The economic threshold level for the pest was found to be 22.5% dead heats, and 17.5% whiteheads (Murthy and Chiranjeevi, 1996).

Based on the study of the influence of pest damage on rice yield loss, the economic threshold of the yellow stem borer was found to be 5% yield loss as admitted level and 7% yield loss as economically important The former is a signal level, whereas the latter is an operative one (Monastyrskii and Sugonyaev 2001).

Afzal *et al.* (2002) conducted an experiment to determine the new economic threshold level (ETL) for chemical control of rice stem borers (*S. incertulus* and *S. innotata*) on rice cv. Super Basmati. There were 7 treatments consisting of simulated infestation levels of 0, 2.5, 5.0, 7.5, 10.0, 12.5 and 15.0%, achieved by clipping the tillers. Clipping was done just before emergence of panicles at the flowering stage, which is the period of maximum attack by stem borers. There was a significant

reduction in grain yield. Economic analysis showed that a single application of cartap (Padan) cost more (Rs. 1442 per ha) than the cost of the grain yield losses resulting from insect infestations below 7.5% (Rs. 1347/ha). Between 7.5 and 10.0% infestation levels, the cost of chemical control (single application) was equal to or less than the cost of the reduction in yield (Rs. 1979 and 4141/ha, respectively). This level can be considered as the new ETL. Two applications of Cartap (as recommended) cost Rs. 2964 per ha. The double Cartap application cost less than the cost of yield losses at 10% infestation.

Catling *et al.* (1978) conducted a series of crop-loss assessments under simulated farmers' field conditions in the 3 main rice cropping seasons in Bangladesh. An economic threshold of 5-10% damaged tillers was calculated for early attacks by the stem borers.

Prasad *et al.* (1992) determined the economic thresholds for *S. incertulas* on deep water rice. Treatments of carbofuran and monocrotophos or quinalphos were used at various pest population densities. A significant reduction yield was obtained if the treatment was delayed until 10% of stems were infested with larvae instead of treatment when 5% of stems were infested.

S. incertulas was inoculated onto 2nd cropping rice plants at 50 larvae per plot of 50 hills at the tillering, jointing, booting and initial heading stages in a study in China. The greatest infestation was recorded in plots treated with 50 larvae at tillering. When 50 egg masses were added per plot yield losses were 59.1 – 74.5%, mainly due to a 22.6% decrease in effective panicles in each hill compared with those in untreated controls. Control thresholds were 100-110 egg masses/mu (1mu=0.067 ha) , 2-3% infested hills and 1 – 1.5% infested plants (Wang *et al.*, 1994).

2.6 Influence of weather on rice stem borer infestation

With a view to explore the feasibility of developing a forecasting system for *S. incertulas* on rice, the relationships between the intensity of attack and meteorological parameters such as rainfall, relative humidity, maximum and minimum temperatures, soil temperatures at 5 cm depth and hours of bright sunshine in the pre- and inter-crop seasons of both rice crops were investigated at Aduthurai in Tamil Nadu. A simple

working rule for warning of the pest was that when the afternoon relative humidity was lower than the normal value of 54% during 31st week, the first standing crop was likely to be more severely infested. In the second crop period, the highest correlations with infestation for weekly rainfall totals in the 45th standard week were negative while these were positive for weekly means of morning soil temperatures for the 47th standard week (Goel *et al*, 1983).

A study was conducted in Cuttack, Orissa to investigate the effect of weather parameters on the population build up of yellow stem borer and its fluctuation was monitored daily using a light trap. The daily data of weather parameters were collected from 1973-2002. From the multiple regression analysis, it was observed that maximum temperature, rainfall, relative humidity and wind velocity, were negatively correlated while minimum temperature, evaporation rate and daily sunshine hour were positively correlated to the moth population recorded in the light trap catch (Padhi and Saha 2004)

Samui *et al.* (2004) investigated weather-based forewarning models for major pests of rice in Pattambi, Kerala. Systematic and daily observations on 5 pests and weather during the *Kharif* and *rabi* seasons were recorded using light trap for 15 years (1987-2001). The multiple regression models developed were validated using meteorological data for 2000 and 2001.

Light-trap data collected in rice-fields at Mandya, Karnataka showed 3 peaks of activity of *S. incertulas* i.e. a low peak in February (the winter generation), a moderate peak in May (the summer generation) and a high peak in November (*Kharif* generation). The pest caused most damage about 2 weeks after the winter-generation adults emerged and a month before the summer and *Kharif* generations. (Manjunath, 1982).

Ye and Li (1991) constructed 2 predicting models for *S. incertulas* on the basis of data on the occurrence of this pest on rice during 1957-86. Tests indicated that the two models were valid and could be used for forecasting (Ye and Li, 1991). Epidemiological studies in relation to the incidence of disease and pests of field crops have shown the stem borer incidence on rice to be high during panicle formation (from mid-September to October) when the temperature was 27-34°C and the relative humidity was 85-90% (Chakraborty, 2002).

Studies on the effect of weather factors on the population buildup of rice pests through light trap collection at Jagdalpur revealed that *S. incertulas* showed significant negative correlation with minimum temperature, evening relative humidity and rainfall. Path analysis revealed that minimum temperature played an important role in the population buildup (Bhatnagar and Saxena, 1999).

Light trap studies on *S. incertulas* at Raichur, Karnataka showed that the first peak activity period of the insect was during October to December coinciding with kharif season crop. The insect catches had negative and significant relationship with average maximum temperature, while positive and significant relationship was noticed with average morning relative humidity in both the years. The positive and significant relationship of the insect catches was observed with average minimum temperature and negative and significant correlation of the insect catches was recorded with average evening relative humidity. The extent of combined influence of all the weather factors on insect catches ranged from 48.72 to 50.69 percent (Nandihalli *et al*, 1990).

Pandya *et al*., (1989) studied the population abundance of *S. incertulas* in Navasari, Gujarat. The number of moths caught during the period of maximum activity correlated with maximum temperature to the tune of 36°C and minimum temperature of 26.8°C.

Prakasa Rao and Padhi (1988) observed that the rainfall during August-November (r=-0.93) and rainy days in October-November (r = -0.82) showed significant negative correlation with borer infestation at Cuttack, Orissa. The mean sunshine hours per day during September-October were positively correlated to borer infestation at heading stage in different years, though not significant. The lesser the rainfall and the number of rainy days and higher the resultant sunshine hours and solar radiation, the greater is the gross borer infestation at harvest and vice versa.

Studies on the adult population of *S. incertulas* and its responsiveness to major weather factors were conducted by trapping them in modified Rothamsted type light trap in Susunia, West Bengal. Correlation of insect factors with temperature was negative and significant when seasonal averages were taken into consideration (Sarkar and Gayen, 1992).

Suwongwan and Catling, (1987) observed that the incidence of lethal days i.e. days with a maximum temperature of 34°C or above with RH below 70% was a useful predictor of mortality. Varma *et al.* (2000) reported that both larval development and adult emergence of YSB were affected at temperatures below 16° C and above 35°C. Maximum temperatures of 29-30°C and minimum of 20°C were the most favourable for YSB development.

Prasad *et al.* (2003) developed regression models to predict the peak light trap catches of *S incertulas* based on weather parameters such as maximum temperature, minimum temperature, morning relative humidity, evening relative humidity, sunshine hours and rain as independent variables. The weekly data from the progress reports of the Directorate of Rice Research from 1975 to 2000 were utilized to develop the models. Among the individual weather parameters, the average minimum temperature in the fourth week of January during *rabi* and total rain in the third week of June during *Kharif* had a decisive influence on the magnitude of peak light trap catches of the stem borer.

Study on the effect of weather factors on the population buildup of rice insect pests through light trap catches at Masodha, Uttar Pradesh revealed that the pest showed significant negative correlation with relative humidity. Path analysis revealed that relative humidity played an important role in population buildup of the pest (Pandey *et al.*, 2001).

2.7 Geographical information systems in pest management

A GIS is a set of computer programs that collect, store, retrieve, transform, display and analyze spatial data (Burrough, 1988). Georeferenced data, such as insect densities, crop type, or soils, can be incorporated in a GIS to produce map layers or "coverages". A map layer, generally composed of only one type of data, is thus considered to have a "theme". Many of these themes that have a similar spatial extent can be combined to form a full GIS database. The GIS serves as a tool for analyzing interactions among and within the various spatially referenced data themes. Managing and analyzing large spatial databases would be impossible without this type of software. While the advent of GIS has allowed entomologists to compile and manipulate spatially referenced data, characterization and modeling of spatial patterns is still difficult without an adequate set of statistical tools.

Pest zoning is a concept that is particularly applicable for large area pest management, in which both tactics and strategies can be merged to achieve optimal management. Pest population dynamic model can be run with requisite weather data and probability of various levels of pest infestation for a site is determined (Yuen and Teng, 1990). Site predictions can then be extrapolated through GIS to carve out the zones of equal epidemic potential for a pest. Knowledge of pest incidence in different zones would allow strategic decisions within each zone with respect to selection of crop cultivars. Probable life of resistant cultivars can also be presumed. This would help extension workers in the selection of appropriate management options in different zones.

Chander *et al.* (2004) analysed leaf folder infestation data in relation to weather factors at Ludhiana (Punjab) and observed a qualitative relationship between pest incidence and temperature. Mean September temperatures ranging from 26.5 to 28.5°C were associated with low pest incidence, while mean September temperatures ranging from 28.2 to 30.5° C were associated with moderate pest incidence. The relationship was validated for Ludhiana and Karnal (Haryana) with approximately 80% agreement between observed and simulated leaf folder incidence level. On the basis of the mean September temperatures prevalent in Haryana, the state was divided into 4 zones using the GIS software IDRISI. Rice areas with low and moderate leaf folder incidence potential could thus be identified

Zheng Jun *et al.* (2001) developed a GIS database for *Chilo suppressalis* in Zhejiang Province in China to analyze the spatio-temporal dynamics of its population. The database can provide powerful assistance for pest managers in spatio-temporal analysis, aside from basic database management functions, such as data inputting, outputting, editing and querying.

Srivastava *et al.* (2001) used a GIS-based approach for predictive habitat modelling for forest malaria vector species in India. Thematic maps of forest cover, altitude, rainfall and temperature were prepared. Overlaying and integration of thematic maps were done and the results were validated through reported distribution, which were found correct.

Digital map of Sal (*Shorea robusta*) forest in Dehra Dun, Uttaranchal infected by the pest (*Hoplocerambyx spinicornis*) was prepared for evolving a

management strategy. The Indian Remote Sensing Satellite data were analysed digitally in conjunction with global positioning system based ground sample information. The GIS database for forest management units and other important physical feature were generated. (Pant *et al.*, 2002).

Ganeshaiah *et al.* (2003) predicted the potential geographical distribution of sugarcane woolly aphid (*Ceratovacuna lanigera Z.*) in India using generic algorithm for rule set prediction (GARP) and DIVA-GIS. The GARP suggested that the woolly aphid was not likely to spread to Tamil Nadu, Kerala, and the coastal areas. Within Karnataka, it was likely to occur along the transitional belt and in the northern and southern dry zones, but was less likely to occur towards south interior Karnataka. The results of the simulations using DIVA-GIS were also identical to those obtained by GARP, although a more restricted distribution with 3 distinct zones of occurrence for woolly aphid infestation was suggested.

Fletcher *et al.* (2004) integrated airborne imagery and GIS technology to map and compare citrus black fly infestations occurring in different years.

Historical climate data from sites have been shown to be useful for classifying the conduciveness of a site for wheat diseases (Coakley, 1990). Similarly, the prediction of riskiness of an environment to tomato viruses was also successfully carried out in Arizona using geostatistics and GIS.

Shepherd *et al.* (1988) digitized historical maps of defoliation caused by the Douglas-fir tussock moth in British Columbia, and overlaid these images to obtain a map of defoliation frequency. This outbreak frequency map was then overlaid with forest type and biogeoclimatic maps to determine how forest type and climate were related to outbreak frequency. Their characterization of sites most prone to outbreaks can be used to predict where outbreaks will occur in the future. In a similar study, GIS was used to examine the relationship between historical grasshopper outbreaks and soil characteristics and between weather and survey counts. (Johnson, 1989)

Liebhold *et al.* (1992) used aerial sketch maps of historical gypsy moth defoliation to determine associations with specific forest types and elevation classes. Twery *et al.* (1990) used elevation and aspect to predict forest type and

consequential susceptibility to gypsy moth defoliation at a 30 m resolution for areas where actual habitat data was not available at that resolution.

Future efforts to characterize habitat susceptibility will probably use remotely sensed data extensively because of their high spatial resolution and its availability in virtually every portion of the globe. For example, Bryceson (1989) used Landsat multispectral data to identify areas in New South Wales, Australia, which were likely to have egg beds of the Australian plague locust. Through the use of a normalized difference vegetation index (NDVI) and maximum-likelihood classification, the location of nymphal bands were predicted from changes in NDVI that resulted from rains during March.

Spears *et al.* (1991) and Ravlin *et al.* (1991) used a GIS to interpolate gypsy moth trap counts and egg mass densities in an integrated pest management demonstration program.They showed how map compilations of these data are useful for documenting the range expansion of this insect and planning suppression activities. Liebhold *et al.* (1992) used GIS to analyze the historical expansion of the range of the gypsy moth as it relates to geographical variation in climate. From this analysis they developed a model that forecasts the future spread into currently uninfested areas.

Brown planthopper (*Nilaparvata lugens*) is a migrant pest which can migrate from tropical areas into subtropical and temperate areas every year and caused a lot of damage in rice production. To understand the migration process of this pest, the Boundary Layer Atmospheric (BLAYER) model and Geographic Information System (GIS) were used to analyse the migration waves in South Korea. (Zhu *et al.*, 2000).

GIS was used to estimate the potato leafhopper, *Empoasca fabae* (Harris), minimum temperature survival and pre-migrant development. The minimum winter temperature was estimated by overlaying minimum temperature isolines with potato leafhopper collection data taken during the winter. The geographic limits of the overwintering range were estimated using the minimum temperature survival to create a condition-based model by using ArcMap-GIS 8.2. (Sidumo *et al.*, 2005).

Carrière *et al.*, (2006) conducted studies to understand the effect of cropping patterns on population dynamics, dispersal, and habitat selection of the western

tarnished plant bug, *Lygus hesperus* (Knight) in cotton in central Arizona. They used a general approach based on GIS combined with spatial statistics to assess the maximum distance at which forage and seed alfalfa, fallow fields with weeds, and cotton affect *L. hesperus* population density. The spatially explicit approach used here provided a direct evaluation of the effects of agro-ecosystem heterogeneity on pest population dynamics, dispersal, and habitat selection, which is a significant asset for the development and improvement of area-wide pest management.

3. MATERIALS AND METHODS

The materials and methods used in the present investigations have been presented under the following heads:

3.1 Quantification of rice stem borer damage mechanisms

3.2 Simulation of rice stem borer damage mechanisms

3.3 Formulation of decision support tools for rice stem borer management

3.4 Establishment of pest-weather modules for rice stem borer

3.5 Agro-ecological zonation for rice stem borer

3.1 Quantification of rice stem borer damage mechanisms

Field experiment was conducted during *Kharif* season, 2005 at Indian Agricultural Research Institute (IARI), New Delhi for the quantification of stem borer damage mechanisms. Experimental data were required to validate simulated yield reductions so that hypothesis about stem bore damage mechanisms could be substantiated. The studies were conducted with the rice variety Pusa Basmati-1, which is highly susceptible to stem borer.

3.1.1 Raising of paddy nursery

The field for raising nursery bed was brought to fine tilth and bunds were made around the plots. Seeds of Pusa Basmati-1 were kept in gunny bags and soaked in water for a day. The sprouted seeds were sown by broadcasting uniformly on the well prepared nursery bed on June 29, 2005. The seed rate for nursery was 50 kg/ha. Fertilizers were applied basally as per recommendations to ensure healthy seedlings. The nursery bed was irrigated daily. In about 25 days after sowing (DAS), the seedlings were ready for transplanting.

3.1.2 Preparation of main field and transplanting

The field was ploughed two times with disc plough and tractor drawn cultivator to get fine tilth. All weeds and stubbles were removed from the field. The field was inundated with water, puddled twice and then leveled. Transplanting was done with 25 days old seedlings with three seedlings having been transplanted per

hill. Gap filling was done after a week to ensure uniform plant population in each plot.

3.1.3 Layout of the experiment

The experiment was laid out in randomized block design. There were eight treatments including untreated control, which were replicated thrice. To minimize border effect on crop and pest incidence, one metre buffer space was left out from the main bunds of the field on all sides.

Between replications 50 cm wide channel was provided to facilitate irrigation, fertilizer and insecticidal application, and recording of observations. Following are the details of the experiment:

Design	:	Randomized Block Design (RBD)
Number of treatments	:	8
Number of replications	:	3
Plot size	:	2 x 2.5 m
Row to row spacing	:	20 cm
Plant to plant	:	15 cm
Date of transplanting	:	24th July 2005

3.1.4 Irrigation and fertilizer application

The experimental field was irrigated daily until the establishment of seedlings. The field was the irrigated on alternate days thereafter. Irrigation was completely stopped ten days prior to harvesting of the crop.

Nitrogen (N), phosphorus (P_2O_5) and potash (K_2O) were applied in the form of urea, single super phosphate (SSP) and muriate of potash (MOP), respectively, at the recommended dose of 120:60:40 kg/ha. One-third of N and the entire amount of P_2O_5 and K_2O were applied as basal dose after the puddling. The remaining N was applied in two splits doses, one at peak tillering stage and the other at panicle emergence stage. The fertilizers were applied by broadcasting uniformly in the plot.

3.1.5 Pesticide application

Endosulfan 35 EC was applied @ 0.07 %, 30 DAT and 50 DAT to avoid damage to the crop due to leaf folder and hispa (Satish, 2004) in all the treatments including control, which was healthy crop without detillering. There was not an appreciable incidence of any disease or nematode, warranting management intervention.

3.1.6 Artificial cutting of tillers

Natural incidence of the stem borer was in traces and not sufficient to cause appreciable yield reduction during previous year as well as during experimental year. Variable infestation levels of the stem borer were thus mimicked by artificial detillering i.e. cutting and removing plant tillers about 1 cm above the ground level (Prasad *et al.*, 1990; Afzal *et al.*, 2002; Daryaei, 2002). The tillers were removed at 40, 50 and 70 DAT on hill basis as per different treatments presented below, when there was negligible surface water in the field. For this, tillers of every hill were counted and number of tillers required to be removed was determined. If the decimal part in the number of tillers to be removed happened to be 0.5 or more, then number of tillers equal to next round number was removed, otherwise number of tillers equal to preceding round number was clipped. If there were 6-9 tillers/hill, then at 10%, one tiller was removed while at 20%, one tiller was removed if there were six or seven tillers but two tillers were removed among eight or nine tillers. The detillering was done up to 30% because stem borer incidence beyond this has rarely been witnessed. In nature, the stem borer infestation on rice is witnessed right from tillering stage to crop maturity (Prasad *et al.*, 1990; Ragini *et al.*, 2001).

Experimental treatments

T_0 Healthy crop (No detillering)

T_1 20% detillering at 40 days after transplanting (DAT)

T_2 30% detillering at 40 DAT

T_3 20% detillering at 50 DAT

T_4 30% detillering at 50 DAT

T_5 10% detillering after flowering (70 DAT)

T_6 20% detillering at 70 DAT

T_7 30% detillering at 70 DAT

3.1.7 Harvesting and threshing

Crop was harvested about 1 cm above ground level and threshing was done manually for all the treatments. All the rows of a plot were harvested without leaving border rows. Care was taken after transplanting to prepare ridges on all sides of plots to separate them from each other. Immediately after harvesting the total fresh biomass of each plot excluding roots was weighed and from this 500 g of sample was oven dried at 70°C for 24 hours to work out the dry weight of biomass. Based on this total dry matter (TDM) of each plot was determined. The fresh weight of grains per plot was recorded as the grain yield. Oven drying of 50g samples taken from each plot, at 70°C for 24 hours was done to estimate the yield on dry basis (weight of storage organs). The moisture content in grains after oven drying was about 8%.

3.2 Simulation of rice stem borer damage mechanisms

InfoCrop (Aggarwal *et al.*, 2004) was used for simulating effect of the stem borer damage on rice biomass and yield. It is a generic crop growth model that can simulate the effects of weather, soil, agronomic management, nitrogen, water and major pests on crop growth and yield. Its general structure is based on a large number of earlier models (Aggarwal *et al.*, 2004). The basic crop model is written in FORTRAN Simulation Environment. It is sensitive to:

Crop variety	:	Physiology
Agronomic management	:	Dates of planting, seed rates, amount and time of irrigation and fertilization
Soil	:	pH, depth, texture, fertility
Environment	:	Radiation, temperature, rainfall, wind speed, vapour pressure, flooding, frost
Pests	:	Population or severity of insects, diseases and weeds

The model simulates the major processes of crop growth, soil water and nutrient balances and crop-pest interactions (Figure 1 & 2). The model can be used for assessment of crop losses due to pests (Figure 3). InfoCrop has been coupled

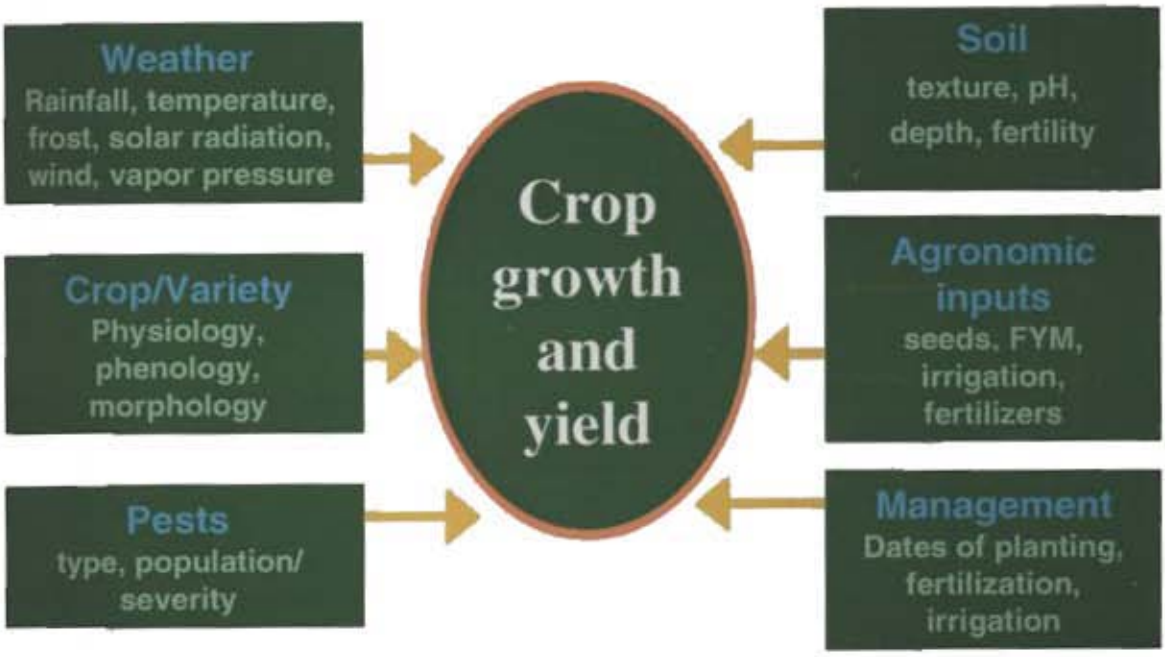


Figure 1: Diagram showing the various components of InfoCrop

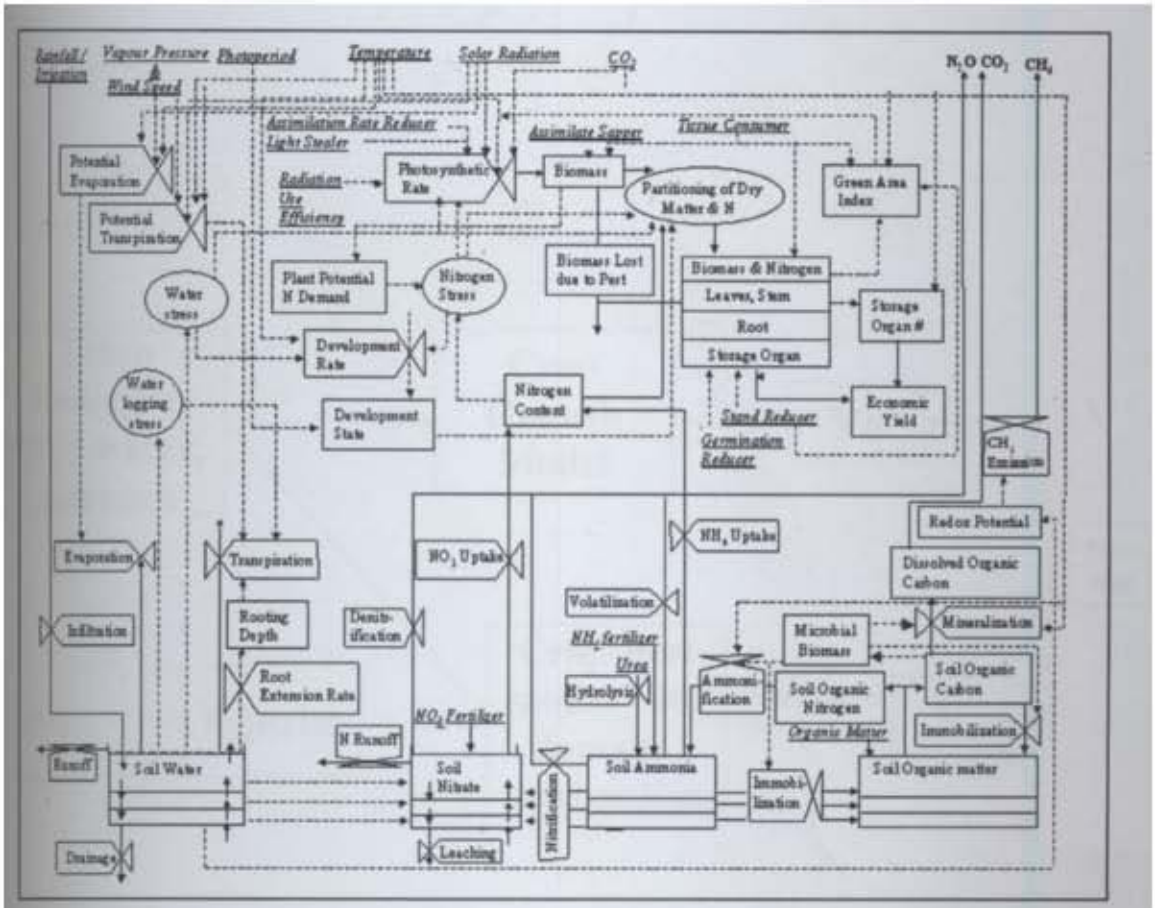


Figure 2: Relational diagram showing the various physiological processes incorporated in InfoCrop (Aggarwal *et al.*, 2004)

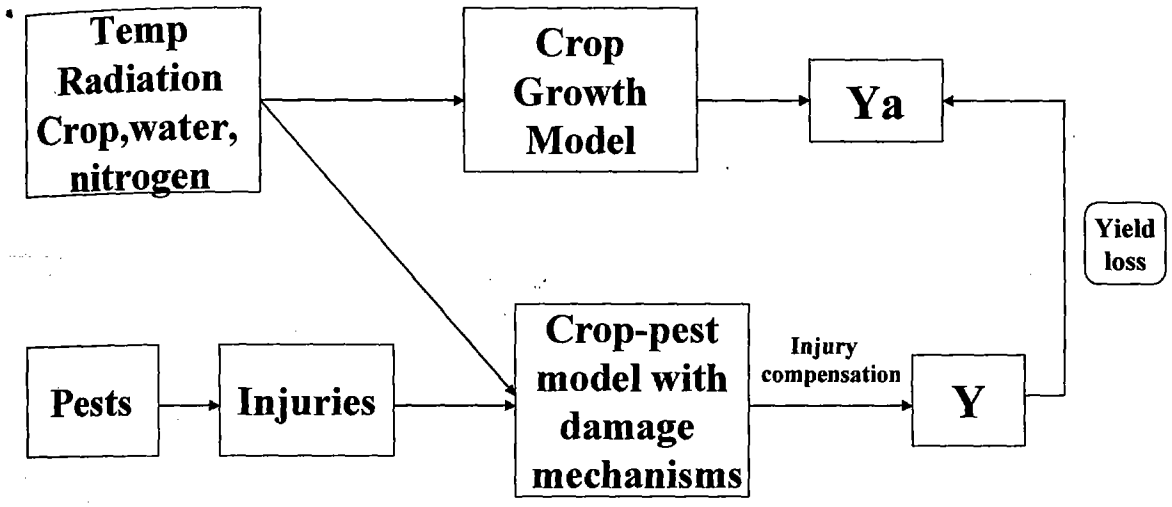


Figure 3: Assessment of crop losses due to pests using simulation models

with various pest damage mechanisms (Figure 4).These are plant physiological processes affected by pests and are categorized as stand reduction, light stealing, assimilation rate reduction, assimilate sapping, tissue consumption and turgor reduction. Pests like stem borers, gall midge, termite, cutworms and diseases like damping off are known as stand reducers. The damage mechanisms of stem borer were coupled to appropriate plant processes (Figure 5 & 6). The extent of yield loss due to stem borer depends upon the number and distribution of lost tillers, compensation ability of remaining tillers and development stage of the crop. Rice crop can compensate for pest damage to certain extent during the tillering stage but not after flowering. The damage mechanism of the stem borer was simulated by reducing rates increase of leaf area index, leaf weight, stem weight, stem area, grain number and storage organ weight of the crop in relation to the pest incidence.

The effect of stem borer on leaf area was simulated by reducing the leaf area rate (RLAI) in proportion to the pest damage (DMGSTR).

RLAI = LAII+GLAI -DLAI-LAI*(1.-PLTR)-LALOSS

LALOSS = LAI* DMGSTR

LAII, GLAI, DLAI, LAI, PLTR and LALOSS refer respectively to initial leaf area index, leaf area growth rate, death rate of leaf area, leaf area index, reduction factor for leaf area due to transplanting and leaf area loss due to stand reducer. Transplanting affects leaf area index of crop due to transplanting shock as there is yellowing of leaves and plants resume their normal activity about one week after transplanting. The DMGSTR represents percent stem borer infestation (SBINRT) as a function (AFGEN) of days after sowing (DAS) such that,

DMGSTR = AFGEN (SBINRT, DAS)/100.

The effect of stem borer on leaf weight was estimated by increasing the death rate of leaf weight (DLV) in proportion to the pest damage (DMGSTR). The equation for rate of dead leaf weight was modified to

DLV = WLVG * ((DLAI/ LAI) + DMGSTR)

WLVG refers to weight of green leaves in kg/ha.

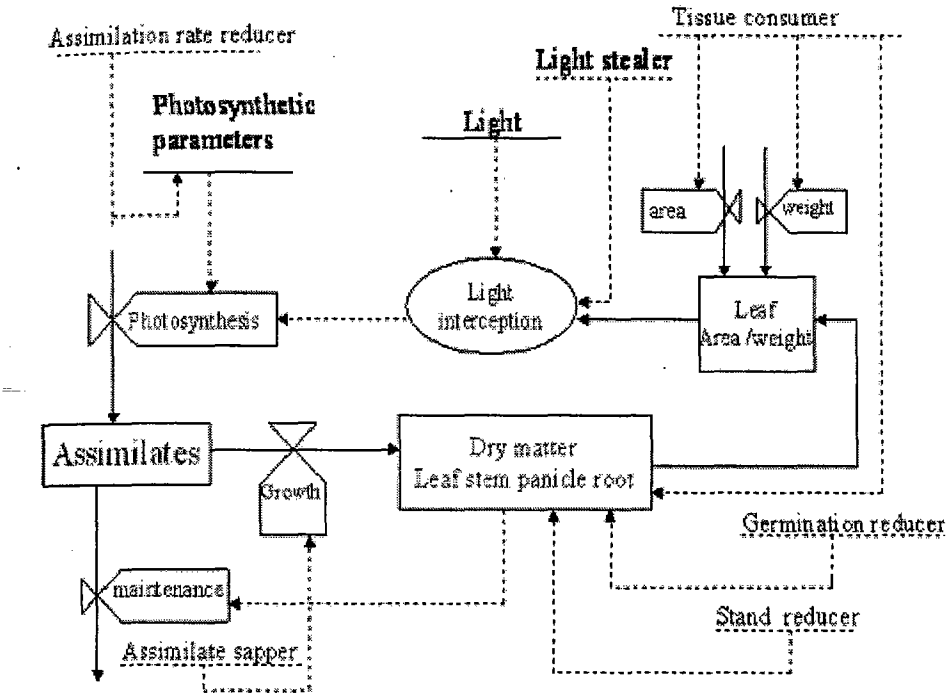


Figure 4: Coupling points of pest damage mechanisms in a crop growth model (Aggarwal *et al.*, 2004).

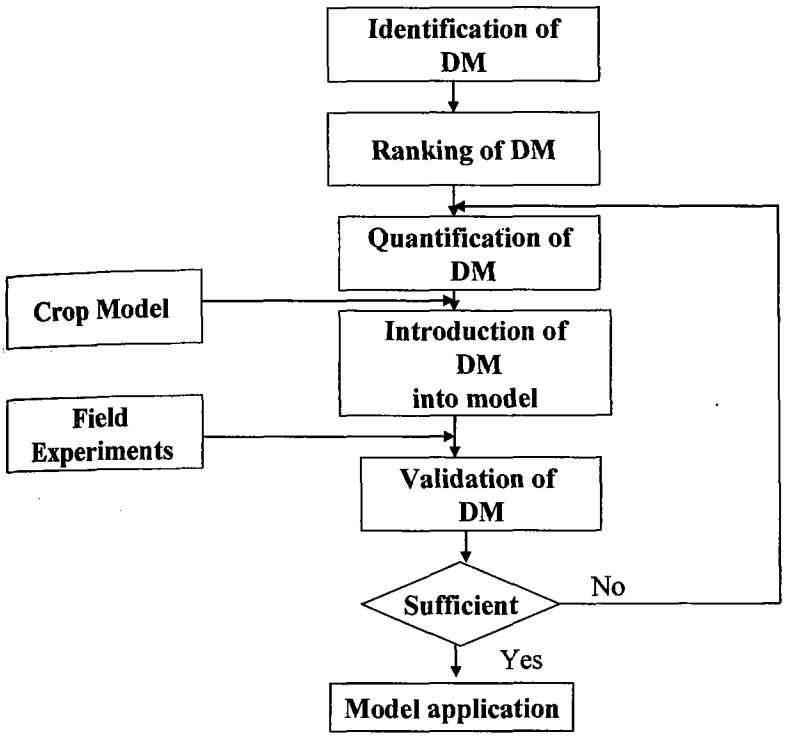


Figure 5: Schematic procedure for assessment of damage mechanisms (DM) on crop growth and production

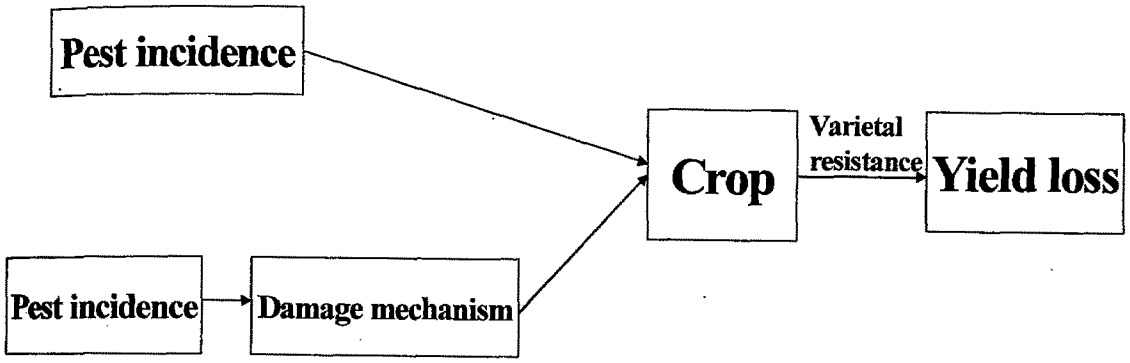


Figure 6: Diagram showing coupling of damage mechanism with crop model

Similarly the effect of stem borer on stem weight was accounted for by increasing death rate of stems (DST) in proportion to the pest damage.

DST = WST*((DSAI * 0.5/SAI) +DMGSTR)

WST, DSAI and SAI represent stem weight, stem area death rate and stem area index, respectively.

The influence of stem borer on stem area index (SAI) was estimated by reducing it in proportion to the pest damage.

SAI = (LAIFLW* AFGEN (LAIFAC, DS) – DSAI) * (1.-DMGSTR)

LAIFLW, LAIFC and DS are maximum leaf area index of crop, crop specific function and crop developmental stage, respectively. The effective green photosynthetic are (EFFLAI) of the crop was calculated as:

EFFLAI = LAI + SAI

The effect on grain number was accounted for by decreasing the rate of grain number increase per day (GNODAY) in proportion to the pest damage.

GNODAY = GCROP * GNOCF- (GNLOSS + STRILE)

GNLOSS = GNO * DMGSTR

GNLOSS, GCROP, GNOCF, GNO and STRILE represent grain loss due to stem borer, assimilates produced/day, number of grains produced/kg biomass, total grain number and grain sterility due to high and low temperature, respectively.

The effect of stem borer on crop nitrogen was modelled by reducing rate of available nitrogen in leaves (NLV), stems (NST) and storage organs (NSO) by a loss rate from leaves (NLOSLV), stems (NLOSST) and storage organs (NLOSSO), respectively in proportion to pest damage from nitrogen present (ANLV, ANST, ANSO) in different plant organs.

NLOSLV = ANLV*DMGSTR

NLOSST = ANST*DMGSTR

NLOSSO = ANSO*DMGSTR

The yield loss (%) was calculated as:

$C = (A-B)/A*100$

Where, C represents percent yield loss while A and B is yield of healthy crop and detillered crop, respectively.

3.3 Calibration and validation of InfoCrop

InfoCrop was calibrated for total dry matter and yield as well as for the stem borer damage mechanisms. The flowering and physiological maturity in the field occurred on 60 and 112 day of the year (DOY), respectively. Crop phenology was calibrated by matching simulated flowering time and physiological maturity time with corresponding observed time in the experiment by adjusting thermal time requirement for flowering (TTVG) and thermal time requirement for physiological maturity (TTGF). The model was run with crop management data of the experiment and Delhi weather data of 2005.

The model was calibrated for total dry matter (TDM) and yield with the data of healthy crop (T_0). The data used for calibration of InfoCrop were seed rate (SEEDRT, kg/ha), sowing depth (SOWDEP, cm), thermal time for germination (TTGM, degree days), thermal time for flowering (TTVG, degree days), thermal time for grain filling (TTGF, degree days), potential grain weight (POTGWT, mg), number of grains per kg dry matter during grain formation stage (GNOCF) and weather data (solar radiation, maximum and minimum temperature, rainfall). The procedure for determining variety data initially involved running the model with the default values of the model and then rerunning the model using a range of values for each coefficient, until a satisfactory level of agreement between simulated and observed values was reached.

The data on yield and TDM for 20% detillering at 40 DAT, were used for calibration of the stem borer damage mechanisms. The data of remaining treatments (T_2 to T_7) were used for validation of the crop-pest interactions. The simulated TDM and yield for each treatment was compared with their observed values under field conditions. Also, percent reduction in TDM and yield for each treatment was compared with the observed values. Likewise, percent variation in simulated TDM and yield over the observed ones was also determined in order to gauge the precision of simulated results.

3.4 Decision support tools for rice stem borer management

Decision support tools viz. economic injury level (EIL) and iso-loss curves were simulated with the validated model.

3.4.1 Economic injury levels

The validated InfoCrop model was run from no infestation (healthy crop) to high incidence up to 15% incidence at 1% intervals. The yield loss for each run was recorded. The monetary value for the loss in grain yield for each run was estimated based on the market price of Pusa Basmati 1 to be Rs. 900 per quintal.

The cost of recommended chemical control measures (two sprays of monocrotophos @ 500g a.i. per hectare) was estimated as follows;

Cost of Monocrotophos 36SL = Rs. 280/ litre

Quantity of spray formulation needed per hectare = 2.78 litre

Cost of spray formulation per hectare = Rs. 778

Labour charges (two man days/spray/ha) = Rs. 416

Sprayer hire charges = Rs. 40

Total expenditure per hectare = Rs. 1234

The expenditure per hectare for three sprays of monocrotophos was worked out as Rs. 1851.

Similarly, the cost of carbofuran granules (Furadan 3G) for one application @ 33 kg/ha at a price of Rs 50/kg was found to be Rs 1650. With addition of labour charges Rs. 208 (two man days/ha), the expenditure would be Rs 1858.

The pest incidence level at which monetary value of yield loss equaled control expenditure was adjudged as EIL.

The EIL is a dynamic entity, which depends on the market value of the product and control expenditure. The changes in EIL corresponding to changes in the market value of Pusa Basmati (Rs 800 to 1000 per quintal) were compared. The change in EIL with control expenditure (three sprays as against two) was also

worked out.

3.4.2 Iso-loss curves

Iso-loss curves were plotted by running the model from zero pest incidence (healthy crop) to high incidence (up to 50%) at each of 30, 40, 50, 60, 70 and 80 DAT with Delhi weather during 2005 (Figure 7). The corresponding yield loss was obtained for each of the crop stages with different incidence levels. These curves indicate the combination of pest intensity and crop age, which result in the same yield loss.

3.5 Formulation of pest-weather modules for rice stem borer

Insecticide evaluation trials are conducted under the All India Coordinated Rice Improvement Project (AICRIP) across the country under the coordination of Directorate of Rice Research (DRR), Hyderabad to assess the relative efficacy of various insecticides against rice pests. The data on stem borer incidence were collected from the DRR reports for the locations mentioned below:

Aduthurai (Tamil Nadu), Coimbatore (Tamil Nadu), Pattambi (Kerala), Warangal (Andhra Pradesh), Karjat (Maharashtra) and Faizabad (Uttar Pradesh).

The data on stem borer damage were collected from the trials conducted from 1991 to 2005 for the above stations. The percent dead heart incidence recorded in control plots i.e. in the absence of any pest management practices, was assumed to be the average stem borer infestation for a particular area during a crop season. In case of more than one data point on the stem borer incidence at a location, these were averaged and mean value was taken. The data on daily meteorological parameters were obtained from the Central Research Institute on Dryland Agriculture (CRIDA), Hyderabad. Only temperature and relative humidity data were used in the present study. Mean values of minimum temperature and maximum temperature along with morning (RH_1) and evening relative humidity (RH_2) during 8 to 15 days prior to the date of observation of damage (2^{nd} lag week) were derived from the weather data.

The software package SPSS was used for multiple regression analysis between meteorological parameters and stem borer infestation. Regression equations i.e. pest-weather modules were developed between percent deadhearts and

maximum temperature, minimum temperature, morning relative humidity (RH_1) and evening relative humidity (RH_2). Although, the relationships were first developed including all the four meteorological factors, but subsequently only two of the most important parameters were considered for further analysis.

The severity of stem borer infestation was classified into four categories i.e. severe, high, moderate and low corresponding to more than 15%, 10 - 15%, 5 - 10% and less than 5% dead heart incidence. The weather conditions which led to each of these categories of infestation severity were worked out based on the pest-weather modules (regression relationships) developed for each of the AICRIP centres. This was done by putting a series of values for the weather factors in the regression equation and thereby finding out the range of temperature and humidity responsible for the four categories of infestation levels.

3.6 Agro-ecological zonation for rice stem borer

The regression equations developed between stem borer damage and weather parameters were useful for site-specific predictions. The pest-weather modules developed depicted the most favourable, moderate and unfavourable weather conditions for the stem borer incidence. The pest-weather modules thus developed were interpolated with the help of 'Geographical Information System' (GIS) for Kerala, Tamil Nadu and Andhra Pradesh. Monthly normal values of temperature and relative humidity recorded in weather stations across these states were obtained from the 'India Meteorological Department' (IMD), New Delhi. These normal values were based on observations recorded from 1951 to 1980. The mean *Kharif* temperature and relative humidity values for these stations were worked out form this information.

Environmental Systems Research Institute (ESRI) ArcGIS package was used for the GIS mapping of agro-ecological zones. To begin with, the weather stations were marked as point data in the state map, along with their corresponding normal values of temperature and humidity. Geostatistical interpolation techniques (kriging) were used to prepare separate maps of temperature and humidity based on normal values for the state. Masking was done to confine the interpolated variables within

the state boundaries. Raster calculations were done based on the regression model applicable for the state to prepare a combined map of temperature and humidity. The map thus obtained was reclassified based on the severity of stem borer infestation into four classes;

Less than 5% damage = Low

5.1 to 10% damage = Moderate

10.1 to 15% damage = High

More than 15% damage = Severe

In nature, stem borer incidence beyond 15% has been observed by various workers (Inaytullah *et al.*, 1989; Prasad *et al.*, 1990; Senapati *et al.*, 1990) and in the AICRP trials.

4. RESULTS

The results of the experimental studies carried out for "Modelling yield loss due to rice stem borer and agro-ecological zonation" are presented under following heads:

4.1 Quantification of rice stem borer damage mechanisms

4.2 Simulation of rice stem borer damage mechanisms

4.3 Formulation of decision support tools for rice stem borer management

4.4 Establishment of pest - weather modules for rice stem borer

4.5 Agro-ecological zonation for rice stem borer

4.1 Quantification of rice stem borer damage mechanisms

In the field experiment, conducted to assess yield losses due to rice stem borer in cultivar Pusa Basmati 1 during *Kharif* 2005, the crop flowered about 60 days after transplanting (DAT) and matured physiologically 112 DAT. The yield (dry weight basis) in different treatments of the experiment varied from 3310 to 4558 kg/ha (Table 1), while total dry matter (TDM) ranged between 6312 and 8529 kg/ha (Table 2). The percent yield loss in relation to healthy crop varied from 4.32 to 27.38 % whereas percent loss in TDM ranged from 4.7 to 26% in different treatments. The percent loss in yield and TDM were the highest with 30% detillering after flowering (70 DAT) and the lowest for 10% detillering at 40 DAT (Table 3).

4.2 Simulation of rice stem borer damage

InfoCrop (Aggarwal *et al.*, 2004), a generic crop growth simulation model developed at the Indian Agricultural Research Institute, New Delhi, was calibrated and validated for stem borer damage mechanisms using the results of the field experiment.

4.2.1 Model calibration

InfoCrop was calibrated for rice growth and yield with the experimental data of healthy crop (T_0). The simulated weight of storage organs (WSO) i.e. yield on dry

Table 1: Yield (dry weight basis) in different treatments of the field experiment conducted during *Kharif* 2005 for quantification of rice stem borer damage in Pusa Basmati 1.

Treatments	Yield on dry weight basis (kg/ha)			
	Replications			Mean
	1	2	3	
Healthy crop (T_0)	4574	4427	4672	4558^{a}
10% detillering 40 DAT* (T_1)	4405	4233	4445	4361^{ab}
20% detillering 40 DAT (T_2)	3899	3809	4192	3967^{ab}
10% detillering 50 DAT (T_3)	4258	4207	4422	4296^{ab}
20% detillering 50 DAT (T_4)	3820	3728	4112	3887^{ab}
10% detillering 70 DAT (T_5)	4154	4068	4323	4182^{ab}
20% detillering 70 DAT (T_6)	3726	3657	3914	3766^{ab}
30% detillering 70 DAT (T_7)	3256	3210	3464	3310^{b}
$S.E._m\pm$	-	-	-	558.9
CV (%)	-	-	-	16.95
C.D. (0.05)				1198.8

*DAT = Days after transplanting, mean yields with same superscript do not differ significantly

Table 2: Total dry matter observed in field experiment conducted in *Kharif* 2005 for quantification of rice stem borer damage mechanisms in Pusa Basmati 1

Treatments	Total dry matter (kg/ha)			
	Replications			Mean
	1	2	3	
Healthy crop (T_0)	8495	8414	8677	8529[a]
10% detillering 40 DAT* (T_1)	8020	8092	8274	8129[ab]
20% detillering 40 DAT (T_2)	7509	7247	7738	7498[ab]
10% detillering 50 DAT (T_3)	8025	7738	8254	8006[ab]
20% detillering 50 DAT (T_4)	7315	7063	7544	7307[ab]
10% detillering 70 DAT (T_5)	7820	7543	8049	7804[ab]
20% detillering 70 DAT (T_6)	6929	6685	7158	6924[ab]
30% detillering 70 DAT (T_7)	6308	6092	6537	6312[b]
S.E.m±	-	-	-	1006.9
C.V. (%)	-	-	-	16.30
C.D. (0.05)	-	-	-	2159.8

*DAT = Days after transplanting, mean yields with same superscript do not differ significantly

Table 3: Percent reduction in yield (dry weight basis) and total dry matter (TDM) in Pusa Basmati 1 rice due to different detillering treatments during *Kharif* 2005

Treatments	Yield (kg/ha)	Loss (%) (C)*	TDM (kg/ha)	Loss (%)
Healthy crop (T_0)	4558 (A)	-	8529	-
10% detillering 40 DAT (T_1)	4361 (B)	4.32	8129	4.7
20% detillering 40 DAT (T_2)	3967	12.97	7498	12.1
10% detillering 50 DAT (T_3)	4296	5.75	8006	6.1
20% detillering 50 DAT (T_4)	3887	14.72	7307	14.3
10% detillering 70 DAT (T_5)	4182	8.25	7804	8.5
20% detillering 70 DAT (T_6)	3766	17.38	6924	18.8
30% detillering 70 DAT (T_7)	3310	27.38	6312	26.0

***C (%) = (A-B)/A x100**

weight basis and TDM for healthy crop was 4687 and 8775 kg/ha, respectively (Table 4). The observed yield (dry basis) was 4558 kg/ha. The simulated yield showed only 2.83% deviation from the observed value (Table 5). The observed TDM experiment was 8529 kg/ha. The simulated TDM showed only 2.88% deviation from the observed value (Table 6). The model was thus assumed to be calibrated satisfactorily for growth and yield of Pusa Basmati 1.

The values of different parameters obtained during the calibration process are presented in table 7. The values of degree days (DD) for germination (TTGERM), DD for grain filling (TTGF) and DD for vegetative growth (TTVG) were calibrated to be 50, 500 and 1650 DD, respectively. The parameter values obtained for potential leaf growth rate (RGRPOT), maximum radiation use efficiency (RUEMAX) and leaf extinction coefficient (KDFMAX) were 0.0092/day, 2.3kg/MJ/day, 0.6 respectively while those for grain filling rate(GFRVAR), specific leaf area (SLAVAR), grain number/ kg dry matter (GNOCF) and potential grain weight (POTGWT) were, 2mg/day, 0.0024m^2/kg, 60000 and 24mg respectively.

The observed data on yield and TDM observed with 10% detillering at 40 DAT (T_1) were used for calibrating the stem borer damage mechanisms. The simulated WSO and TDM for the treatment were found to be 4407 and 8250 kg/ha respectively in comparison to 4361 and 8129 kg/ha observed ones in the field experiment (Table 8 & 9). The simulated yield and TDM varied by 1.05% and 1.48% respectively over their corresponding observed counterparts, thereby indicating appropriate calibration of the stem borer damage mechanisms.

Stem borer acted as stand reducer affecting leaf area, leaf weight, stem weight, stem area, grain number and weight of storage organ of the crop. In InfoCrop, the effect of the stem borer on leaf area was simulated by reducing leaf area growth rate in proportion to the pest damage.

4.2.2 Validation

The data on yield and TDM for the rest of the treatments (T_2-T_7) were used for validation of the stem borer damage mechanisms. Simulated yield for these treatments varied from 3656 to 4358 kg/ha as compared to 3310 to 4296 kg/ha observed yield. Likewise, simulated TDM for these treatments ranged between 6844 and 8159 kg/ha in comparison to 6312 to 8006 kg/ha observed TDM. The yield and

Table 4: Simulated reduction in weight of storage organs (WSO) and total dry matter (TDM) due to different detillering treatments in Pusa Basmati 1 during *Kharif* 2005

Treatments	WSO* (kg/ha)	Loss (%)	TDM (kg/ha)	Loss (%)
Healthy crop (T_0)	4687	-	8775	-
10% detillering 40 DAT (T_1)	4407	5.98	8250	6.0
20% detillering 40 DAT (T_2)	4154	11.38	7776	11.4
10% detillering 50 DAT (T_3)	4358	7.01	8159	7.0
20% detillering 50 DAT (T_4)	4082	12.92	7641	12.9
10% detillering 70 DAT (T_5)	4344	7.32	8132	7.3
20% detillering 70 DAT (T_6)	3999	14.68	7487	14.7
30% detillering 70 DAT (T_7)	3656	22.00	6844	22.0

*WSO- grain yield on dry basis

Table 5: Comparison between observed yield (dry weight basis) and simulated weight of storage organs (WSO) of Pusa Basmati 1 rice during *Kharif* 2005

Treatments	Observed yield (kg/ha)	Simulated WSO (kg/ha)	Variation (%)
Healthy crop (T_0)	4558	4687	2.83
10% detillering 40 DAT (T_1)	4361	4407	1.05
20% detillering 40 DAT (T_2)	3967	4154	4.71
10% detillering 50 DAT (T_3)	4296	4358	1.45
20% detillering 50 DAT (T_4)	3887	4082	5.01
10% detillering 70 DAT (T_5)	4182	4344	3.87
20% detillering 70 DAT (T_6)	3766	3999	6.19
30% detillering 70 DAT (T_7)	3310	3656	10.45

Table 6: Comparison between observed and simulated total dry matter (TDM) of Pusa Basmati 1 in different treatments during *Kharif* 2005

Treatments	TDM (kg/ha)		Variation (%)
	Observed	Simulated	
Healthy crop (T_0)	8529	8775	2.88
10% detillering 40 DAT (T_1)	8129	8250	1.48
20% detillering 40 DAT (T_2)	7498	7776	3.71
10% detillering 50 DAT (T_3)	8006	8159	1.92
20% detillering 50 DAT (T_4)	7307	7641	4.57
10% detillering 70 DAT (T_5)	7804	8132	4.20
20% detillering 70 DAT (T_6)	6924	7487	8.12
30% detillering 70 DAT (T_7)	6312	6844	8.43

Table 7 Values of parameters and coefficients obtained during calibration of InfoCrop for Pusa Basmati 1 rice

Parameter	Description	Value
TTGERM	Degree days for germination	50 DD
TTGF	Degree days for grain filling	500 DD
TTVG	Degree days for vegetative growth	1650 DD
RGRPOT	Potential leaf growth rate	0.0092/day
SLAVAR	Specific leaf area	0.0024m^2/kg
RUEMAX	Maximum radiation use efficiency	2.3kg/MJ/Day
KDFMAX	Leaf extinction coefficient	0.6
GNOCF	Grain number per kg dry matter	60000 grains/kg
GFRVAR	Grain filling rate	2mg/day
POTGWT	Potential grain weight	24mg

Table 8: Observed and simulated reduction in yield (dry weight basis) of Pusa Basmati 1 due to different detillering treatments during *Kharif* 2005

Treatments	Yield on dry weight basis (kg/ha)			
	Observed	Loss (%)	Simulated	Loss (%)
Healthy crop (T_0)	4558	-	4687	-
10% detillering 40 DAT (T_1)	4361	4.32	4407	5.98
20% detillering 40 DAT (T_2)	3967	12.97	4154	11.38
10% detillering 50 DAT (T_3)	4296	5.75	4358	7.01
20% detillering 50 DAT (T_4)	3887	14.72	4082	12.92
10% detillering 70 DAT (T_5)	4182	8.25	4344	7.32
20% detillering 70 DAT (T_6)	3766	17.38	3999	14.68
30% detillering 70 DAT (T_7)	3310	27.38	3656	22.00

Table 9: Observed and simulated reduction in total dry matter (TDM) due to different detillering treatments in Pusa Basmati 1 during *Kharif* 2005

Treatments	Total Dry Matter (kg/ha)			
	Observed	Loss (%)	Simulated	Loss (%)
Healthy crop (T_0)	8529	-	8775	-
10% detillering 40 DAT (T_1)	8129	4.69	8250	5.99
20% detillering 40 DAT (T_2)	7498	12.09	7776	11.38
10% detillering 50 DAT (T_3)	8006	6.13	8159	7.01
20% detillering 50 DAT (T_4)	7307	14.33	7641	12.92
10% detillering 70 DAT (T_5)	7804	8.50	8132	7.33
20% detillering 70 DAT (T_6)	6924	18.82	7487	14.68
30% detillering 70 DAT (T_7)	6312	25.99	6844	22.00

TDM were always slightly overestimated by the model. The simulated and observed yields as well as TDM for different treatment were however close to each other. Simulated yields varied by 1.45 to 10.45% over the observed yields whereas, simulated TDM differed by 1.92 to 8.43% over the observed TDM. The stem borer damage mechanisms were thus validated appropriately on Pusa Basmati 1 rice.

Simulated yield loss in different treatments varied from 5.98 to 22% as compared with the 4.32 to 27.38% observed yield loss. Similarly, the simulated loss in TDM varied from 5.99% to 22% compared with 4.69 to 25.99% observed TDM loss. The loss in yield and TDM were overestimated by the model for 20% detillering at 40 DAT and 50 DAT whereas the model underestimated the losses for the other treatments.

4.3 Formulation of decision support tools for rice stem borer management

The decision support tools *viz.* economic injury levels and isoloss curves were formulated using InfoCrop.

4.3.1 Economic injury levels

InfoCrop model after proper validation was used for establishing economic injury levels (EILs) by simulating yield loss with 1 to 15% stem borer damage from 30 to 80 DAT at 10 days interval. Simulation models being based on crop physiological and ecological processes can be used for simulating crop growth and yield even for environmental conditions different from those under which these are developed. These can account for changes in weather, management, soil, water and pest situations encountered at different locations. The yield simulations were thus also done at 30 and 80 DAT besides 40, 50, 60 and 70 DAT. The EIL calculation for different crop growth stages was done with expenditure incurred on optimum number of pesticide applications required, which happened to be two applications with monocrotophos during the crop season. The model when run at 30 DAT, a monetary loss of Rs. 72 was obtained for 1% crop damage by stem borer based on market price of Pusa Basmati-1 as Rs. 9/kg. The monetary loss was calculated as Rs.1179 for 7% damage while it was Rs.1485 for 8% damage. The expenditure on control (two sprays of monocrotophos) was estimated as Rs. 1234/ha. As EIL is the

damage which justifies the use of control measures or at which value of crop loss is at least equal to expenditure on control measures, 7.5% dead hearts was adjudged as the EIL as the control expenditure was between 1188 and 1368 (Table 10).

At 40 DAT, a monetary loss of Rs. 1224 was obtained for 6% stem borer damage which was very near to Rs. 1234. Hence, the EIL was adjudged as 6.0% (Table 11). At 50 DAT, 5% dead hearts resulted in a loss of Rs.1161 while 6% resulted in Rs. 1395. So, the EIL was estimated to be 5.5% (Table 12).

At 60 DAT, 5% dead hearts resulted in a loss of Rs.1233 which being close to the control expenditure was adjudged as EIL (Table 13). At 70 DAT, 4% dead hearts resulted in a loss of Rs.1179 while 5% resulted in Rs. 1494. Therefore, EIL was estimated to be 4.5% (Table 14).

At 80 DAT, 3% dead hearts results in a monetary loss of Rs.1152 while 4% results in a loss of Rs.1539 as per the model. Hence, the EIL was worked out to be 3.5% dead hearts (Table 15).

Economic injury level is a dynamic entity which changes with crop age and market value of the crop. Tables 16 to 21 show the simulation of economic injury level with market price of Pusa Basmati-1 as Rs. 8/kg. Tables 22 to 27 show the economic injury level calculations when the market price is taken as Rs. 10/kg. The changes in EIL with crop age and market value are given in Table 28. The expenditure on chemical control was estimated as Rs.1851 if three sprays of Monocrotophos are to be used instead of two. The changes in EIL with change in control expenditure are depicted in Table 29.

At 30 DAT, 7% was the EIL at a market price of Rs. 800 whereas it was 6.5 and 5.5% at market values of Rs. 900 and 10/kg respectively. At 30 DAT, the EIL was adjudged to be as 6.5% for two sprays of Monocrotophos and 8.5% for three sprays.

The EILs were also determined in relation to expenditure on one application of carbofuran 3G @33 kg/ha. The expenditure on one application would be Rs. 1858. The EILs were determined to be 9.5, 8.5, 7.5, 7.5, 6.5 and 5.5, respectively at 30, 40, 50, 60, 70 and 80 DAT at market value of produce as Rs. 8/kg. These were found to be 8.5, 7.5, 7.5, 6.5, 6.0 and 4.5 at 30, 40, 50, 60, 70 and 80 DAT,

Table 10: Economic injury level for rice stemborer on Pusa Basmati-1 at 30 DAT as simulated with InfoCrop with control expenditure Rs. 1234 and market price Rs. 9/kg

Per cent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Monetary Value of Yield Loss (Rs./ha)
0	4687	0	0
1	4679	8	72
2	4672	15	135
3	4652	35	315
4	4622	65	585
5	4604	83	747
6	4573	114	1026
7	4556	131	**1179**
8	4522	165	**1485**
9	4470	217	1953
10	4431	256	2304
11	4403	284	2556
12	4388	299	2691
13	4368	319	2871
14	4357	330	2970
15	4340	347	3123

Table 11: Economic injury level for rice stemborer on Pusa Basmati-1 at 40 DAT as simulated with InfoCrop with control expenditure Rs. 1234 and market price Rs. 9/kg

Percent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Monetary Value of Yield Loss (Rs./ha)
0	4687	0	0
1	4672	15	135
2	4653	34	306
3	4639	48	432
4	4611	76	684
5	4596	91	819
6	4551	136	**1224**
7	4513	174	1566
8	4469	218	1962
9	4438	249	2241
10	4407	280	2520
11	4381	306	2754
12	4356	331	2979
13	4329	358	3222
14	4311	376	3384
15	4291	396	3564

Table 12: Economic injury level for rice stemborer on Pusa Basmati-1 at 50 DAT as simulated with InfoCrop with control expenditure Rs. 1234 and market price Rs. 9/kg

Percent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Monetary Value of Yield Loss (Rs/ha)
0	4687	0	0
1	4666	21	189
2	4649	38	342
3	4611	76	684
4	4601	86	774
5	4558	129	**1161**
6	4532	155	**1395**
7	4489	198	1782
8	4449	238	2142
9	4397	290	2610
10	4358	329	2961
11	4321	366	3294
12	4297	390	3510
13	4279	408	3672
14	4261	426	3834
15	4236	451	4059

Table 13: Economic injury level for rice stemborer on Pusa Basmati-1 at 60 DAT as simulated with InfoCrop with control expenditure Rs. 1234 and market price Rs. 9/kg

Percent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Monetary Value of Yield Loss (Rs./ha)
0	4687	0	0
1	4653	34	306
2	4634	53	477
3	4601	86	774
4	4572	115	1035
5	4550	137	**1233**
6	4505	182	1638
7	4463	224	2016
8	4432	255	2295
9	4394	293	2637
10	4352	335	3015
11	4314	373	3357
12	4292	395	3555
13	4266	421	3789
14	4234	453	4077
15	4205	482	4338

Table 14: Economic injury level for rice stemborer on Pusa Basmati-1 at 70 DAT as simulated with InfoCrop with control expenditure Rs. 1234 and market price Rs. 9/kg

Percent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Monetary Value of Yield Loss (Rs./ha)
0	4687	0	0
1	4654	33	297
2	4622	65	585
3	4590	97	873
4	4556	131	**1179**
5	4521	166	**1494**
6	4484	200	1800
7	4449	238	2142
8	4413	274	2466
9	4378	309	2781
10	4344	343	3087
11	4309	378	3402
12	4275	412	3708
13	4241	446	4014
14	4206	481	4329
15	4172	515	4635

Table 15: Economic injury level for rice stemborer on Pusa Basmati-1 at 80 DAT as simulated with InfoCrop with control expenditure Rs. 1234 and market price Rs. 9/kg

Percent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Monetary Value of Yield Loss (Rs./ha)
0	4687	0	0
1	4646	41	369
2	4603	84	756
3	4559	128	**1152**
4	4516	171	**1539**
5	4474	213	1917
6	4430	257	2313
7	4388	299	2691
8	4344	343	3087
9	4302	385	3465
10	4258	429	3861
11	4216	471	4239
12	4173	514	4626
13	4130	557	5013
14	4087	600	5400
15	4044	643	5787

Table 16: Economic injury level for rice stemborer on Pusa Basmati-1 at 30 DAT as simulated with InfoCrop with control expenditure Rs. 1234 and market price Rs. 8/kg

Percent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Monetary Value of Yield Loss (Rs./ha)
0	4687	0	0
1	4679	8	64
2	4672	15	120
3	4652	35	280
4	4622	65	520
5	4604	83	664
6	4573	114	912
7	4556	131	**1048**
8	4522	165	**1320**
9	4470	217	1736
10	4431	256	2048
11	4403	284	2272
12	4388	299	2392
13	4368	319	2552
14	4357	330	2640
15	4340	347	2776

Table 17: Economic injury level for rice stemborer on Pusa Basmati-1 at 40 DAT as simulated with InfoCrop with control expenditure Rs. 1234 and market price Rs. 8/kg

Percent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Monetary Value of Yield Loss (Rs./ha)
0	4687	0	0
1	4672	15	120
2	4653	34	272
3	4639	48	384
4	4611	76	608
5	4596	91	728
6	4551	136	**1088**
7	4513	174	**1392**
8	4469	218	1744
9	4438	249	1992
10	4407	280	2240
11	4381	306	2448
12	4356	331	2648
13	4329	358	2864
14	4311	376	3008
15	4291	396	3168

Table 18 Economic injury level for rice stemborer on Pusa Basmati-1 at 50 DAT as simulated with InfoCrop with control expenditure Rs. 1234 and market price Rs. 8/kg

Percent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Monetary Value of Yield Loss (Rs./ha)
0	4687	0	0
1	4666	21	168
2	4649	38	304
3	4611	76	608
4	4601	86	688
5	4558	129	**1032**
6	4532	155	**1240**
7	4489	198	1584
8	4449	238	1904
9	4397	290	2320
10	4358	329	2632
11	4321	366	2928
12	4297	390	3120
13	4279	408	3264
14	4261	426	3408
15	4236	451	3608

Table 19: Economic injury level for rice stemborer on Pusa Basmati-1 at 60 DAT as simulated with InfoCrop with control expenditure Rs. 1234 and market price Rs. 8/kg

Percent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Monetary Value of Yield Loss (Rs./ha)
0	4687	0	0
1	4653	34	272
2	4634	53	424
3	4601	86	688
4	4572	115	920
5	4550	137	**1096**
6	4505	182	**1456**
7	4463	224	1792
8	4432	255	2040
9	4394	293	2344
10	4366	321	2568
11	4333	354	2832
12	4297	390	3120
13	4266	421	3368
14	4234	453	3624
15	4205	482	3856

Table 20: Economic injury level for rice stemborer on Pusa Basmati-1 at 70 DAT as simulated with InfoCrop with control expenditure Rs. 1234 and market price Rs. 8/kg

Percent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Monetary Value of Yield Loss (Rs./ha)
0	4687	0	0
1	4654	33	264
2	4622	65	520
3	4590	97	776
4	4556	131	**1048**
5	4521	166	**1328**
6	4484	200	1600
7	4449	238	1904
8	4413	274	2192
9	4378	309	2472
10	4344	343	2744
11	4309	378	3024
12	4275	412	3296
13	4241	446	3568
14	4206	481	3848
15	4172	515	4120

Table 21: Economic injury level for rice stemborer on Pusa Basmati-1 at 80 DAT as simulated with InfoCrop with control expenditure Rs. 1234 and market price Rs. 8/kg

Percent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Monetary Value of Yield Loss (Rs./ha)
0	4687	0	0
1	4646	41	328
2	4603	84	672
3	4559	128	**1024**
4	4516	171	**1368**
5	4474	213	1704
6	4430	257	2056
7	4388	299	2392
8	4344	343	2744
9	4302	385	3080
10	4258	429	3432
11	4216	471	3768
12	4173	514	4112
13	4130	557	4456
14	4087	600	4800
15	4044	643	5144

Table 22: Economic injury level for rice stemborer on Pusa Basmati-1 at 30 DAT as simulated with InfoCrop with control expenditure Rs. 1234 and market price Rs. 10/kg

Percent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Monetary Value of Yield Loss (Rs./ha)
0	4687	0	0
1	4679	8	80
2	4672	15	150
3	4652	35	350
4	4622	65	650
5	4604	83	830
6	4573	114	**1140**
7	4556	131	**1310**
8	4522	165	1650
9	4470	217	2170
10	4431	256	2560
11	4403	284	2840
12	4388	299	2990
13	4368	319	3190
14	4357	330	3300
15	4340	347	3470

Table 23: Economic injury level for rice stemborer on Pusa Basmati-1 at 40 DAT as simulated with InfoCrop with control expenditure Rs. 1234 and market price Rs. 10/kg

Percent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Monetary Value of Yield Loss (Rs./ha)
0	4687	0	0
1	4672	15	150
2	4653	34	340
3	4639	48	480
4	4611	76	760
5	4596	91	**910**
6	4551	136	**1360**
7	4513	174	1740
8	4469	218	2180
9	4438	249	2490
10	4407	280	2800
11	4381	306	3060
12	4356	331	3310
13	4329	358	3580
14	4311	376	3760
15	4291	396	3960

Table 24: Economic injury level for rice stemborer on Pusa Basmati-1 at 50 DAT as simulated with InfoCrop with control expenditure Rs. 1234 and market price Rs. 10/kg

Percent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Monetary Value of Yield Loss (Rs./ha)
0	4687	0	0
1	4666	21	210
2	4649	38	380
3	4611	76	760
4	4601	86	**860**
5	4558	129	**1290**
6	4532	155	1550
7	4489	198	1980
8	4449	238	2380
9	4397	290	2900
10	4358	329	3290
11	4321	366	3660
12	4297	390	3900
13	4279	408	4080
14	4261	426	4260
15	4236	451	4510

Table 25: Economic injury level for rice stemborer on Pusa Basmati-1 at 60 DAT as simulated with InfoCrop with control expenditure Rs. 1234 and market price Rs. 10/kg

Percent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Monetary Value of Yield Loss (Rs./ha)
0	4687	0	0
1	4653	34	340
2	4634	53	530
3	4601	86	860
4	4572	115	**1150**
5	4550	137	**1370**
6	4505	182	1820
7	4463	224	2240
8	4432	255	2550
9	4394	293	2930
10	4366	321	3210
11	4333	354	3540
12	4297	390	3900
13	4266	421	4210
14	4234	453	4530
15	4205	482	4820

Table 26: Economic injury level for rice stemborer on Pusa Basmati-1 at 70 DAT as simulated with InfoCrop with control expenditure Rs. 1234 and market price Rs. 10/kg

Per cent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Monetary Value of Yield Loss (Rs./ha)
0	4687	0	0
1	4654	33	330
2	4622	65	650
3	4590	97	**970**
4	4556	131	**1310**
5	4521	166	1660
6	4484	200	2000
7	4449	238	2380
8	4413	274	2740
9	4378	309	3090
10	4344	343	3430
11	4309	378	3780
12	4275	412	4120
13	4241	446	4460
14	4206	481	4810
15	4172	515	5150

Table 27: Economic injury level for rice stemborer on Pusa Basmati-1 at 80 DAT as simulated with InfoCrop with control expenditure Rs. 1234 and market price Rs. 10/kg

Percent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Monetary Value of Yield Loss (Rs./ha)
0	4687	0	0
1	4646	41	410
2	4603	84	**840**
3	4559	128	**1280**
4	4516	171	1710
5	4474	213	2130
6	4430	257	2570
7	4388	299	2990
8	4344	343	3430
9	4302	385	3850
10	4258	429	4290
11	4216	471	4710
12	4173	514	5140
13	4130	557	5570
14	4087	600	6000
15	4044	643	6430

Table 28: Economic injury levels for rice stemborer as influenced by crop age and monetary value of the crop

Days after transplanting	Economic Injury Levels		
	Market Price Rs. 8/kg	Market Price Rs. 9/kg	Market Price Rs. 10/kg
30	7.5	7.5	6.5
40	6.5	6.0	5.5
50	6.0	5.5	4.5
60	5.5	5.0	4.5
70	4.5	4.5	3.5
80	3.5	3.5	2.5

Table 29: Economic injury levels for rice stemborer as influenced by crop age and control expenditure

Days after transplanting	Control expenditure	
	Two sprays (Rs. 1234)	Three Sprays (Rs. 1851)
30	7.5	9.5
40	6.0	8.5
50	5.5	7.5
60	5.0	7.5
70	4.5	6.5
80	3.5	5.5

respectively with market value of the produce as Rs. 9/kg. With market value of produce as Rs 10/kg, the EILs were 8.5, 7.5, 6.5, 6.0, 5.5 and 4.5 at 30, 40, 50, 60, 70 and 80 DAT, respectively.

4.3.2 Isoloss curves

InfoCrop was run from zero to very high levels of infestation at 30 to 80 DAT to plot isoloss curves. At 30 DAT, 5, 10, 15, 20 and 25% stem borer damage resulted in 9.5, 21, 30.5, 40.5 and 51% yield loss respectively (Table 30) whereas the corresponding yield losses at 40 DAT were 8.5, 18, 25.5, 36.5 and 46.5 respectively (Table 31).

At 50 DAT, 5, 10, 15, 20 and 25% stem borer damage resulted in 8, 15.5, 23, 30.5 and 39.5% yield loss respectively (Table 32) whereas the corresponding yield losses at 60 DAT were 7.5, 14.5, 21.5, 28.5 and 36 respectively (Table 33). At 70 DAT, 6.5, 13.5, 20.5, 27.5 and 34.5% yield loss were caused by 5, 10, 15, 20 and 25% stem borer damage respectively (Table 34) whereas the corresponding yield losses at 80 DAT were 5.5, 11, 16.5, 21.5 and 27.5, respectively (Table 35).

Yield losses simulated corresponding to different combinations of rice stem borer damage and crop age were worked out (Table 36). Isoloss curves which show the combinations of pest damage and crop age resulting in the same yield loss were plotted (Figure 7).

4.4 Establishment of pest - weather modules for rice stem borer

The data on insecticide evaluation trials under the All India Coordinated Rice Improvement Project (AICRIP) were used for the formulation of regression relationships (pest-weather modules).

The results of the regression analysis between weather parameters and stem borer damage are given in Table 37. Preliminary analysis indicated that weather factors during the 2^{nd} lag week were strongly correlated with pest incidence. Maximum temperature (T_{max}), minimum temperature (T_{min}), morning relative humidity (RH_1) and afternoon relative humidity (RH_2) were taken into consideration to develop the regression models (pest-weather modules) at various locations as these factors exhibited relation with the stem borer damage individually.

Table 30: Yield loss simulated with InfoCrop for various levels of rice stemborer damage at 30 DAT in Pusa Basmati-1 during *Kharif* 2005

Percent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Percent yield loss	Percent Damage	Yield (kg/ha)	Yield loss (kg/ha)	Per cent yield loss
0	4687	0	0	26	4079	608	13.0
1	4679	8	0.17	27	4058	629	13.4
2	4672	15	0.31	28	4038	649	13.9
3	4652	35	0.75	29	4017	670	14.3
4	4622	65	1.4	30	3996	691	14.8
5	4604	83	1.8	31	3974	713	15.2
6	4573	114	2.4	32	3948	739	15.8
7	4556	131	2.8	33	3925	762	16.3
8	4522	165	3.5	34	3902	785	16.8
9	4470	217	4.6	35	3878	809	17.3
10	4431	256	5.5	36	3854	833	17.8
11	4403	284	6.1	37	3829	858	18.3
12	4388	299	6.4	38	3804	883	18.8
13	4368	319	6.8	39	3778	909	19.4
14	4357	330	7.0	40	3757	930	19.8
15	4340	347	7.4	41	3725	962	20.5
16	4321	366	7.8	42	3699	988	21.1
17	4300	387	8.3	43	3678	1009	21.5
18	4274	413	8.8	44	3658	1029	22.0
19	4255	432	9.2	45	3636	1051	22.4
20	4242	445	9.5	46	3615	1072	22.9
21	4214	473	10.1	47	3593	1094	23.3
22	4128	559	11.9	48	3572	1115	23.8
23	4120	567	12.1	49	3544	1143	24.4
24	4113	574	12.3	50	3529	1158	24.7
25	4099	588	12.6	51	3515	1172	25.0

Table 31: Yield loss simulated for various levels of rice stemborer damage at 40 DAT in Pusa Basmati-1 using InfoCrop during *Kharif* 2005

Percent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Percent yield loss	Percent Damage	Yield (kg/ha)	Yield loss (kg/ha)	Percent yield loss
0	4687	0	0	24	4044	643	13.7
1	4672	15	0.33	25	4013	674	14.4
2	4653	34	0.73	26	3958	729	15.6
3	4639	48	1.0	27	3930	757	16.1
4	4611	76	1.6	28	3910	777	16.6
5	4596	91	1.9	29	3889	798	17.0
6	4551	136	2.9	30	3875	812	17.3
7	4513	174	3.7	31	3865	822	17.5
8	4469	218	4.6	32	3849	839	17.9
9	4438	249	5.3	33	3818	869	18.6
10	4407	280	6.0	34	3798	889	19.0
11	4381	306	6.5	35	3782	905	19.3
12	4356	316	6.7	36	3759	928	19.8
13	4329	358	7.6	37	3739	948	20.2
14	4311	376	8.0	38	3706	981	20.9
15	4291	396	8.4	39	3686	1001	21.4
16	4265	422	9.0	40	3666	1021	21.8
17	4239	448	9.6	41	3652	1035	22.1
18	4212	475	10.1	42	3624	1035	22.1
19	4188	499	10.6	43	3586	1101	23.5
20	4154	533	11.4	44	3564	1123	24.0
21	4123	564	12.0	45	3554	1133	24.2
22	4089	598	12.8	46	3529	1158	24.7
23	4067	620	13.2	47	3505	1182	25.2

Table 32: Yield loss simulated for various levels of rice stemborer damage at 50 DAT in Pusa Basmati-1 using InfoCrop

Percent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Percent yield loss	Percent Damage	Yield (kg/ha)	Yield loss (kg/ha)	Percent yield loss
0	4687	0	0	21	4044	643	13.7
1	4666	22	0.5	22	4005	682	14.6
2	4649	38	0.8	23	3981	706	15.1
3	4611	76	1.6	24	3944	743	15.9
4	4601	86	1.8	25	3912	775	16.5
5	4558	129	2.8	26	3880	807	17.2
6	4532	155	3.3	27	3848	839	17.9
7	4489	198	4.2	28	3809	878	18.7
8	4449	238	5.1	29	3781	906	19.3
9	4397	290	6.2	30	3758	929	19.8
10	4358	329	7.0	31	3733	954	20.3
11	4321	366	7.8	32	3711	976	20.8
12	4297	390	8.3	33	3663	1050	22.4
13	4279	409	8.7	34	3637	1050	22.4
14	4261	426	9.1	35	3607	1080	23.0
15	4236	451	9.6	36	3583	1104	23.6
16	4206	481	10.3	37	3563	1124	24.0
17	4179	508	10.8	38	3547	1140	24.3
18	4147	540	11.5	39	3524	1163	24.8
19	4119	568	12.1	40	3500	1187	25.3
20	4082	605	12.9				

Table 33: Yield loss simulated for various levels of rice stemborer damage at 60 DAT in Pusa Basmati-1 using InfoCrop

Percent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Per cent yield loss	Per cent Damage	Yield (kg/ha)	Yield loss (kg/ha)	Percent yield loss
0	4687	0	0	20	4029	658	14.0
1	4653	34	0.72	21	3997	690	14.7
2	4634	53	1.1	22	3956	731	15.6
3	4601	86	1.8	23	3934	753	16.1
4	4572	115	2.5	24	3899	788	16.8
5	4550	137	2.9	25	3864	823	17.6
6	4505	182	3.9	26	3828	859	18.3
7	4463	224	4.8	27	3796	891	19.0
8	4432	255	5.4	28	3760	927	19.8
9	4394	293	6.3	29	3724	963	20.6
10	4352	335	7.1	30	3682	1005	21.4
11	4314	373	7.9	31	3653	1034	22.1
12	4292	395	8.4	32	3609	1078	23.0
13	4266	421	9.0	33	3569	1118	23.9
14	4234	453	9.7	34	3539	1148	24.5
15	4205	482	10.3	35	3531	1156	24.7
16	4164	523	11.2	36	3511	1176	25.1
17	4137	550	11.7	37	3482	1205	25.7
18	4101	586	12.5	38	3455	1232	26.3
19	4067	620	13.2				

Table 34: Yield loss simulated for various levels of rice stemborer damage at 70 DAT in Pusa Basmati-1 using InfoCrop

Percent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Per cent yield loss	Per cent Damage	Yield (kg/ha)	Yield loss (kg/ha)	Per cent yield loss
0	4687	0	0	18	4068	619	13.2
1	4651	36	0.77	19	4033	654	13.9
2	4622	65	1.4	20	3999	688	14.7
3	4590	97	2.1	21	3965	722	15.4
4	4556	131	2.8	22	3930	757	16.1
5	4521	166	3.5	23	3896	791	16.9
6	4484	203	4.3	24	3861	826	17.6
7	4449	238	5.1	25	3828	859	18.3
8	4413	274	5.9	26	3793	894	19.1
9	4378	309	6.6	27	3759	928	19.8
10	4344	343	7.3	28	3725	962	20.5
11	4309	378	8.1	29	3690	997	21.3
12	4275	412	8.8	30	3656	1031	22.0
13	4241	446	9.5	31	3621	1066	22.7
14	4206	481	10.3	32	3587	1100	23.5
15	4172	515	11.0	33	3553	1134	24.2
16	4137	550	11.7	34	3519	1168	24.9
17	4102	585	12.5	35	3485	1202	25.7

Table 35: Yield loss simulated for various levels of rice stemborer damage at 80 DAT in Pusa Basmati-1 using InfoCrop

Percent Damage	Yield (kg/ha)	Yield Loss (kg/ha)	Per cent yield loss	Percent Damage	Yield (kg/ha)	Yield loss (kg/ha)	Percent yield loss
0	4687	0	0	15	4044	643	13.7
1	4646	41	0.88	16	4001	686	14.6
2	4603	84	1.8	17	3958	729	15.6
3	4559	128	2.7	18	3915	772	16.5
4	4516	171	3.7	19	3872	815	17.4
5	4474	213	4.6	20	3829	858	18.3
6	4430	257	5.5	21	3786	901	19.2
7	4388	299	6.4	22	3742	945	20.2
8	4344	343	7.3	23	3700	987	21.1
9	4302	385	8.2	24	3656	1031	22.0
10	4258	429	9.2	25	3614	1073	22.9
11	4216	471	10.1	26	3570	1117	23.8
12	4173	514	11.0	27	3528	1159	24.7
13	4130	557	11.9	28	3484	1203	25.7
14	4087	600	12.8	29	3442	1245	26.6

Table 36: Pest damage simulated for Pusa Basmati 1 using InfoCrop for various levels of yield losses at given crop growth stages

At days after transplanting	To record yield loss (%)				
	5	10	15	20	25
	Required pest damage (%)				
30	9.5	21	30.5	40.5	51
40	8.5	18	25.5	36.5	46.5
50	8	15.5	23	30.5	39.5
60	7.5	14.5	21.5	28.5	36
70	6.5	13.5	20.5	27.5	34.5
80	5.5	11	16.5	21.5	27.5

Table 37: Yellow stem borer damage-weather modules developed for AICRIP centres

Station	Intercept	Regression Coefficients					R^2
		T_{max}	T_{min}	T_{avg}	RH_1	RH_2	
Aduthurai	57.508	-0.864	-	-	-	-0.331	0.513
Coimbatore	156.518	-	-3.509	-	-0.785	-	0.622
Pattambi	43.483	-	-0.418	-	-0.283	-	0.515
Warangal	-66.849	2.102	-	-	0.095	-	0.673
Karjat	87.662	-	2.133	-	-1.351	-	0.554
Faizabad	200.990	-	-	-2.716	-1.185	-	0.627

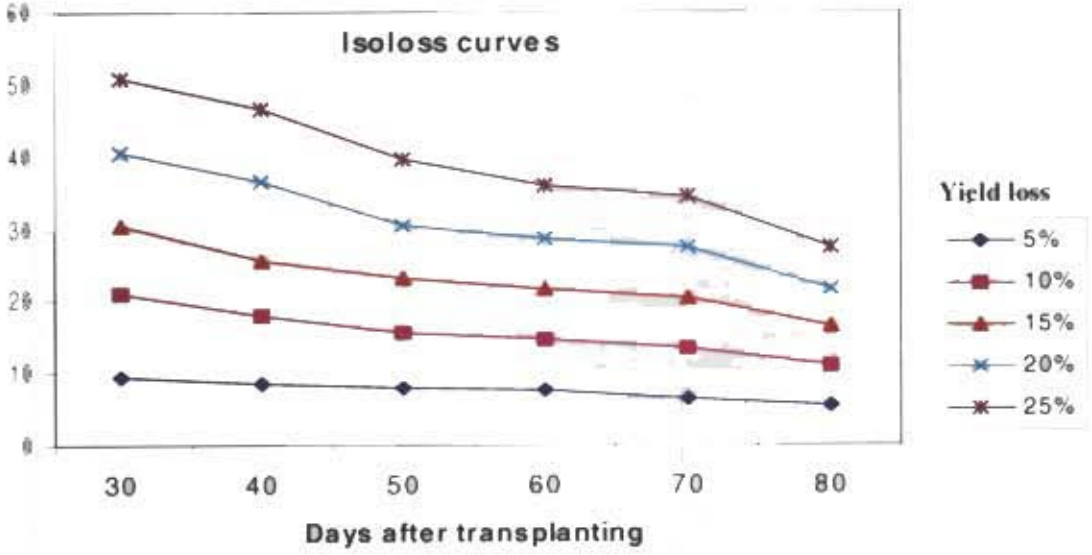


Figure 7: Isoloss curves for rice stem borer in Pusa Basmati-1 simulated using InfoCrop

The data on stem borer damage recorded at Aduthurai, Tamil Nadu along with the corresponding weather parameters *viz.* mean values of maximum temperature, minimum temperature and relative humidity during 8 to 15 days (2^{nd} lag week) prior to the observation of damage are presented in Table 39. The lowest level of damage (1.8%) was observed during *Kharif* 2004 while the highest damage (12.7%) was during *Kharif* 2000. On an average 8.4% dead hearts were recorded on untreated plots in Aduthurai. Mean maximum temperature for 8-15 days lag period (2^{nd} lag week) varied from 26.8 to 35.8°C whereas the mean minimum temperature ranged from 17.4 to 25.7°C. The mean morning relative humidity (RH_1) recorded at Aduthurai during the period varied from 69.8 to 95.9% while the mean afternoon relative humidity (RH_2) was observed to be from 43.1 to 84.3%. The pest-weather module for Aduthurai involving all four weather parameters (T_{max}, T_{min}, RH_1, RH_2) factors was established as:

$$DH = 20.050 - 0.782\ T_{max} + 0.580\ T_{min} + 0.317\ RH_1 - 0.422\ RH_2$$

Further stepwise regression indicated that maximum temperature (T_{max}) and afternoon relative humidity (RH_2) were the most important factors influencing the stem borer damage. The final pest-weather module thus developed between percent dead hearts (DH) and T_{max} and RH_2 was as:

$$DH = 57.508 - 0.864\ T_{max} - 0.331\ RH_2 \qquad (R^2 = 0.513)$$

Maximum temperature and RH_2 thus accounted for more than 51% variation in DH incidence. Regression coefficients for T_{max} and RH_2 were -0.864 and -0.331 respectively with an intercept of 57.508 (Table 40).

Table 41 shows the data on stem borer damage recorded at Coimbatore, Tamil Nadu along with the corresponding weather parameters. The lowest level of damage (2.2%) was observed on *Kharif* 2000 while the highest (31.1%) on *rabi* 1990. The mean percent dead hearts observed at Coimbatore was 13.7. The mean maximum temperature for 8-15 days lag period (2^{nd} lag week) varied from 28.6 to 36.7°C while the mean minimum temperature ranged from 17.4 to 23.6°C. The mean morning relative humidity recorded at Coimbatore during the period varied from 71 to 92% while the mean afternoon relative humidity was observed to be from 27 to

Table 38: Multiple linear regressions between per cent deadhearts and weather at AICRIP centres

Station	Intercept	Regression Coefficients				R^2
		T_{max}	T_{min}	RH_1	RH_2	
Aduthurai	20.050	-0.782	0.580	0.317	-0.422	66.0
Coimbatore	184.922	-1.534	-1.586	-0.701	-0.604	81.3
Pattambi	60.144	-1.209	0.377	-0.061	-0.288	74.0
Warangal	-61.057	1.792	0.404	0.103	-0.090	75.9
Faizabad	166.296	-1.128	-1.104	-1.300	0.420	82.7
Karjat	136.117	-0.783	1.904	-1.569	-	63.7

Table 39: Incidence of rice stem borer and weather factors during different years at Aduthurai

Year	Season	Deadhearts (%)	$T_{max.}$ (°C)	$T_{min.}$ (°C)	RH_1	RH_2
1991	*Kharif*	10.9	34.9	25.6	70.1	43.1
1992	*Kharif*	10.9	33.9	24.6	83.4	60.0
1998	*Kharif*	6	34.5	25.2	85.3	63.7
2000	*Kharif*	12.7	35.5	25.5	82.6	51.9
2000	*Rabi*	7.6	28.7	21.6	94.6	70.7
2001	*Kharif*	8.5	33.7	23.3	89.0	69.4
2002	*Kharif*	12.6	34.2	25.0	80.4	55.8
2002	*Rabi*	8.5	26.8	22.4	95.4	84.3
2003	*Rabi*	11	30.2	18.4	95.9	62.6
2004	*Kharif*	1.8	33.6	25.1	84.7	68.4
2004	*Kharif*	6.3	35.8	24.6	79.0	57.0
2004	*Rabi*	7	30.0	21.7	93.4	77.4
2004	*Rabi*	10.3	29.8	17.4	93.6	62.4
2005	*Kharif*	4.6	35.1	25.7	69.8	59.7
2005	*Rabi*	3.6	29.1	21.0	88.3	79.9
2005	*Rabi*	12	31.6	19.5	93.3	55.9

Table 40: Multiple linear regression between percent deadhearts and weather factors *viz* maximum temperature and evening relative humidity at Aduthurai, Tamil Nadu.

Model summary	R^2	**Predictors**	**Coefficients**	**Std. error**	**t**	**Significance**
F=6.857**		Constant	57.508 (a)	15.750	3.651	.003
	0.513	(intercept)				
d.f.= 2, 13		T_{max}	-.864 (b_1)	0.340	-2.545	.024
Sig = .009		RH_2	-.331(b_2)	0.090	-3.690	.003

Table 41: Incidence of rice stem borer and weather factors during different years at Coimbatore

Year	Season	Dead heart (%)	T_{max} (°C)	T_{min} (°C)	RH_1	RH_2
1990	*Rabi*	31.1	35.7	20.6	75	27
1991	*Kharif*	12.3	29.7	23.2	78	63
1991	*Kharif*	7.3	31.6	21.8	85	51
1991	*Rabi*	15	36.7	23.4	78	31
1993	*Kharif*	8.6	32.5	22.4	83	52
2000	*Kharif*	2.2	32.7	22.6	92	53
2001	*Kharif*	6.3	30.4	22.7	81	56
2002	*Kharif*	15.9	32.8	21.1	88	41
2002	*Kharif*	14.9	34.1	23.1	86	41
2002	*Rabi*	6.3	35.5	23.6	89	44
2003	*Rabi*	15.4	34.4	20.6	89	28
2003	*Kharif*	11.3	31.8	24.5	71	55
2004	*Kharif*	14.3	28.6	18.2	90	56
2004	*Kharif*	29.7	29.7	17.4	89	37
2005	*Rabi*	17.1	35.1	21.9	88	35
2005	*Kharif*	8.6	31.6	23	84	53
2005	*Kharif*	16.6	29.6	24.2	74	63

63%. The pest-weather module based on the four weather parameters (T_{max}, T_{min}, RH_1, RH_2) was:

$$DH = 184.922 - 1.534\ T_{max} - 1.586\ T_{min} - 0.701\ RH_1 - 0.604\ RH_2$$

Stepwise regression revealed the minimum temperature (T_{min}) and morning relative humidity (RH_1) to be the most important factors affecting stem borer damage at Coimbatore, Tamil Nadu. Correlation coefficient (r) and coefficient of determination (R^2) were 0.789 and 62.2%, respectively. The regression coefficients for T_{min} and RH_1 were -3.509 and -0.785 respectively with an intercept of 156.518 (Table 42). The final pest-weather module for stem borer damage at Coimbatore was found to be:

$$DH = 156.518 - 3.509\ T_{min} - 0.785\ RH_1 \qquad (R^2 = 62.2\%)$$

The data on stem borer damage recorded at Pattambi, Kerala along with the corresponding weather parameters are given in Table 43. The lowest level of damage (3%) was observed during *Kharif* 2005 while the highest damage (16.8%) was during rabi 2001. On an average 9.4% dead hearts were recorded on untreated plots in Pattambi. Mean maximum temperature for 8-15 days lag period (2^{nd} lag week) varied from 26.9 to 34°C whereas the mean minimum temperature ranged from 18.3 to 23.8°C. The mean morning relative humidity recorded at Pattambi during the period varied from 66.8 to 96.1% while the mean afternoon relative humidity was found to be 33.6 to 82.3%. The pest-weather module encompassing the four weather parameters (T_{max}, T_{min}, RH_1, RH_2) was established to be:

$$DH = 60.144 - 1.209\ T_{max} + 0.377\ T_{min} - 0.061\ RH_1 - 0.288\ RH_2$$

Further stepwise linear regression at Pattambi, Kerala indicated that minimum temperature and morning relative humidity were the most important weather parameters contributing to stem borer damage. Correlation coefficient (r) and coefficient of determination (R^2) were 0.718 and 51.5%, respectively. The regression coefficients for T_{min} and RH_1 were -0.418 and -0.283, respectively with an intercept of 43.483 (Table 44). The resulting pest-weather module for stem borer damage at Pattambi was found to be:

$$DH = 43.483 - 0.418\ T_{min} - 0.283\ RH_1 \qquad (R^2 = 51.5\%)$$

Table 42: Multiple linear regression between per cent deadhearts and weather factors *viz* minimum temperature and morning relative humidity at Coimbatore, Tamil Nadu

Model summary	R^2	Predictors	Coefficients	Std. error	t	Significance
F=11.526**	0.622	Constant (intercept)	156.518 (a)	31.331	4.996	.000
d.f.= 2, 14		T_{min}	-3.509 (b_1)	0.753	-4.663	.000
Sig = .001		RH_1	-.785 (b_2)	0.232	-3.388	.004

Table 43: Incidence of rice stem borer damage and weather factors during different years at Pattambi

Year	Season	Deadhearts (%)	T_{max} (°C)	T_{min} (°C)	RH_1 (%)	RH_2 (%)
1990	*Kharif*	8.4	28	22.2	93.8	73.6
1990	*Kharif*	13.9	26.9	23.7	82.1	62.1
1993	*Kharif*	5.3	29.6	21.4	94.6	72.7
1994	*Rabi*	9.2	31.7	18.3	86	43.9
1997	*Kharif*	7	28.9	23.2	95.3	68.5
1997	*Rabi*	10.2	32.2	20.6	82.3	52.9
1998	*Rabi*	4.8	32.5	23.6	89.4	61.3
1998	*Rabi*	9.9	34	21.2	93.9	41
2001	*Kharif*	9.5	31.5	22.8	95	57.1
2001	*Rabi*	16.8	33.2	20.7	75.9	36.6
2002	*Kharif*	6	28.2	23.2	96.1	82.3
2002	*Kharif*	8.3	30.9	23.8	94	64.1
2002	*Rabi*	8.9	32.5	22.9	81	45.2
2003	*Rabi*	9.8	32.9	18.9	88.8	33.6
2003	*Rabi*	13.1	33	22.6	66.8	36.4
2003	*Kharif*	7.8	30	23.1	94	70.9
2004	*Rabi*	15.3	33.2	21.5	86	37
2005	*Rabi*	11.7	33.3	22.1	77	36.6
2005	*Kharif*	3	29.8	24	94.6	80.6

Table 44: Multiple linear regression between percent deadhearts and weather factors viz. minimum temperature and morning relative humidity at Pattambi, Kerala

Model summary	R^2	Predictors	Coefficients	Standard error	t	Significance
F=8.493**		Constant	43.483 (a)	9.907	4.389	.000
	0.515	(intercept)				
d.f.= 2, 16		T_{min}	-.418 (b_1)	0.396	-1.056	0.307
Sig = .003		RH_1	-.283 (b_2)	0.077	-3.682	0.002

Table 45 shows the data on stem borer damage recorded at Warangal, Andhra Pradesh along with the corresponding weather parameters. The lowest level of damage (4.2%) was observed during rabi 2000 while the highest damage (19.1%) occurred during rabi 2003. The mean percent dead heart damage was observed to be 8.5 at Warangal. The mean maximum temperature for 8-15 days lag period (2^{nd} lag week) varied from 29.3 to 35.1°C while the mean minimum temperature ranged between 13.4 and 25.4°C. The mean morning relative humidity varied from 61 to 99% while the mean afternoon relative humidity ranged from 38 to 79%. The pest-weather module based on the four weather parameters (T_{max}, T_{min}, RH_1, RH_2) at Warangal was:

$$DH = -61.057 + 1.792 + 0.404 + 0.103\ RH_1 - 0.090\ RH_2$$

Further stepwise regression indicated that maximum temperature (T_{max}) and morning relative humidity (RH_1) were the most important factors affecting stem borer damage at Warangal, Andhra Pradesh. Correlation coefficient (r) and coefficient of determination (R^2) were 0.82 and 67.3%, respectively. The regression coefficients for T_{max} and RH_1 were 2.102 and 0.095, respectively with an intercept of -66.849 (Table 46). The final pest-weather module stem borer damage at Warangal was established as:

$$DH = -66.849 + 2.102\ T_{max} + 0.095\ RH_1 \qquad (R^2 = 67.3\%)$$

The data on stem borer damage recorded at Karjat, Maharashtra along with the corresponding weather parameters are given in Table 47. The lowest level of damage (3%) was observed during rabi 2003 while the highest damage (30.8%) was observed during *Kharif* 2000. On an average 12.4% dead hearts were recorded on untreated plots in Karjat. Mean maximum temperature for 8-15 days lag period (2^{nd} lag week) was found to be 26.8 to 38.8 °C whereas the mean minimum temperature varied from 11.3 to 23.9°C. The mean morning relative humidity varied from 76.1 to 96.1%. Data on afternoon relative humidity was not available for this station. The pest-weather module based on three weather parameters (T_{max}, T_{min}, RH_1) at Karjat was found to be:

Karjat: $$DH = 136.117 - 0.783\ T_{max} + 1.904\ T_{min} - 1.569\ RH_1$$

Stepwise regression further revealed that minimum temperature and morning relative humidity were the most important weather parameters contributing to stem

Table 45: Incidence of rice stem borer damage and weather factors during different years at Warangal

Year	Season	Deadhearts (%)	T_{max} (°C)	T_{min} (°C)	RH_1 (%)	RH_2 (%)
1991	*Rabi*	9	33.8	20.6	70.8	47.5
1993	*Kharif*	4.6	32.2	24.8	78	73
1995	*Kharif*	7.6	31	23.9	88	77
1995	*Kharif*	9.2	32.2	25.4	83	79
1997	*Kharif*	5.5	31.8	13.4	90	63
1998	*Rabi*	10.6	33.5	23.1	86	63
2000	*Rabi*	4.2	30.8	20.4	95	64
2000	*Kharif*	7.7	31.4	24	78	72
2001	*Kharif*	8.7	32.2	24.3	97	73
2001	*Rabi*	9.7	34.4	20.6	61	53
2002	*Kharif*	7.9	31.2	24.8	94	74
2002	*Kharif*	16.1	34.1	24	82	59
2002	*Rabi*	5.2	29.7	19.6	89	51
2003	*Rabi*	8.8	31.6	20.8	99	51
2003	*Rabi*	19.1	35.1	22.4	87	38
2003	*Kharif*	8.2	31.2	23.9	88	60
2005	*Rabi*	4.9	29.3	20.3	74.6	60
2005	*Rabi*	6.8	31.7	21.5	77.5	38

Table 46: Multiple linear regression between per cent deadhearts and weather factors *viz* maximum temperature and morning relative humidity at Warangal, Andhra Pradesh

Model summary	R^2	Predictors	Coefficients	Std. error	t	Significance
F=15.435***		Constant	-66.849 (a)	14.675	-4.555	.000
	0.673	(intercept)				
d.f.= 2, 15		T_{max}	2.102 (b_1)	.379	5.549	.000
Sig = .000		RH_1	.095 (b_2)	.061	1.554	0.141

Table 47: Incidence of rice stem borer damage and weather factors during different years at Karjat

Year	Season	Deadhearts (%)	T_{max} (°C)	T_{min} (°C)	RH_1 (%)
1990	*Kharif*	5.3	26.9	23.4	95.6
1990	*Kharif*	12.9	28.5	24	93.4
1991	*Kharif*	16.1	28.9	23.5	93.1
1992	*Kharif*	11.7	27.6	23.9	96.1
1994	*Rabi*	16.7	38.8	22.6	86.2
1997	*Rabi*	5.7	33.51	13.49	85.7
1998	*Rabi*	12	31.5	11.3	79.6
2000	*Kharif*	30.8	30.7	24	88.8
2001	*Rabi*	6.4	35.9	16	85.1
2002	*Kharif*	20.7	27.1	23.9	86.8
2002	*Kharif*	30.3	26.8	23.7	83
2003	*Rabi*	3	37.9	12.1	76.1
2003	*Kharif*	4.3	28.3	24.2	97
2004	*Kharif*	6.3	27	24.3	93.7
2005	*Rabi*	3.2	38.2	18.7	84.1

borer damage at Karjat. Correlation coefficient (r) and coefficient of determination were (R^2) 0.744 and 55.4%, respectively. The regression coefficients for T_{min} and RH_1 were 2.133 and -1.351, respectively with an intercept of 87.662 (Table 48). The resulting pest-weather module for stem borer damage at Karjat was:

$$DH = 87.662 + 2.133\ T_{min} - 1.351\ RH_1 \qquad (R^2 = 55.4\%)$$

Table 49 shows the data on stem borer damage recorded at Faizabad, Uttar Pradesh along with the corresponding weather parameters. The lowest level of damage (7%) was observed on *Kharif* 2004 while the highest (26.5%) on *Kharif* 1998. The mean percent dead hearts observed at Faizabad was 14. The mean maximum temperature for 8-15 days lag period (2^{nd} lag week) varied from 26.3 to 35.4 °C while the mean minimum temperature ranged from 24.6 to 26.8 °C. The mean morning relative humidity varied from 84.9 to 96.3% while the mean afternoon relative humidity was found to be from 61.7 to 85%. The pest-weather module based on the four weather parameters (T_{max}, T_{min}, RH_1, RH_2) at Faizabad found to be:

$$DH = 166.296 - 1.128\ T_{max} - 1.104\ T_{min} - 1.300\ RH_1 + 0.420\ RH_2$$

Stepwise regression further indicated that mean temperature (T_{avg}) instead of Tmax and Tmin separately and morning relative humidity (RH_1) were found to be the most important factors affecting stem borer damage at Faizabad, Uttar Pradesh. Correlation coefficient (r) and coefficient of determination (R^2) were 0.792 and 62.7% respectively. The regression coefficients for T_{avg} and RH_1 were -2.716 and -1.185, respectively with an intercept of 200.99 (Table 50). The resulting pest-weather module for stem borer damage at Faizabad was established to be:

$$DH = 200.99 - 2.716\ T_{avg} - 1.185\ RH_1 \qquad (R^2 = 62.7\%)$$

The combination of weather factors responsible for different levels of stem borer incidence in a state were based on the assumption that the observations recorded at selected stations within the state represented the whole state. These modules can be used for predicting stem borer damage for a particular area within the state with the projected values of weather variables.

Table 48: Multiple linear regression between per cent deadhearts and weather factors *viz* minimum temperature and morning relative humidity at Karjat, Maharashtra

Model summary	R^2	Predictors	Coefficients	Std. error	t	Significance
F=7.441**	0.554	Constant (intercept)	87.662 (a)	30.127	2.910	.013
d.f.= 2, 12		T_{min}	2.133 (b_1)	0.555	3.842	0.002
Sig = .008		RH_1	-1.351 (b_2)	0.429	-3.150	0.008

Table 49: Incidence of rice stem borer damage and weather factors during different years at Faizabad

Year	Season	Deadhearts (%)	T_{max} (°C)	T_{min} (°C)	RH_1 (%)	RH_2 (%)
1995	*Kharif*	12.7	32.4	26.4	94.4	78.9
1995	*Kharif*	13.2	31	26.2	90.6	76.4
1997	*Kharif*	14.2	32.5	25.5	87.9	73.9
1998	*Kharif*	21.4	30.1	25.9	91.3	80.9
1998	*Kharif*	26.5	31.3	25.7	84.9	80
2000	*Kharif*	11.2	33.4	25.4	90.4	73
2000	*Kharif*	13.2	31.1	24.6	96.3	85
2001	*Kharif*	19.3	32.4	26.4	87.9	76.1
2001	*Kharif*	21.8	32.6	25	89	76.3
2002	*Kharif*	15.3	33.6	26.3	90	71.1
2002	*Kharif*	14.1	26.3	25.7	93.6	64.3
2003	*Kharif*	9	34.8	26.6	93.6	75.6
2003	*Kharif*	9	32.9	26.3	93.1	74.9
2004	*Kharif*	7	33.8	26.8	92.3	72
2004	*Kharif*	7.8	35.4	25.9	90.3	61.7
2005	*Kharif*	10.8	33.7	26.5	89	67.7
2005	*Kharif*	12.1	34.9	27.1	86.9	68.6

Table 50: Multiple linear regression between per cent deadhearts and weather factors *viz* minimum temperature and morning relative humidity at Faizabad, Uttar Pradesh

Model summary	R^2	Predictors	Coefficients	Std. error	t	Significance
F=11.785**		Constant	200.990 (a)	38.65	5.201	.000
	0.627	(intercept)				
d.f.= 2, 14		Tavg	-2.716(b1)	.723	-3.756	0.002
Sig = .001		RH_1	-1.185(b2)	.305	-3.887	0.002

4.5 Agro-ecological zonation for rice stem borer

Agro-ecological zonation for rice stem borer was done for the states of Tamil Nadu, Kerala and Andhra Pradesh by extrapolating the pest-weather modules developed at different stations in these states, using Geographical Information System (GIS).

Four classes of the stem borer infestation *viz.* severe (more than 15% dead hearts), high (10 to 15% dead hearts), moderate (5 to 10% dead hearts) and low (less than 5% dead hearts) were considered for ecological zonation purpose. The range of temperature and relative humidity which resulted in these four levels of stem borer infestation were determined through the pest-weather modules developed at different locations (Table 51).

The pest-weather module developed for Coimbatore was used for agro-ecological zonation for Tamil Nadu. Minimum temperature and morning relative humidity were the most important factors contributing to stem borer damage at Coimbatore. Minimum temperature less than 22°C and a morning relative humidity less than 73% were found to be associated with severe infestation of stem borer. The weather conditions favourable for high (10 to 15%) infestation were minimum temperature of 22 to 25°C and morning relative humidity of 73 to 79%. Within the same range of humidity a minimum temperature range of 25 to 27°C resulted in moderate (5 to 10%) level of infestation whereas minimum temperature greater than 27°C and morning relative humidity greater than 79% were found to be least conducive for stem borer damage.

Normal values of minimum temperature and morning relative humidity for *Kharif* season recorded at weather stations across Tamil Nadu are given in table 52. The minimum temperature varied from 10.5 to 26.2°C while the morning relative humidity ranged from 64.6 to 86.6%. The weather stations with their corresponding data on temperature and relative humidity were located on digitized and georeferenced map of Tamil Nadu. The pest-weather module indicating the set of weather conditions was then used to carve out zones of equal epidemic potential on the map (Figure 8). Most of the districts in the south-western part of the state were found to be highly prone to stem borer damage (more than 15%) while moderate (5 to 10%) infestation was shown for the coastal areas in northern Tamil Nadu. The

Table 51: Rice stemborer damage-weather module for Tamil Nadu

Classes	Per cent damage	Range of weather	
		T_{min} (°C)	RH_1 (%)
Severe	>15	<22	<73
High	10 – 15	22 – 25	73 – 79
Moderate	5 – 10	25 – 27	73 – 79
Low	<5	>27	>79

Table 52: Normal values of minimum temperature and morning relative humidity for *Kharif* season recorded at weather stations across Tamil Nadu along with the corresponding latitude and longitude (Anonymous, 1990).

ID	Station	Latitude	Longitude	T_{min} (°C)	RH_1 (%)
1	Adiramapatinam	10° 20'	79° 23'	25.4	72.6
2	Aduthurai	11° 01'	79° 28'	25.5	77.0
3	Chennai	13° 04'	80° 15'	25.6	72.8
4	Coimbatore	11° 00'	76° 58'	22.0	79.2
5	Coonoor	11° 21'	76° 48'	14.0	70.6
6	Cuddalore	11° 46'	79° 46'	25.2	73.0
7	Kallakkurichi	11° 44'	78° 58'	24.8	74.2
8	Kanyakumari	08° 05'	77° 30'	24.0	78.2
9	Kodaikanal	10° 14'	77° 28'	11.3	81.6
10	Kovilpatti	09° 10'	77° 52'	24.9	70.7
11	Madurai	09° 05'	78° 05'	24.8	64.6
12	Mettur Dam	11° 48'	77° 49'	24.0	72.0
13	Palayamkottai	08° 44'	77° 45'	25.9	61.6
14	Pamban	09° 16'	79° 18'	26.2	79.2
15	Parangipettai	11° 30'	79° 46'	24.3	73.6
16	Salem	11° 39'	78° 10'	23.5	76.0
17	Tiruchirappalli	10° 46'	78° 43'	25.3	67.8
18	Tirupattur	12° 29'	78° 34'	22.7	84.4
19	Tondi	09° 44'	79° 02'	25.3	73.2
20	Tuticorin	08° 48'	78° 09'	25.8	62.2
21	Uthagamandalam	11° 24'	76° 44'	10.5	86.6
22	Vedaranniyam	10° 22'	79° 51'	25.0	66.4
23	Vellore	12° 55'	79° 09'	24.5	71.2

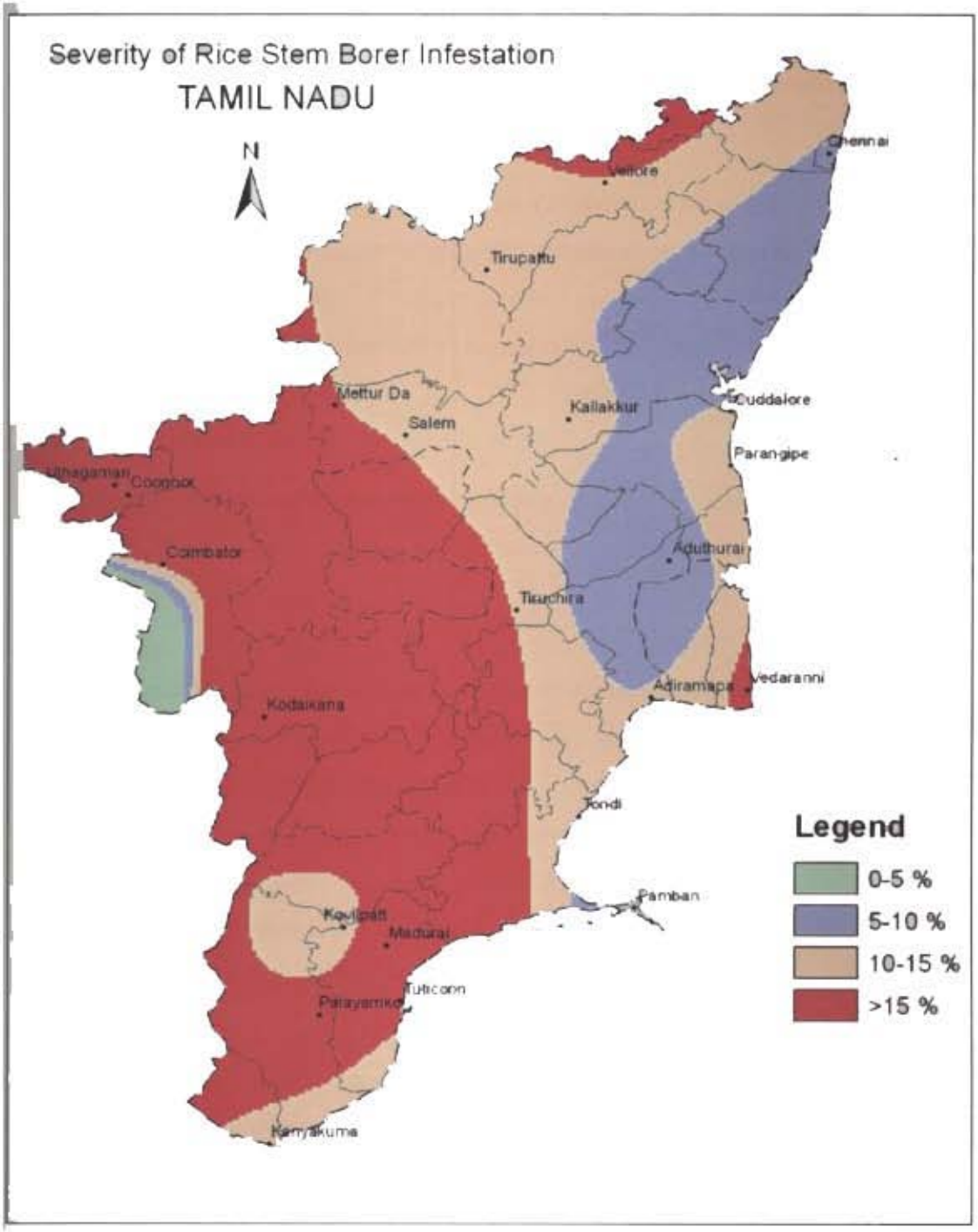


Figure 8 Agro-ecological zonation for rice stem borer infestation in Tamil Nadu

high altitude areas bordering Kerala were least favourable for the pest whereas high (10 to 15%) level of infestation was revealed for rest of the state.

Agro-ecological zonation for Kerala was done based on the pest-weather module developed for Pattambi. Minimum temperature less than 11°C and morning relative humidity less than 90% were associated with severe stem borer infestation at Pattambi. Within the same range of humidity minimum temperature of 11 to 18°C led to high (10 to 15%) levels of infestation while morning relative humidity greater than 90% was found not favourable for the pest infestation. Minimum temperature of 18 to 24°C resulted in moderate (5 to 10%) damage whereas greater than 24°C resulted in low (less than 5%) damage (Table 53).

Normal values of minimum temperature and morning relative humidity for *Kharif* season recorded at weather stations across Kerala are given in table 54. The minimum temperature varied from 22.5 to 23.8°C while the morning relative humidity ranged from 86.6 to 95.2%. The weather stations with their corresponding data on normal values of temperature and relative humidity were located on digitized and georeferenced map of Kerala. The pest-weather module indicating the set of weather conditions was then used to carve out zones of equal epidemic potential on the map. Most of the districts in Kerala were shown to be moderately prone to stem borer infestation (Figure 9). The southern coastal areas and the northern high altitude areas adjoining Karnataka had conditions least favourable for the pest. The high altitude areas in southern Kerala were highly favourable for stem borer damage.

The pest-weather module developed for Warangal was used for agro-ecological zonation for Andhra Pradesh. Maximum temperature and morning relative humidity were the most important factors contributing to stem borer damage. Maximum temperature greater than 35°C and a morning relative humidity greater than 82% were found to be associated with severe infestation of the stem borer while the weather conditions favourable for high (10 to 15%) infestation were maximum temperature of 33 to 35°C and morning relative humidity of 78 to 82%. With 78-82% morning relative humidity, a maximum temperature range of 31 to 33°C caused moderate (5 to 10%) infestation but maximum temperature less than 31°C and morning relative humidity less than 78% were found to be least conducive for stem borer damage (Table 55).

Table 53: Rice stemborer damage-weather module for Kerala

Classes	Per cent damage	Range of weather	
		T_{min} (°C)	RH_I (%)
Severe	>15	<11	<90
High	10 – 15	11 – 18	<90
Moderate	5 – 10	18 – 24	>90
Low	<5	>24	>90

Table 54: Normal values of minimum temperature and morning relative humidity for *Kharif* season recorded at weather stations across Kerala along with the corresponding latitude and longitude

ID	Station	Latitude	Longitude	T_{min} (°C)	RH_1 (%)
1	Alappuzha	09° 33'	76° 25'	23.7	89.4
2	Fort Cochin	09° 58'	76° 14'	23.8	86.6
3	Kasargode	12° 30'	75° 00'	23.2	93.2
4	Kayamkulam	09° 10'	76° 30'	23.7	94.4
5	Kochi	09° 57'	76° 16'	23.8	87.8
6	Kottayam	09° 34'	76° 31'	23.0	91.6
7	Kozhikode	11° 15'	75° 47'	23.7	89.4
8	Ollukkara	10° 28'	76° 13'	23.4	93.6
9	Palakkad	10° 46'	76° 39'	22.9	89.0
10	Pattambi	10° 49'	76° 12'	22.9	95.2
11	Punalur	09° 00'	76° 55'	22.5	92.2
12	Thiruvananthapuram	08° 29'	76° 57'	23.3	87.8
13	Vellayani	08° 28'	76° 55'	23.5	90.8

Table 55: Rice stemborer damage-weather module for Andhra Pradesh

Classes	Per cent damage	Range of weather	
		T_{max} (°C)	RH_1 (%)
Severe	>15	>35	>82
High	10 – 15	33 – 35	78 – 82
Moderate	5 – 10	31 – 33	78 – 82
Low	<5	<31	<78

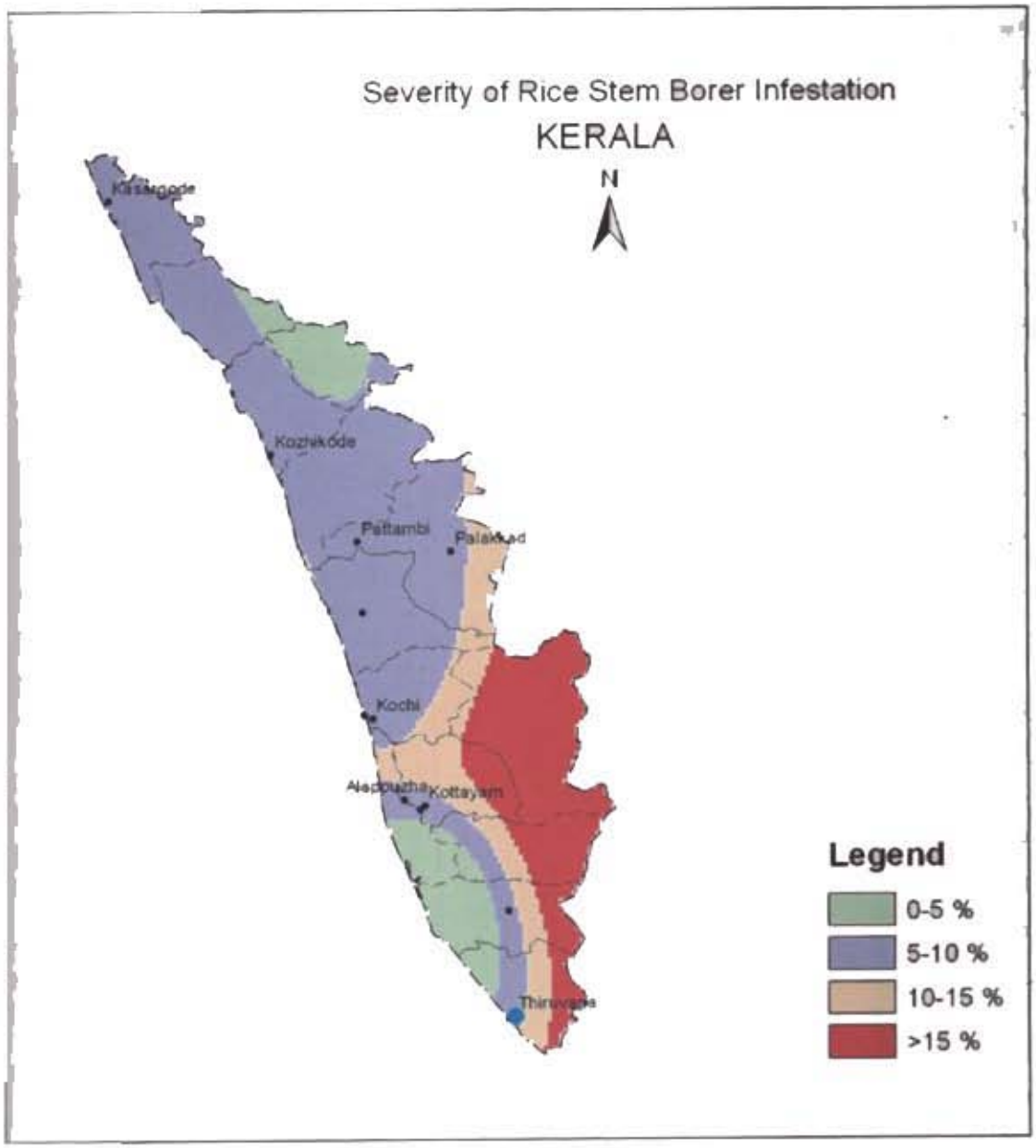


Figure 9: Agro-ecological zonation for rice stem borer infestation in Kerala

Normal values of maximum temperature and morning relative humidity for *Kharif* season recorded at weather stations across Andhra Pradesh are given in table 56. The maximum temperature varied from 31 to 35.1°C while the morning relative humidity ranged from 71.2 to 89.8%. The weather stations with their corresponding data on normal values of temperature and relative humidity were located on digitized and geo-referenced map of Andhra Pradesh. The pest-weather module indicating the set of weather conditions was then used to carve out zones of equal epidemic potential on the map. The GIS map for the state (Figure 10) clearly showed high levels stem borer damage for most of the districts. Low and moderate levels of damage were revealed for western parts of the state and for a few isolated areas in the northern coast. The areas most favourable for stem borer damage were those bordering Orissa.

Agro-ecological zonation carried out for the states were based on the assumption that the observations recorded at selected stations within the state represent the whole state.

Table 56: Normal values of minimum temperature and morning relative humidity for *Kharif* season recorded at weather stations across Andhra Pradesh along with the corresponding latitude and longitude

ID	Station	Latitude	Longitude	T_{max} (°C)	RH_I (%)
1	Hyderabad	17° 27'	78° 28'	31.0	77.8
2	Kakinada	16° 57'	82° 14'	32.9	79.2
3	Kalingapatanam	18° 20'	84° 08'	32.0	84.4
4	Khammam	17° 15'	80° 09'	33.4	79.4
5	Kothagudem	17° 33'	80° 38'	33.2	80.2
6	Kurnool	15° 50'	78° 04'	33.0	75.0
7	Mahbubnagar	16° 45'	78° 00'	31.4	77.4
8	Masulipatnam	16° 10'	81° 7'	32.8	79.4
9	Nandyal	15° 28'	78° 29'	33.9	75.4
10	Nellore	14° 27'	79° 59'	35.1	71.2
11	Nidadavolu	16° 55'	81° 40'	32.6	83.6
12	Nizamabad	18° 40'	78° 06'	32.3	75.0
13	Ongole	15° 34'	80° 03'	34.7	73.0
14	Rajahmundry	16° 58'	81° 46'	33.6	86.4
15	Rajendranagar	17° 19'	78° 22'	32.0	82.4
16	Ramagundam	18° 46'	79° 26	33.5	75.8
17	Rentachintala	16° 33'	79° 33'	34.6	72.4
18	Rudrur	18° 34'	77° 52'	32.5	78.9
19	Samalkot	17° 03'	82° 10'	33.2	89.8
20	Vishakhapatnam	17° 43'	83° 14'	33.0	77.2
21	Warangal	18° 00'	79° 34'	33.5	80.4

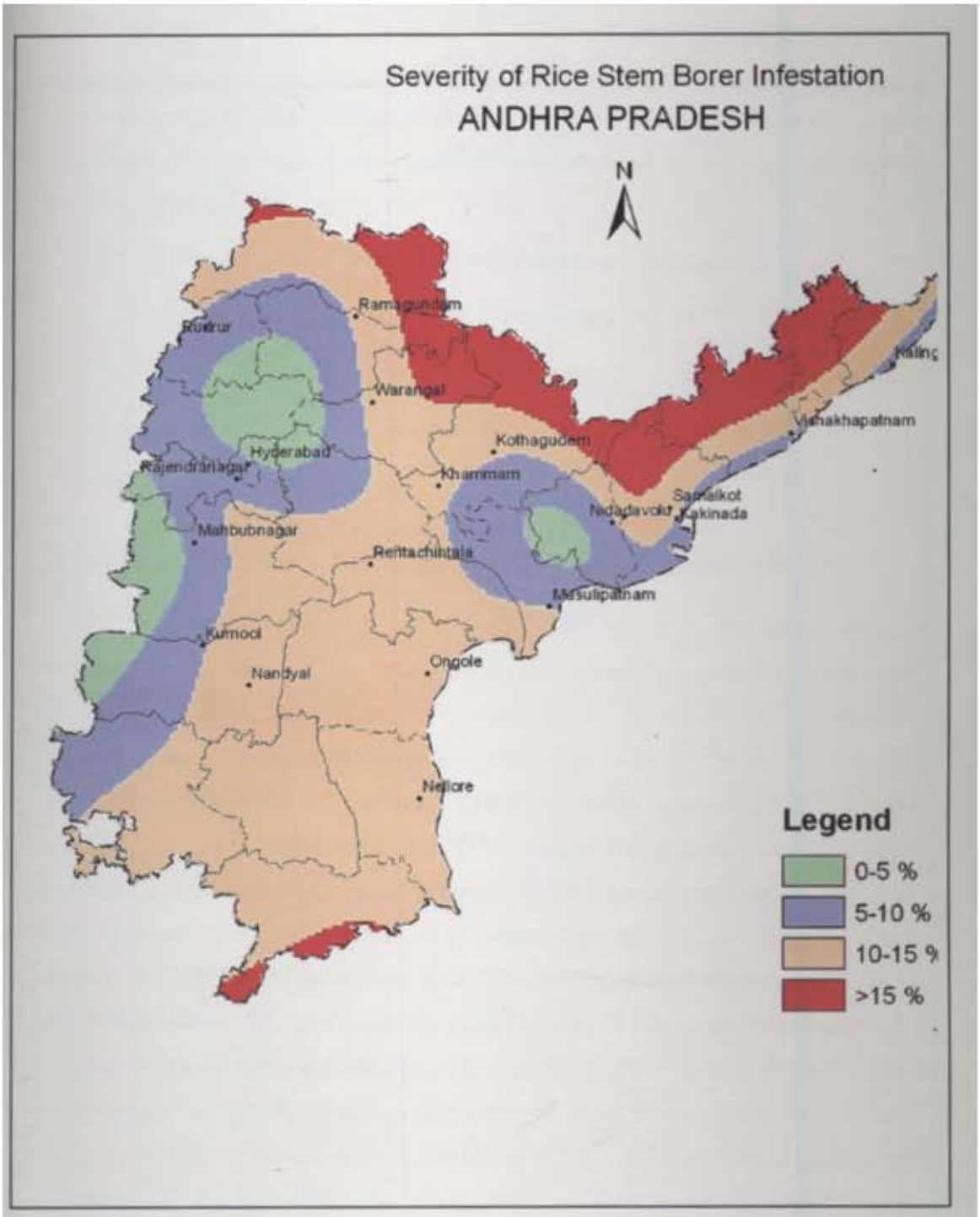


Figure 10: Agro-ecological zonation for rice stem borer infestation in Andhra Pradesh

5. DISCUSSION

The results of the experimental studies on "Modelling yield loss due to rice stem borer and agro-ecological zonation" are discussed in the light of relevant literature under the following heads:

5. 1. Quantification of rice stem borer damage mechanisms

5. 2. Simulation of rice stem borer damage mechanisms

5. 3. Formulation of decision support tools for rice stem borer management

5. 4. Establishment of pest - weather modules for rice stem borer

5. 5. Agro-ecological zonation for rice stem borer

5. 1. Quantification of rice stem borer damage mechanisms

The plant physiological processes affected by pests are called damage mechanisms (Rabbinge *et al.*, 1994). Rice stem borers belong to the category of stand reducers. Field experiments were conducted during *Kharif* 2005 to quantify the damage mechanisms of rice stem borer in Pusa Basmati 1. The yield (dry weight basis) in different detillering treatments of the experiment varied from 3310 to 4558 kg/ha (Table 1), while total dry matter (TDM) ranged between 6312 and 8529 kg/ha (Table 2). The percent yield loss in different detillering treatments varied from 4.32 to 27.38 % whereas percent loss in TDM ranged from 4.7 to 26%. The percent loss in yield and TDM were the highest with 30% detillering after flowering (70 DAT) and the lowest for 10% detillering 40 DAT (Table 3). Percent yield loss was always found to be less than the percent tiller removal. Prasad *et al.* (1992) mimicked stem borer damage in rice by artificial tiller removal at different intensities at various stages of crop growth. Catling *et al.* (1987) observed yield losses due to stem borer in deepwater rice to be 27-34%, where 1% yield loss was associated with 2% damaged stems at harvest.

The study revealed that the same level of detillering resulted in higher yield and dry matter loss with advancing crop age. As 10% detillering 40 DAT resulted in 4.32% yield loss whereas it caused 5.75% and 8.25% yield loss at 50 DAT and 80 DAT, respectively. This happened because rice plants could compensate for the stem borer damage during early growth stages due to production of new tillers (Rubia and

Penning de Vries 1989; Dale 1994). The TDM loss (%) with 10% detillering each at 40, 50 and 70 DAT, and 20% detillering at 70 DAT exceeded the yield loss while for other treatments, it was less than the latter (Table 3). The TDM loss was thus more than the yield loss at lower pest damage indicating that plants compensated the storage organs at the cost of leaves and stems. While at higher pest damage, the extent of compensation for storage organs could not be maintained.

Rubia *et al.* (1990) simulated reduction in rice yield caused by stem borer in irrigated IR 64 and concluded that up to 20% dead hearts at the vegetative stage up to 50 DAT did not cause any significant decrease in grain yield, while damage at the grain filling stage (white heads) caused an almost proportionate yield reduction. In the present study, the 20% detillering at 40 and 50 DAT although resulted in 12.97 and 14.72% yield loss, which was however non significant. Only 30% detillering at 70 DAT inflicted significant loss as compared with healthy crop (Table 8). Pandya *et al.* (1994) estimated losses due to rice stem borer and reported that the influence of white ear heads was much greater than that of dead hearts on yield. Prasad *et al.* (2002) observed more reduction in yield due to detillering at panicle emergence stage than at the vegetative stage because there might not be nay further addition of new effective tillers.

Afzal *et al.* (2002) mimicked stem borer damage by clipping the tillers just before flowering, which is the period of maximum attack and observed significant reduction in grain yield. Daryaei (2003) reported that artificial tiller removal @ 25-50 % at 50 DAT and 70 DAT resulted in 11-27.2 % and 16-30% yield loss, respectively.

A study of the compensation mechanisms in rice crop including increased tillering, increased percentage of productive tillers, and increased grain weight, revealed that assimilates were translocated from stem borer-injured tillers to healthy tillers. There was an increase in the photosynthesis rate of green leaves in stem borer-injured plants (Rubia *et al.*, 1996). This process might differ slightly in detillered plants because natural stem borer infestation kills tillers over a period of time while in detillering, the tillers were removed instantly. However, the assimilates from leftover stub of stem might get translocated to healthy tillers. Energy requirement for healing of cuts might be similar in naturally infested as well as artificially removed tillers a plants have to heal cuts in both cases. According to Taylor (1996), there was little or no correlation between early or mid-season borer infestation and yield and that stem

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density always declined from a pre-flood maximum, irrespective of borer infestation. Late-season infestations, however, could lead to serious crop loss.

5. 2 Simulation of rice stem borer damage mechanisms

A model can be termed as simplified representation of a system. Since the appearance of biological systems keeps on changing they are known as continuous dynamic systems and hence they are better represented by continuous dynamic models (de Wit and Goudriaan, 1974). Simulation is the process of building models and their applications to study the behaviour of the system. InfoCrop is a generic crop growth simulation model for annual crops in tropical environments developed at the Indian Agricultural Research Institute, New Delhi (Aggarwal *et al.*, 2004).

InfoCrop model was calibrated for crop phenology, rice growth and yield, and stem borer damage mechanisms for Pusa Basmati 1 rice with the experimental data of treatments viz. healthy crop (T_0) and detillering @ 10% at 40 DAT (T_1) by logically adjusting various thermal times, parameters and coefficients. As a result, simulated yield as well as total dry matter (TDM) for these treatments were found to be very close to their observed counterparts. The simulated yields for these treatments differed by 1.05-2.83% from the observed yields while simulated TDM varied by 1.48-2.88% over the observed ones (Figure 11 & 12).

The model was further validated for stem borer damage mechanisms with the experimental data on yield and TDM of the rest of the treatments (T_2-T_7). The simulated and observed yields as well as TDM for different treatment were however close to each other. Simulated yields varied by 1.45 to 10.45% over the observed yields whereas simulated TDM differed by 1.92 to 8.43% over the observed TDM. Some difference in simulated and observed values are always bound to be there because model being a simplified representation of a system, cannot capture all the interactions among system components in their totality. These variations up to around 10% are thus acceptable from a practical point of view. The damage mechanism of the stem borer as stand reducer (Rubia and Penning de Vries, 1990) was thus confirmed and the pest thus reduced crop yield by affecting leaf area, leaf weight, stem weight, stem area, grain number and weight of storage organs of the crop.

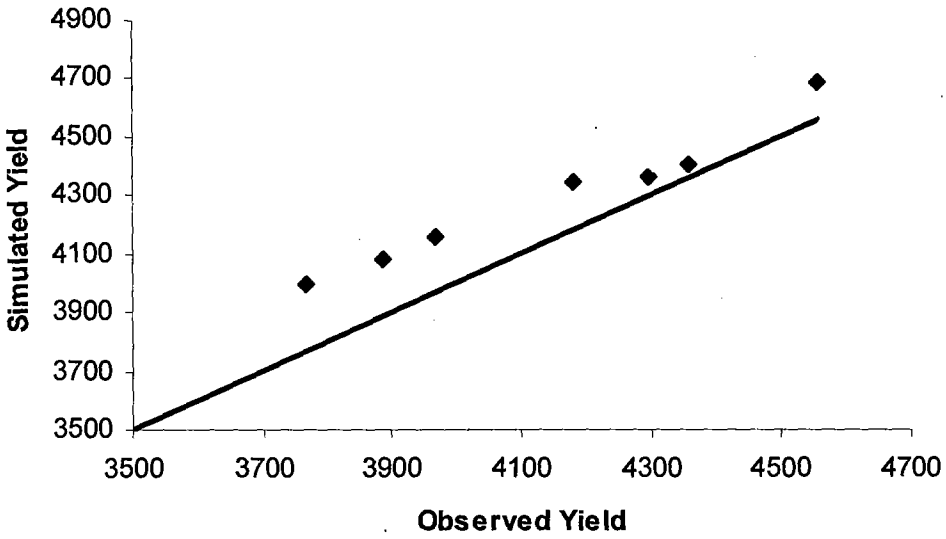


Figure 11: Observed and simulated yield on dry weight basis (weight of storage organs) due to different detillering treatments in Pusa Basmati 1 during *Kharif* 2005

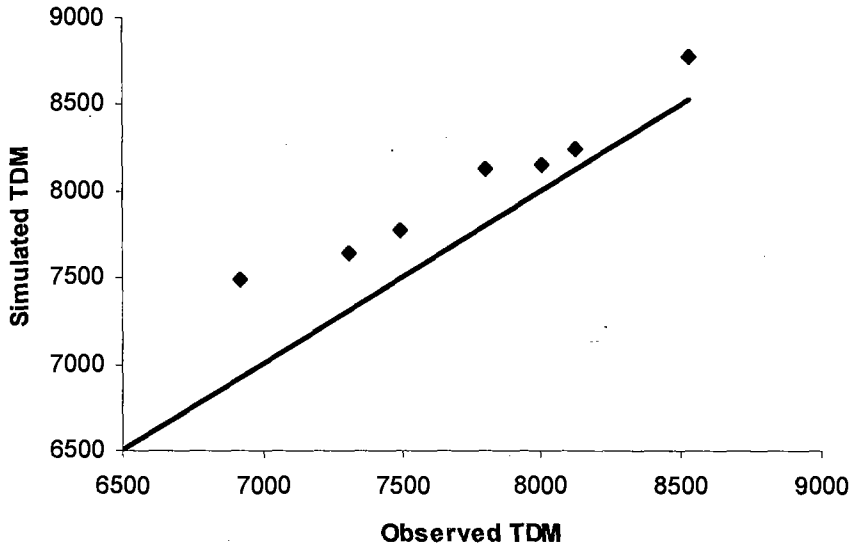


Figure 12: Observed and simulated total dry matter (TDM) due to different detillering treatments in Pusa Basmati 1 during *Kharif* 2005

Simulated yield loss in different treatments varied from 5.98 to 22% as compared with the 4.32 to 27.38% observed yield loss. Similarly, the simulated loss in TDM varied from 5.99% to 22% compared with 4.69 to 25.99% observed TDM loss (Table 8 & 9). The loss in yield and TDM were overestimated by the model for 20% detillering at 40 DAT and 50 DAT whereas the model underestimated the losses for the other treatments (Figures 13 & 14). The maximum variation in simulated yield loss and TDM loss over their observed counterparts was found to be about 5 and 4 %, respectively. Such variations might occur as models are simplified representation of the systems.

InfoCrop simulated stem borer damage mechanisms satisfactorily because it is based on crop physiological and ecological processes and pest effects has been coupled at with plant organ weights, radiation use efficiency (RUE) and interception of photosynthetically active radiation (PARINT) (Aggarwal *et al.*, 2004). To estimate the effect of pest infestations on different crop cultivars grown in different soil type and sites and under different management practices requires that physiological crop growth simulation models be used (Teng *et al.*, 1987). The CERES-RICE model (Ritchi *et al.*, 1986) developed under the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) was the first model to be coupled with pest damage mechanisms (Pinnschmidt *et al.*, 1990). The coupling points for damage mechanisms are located at the process level (photosynthesis, respiration, translocation) or at the state level (leaf area, leaf weight, stem weight, panicle weight) (Rabbinge *et al.*, 1994). Teng *et al.* (1998) used the CERES-RICE and CROPGRO models to exemplify coupling points for linking pest damage mechanisms to crop growth development. Willocquet et al. (1999) tested the yield loss simulation (YLS) model for rice pests under different production systems of South Asia and Southeast Asia. Chander *et al.* (2002) modeled the effect of stem borer on growth and yield of rice through yield loss simulation (YLS) model and MACROS model.

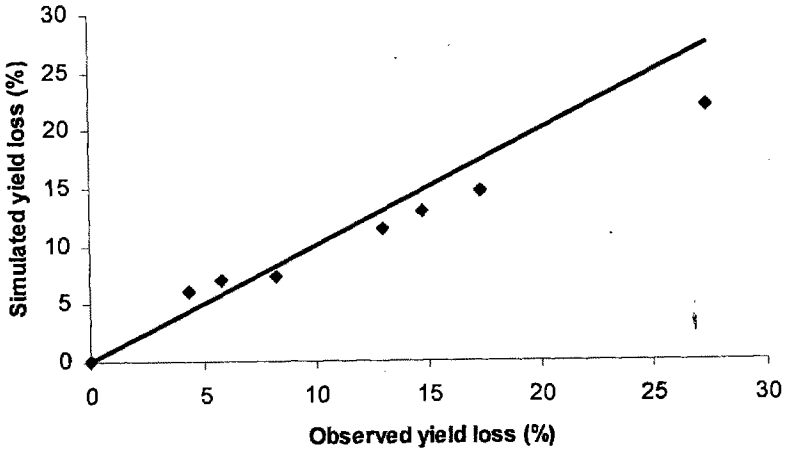


Figure 13: Observed and simulated yield loss due to different detillering treatments in Pusa Basmati 1 during *Kharif* 2005

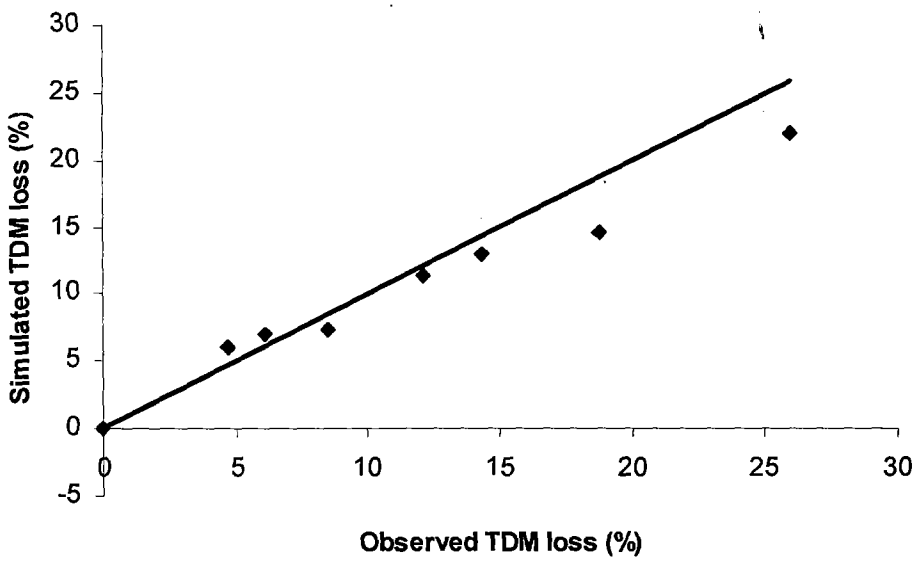


Figure 14: Observed and simulated loss in total dry matter (TDM) due to different detillering treatments in Pusa Basmati 1 during *Kharif* 2005

5. 3 Formulation of decision support tools for rice stem borer management

5. 3. 1 Economic injury levels

InfoCrop model after proper validation for stem borer damage mechanisms was used for establishing economic injury levels (EILs) for the pest (Tables 10 to 15). Simulated EIL with control expenditure of Rs. 1234 and market price of Pusa Basmati 1 as Rs. 9/kg was found to be 7.5% dead hearts at 30 DAT, 6.0% at 40 DAT, 5.5% at 50 DAT, 5.0% at 60 DAT, 4.5% at 70 DAT and 3.5% at 80 DAT (Figure 15). The EIL thus decreased with an increase in crop age because crop could compensate pest damage to certain extent during vegetative growth phase, which however is not possible after flowering (Rubia and Penning de Vries 1989).

EIL was found to have a negative relationship with market price of Pusa Basmati 1 rice because at higher market value, even less damage would cause economic loss. At 30 DAT, 7.5% was the EIL at a market price of Rs. 800 whereas it was 7.0 and 6.5% at market values of Rs. 9 and 10/kg, respectively (Figure 16).

On the other hand, the EIL exhibited positive relationship with expenditure on control measures because with increasing expenditure more damage is required to justify the application of pest management measures. At 30 DAT, the EIL was adjudged to be as 7.5% when two sprays of monocrotophos were to be used, while it was 9.5% for three sprays at market value of produce as Rs. 9/kg (Figure 17).

The EILs with carbofuran 3G at different crop ages and market value of produce, were found to be higher than those with two applications of monocrotophos due to more expenditure involved. However, these were at par with those for three application of monocrotophos. The expenditure incurred on two and three applications of monocrotophos was Rs. 1234 and Rs. 1851, respectively while it was Rs. 1858 on one application of carbofuran granules.

In present study, with 2-3 applications of monocrotophos and one application of carbofuran 3G at Rs. 8, 9 and 10/kg market value of Pusa Basmati-1, the simulated EILs ranged from 2.5-8.5. Earlier Prasad *et al.* (1992) computed the EIL for the stem borer as 5% while Afzal *et al.* (2002) determined the EIL for the stem

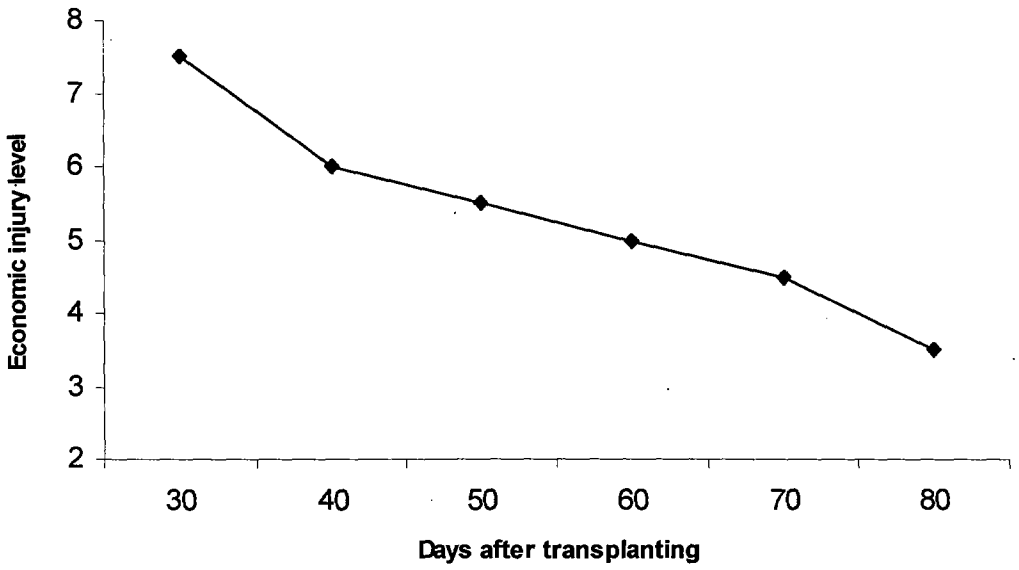


Figure 15: Changes in EIL for rice stem borer with crop age as simulated using InfoCrop

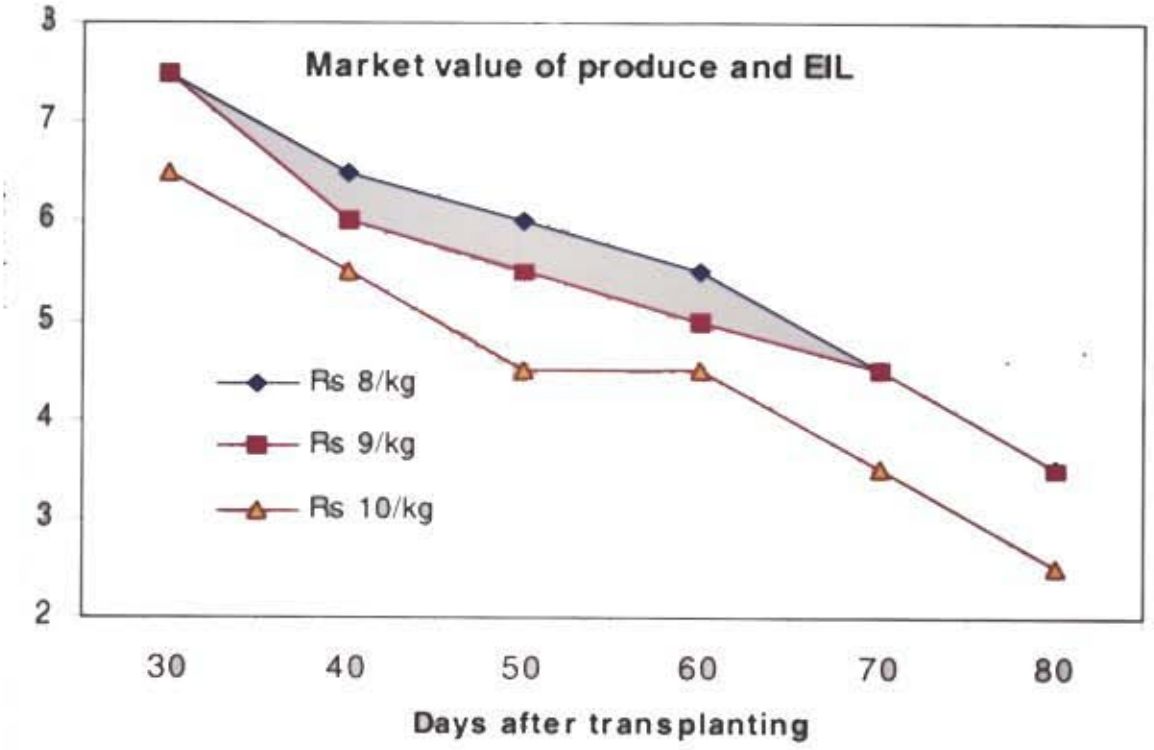


Figure 16: Changes in EIL for rice stem borer with market value of Pusa Basmati-1 as simulated using InfoCrop

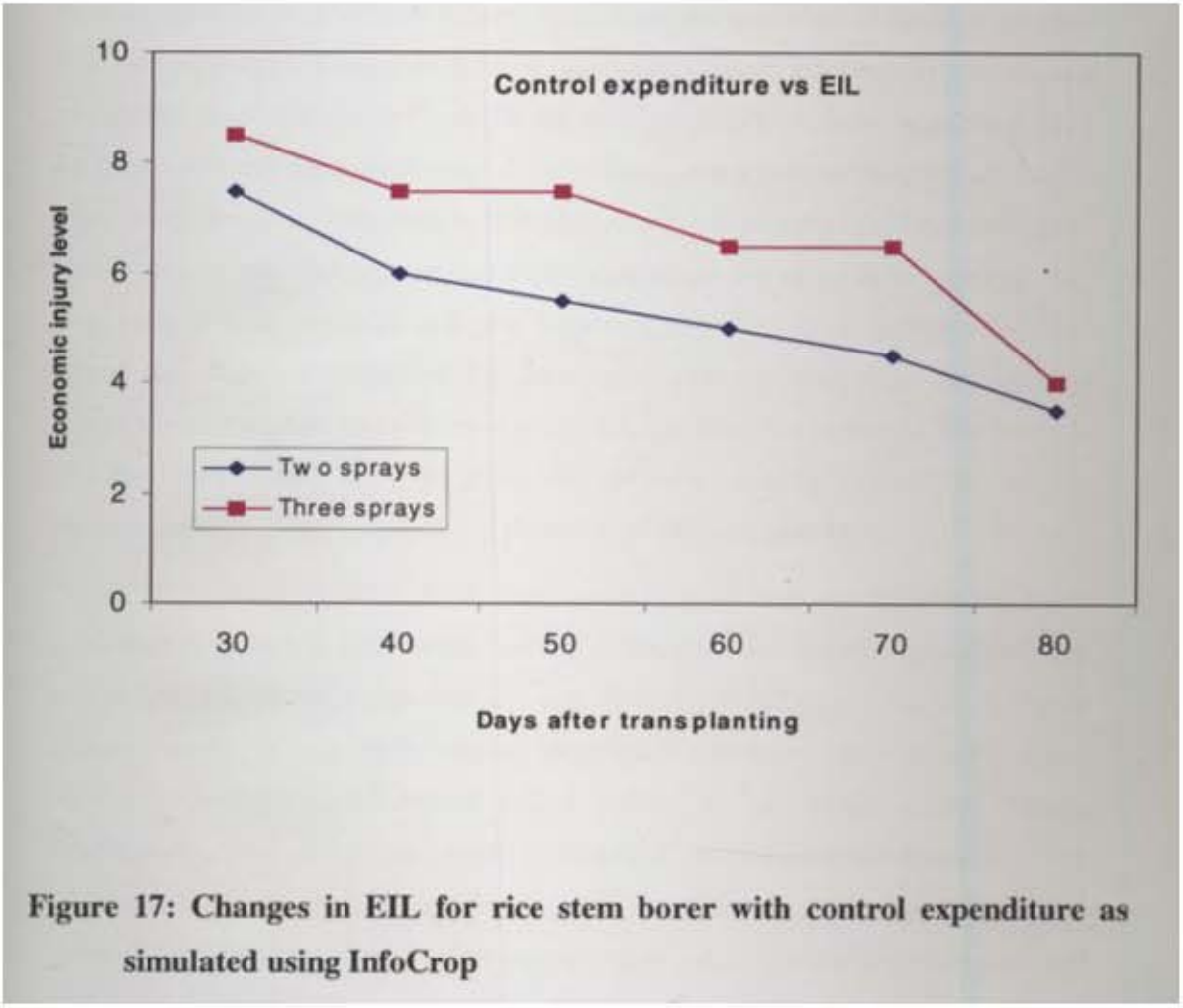


Figure 17: Changes in EIL for rice stem borer with control expenditure as simulated using InfoCrop

borer on rice variety Super Basmati through artificial clipping to be between 7.5 and 10%. The EILs simulated in the present study thus seem to be realistic and practical.

Simulation model once calibrated and validated for a particular experimental situation, its can then does not change for that situation. The EILs will not thus be affected. Crop-pest simulation models can be adapted to establish location and weather-specific EILs thereby helping to increase the precision of decision making. The empirical EILs developed through regression models are location specific and can not be applied elsewhere without risk of error. However determination of EILs for each and every location through experimentation is a tedious proposition. On the other hand, the simulation models being based on crop physiological and ecological processes and pest damage mechanisms can account fro changes in weather, soil, crop management practices and pest situations encountered at different location. These can thus be calibrated for local environmental and crop management conditions and applied for determining location specific EILs promptly. The location specific EILs could then be used for decision making instead of blanket recommendation, thereby enhancing precision of decision making.

Information on EILs can be used to obtain an optimal control of pests, avoid unwarranted pesticide application, saving producers unnecessary expenditure and conserving the environment (Archer and Bynum, 1992). The EIL is a highly dynamic entity, it may differ among geographic locations, plant growth stages, control expenditures and market prices (Girma *et al.*, 1993; Archer, 1994). Traditionally, the EILs for pests are based on empirical yield-infestation relationships, which are site specific and have little scope for extrapolation. It would however be very expensive and time consuming to use field experiments to establish such yield-infestation relationships for different pest species, crops and locations.

Coupled models have been used for simulating EILs for the bean leaf beetle infesting soybean (Nordh *et al.*, 1988), Russian wheat aphid damage in winter wheat (Chander *et al.*, 2006) and leaf folder damage in rice (Satish, 2004). These can also be used for establishing EILs for multiple pests associated with crop.

5. 3. 2 Isoloss curves

Crop-pest models may be used to generate iso-loss curves, which may then be used in surveillance programme in which preset levels of acceptable loss are used

to decide on the timing of control measures (Teng and Savary, 1992). InfoCrop was run from zero to high level (50%) of infestation at 30 to 80 DAT to formulate iso-loss curves for the stem borer incidence on Pusa Basmati 1 rice. These curves show various combinations of pest damage and crop age resulting in the same yield loss (Figure 7). The 10 % yield loss was inflicted by 21, 18, 15.5, 14.5, 13.5 and 11 % stem borer damage whereas, 20% yield loss was caused by 40.5, 36.5, 30.5, 28.5, 27.5 and 21.5% damage at 30, 40, 50, 60, 70 and 80 DAT respectively. The crop thus became more and more vulnerable to stem borer attack with advancing crop age probably because damage compensation did not occur after flowering of the crop (Rubia and Penning de Vries 1989).

Daryaei *et al.* (2003) used InfoCrop model to devise iso-loss curves for stem borer and bacterial leaf blight incidence in rice and stem borer and leaf rust incidence in wheat. Similarly simplified pest models or simplified decision rules from crop-pest models with economic values assigned to their outputs have been used for managing sweet corn common rust (Teng, 1987), wheat diseases (Zadoks, 1989) and rice blast (Surin *et al.*, 1991).

5. 4 Establishment of pest-weather modules for rice stem borer

The data on stem borer incidence in untreated control of insecticide evaluation trials under the All India Coordinated Rice Improvement Project (AICRIP) were used for the formulation of regression relationships (pest-weather modules). The dominant species among rice stem borer in India is the yellow stem borer, *Scirpophaga incertulas*. The other species which are of economic significance include striped borer, *Chilo suppressalis;* dark headed borer, *Chilo polychrysus;* pink borer, *Sesamia inferens* and white borer, *Scirpophaga innotata* (Nair, 1995). Since the nature of damage to rice crop due to these borers is the same, and the data available on their damage was not assorted species-wise, all these species were considered together in the present study under the category of rice stem borer.

Pest–weather modules were developed between stem borer damage and the weather parameters viz. mean values of maximum temperature, minimum temperature and relative humidity observed during 8 to 15 days prior to the observation of damage (2^{nd} lag week) at different locations. The weather of 2^{nd} lag week was used in the study because preliminary analysis indicated stronger

relationship between stem borer damage and 2nd lag week weather than 1st lag week weather.

At Aduthurai, Tamil Nadu, stem borer damage ranged from the lowest level of 1.8% during *Kharif* 2004 to the highest 12.7% dead hearts during *Kharif* 2000 (Figure 18). Mean maximum temperature during 2nd lag week during different years varied from 26.8 to 35.8°C whereas the mean minimum temperature ranged from 17.4 to 25.7°C. The mean morning relative humidity (RH_1) recorded at Aduthurai during the period varied from 69.8 to 95.9% while the mean afternoon relative humidity (RH_2) varied from 43.1 to 84.3%.

Multiple linear regressions between the weather parameters and stem borer damage at Aduthurai indicated that maximum temperature (T_{max}) and afternoon relative humidity (RH_2) were the most important factors influencing the stem borer damage, accounting for 51% variation in DH incidence (Figure 19). The pest-weather model thus developed between percent dead hearts (DH) and T_{max} and RH_2 is:

$$DH = 57.508 - 0.864\ T_{max} - 0.331\ RH_2 \qquad (R^2 = 0.513)$$

Goel *et al.* (1983) investigated the relationships between the intensity of attack and different meteorological parameters in the pre- and inter-crop seasons of rice crops at Aduthurai and concluded that when the afternoon relative humidity was lower than the normal value of 54% for that week, the first standing crop was likely to be more severely infested, but when the value was higher than 54%, the first standing crop might escape damage, but the second crop was likely to be much more severely infested.

At Coimbatore, Tamil Nadu, the lowest damage (2.2%) was recorded during *Kharif* 2000, while the highest incidence (31.1%) of the pest was witnessed during *rabi* 1990 (Figure 20). The mean maximum temperature and mean minimum temperature during 2nd lag week in different years varied from 28.6 to 36.7 °C and from 17.4 to 23.6°C, respectively. The mean morning relative humidity (RH_1) varied from 71 to 92% while the mean afternoon relative humidity (RH_2) ranged from 27 to 63%.

Minimum temperature (T_{min}) and morning relative humidity (RH_1) were found to be the most important factors affecting stem borer damage at Coimbatore

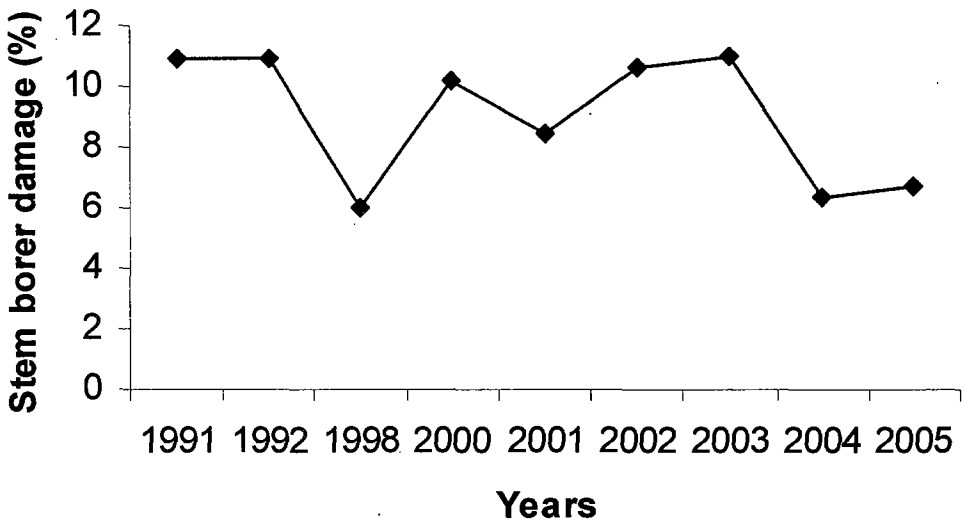


Figure 18: Severity of rice stem borer damage observed at Aduthurai, Tamil Nadu, over the years

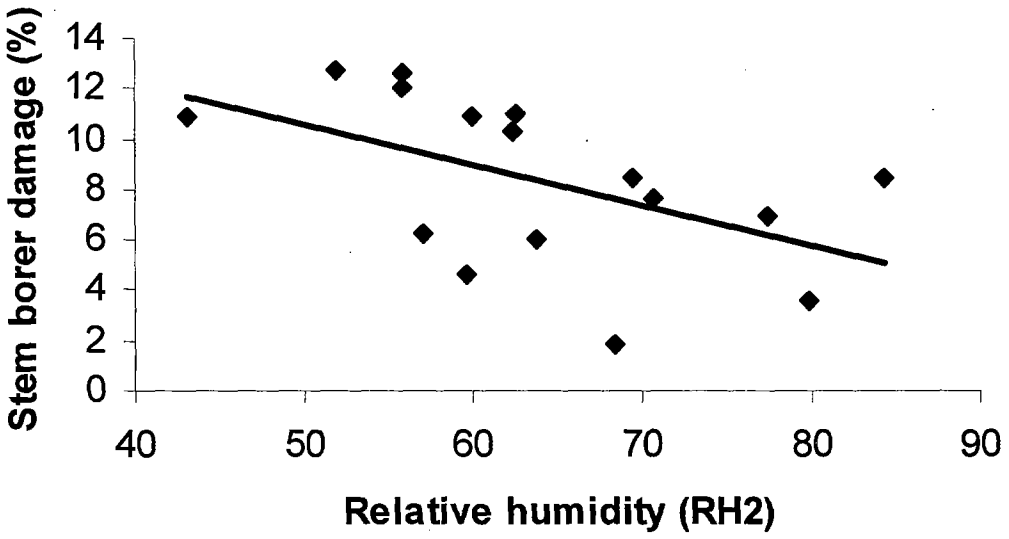


Figure 19: Stem borer damage vis-à-vis relative humidity (RH_2) at Aduthurai, Tamil Nadu

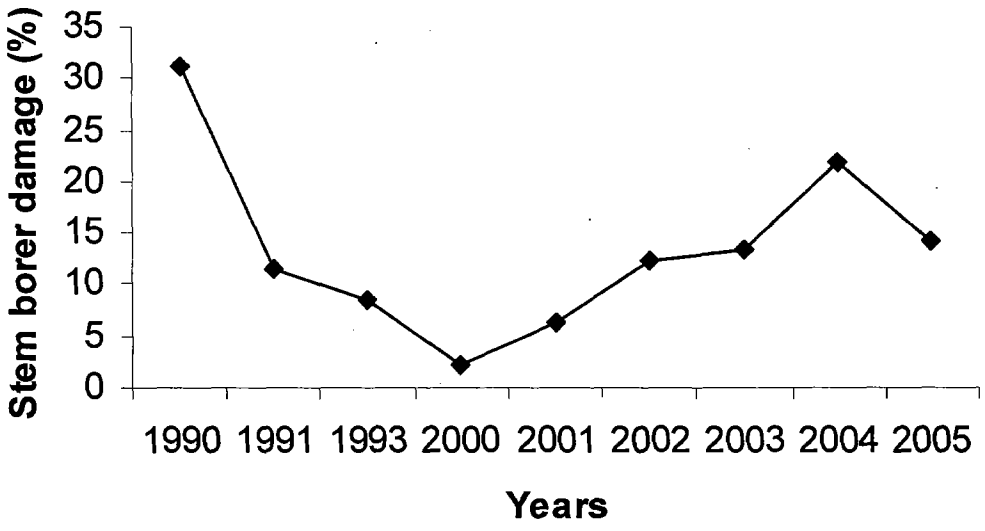


Figure 20: Severity of stem borer damage observed at Coimbatore, Tamil Nadu, over the years

and accounted for 62% variation in pest incidence. Both temperature and relative humidity were negatively correlated with stem borer damage (Figure 21 & 22). The pest-weather module for stem borer damage at Coimbatore was established as:

$$DH = 156.518 - 3.509\ T_{min} - 0.785\ RH_1 \qquad (R^2 = 0.622)$$

At Pattambi, Kerala the stem borer damage ranged from the lowest (3%) during *Kharif* 2005 to the highest (16.8%) during rabi 2001 (Figure 23). Mean maximum temperature during 2nd lag week varied from 26.9 to 34°C whereas the mean minimum temperature ranged from 18.3 to 23.8°C. The mean morning relative humidity (RH_1) recorded at Pattambi during the period varied from 66.8 to 96.1% while the mean afternoon relative humidity (RH_2) was found to be 33.6 to 82.3%.

Minimum temperature (T_{min}) and morning relative humidity (RH_1) were observed to be the most important weather parameters, accounting for 52% variability in pest incidence. Stem borer incidence showed negative correlation with temperature and relative humidity (Figure 24 & 25). Pest-weather module for stem borer damage at Pattambi was established as:

$$DH = 43.483 - 0.418\ T_{min} - 0.283\ RH_1 \qquad (R^2 = 0.515)$$

Samui *et al* (2004) investigated weather-based forewarning models for major pests of rice in Pattambi and validated multiple regression models using meteorological data for 2000 and 2001. The forewarning models for stem borer showed 67% population variations.

At Warangal, Andhra Pradesh the minimum pest damage (4.2%) was observed during *rabi* 2000 while the maximum incidence (19.1%) was during rabi 2003 (Figure 26). The mean maximum temperature during 2nd lag week varied from 29.3 to 35.1°C while the mean minimum temperature was from 13.4 to 25.4 °C. The mean morning relative humidity (RH_1) was between 61 and 99% whereas the mean afternoon relative humidity (RH_2) varied from 38 to 79%.

Maximum temperature (T_{max}) and morning relative humidity (RH_1) were found to be the most important factors which could explain 67% variation in stem borer incidence. Temperature and relative humidity were positively correlated with stem borer infestation at this station (Figure 27 & 28). The pest-weather module for stem borer damage at Warangal was determined to be:

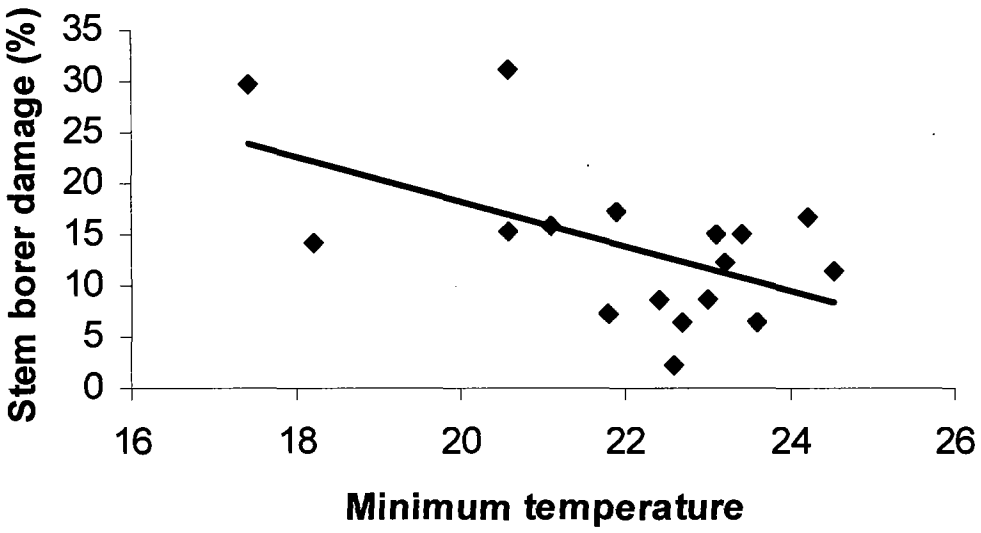


Figure 21: Stem borer damage vis-à-vis minimum temperature at Coimbatore, Tamil Nadu

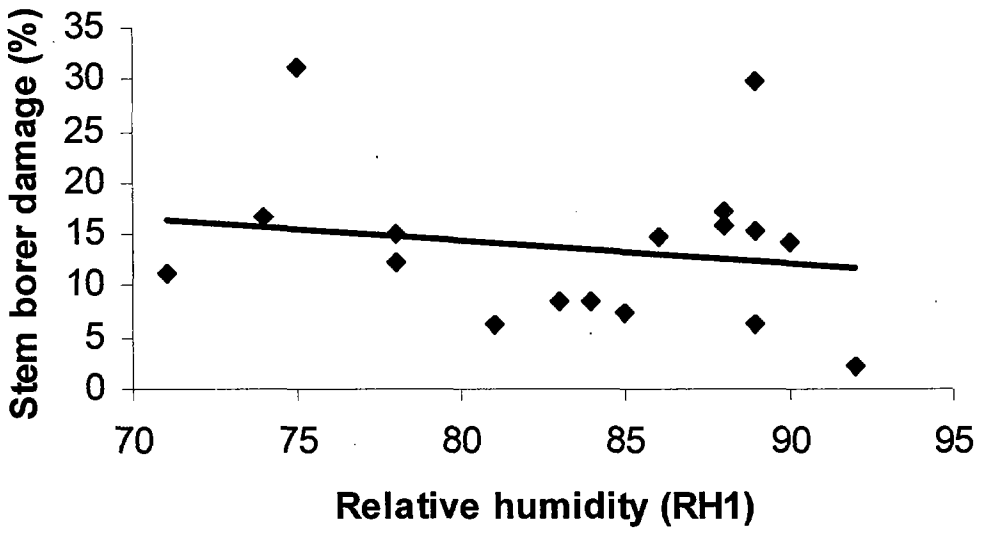


Figure 22: Stem borer damage vis-à-vis relative humidity (RH_1) at Coimbatore, Tamil Nadu

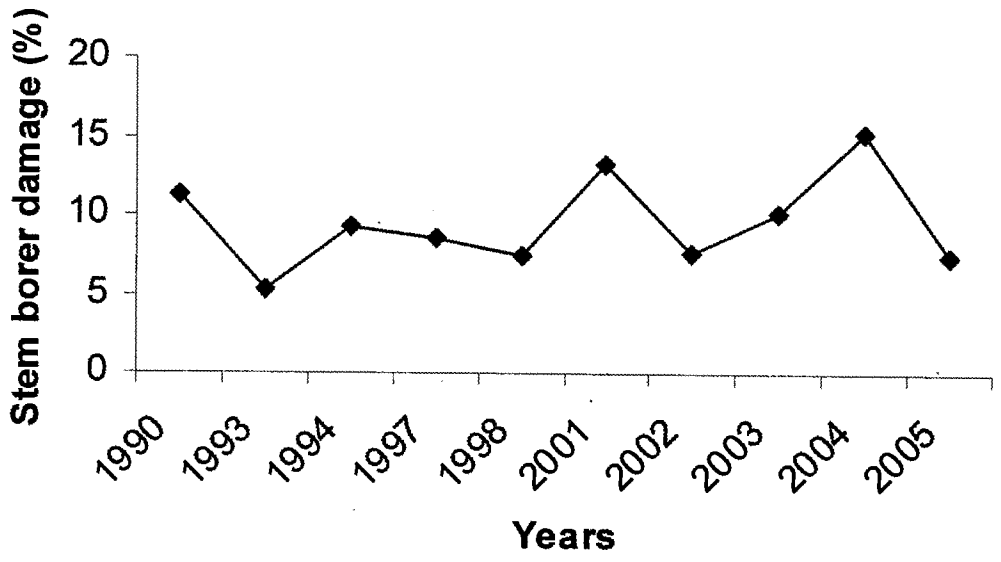


Figure 23: Severity of rice stem borer damage observed at Pattambi, Kerala over the years

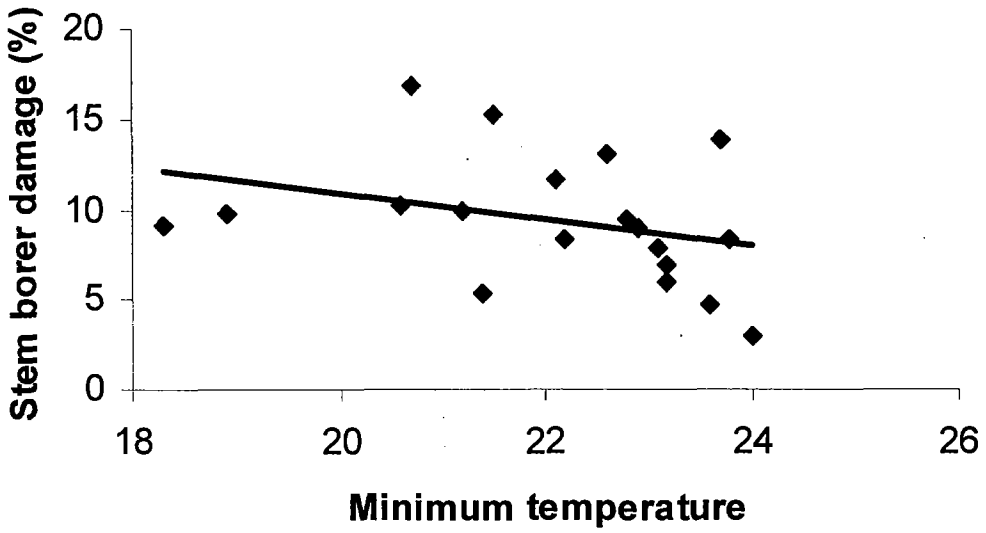


Figure 24: Stem borer damage vis-à-vis minimum temperature at Pattambi, Kerala

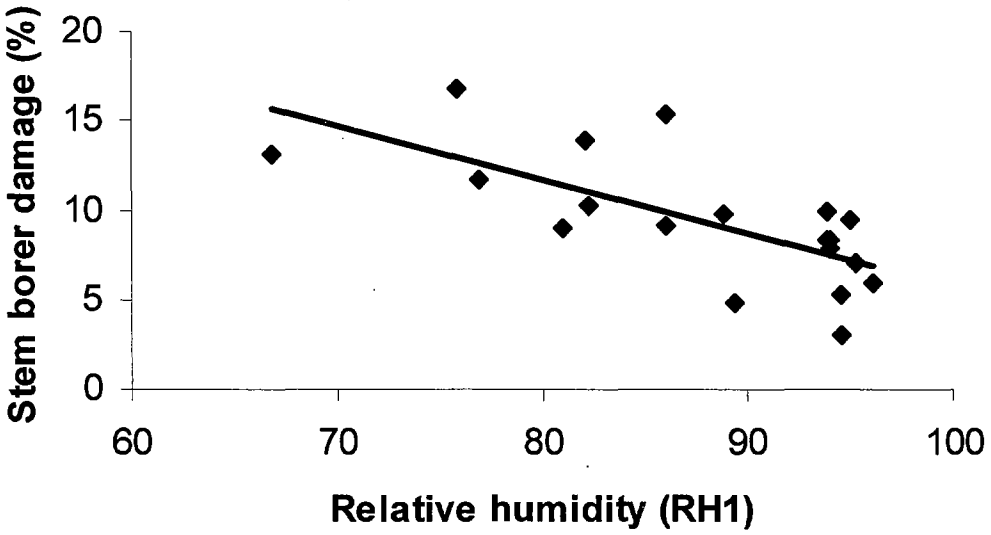


Figure 25: Stem borer damage vis-à-vis relative humidity (RH_1) at Pattambi, Kerala

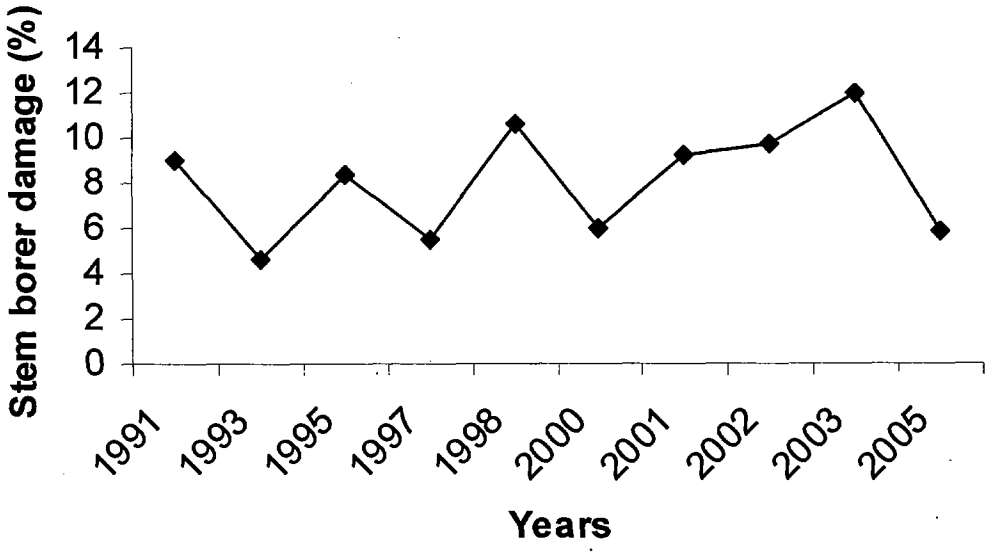


Figure 26: Severity of stem borer damage observed at Warangal, Andhra Pradesh over the years

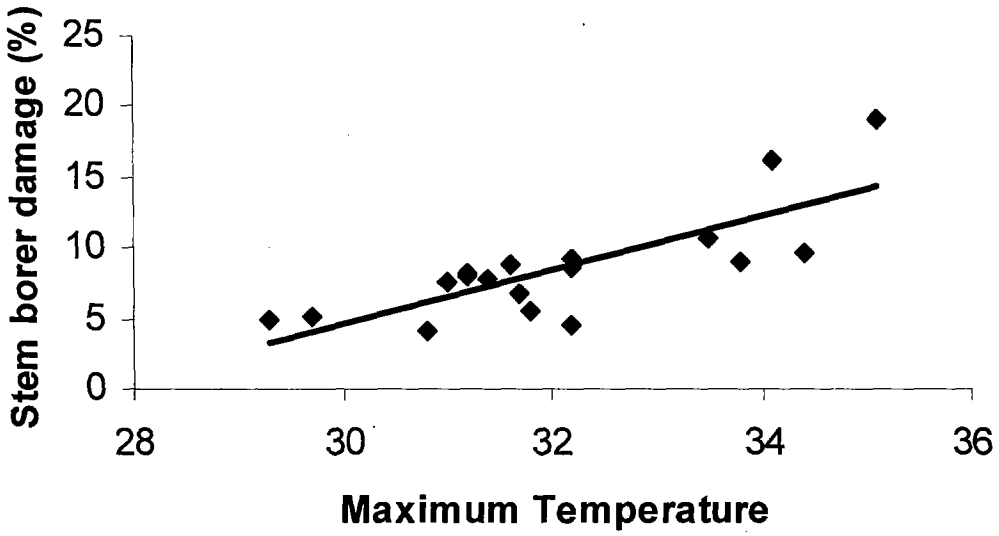


Figure 27: Stem borer damage vis-à-vis maximum temperature at Warangal, Andhra Pradesh

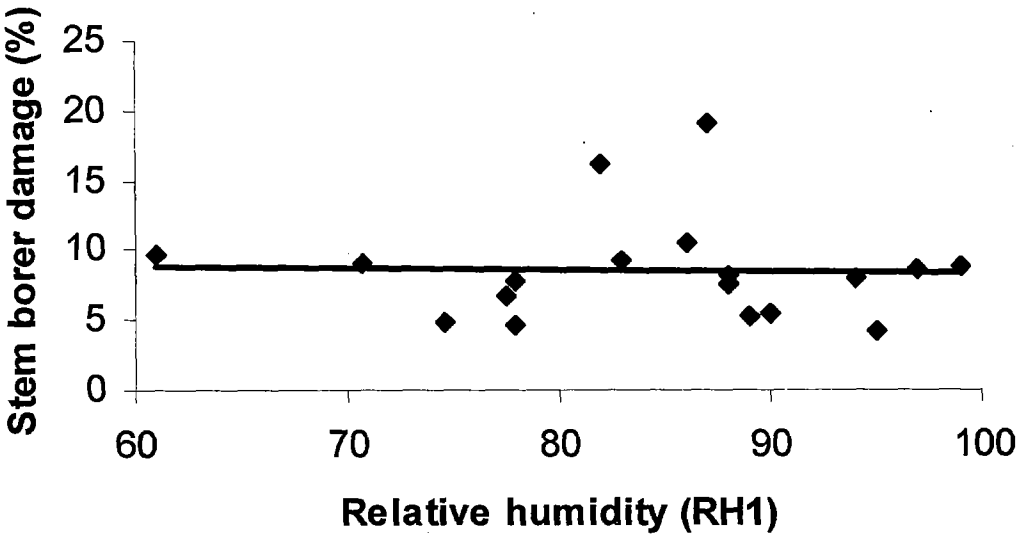


Figure 28: Stem borer damage vis-à-vis relative humidity (RH_1) at Warangal, Andhra Pradesh

$$DH = -66.849 + 2.102\ T_{max} + 0.095\ RH_1 \qquad (R^2 = 0.673)$$

At Karjat, Maharashtra the stem borer damage ranged from 3% during *rabi* 2003 to 30.8% during *Kharif* 2000 (Figure 29). Mean maximum temperature during 2nd lag week varied from 26.8 to 38.8°C whereas the mean minimum temperature was found to be 11.3 to 23.9°C. The mean morning relative humidity (RH_1) varied from 76.1 to 96.1% while data on afternoon relative humidity (RH_2) were not available for this station.

Minimum temperature (T_{min}) and morning relative humidity (RH_1) were observed to be the most important weather parameters accounting for 55% variation in stem borer damage. Temperature was positively correlated while relative humidity was negatively correlated with pest incidence (Figure 30 & 31). The pest-weather module for stem borer damage at Karjat was established to be:

$$DH = 87.662 + 2.133\ T_{min} - 1.351\ RH_1 \qquad (R^2 = 0.554)$$

At Faizabad, Uttar Pradesh, the lowest and highest stem borer damage was observed to be 7% during *Kharif* 2004 and 26.5% during *Kharif* 1998 (Figure 32). The mean maximum temperature of 2nd lag week during different years varied from 26.3 to 35.4 °C while the mean minimum temperature was observed to be 24.6 to 26.8 °C. The mean morning relative humidity (RH_1) varied from 84.9 to 96.3% while the mean afternoon relative humidity (RH_2) ranged from 61.7 to 85%.

Average temperature (T_{avg}) and morning relative humidity (RH_1) were found to be the most important factors accounting for about 63% variation in stem borer damage. Temperature and relative humidity showed negative correlation with stem borer incidence (Figure 33 & 34). The pest-weather module for stem borer damage at Faizabad was

$$DH = 200.99 - 2.716\ T_{avg} - 1.185\ RH_1 \qquad (R^2 = 0.627)$$

Pandey *et al.*, (2001) studied the effect of weather factors on the population build up of rice stem borer using path analysis and reported that relative humidity was negatively correlated with pest incidence and played an important role in the population build-up.

Perusal of the pest-weather modules developed at different locations revealed that the most important weather parameters in relation to stem borer incidence were:

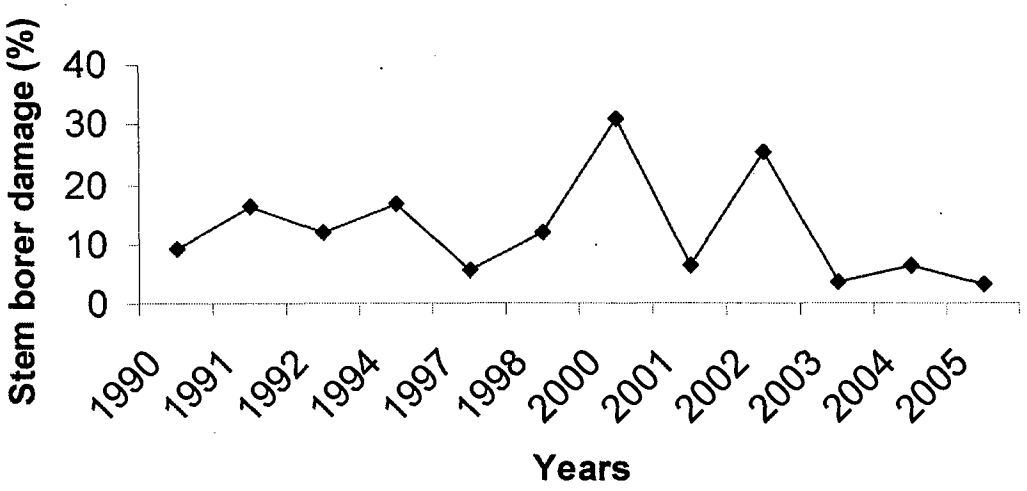


Figure 29: Severity of stem borer damage observed at Karjat, Maharashtra over the years

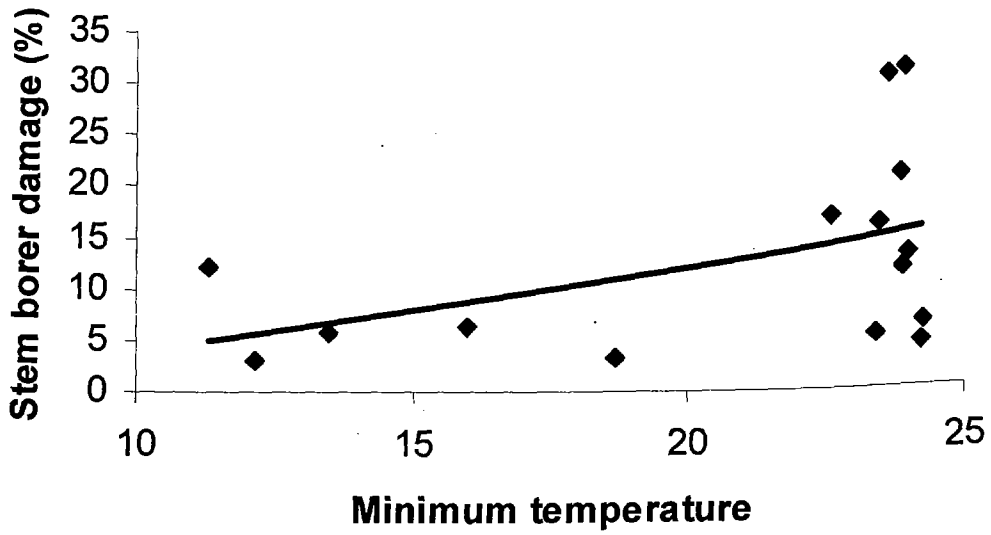


Figure 30: Stem borer damage vis-à-vis minimum temperature at Karjat, Maharashtra

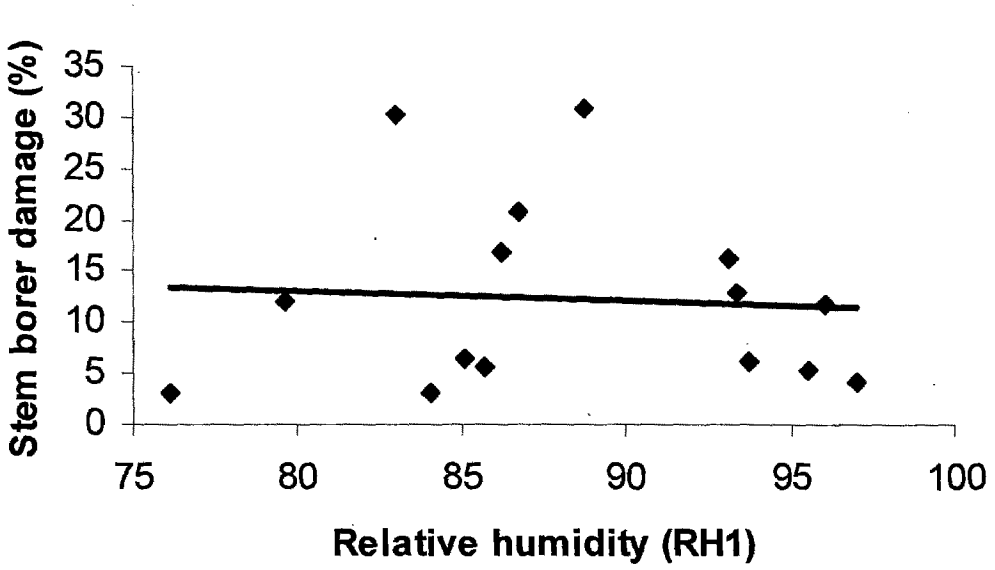


Figure 31: Stem borer damage vis-à-vis relative humidity (RH_1) at Karjat, Maharashtra

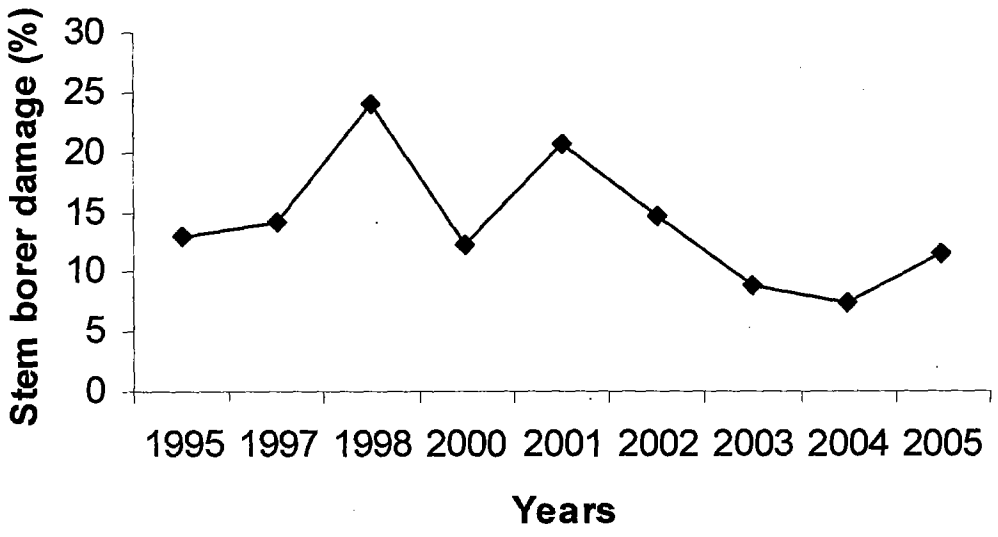


Figure 32: Severity of stem borer damage observed at Faizabad, Uttar Pradesh, over the years

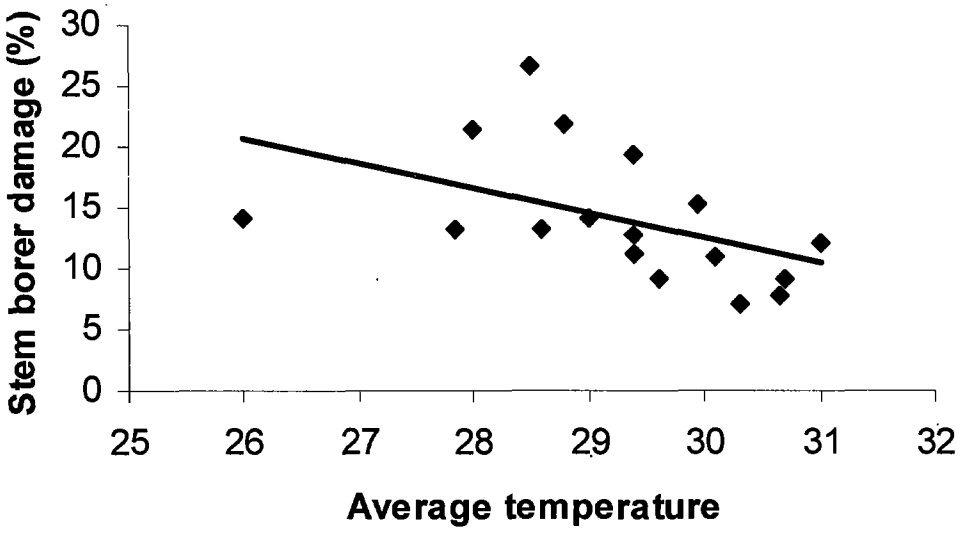


Figure 33: Stem borer damage vis-à-vis average temperature at Faizabad, Uttar Pradesh

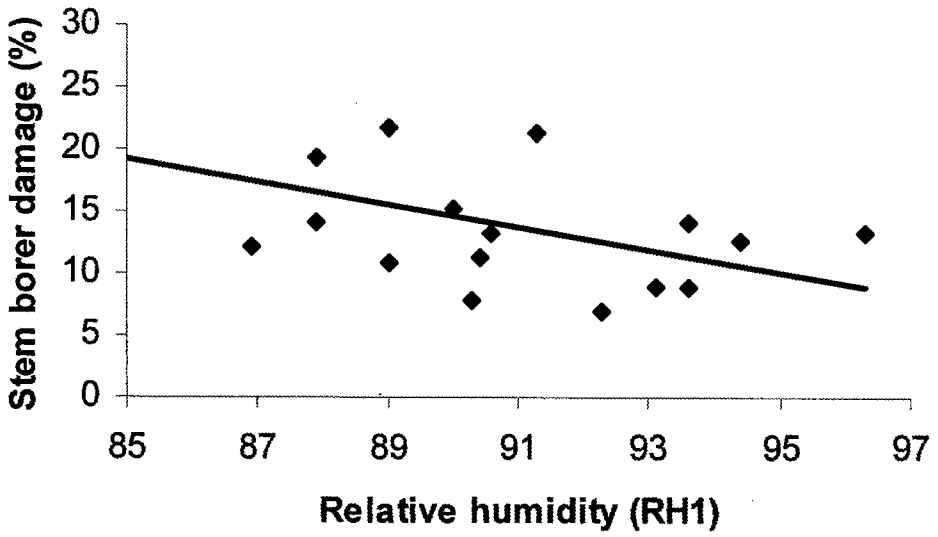


Figure 34: Stem borer damage vis-à-vis relative humidity (RH_1) at Faizabad, Uttar Pradesh

T_{max} and RH_2 at Aduthurai; T_{min} and RH_1 at Coimbatore, Pattambi and Karjat; T_{max} and RH_1 at Warangal; and T_{avg} and RH_1 at Faizabad. Among the weather parameters onserved to be important during the analysis, RH_1 was found to be important at 5 out of 6 locations while T_{min}, T_{max}, T_{avg} and RH_2 were observed to be dominant at 3, 2, 1 and 1 location(s) respectively. The RH_1 was negatively correlated with stem borer damage at Coimbatore, Pattambi, Karjat and Faizabad but had positive relation with pest incidence at Warangal. The RH_2 on the other hand was negatively correlated with pest incidence at Aduthurai. The Tmax was positively correlated with pest incidence at Warangal and negatively at Aduthurai while T_{min} bore negative relation at Coimbatore and Pattambi but positive one at Karjat. The T_{avg} was negatively related to pest incidence at Faizabad. Coefficient of determination (R^2) for the pest-weather modules at different locations ranged from 0.513-0.673, meaning thereby that combination of weather factors accounted for 51-67% variation in stem borer incidence.

Prasad *et al* (2003) developed regression models to predict the peak light trap catches of *Scirpophaga incertulas* based on different weather parameters and found that the average minimum temperature in the fourth week of January during rabi and total rainfall in the third week of June during *Kharif* had a decisive influence on the magnitude of peak light trap catches of the pest.

Padhi and Saha (2004) observed that maximum temperature, rainfall, relative humidity and wind velocity were negatively correlated while minimum temperature, evaporation rate and daily sunshine hour were positively correlated to the moth population recorded in the light trap catches.

Chakraborty and Chatterjee (2002) found that temperature range of 27-34°C and the relative humidity of 85-90% was conducive for rice stem borer incidence. Minimum temperature played an important role in the population buildup of yellow stem borer, the incidence of the pest being negatively correlated with minimum temperature, evening relative humidity and rainfall (Bhatnagar and Saxena, 1999).

Nandihalli *et al.* (1990) observed significant negative relation of the light trap catches of rice stem borer with average maximum temperature, while significant positive relationship was noticed with average morning relative humidity.

Maximum temperature to the tune of 36°C and minimum temperature of 26.8°C. was favourable for stem borer incidence (Pandya *et al*, 1989). Significant negative correlation with temperature and stem borer incidence was reported by Sarkar and Gayen (1992).

Suwongwan and Catling (1987) correlated the stem borer survival with maximum daily temperature and minimum daily relative humidity and found that conditions were particularly lethal when temperature above 33°C was combined with RH below 70%.

Above discussion reveals that various weather parameters have been found important for stem borer activity at different locations. These relationships are empirical relations which are site specific and thus vary temporally and spatially (James and Teng, 1979).

5. 5 Agro-ecological zonation for rice stem borer

Agro-ecological zonation for rice stem borer was done for the states of Tamil Nadu, Kerala and Andhra Pradesh by extrapolating the pest-weather modules developed at stations in these states using Geographical Information System (GIS).

The pest-weather module developed for Coimbatore was used for determining combination of weather factors responsible for various incidence levels of stem borer. Minimum temperature (Tmin) from 22 to 25°C and morning relative humidity (RH1) from 73% to 79% were associated with high (10-15%) pest incidence, Tmin range from 25 to 27°C and RH1 from 73% to 79% with moderate (5-10%) infestation, Tmin greater than 27°C and RH1 greater than 79% with low stem borer damage. The normal minimum temperature during *Kharif* season varies from 10.5 to 26.2°C while the normal morning relative humidity varies from 64.6 to 86.6%.

The weather stations with their corresponding data on temperature and relative humidity were located as point data on digitized map of Tamil Nadu. The pest-weather module indicating the set of weather conditions was then used to carve out zones of equal epidemic potential on the map. The map prepared for Tamil Nadu (Figure 9) shows the areas of equal vulnerability to stem borer infestation

within the state. Most of the districts in the south-western part of the state were found to be highly prone to stem borer damage (>15%) while moderate (5-10%) infestation was shown for the coastal areas in northern Tamil Nadu. The high altitude areas bordering Kerala were least favourable for the pest whereas high (10 to 15%) level of infestation was revealed for rest of the state.

Agro-ecological zonation for Kerala was done based on the pest-weather module developed at Pattambi. Minimum temperature (Tmin) less than 11°C and morning relative humidity (RH_1) less than 90% were found to be responsible for severe incidence; minimum temperature (Tmin) from 11 to 18°C and morning relative humidity (RH1) less than 90% for high infestation (10-15%); minimum temperature (Tmin) from 18 to 24°C for moderate damage (5-10%); and minimum temperature (Tmin) greater than 24°C for low damage (< 5%). The normal values of minimum temperature during *Kharif* season varied from 22.5 to 23.8°C while the morning relative humidity ranged from 86.6% to 95.2%.

Rice crop in the most of the districts in Kerala were shown to be moderately susceptible to stem borer infestation (Figure 10). The southern coastal areas and the northern high altitude areas adjoining Karnataka had conditions least favourable for the pest while high altitude areas in southern Kerala were highly favourable for pest damage.

The pest-weather module developed for Warangal was used for agro-ecological zonation for Andhra Pradesh. Maximum temperature (Tmax) greater than 35°C and a morning relative humidity (RH1) greater than 82% were found to be associated with severe infestation, Tmax from 33 to 35°C and RH_1 from 78 to 82% with high infestation (10-15%), Tmax range from 31 to 33°C and RH_1 from 78 to 82% with moderate (5-10%) incidence and Tmax) less than 31°C and RH_1 less than 78% with low stem borer incidence. The normal maximum temperature during *Kharif* season varied from 31 to 35.1°C while the normal morning relative humidity varied from 71.2 to 89.8%.

The GIS map for Andhra Pradesh (Figure 11) clearly showed high levels of stem borer damage for most of the districts. Low and moderate levels of damage was revealed for western parts of the state and for a few isolated areas in the northern

coast while areas most favourable for stem borer damage were those bordering Orissa.

Pest zoning is a concept that is particularly applicable for large area pest management, in which both tactics and strategies can be merged to achieve optimal management (Teng and Savary, 1992). Pest population dynamics model can be run with requisite weather data and probability of various levels of pest infestation for a site is determined (Yuen and Teng, 1990). Site predictions can then be extrapolated through geographic information system (GIS) to carve out the zones of equal epidemic potential for a pest. Knowledge of pest incidence in different zones would allow strategic decisions within each zone with respect to selection of crop cultivars. Probable life of resistant cultivars can also be presumed. This would help extension workers in the selection of appropriate management options in different zones

Chander *et al.* (2004) carried out agro-ecological zonation of the leaf folder incidence on rice in Haryana and based on relation between pest incidence and mean September temperature, areas with low and moderate leaf folder incidence potential were identified. Srivastava *et al.* (2001) used a GIS-based approach for predictive habitat modelling for forest malaria vector species in India, whereby thematic maps of forest cover, altitude, rainfall and temperature were prepared.

Pant *et al.* (2002) prepared the digital map of Sal (*Shorea robusta*) forest infected by *Hoplocerambyx spinicornis* for evolving the management strategy for its prevention and control. The geographical information systems (GIS) database for forest management units and other important physical feature were generated.

Ganeshaiah *et al.* (2003) predicted the potential geographical distribution of sugarcane woolly aphid (*Ceratovacuna lanigera* Z.) in India using generic algorithm for rule set prediction (GARP) and DIVA-GIS. GARP suggested that the woolly aphid was not likely to spread to Tamil Nadu, Kerala, and the coastal areas. Within Karnataka, it was likely to occur along the transitional belt and in the northern and southern dry zones, but was less likely to occur towards south interior Karnataka. Fletcher *et al.* (2004) integrated airborne imagery and GIS technology to map and compare citrus black fly infestations occurring in different years.

Simulation models can account for changes in weather, soil and management practices and hence models coupled with pest damage mechanisms can serve as

useful tools in pest management and along with GIS, can be used for large area pest management.

6. SUMMARY

Field experiments were conducted with rice variety Pusa Basmati 1 during *Kharif* season, 2005 at the Indian Agricultural Research Institute (IARI), New Delhi for the quantification of stem borer damage mechanisms. Since, natural incidence of the stem borer was in traces, variable infestation levels of the stem borer were mimicked by artificial detillering at the rate of 10 and 20 % at each of 40 and 50 days after transplanting (DAT), and 10, 20 and 30% at 70 DAT. InfoCrop, a generic crop-pest model, was used for simulating the effect of stem borer damage on rice biomass and yield.

The yield (dry weight basis) in different treatments of the experiment varied from 3310 to 4558 kg/ha, while total dry matter (TDM) ranged between 6312 and 8529 kg/ha. The percent yield loss varied from 4.32 to 27.38 % whereas percent loss in TDM ranged from 4.7 to 26% in different treatments. The percent loss in yield and TDM were the highest with 30% detillering after flowering (70 DAT) and the lowest for 10% detillering at 40 DAT. Same level of detillering resulted in higher yield and dry matter loss with advancing crop age because rice plants could compensate for the stem borer damage during early growth stages due to production of new tillers.

InfoCrop was calibrated for phenology, growth and yield of rice crop with the experimental data of healthy crop (T_0), by logically adjusting various thermal times, parameters and coefficients. The simulated yield and total dry matter (TDM) of T_0 showed only 2.83 and 2.88% variation their observed counterparts. The values of degree days (DD) for germination (TTGERM), DD for grain filling (TTGF) and DD for vegetative growth (TTVG) were calibrated to be 50, 500 and 1650 DD, respectively. The parameter values obtained for potential leaf growth rate (RGRPOT), maximum radiation use efficiency (RUEMAX) and leaf extinction coefficient (KDFMAX) were 0.0092/day, 2.3kg/MJ/day, 0.6 respectively while those for grain filling rate(GFRVAR), specific leaf area (SLAVAR), grain number/ kg dry matter (GNOCF) and potential grain weight (POTGWT) were, 2mg/day, 0.0024m^2/kg, 60000 and 24mg respectively.

The observed data on yield and TDM for the rest of the treatments (T_2-T_7) were used for validation of the stem borer damage mechanisms. Simulated yields

varied by 1.45 to 10.45% over the observed yields whereas, simulated TDM differed by 1.92 to 8.43% over the observed TDM. The stem borer damage mechanisms were thus validated appropriately on Pusa Basmati 1 rice.

InfoCrop model was used for establishing economic injury levels by simulating yield loss with 1 to 15% stem borer damage at different crop growth stages. The EIL at 30, 40, 50, 60, 70, 80 days after transplanting were estimated to be 7.5, 6.0, 5.5, 5.0, 4.5 and 3.5%, respectively. EIL was found to have a negative relationship with market price of Pusa Basmati 1 rice because at higher market value, even less damage would cause economic loss. On the other hand, the EIL exhibited positive relationship with expenditure on control measures because with increasing expenditure more damage is required to justify the application of pest management measures.

The model was run from zero to very high levels of infestation at 30 to 80 DAT and isoloss curves, which show the combinations of pest damage and crop age resulting in the same yield loss, were plotted. The 10 % yield loss was inflicted by 21, 18, 15.5, 14.5, 13.5 and 11 % stem borer damage whereas, 20% yield loss was caused by 40.5, 36.5, 30.5, 28.5, 27.5 and 21.5% damage at 30, 40, 50, 60, 70 and 80 DAT respectively. The crop thus became more and more vulnerable to stem borer attack with advancing crop age because damage compensation did not occur after flowering of the crop.

The data on stem borer incidence in untreated control in insecticide evaluation trials under the All India Coordinated Rice Improvement Project (AICRIP) was used for developing pest-weather modules at Aduthurai (Tamil Nadu), Coimbatore (Tamil Nadu), Pattambi (Kerala), Warangal (Andhra Pradesh), Karjat (Maharashtra) and Faizabad (Uttar Pradesh). Since the data on stem borer damage was not assorted species-wise, all these species were considered together in the present study under the category of rice stem borer although, the dominant species was yellow stem borer, *Scirpophaga incertulas.*

Preliminary analysis indicated that weather factors during 2nd lag week were strongly correlated with stem borer incidence. Pest-weather modules were developed by regression analysis of percent stem borer damage (DH) and weather parametrs viz. maximum temperature (T_{max}), Minimum temperature (T_{min}), morning relative humidity (RH_1) and afternoon relative humidity (RH_2). However based on stepwise regression, only the two most important factors were retained. The final pest-

weather modules were found to be as:

Aduthurai, $DH = 57.508 - 0.864\ T_{max} - 0.331\ RH_2$ $(R^2 = 0.513)$

Coimbatore, $DH = 156.518 - 3.509\ T_{min} - 0.785\ RH_1$ $(R^2 = 0.622)$

Pattambi, $DH = 43.483 - 0.418\ T_{min} - 0.283\ RH_1$ $(R^2 = 0.515)$

Warangal, $DH = -66.849 + 2.102\ T_{max} + 0.095\ RH_1$ $(R^2 = 0.673)$

Karjat, $DH = 87.662 + 2.133\ T_{min} - 1.351\ RH_1$ $(R^2 = 0.554)$

Faizabad, $DH = 200.99 - 2.716\ T_{avg} - 1.185\ RH_1$ $(R^2 = 0.627)$

Four classes of infestation viz. severe (more than 15% dead hearts), high (10 to 15% dead hearts), moderate (5 to 10% dead hearts) and low (less than 5% dead hearts) were considered for agro-ecological zonation of rice stem borer. The pest-weather modules were used for finding out combinations of weather factors associated with these four classes.

Minimum temperature less than 22°C and a morning relative humidity less than 73% were found to be associated with severe infestation by rice stem borer at Coimbatore, while minimum temperature less than 11°C and morning relative humidity less than 90% were associated with severe stem borer infestation at Pattambi. Severe infestation by rice stem borer at Warangal was found to be associated with maximum temperature greater than 35°C and a morning relative humidity greater than 82%.

The weather stations along with the corresponding data on normal values of weather variables during *Kharif* season were marked as point data on georeferenced maps of Tamil Nadu, Kerala and Andhra Pradesh. Agro-ecological zonation for rice stem borer was done by extrapolating the pest-weather relationships developed for Coimbatore, Pattambi and Warangal, respectively.

The map prepared for Tamil Nadu showed the areas of equal vulnerability to stem borer infestation within the state. Most of the districts in the south-western part of the state were found to be highly prone to stem borer damage while moderate infestation was shown for the coastal areas in northern Tamil Nadu.

The high altitude areas bordering Kerala were least favourable for the pest whereas high level of infestation was revealed for rest of the state. Rice in the most of the districts in Kerala was shown to be moderately susceptible to stem borer infestation. The southern coastal areas and the northern high altitude areas adjoining

Karnataka had conditions least favourable for the pest while high altitude areas in southern Kerala were highly favourable for pest damage.

The GIS map for Andhra Pradesh clearly showed high levels of stem borer damage for most of the districts. Low and moderate levels of damage was revealed for western parts of the state and for a few isolated areas in the northern coast while areas most favourable for stem borer damage were those bordering Orissa.

Simulation models can account for changes in weather, soil and management practices and hence models coupled with pest damage mechanisms could serve as useful tools in pest management and along with GIS can be used for large area pest management.

Abstract

Field experiments were conducted with rice variety Pusa Basmati 1 during *Kharif* 2005 at the Indian Agricultural Research Institute (IARI), New Delhi for the quantification of stem borer damage. Since, natural incidence of the stem borer was in traces, variable infestation levels of the stem borer were mimicked by artificial detillering. InfoCrop, a generic crop-pest model, was used for simulating the effect of stem borer damage on rice biomass and yield.

The percent yield loss in different treatments varied from 4.32 to 27.38 % whereas percent loss in total dry matter (TDM) ranged from 4.7 to 26%. Same level of detillering resulted in higher yield and dry matter loss with advancing crop age because rice plants could compensate for the stem borer damage during early growth stages due to production of productive tillers.

InfoCrop was calibrated for phenology, growth and yield of rice crop with the experimental data of healthy crop by logically adjusting various thermal times and parameters viz. degree days (DD) for germination (TTGERM), DD for grain filling (TTGF), DD for vegetative growth (TTVG), potential leaf growth rate (RGRPOT), maximum radiation use efficiency (RUEMAX), leaf extinction coefficient (KDFMAX), grain filling rate(GFRVAR), specific leaf area (SLAVAR), grain number/ kg dry matter (GNOCF) and potential grain weight (POTGWT).

The observed data on yield and TDM for different detillering treatments were used for validation of the stem borer damage mechanisms. Simulated yields varied by 1.45 to 10.45% over the observed yields whereas, simulated TDM differed by 1.92 to 8.43% over the observed TDM, thereby indicating appropriate validation of stem borer damage mechanisms on Pusa Basmati 1 rice.

The economic injury levels (EIL) at 30, 40, 50, 60, 70, 80 days after transplanting were simulated to be 7.5, 6.0, 5.5, 5.0, 4.5 and 3.5% tiller damage, respectively. The EIL was found to have a negative relationship with market price of Pusa Basmati 1 rice and positive relationship with expenditure on control measures. The model was also used to plot iso loss curves for the stem borer damage, which showed the combinations of pest damage and crop age resulting in the same yield loss. These curves can be used in pest surveillance programmes for deciding the timing of management interventions.

Pest-weather modules were developed at Aduthurai (Tamil Nadu), Coimbatore (Tamil Nadu), Pattambi (Kerala), Warangal (Andhra Pradesh), Karjat (Maharashtra) and Faizabad (Uttar Pradesh) by regression analysis of percent stem borer damage (DH) and weather parameters *viz.* maximum temperature (T_{max}), Minimum temperature (T_{min}), morning relative humidity (RH_1) and afternoon relative humidity (RH_2).

Four classes of infestation viz. severe (more than 15% dead hearts), high (10 to 15% dead hearts), moderate (5 to 10% dead hearts) and low (less than 5% dead hearts) were considered for agro-ecological zonation of rice stem borer. The pest-weather modules were used for finding out combinations of weather factors associated with these four classes. Minimum temperature less than 22^0C and a morning relative humidity less than 73% were found to be associated with severe infestation by rice stem borer at Coimbatore, while minimum temperature less than 11^0C and morning relative humidity less than 90% were associated with severe stem borer infestation at Pattambi. Severe infestation by rice stem borer at Warangal was found to be associated with maximum temperature greater than 35^0C and a morning relative humidity greater than 82%.

The weather stations along with the corresponding data on normal values of weather variables during *Kharif* season were marked as point data on geo-referenced maps of Tamil Nadu, Kerala and Andhra Pradesh and agro-ecological zonation for rice stem borer was done by extrapolating the pest-weather relationships developed for Coimbatore, Pattambi and Warangal, respectively. The maps thus prepared showed the areas of equal epidemic potential in relation to stem borer infestation within the states.

Simulation models could account for changes in weather, soil, pest effects and management practices and hence these could be used for developing decision support tools, which along with GIS would increase efficiency of pest management practices.

सारांश

भारतीय कृषि अनुसंधान संस्थान, नई दिल्ली में वर्ष 2005 में खरीफ़ की फसल के दौरान, तना बेधक कीट के कारण होने वाली क्षति के परिमाण का पता लगाने के लए पूसा बासमती 1 किस्म के साथ खेत परीक्षण किए गए। चूंकि तना बेधक के प्राकृतिक प्रकोप का पता लगाया जा चुका था लेकिन कृत्रिम रूप से दोजी रहित करके तना बेधक के भिन्न–भिन्न संक्रमण स्तरों का पता लगाया गया। धान के जैवद्रव और उपज पर तना बेधक द्वारा की गई क्षति के प्रभाव के अनुरेखन के लिए जेनरिक फसल–नाशीजीव मॉडल, 'इन्फ़ो क्रॉप' का प्रयोग किया गया।

विभिन्न उपचारों के तहत उपज हानि के प्रतिशत में 4.32 से 27.38% तक अंतर था जबकि कुल शुष्क पदार्थ (TDM) में प्रतिशत 4.7 से 26 % तक था। डीटिलरिंग (दोजी रहित) करने के समान स्तर के परिणामस्वरूप उपज में वृद्धि हुई और फसल अवधि बढ़ने के साथ शुष्क पदार्थ हानि भी कम हुई क्योंकि धान के पौधे, आरंभिक बढ़वार स्थिति में नई दोजियों के निकलने के कारण तना बेधक द्वारा की गई हानि की क्षतिपूर्ति कर लेते हैं।

ऋतु जैविकी (फिनोलॉजी), धान की फसल की बढ़वार व उपज के साथ स्वस्थ फसल के परीक्षणात्मक आंकड़ों के साथ 'इन्फ़ोक्रॉप' मॉडल में संशोधन किया गया। यह संशोधन, विभिन्न ताप समय का तर्कसंगत समयोजन और प्राचलों जैसे – अंकुरण के लिए डिग्री दिवस (DD), दाना भराव के डिग्री दिवस (TTGF), वानस्पतिक बढ़वार के डिग्री दिवस (TTVG), संभावित पत्ती बढ़वार दर (RGRPOT), अधिकतम विकिरण प्रयोग क्षमता (RUEMAX), पर्ण निर्वादन सह क्षमता (KDFMAX), दाना भराव दर (GFRVAR), विशिष्ट पत्ती क्षेत्र (SLAVAR), दाना संख्या/कि.ग्रा. शुष्क पदार्थ (GNOCF) और संभावित दाना भार (POTGWT) के द्वारा किया गया।

विभिन्न डीटिलरिंग उपचारों के लिए उपज और कुल शुष्क पदार्थ (TDM) पर पर्यवेक्षित आंकड़ों का तना बेधक क्षति प्रक्रिया के मान्यकरण के लिए प्रयोग किया गया। पर्यवेक्षित उपज की तुलना में उत्साहवर्धक पैदावार में 1.45 से 10.45% का अन्तर था जबकि पर्यवेक्षित कुल शुष्क पदार्थ (TDM) की तुलना में उत्साहवर्धक TDM में 1.92 से 8. 43% भिन्नता थी, इस प्रकार पूसा बासमती 1 चावल की किस्म पर तना बेधक द्वारा क्षति प्रक्रिया का उपयुक्त पुष्टिकरण होता है।

प्रतिरोपण के 30, 40, 50, 60, 70, 80 दिनों के बाद आर्थिक क्षति स्तर (इकोनोमिक इंजरी लेवल अर्थात ईआईएल) क्रमशः 7.5, 6.0, 5.5, 5.0, 4.5 और 3.5% दोजी क्षति का था। इस प्रकार पूसा बासमती 1 के बाजार–मूल्य के साथ ईआईएल का सम्बन्ध नकारात्मक पाया गया तथा नियंत्रक उपायों पर व्यय सम्बन्ध सकारात्मक था। इस मॉडल का इस्तेमाल

तना बेधक क्षति के लिए आइसोलेस कर्व्स तैयार किये गये जिससे उसी उपज क्षति में नाशीजीव द्वारा की गई क्षति और फसल जीर्णन प्रदर्शित हुई। तना बेधक क्षति के प्रतिशत के परावर्तन विश्लेषण और मौसम प्राचलों जैसे अधिकतम तापक्रम (Tmass), न्यूनतम तापक्रम (Tmin), प्रातःकालीन आपेक्षिक आर्द्रता (RH_1) और दोपहर की आपेक्षिक आर्द्रता (RH_2) के द्वारा अदुथुरई, कोयम्बटूर (तमिलनाडु) पट्टाम्बी (केरल), वारंगल (आंध्र प्रदेश), करजत (महाराष्ट्र) और फैजाबाद (उ.प्र.) के लिए पैस्ट वैदर मॉड्यूल विकसित किया गया।

संक्रमण के चार वर्गों, नामतः गम्भीर (15% से अधिक डैड हर्ट), उच्च (10 से 15% तक डैड हर्ट), सामान्य (5 से 10% डैड हर्ट), और कम (5% से कम डैड हर्ट) पर धान के तना बेधक के कृषि पारिस्थितिक आंचलीकरण पर विचार किया गया। इन चार वर्गों से जुड़े मौसम संबंधी तथ्यों के परस्पर संबंध का पता लगाने के लिए पैस्ट वैदर मॉड्यूल का प्रयोग किया गया। कोयम्बटूर में धान के तना बेधक के गंभीर संक्रमण से, न्यूनतम तापक्रम 22^0से. से कम और 73% से कम प्रातःकालीन आपेक्षिक आर्द्रता का सम्बन्ध पाया गया जबकि पट्टाम्बी में, 11^0से. से कम न्यूनतम तापक्रम और 90% से कम प्रातःकालीन आपेक्षिक आर्द्रता का सम्बन्ध तना बेधक के गंभीर संक्रमण से पाया गया। वारंगल में 35^0 से. से ज्यादा अधिकतम तापक्रम और प्रातःकालीन आपेक्षिक आर्द्रता 82% से अधिक के साथ चावल के तना बेधक का गंभीर प्रकोप पाया गया।

खरीफ़ की फसल के दौरान, जलवायु भिन्नताओं के सामान्य मानों पर बताए गए आंकड़ों के साथ जलवायु केन्द्रों को, तमिल नाडु, केरल और आंध्र प्रदेश के भू–संदर्भित मानचित्रों पर अंकित किया गया और क्रमशः कोयम्बटूर, पट्टाम्बी और वारंगल के लिए विकसित नाशीजीव–मौसम सम्बन्धों के एक्स्ट्रा प्लॉटिंग द्वारा धान के तना बेधक के लिए कृषि–पारिस्थितिक आंचलीकरण किया गया। इस प्रकार तैयार किए गए मानचित्रों में राज्यों में तना बेधक संक्रमण से संबंधित संक्रमित हो सकने वाले क्षेत्रों को प्रदर्शित किया गया।

सिमुलेशन मॉडलों का, मौसम मृदा, नाशजीव प्रभाव और प्रबन्ध प्रक्रियाओं के लिए प्रयोग किया जा सकता है और इस प्रकार इनका निर्णय क्षम उपकरणों के विकास में उपयोग किया जा सकता है। जिनका नाशीजीव प्रबंध प्रक्रियाओं की दक्षता बढ़ाने के लिए जीआईएस के साथ प्रयोग में लाया जा सकता है।

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