MANAGEMENT OF INSECTS IN TRADITIONAL AND MODERN RICE SYSTEMS

J. A. Litsinger, Entomologist

Department of Entomology

International Rice Research Institute

P. O. Box 933

Manila, Philippines

Michael E. Loevinsohn

Program Officer

International Research and Development Center

P. O. Box 8500

Ottawa, Canada K1G 3H9

E. A. Heinrichs

Head

Department of Entomology

Louisiana State University

Baton Rouge, Louisiana 70803

U. S. A.

Origins

The progenitor of wild Oryza species and its two domesticated species, O. sativa in Asia and O. glaberrima in Africa, is believed to have been widespread in the ancient supercontinent Gondwana (Chang, 1976). The drifting apart of Gondwana left Oryza species in Asia, Africa, South America, and Australia. Annual and perennial wild rices are found along a wide belt in Asia from India to China and man probably domesticated O. sativa independently from annual wild rices in a number of different environments more than 7 million years ago. Ecological diversification resulted when ancestral forms were carried by farmers and traders to higher latitudes, higher altitudes, dryland sites, deep water areas, and to tidal swamps. The combined forces of natural and human inputs and diverse climates, seasons and varied cultural practices led to the enormous ecological diversity now found in the 100,000 Asian cultivars grown by farmers in 100 countries (IRRI 1985).

Environments

Rices have been carefully selected by man to suit local environmental conditions. The three subspecies of O. sativa; indica, sinica (formerly japonica), and javanica show its adaptability to divergent environments. Indica rices are photoperiod sensitive and adapted to the monsoon tropics typified by distinct wet and dry seasons. The wide range of photoperiod sensitivity of indica rices represents man's selection in locations of differing rainy season durations (Vergara and Chang, 1976). Rice flowers during the short days at the end of monsoon rainy season from October to December depending on the location. Rainy seasons vary from 4 to more than 9 months. Rice is harvested at the end of the rainy season and sun dried for year long storage. Strong seed dormancy prevents the grains from sprouting on the panicle from untimely rainfall. Indica rices were also selected locally for tolerance to floods, desiccation, salinity, heat, and soil deficiencies or toxicities.

Lowland indica rices are grown in areas subject to inundation and therefore must be tall to survive flooding. Rice can grow in standing water because of the system of linked air conduits from the stomata through the shoot into the roots (Yoshida,1981). The plant can survive if any part of the shoot is above water. Submergent-tolerant varieties can survive over 1 week under water. In large river deltas subject to seasonal deep water, fast growing rices were selected which elongated with the rising flood waters. In water several meters deep, rice plants of the floating rices break from the soil and sprout adventitious roots to take up nutrients from flood waters. Indicas were later taken to upland areas as populations expanded.

Javanica rices are tall and stout representing an independent adaptation to flood prone areas. This subspecies of bulu (awned) and undil (awnless) rices evolved along side the indica rices in Indonesia.

Japonica rices are adapted to the temperate lowlands. Many are photoperiod insensitive in order to be grown in short seasons. The short season quality is highly desirable for dryland environments where japonicas are grown, particularly the cool hilly areas. The japonicas have less resistance to pests and stresses than indicas but have higher yield potential. Traditional rices in general are low yielding but bring stable yields through their tolerances to environmental extremes.

Traditional Rice Culture

Man first domesticated rice in flooded environments. Planting rice in areas with seasonal floods overcame its relative intolerance to desiccation and provided weed control as rice, but not most weeds, is adapted to growing in standing water (De Datta, 1981). Better weed control was obtained if the soil was plowed while wet, turning weed seeds into an anaerobic environment where they could not germinate. Puddling however causes the soil to lose its structure and when the heavy clays dry, they become very hard and crack. In addition, a hard pan forms below the plow layer from small clay particles seeping down and blocking water pores. This form of land preparation makes growing dryland crops without irrigation, after rice, difficult.

In lowland areas, rice is grown from seed in a nursery in order to let the plants grow sufficiently tall to be transplanted into standing water. Neither rice nor weed seeds will germinate under several centimeters of water. Transplanting rice into standing water therefore minimizes weed problems.

In rainfed lowlands, farmers sow their nurseries in well-drained areas. A 500 m^2 seedbed will produce enough seedlings to transplant 1 ha. The dense seedbed causes the seedlings to elongate. Seedbeds are established by the calendar if the onset of the monsoon is normal. The farmers then wait for heavy rainfall so the soil can be presoaked, plowed and puddled. When sufficient rains fall, the farmer must hurry to prepare as much land as possible before the soil dries out. Monsoon rains come in pulses; and if rainfall pulses are far apart, land preparation and planting may become staggered over 2 to 4 months. Farmers have several fields and prepare only one or two at a time so at least some rice is planted each year. If the rains are good, the whole farm will be planted, in bad years only a portion may be planted. With photoperiod sensitive varieties, farmers terminate planting as the season turns to shorter days. If the crop is planted too late it will not flower that year. Seedlings 1 to 4 months old are transplanted. For low yielding traditional varieties seedling age has little effect on eventual yield. Farmers may get desperate in low rainfall years and transplant only after a single plowing. Weed growth will be excessive, but the farmer has little choice.

In traditional rice culture, after planting, management is minimal and the farm family undertakes other activities leaving the rice crop until harvest. Crop management has little effect on yield. Fertilizer causes the plants to grow tall and lodge at heading leaving the panicles to rot in the flood water. If weeds are a problem, the farmer may attempt to hand weed; but soon finds he does not have sufficient labor to do a good job. Insect control is also labor intensive -- hand picking, netting, trapping -- but mostly ignored.

Modern Varieties

The low rice yields of tropical Asia in the 1950's set against rapidly increasing human population prompted international agricultural development agencies to develop a strategy designed to increase rice production (Chandler, 1982). Rice is the major food of one-third of the world. Per capita consumption is 100 kg per year in populated Asia. The Japanese were successful in increasing production by breeding japonica rices that yielded more with increased fertilization. This model was used in indica rice breeding programs in Asia and by the

International Rice Research Institute which was established in 1960 in the Philippines.

The tall traditional variety Peta, from Indonesia, was crossed with the high tillering simi-dwarf variety, Dee-geo-woo-gen, from China to produce IR8, a new plant type which was released in 1966. Peta was popularly grown in the Philippines at that time because of its vigorous growth and resistance to some pests. The new plant type captured most of the best traits of both parents to produce a high yielding variety. IR8 is short with stiff culms and responds to fertilizer applications by producing grain rather than vegetative growth (Fig. 1) and can support the weight of the grains without lodging. The high tillering capability allows the plant to fill in empty spaces in the field. IR8 has moderate seed dormancy and is photoperiod insensitive. As of 1986, there have been 26 IR varieties released in the Philippines for lowland irrigated environments (Table 1). The yield potential of the new varieties is equal to that of IR8; but the latest varieties have broader resistance to stresses and better eating quality.

The adoption of modern varieties by Filipino farmers has been very rapid in lowland areas. Area planted to modern varieties increased from 0% in 1965 to 85% in 1982 (IRRI 1985). Adoption of fertilizers occurred at a rate similar to that of modern varieties. Stem borers were the principal rice pests when IRRI was established but emphasis quickly changed to brown planthopper *Nilaparvata lugens* (Stal) and green leafhopper *Nephotettix virescens* (Distant), hitherto minor pests. Outbreaks of the brown planthopper (Dyck and Thomas, 1979) and green leafhopper (Sogawa, 1976) have occurred in rapid succession after the release of IR8 in 1966. The Philippines represents a typical case in point.

In 1970-72 outbreaks of the green leafhopper and tungro virus covering hundreds of thousands of hectares plagued the Philippines. IR20 with the TKM6 gene (moderately resistant to the green leafhopper and moderately susceptible to tungro) was released in 1969 and eventually became sufficiently widespread to quell the pest problem. IR 26 released in 1973 was quickly overcome by a new biotype of brown planthopper. Green leafhopper outbreaks also occurred in 1974. IR36 with the PTB 18 gene (moderately resistant to both green leafhopper and tungro) and with the bph 2 gene (resistant to brown planthopper biotypes 1 and 2) was released in 1968 and held until 1982 at which time a biotype of the brown planthopper caused small outbreaks in Mindanao and the green leafhopper caused tungro outbreaks in several areas. As a result IR56 was released. IR56 has the Bph 3 gene for brown planthopper resistance and Gam Pai gene for resistance to the green leafhopper and moderate resistance to tungro. To date the Bph 3 gene has held for brown planthopper, but tungro has repeatedly occurred in small areas on IR58, IR60, IR62, and IR64. Genetic diversity has been increased in recently released varieties. IR64, for example, has 20 traditional varieties in its ancestry (Fig. 2). Breeding lines with improved resistance to green leafhopper and tungro will be released as new varieties soon.

Modern Rice Culture

The modern photoperiod insensitive lowland varieties have a reduced vegetative period compared to traditional photoperiod sensitive varieties. The short growth period of modern varieties limits their ability to compensate from injury caused by plant stresses. Rice is particularly vulnerable to desiccation; therefore, modern varieties flourish well when irrigated. Modern varieties are high yielding in part because they tiller profusely, but tillering is reduced if seedlings older than 3-4 weeks are transplanted.

Seedbeds of modern varieties are established with irrigation ensuring vigorous seedling growth. Young seedlings (three weeks after sowing) are transplanted into rice fields that are continuously flooded until the crop is ready for harvest. These changes in cultural practices have increased the importance of aquatic insect pests in modern rice culture. These pests were present in traditional rice culture but became more abundant with irrigation. The rice whorl maggot *Hydrellia philippina* (Ferino), green semilooper *Naranga aenescens* (Moore), hairy caterpillar *Rivula atimeta* (Swinhoe), and rice caseworm *Nymphula depunctalis* (Guenee) are found only in aquatic habitats and are most abundant on vegetative stage rice.

Chronic insect pests can cause high levels of damage each season. Yield loss studies in five irrigated lowland sites in the Philippines from 1978-84 representing more than 30 crops indicated that chronic pests caused an average of 18% yield reduction from a 3.8 t/ha yield. Of this 0.68 t/ha, 44% was lost during the vegetative stage. The high yield loss is believed to be in part because of the inability of the early maturing rices to compensate from damage. IR58, one of the earliest maturing IR varieties (108 d) registered a 40% yield loss compared to a 5% yield loss in IR42 a 132-day variety. Both locations have similar pest abundance (Litsinger et al., 1987).

Early maturing varieties on the other hand reduce the period for pest buildup on a crop. Pests such as stem borers which do not readily disperse are decimated upon harvest if the straw and stubble are destroyed. Hoppers, however, can readily disperse to nearby younger fields.

The use of fertilizer by farmers in Asia went hand in hand with adoption of modern varieties (Fig. 3). Nitrogen increased the nutritive value of the rice plant leading to higher populations of brown planthopper and leaffolders Cnaphalocrocis medinalis (Guenee) in particular. Feeding rates increased leading to greater damage. Survival rates also increased from better nutrition, and larger, more fecund progeny developed. Nitrogen caused tillers to rapidly elongate making them more vulnerable to penetration by neonate stem borer larvae (a high natural mortality occurs if larvae bore into slow growing tillers). However, fertilizer itself is not a primary cause for pest outbreaks. Upland rice farmers in Batangas apply over 60 kg N/ha and have no stem borer or hopper problems.

Insecticide usage also increased with the adoption of modern varieties. Resurgence of the brown planthopper and leaffolder have been traced to application of insecticides which selectively killed natural enemies (Kenmore et al., 1984). Brown planthopper outbreaks are normally associated with high insecticide use.

With irrigation the photoperiod insensitive modern varieties can be planted year-round. In areas with ample water, farmers could plant from two to three rice crops per year. Often in such areas, farmers plant independently of their neighbors resulting in staggered year-round rice monoculture. These spatio-temporal parameters greatly increased the carrying capacity of the environment.

Monoculture rice resulted in a shift to monophagous pests. The yellow stem borer Scirpophaga incentulas (Walker) is the only monophagous rice borer in Asia, and its population supplanted the white stem borer *Scirpophaga innotata* (Walker) which was adapted to a single wet season crop. The white stem borer passed the dry season as a larva in aestivation in the crown of stubble. Its populations have been reduced by dry season plantings. *Chilo polychrysus* (Meyrick) which is oligophagous was supplanted by yellow stem borer in the early 1970's in Malaysia (Fig. 4).

The insertion of an irrigated dry season rice crop into the traditional fallow period provided the stepping stone for rice pests to carry-over from one wet season to another. A carry-over index developed to measure this effect is the ratio of the pest population at the beginning of the next wet season to its peak during the preceding wet season. Yellow stem borer and green leafhopper numbers were recorded in light traps before and after irrigation expanded in Malaysia from 1965 to 1975. A positive exponential increase in the carry-over of the green leafhopper and yellow stem borer population from wet season to wet season occurred as the double cropped area expanded (Fig. 5). The brown planthopper, previously not considered a pest, was only recorded after the irrigation system expanded.

Multiple regression comparisons of spatial (rice area) and temporal (number of rice crops and planting asynchrony) parameters of rice intensification were performed on an insect pest data set of annual light trap collections from Philippine rainfed and irrigated sites. Explanatory correlations were highest for number of rice crops followed by rice area and asynchrony. Comparisons of sites differing from 1 to 1.9 rice crops per year showed increasing brown planthopper and yellow stem borer numbers with more rice crops. The rate of pest population increase did not double with an additional rice crop but increased exponentially (Fig. 6). The logrithmic regression curve of the green leafhopper Y = 6.71 + 0.837 X followed a similar trend but was significant only at the 20% level suggesting that the well known density dependence of this pest limited its exponential growth.

Rice area among the Philippine sites varied from 46 to 94% as measured within a 1 km radius of the light traps. The increase in yellow stem borer and green leafhopper was not exponential as it was for number of rice crops (Fig. 7). Pest abundance leveled off after about 75% of the area was in rice. This relationship is similar for dispersing spores with no ability to search. The degree of staggered planting was expressed as the standard deviation of planting dates between neighboring fields around 23 light trap stations in an irrigation rice area in Nueva Ecija Province with similar number of rice crops and rice area. Correlations of asynchrony were made for circular areas from the central light trap of 200 m to 2 km radii. The distance from the light trap showing the highest correlation to asynchrony was also considered to be the effective dispersal distance of the insect. The best fit for yellow stem borer was 400 m and for the brown planthopper 2 km (Fig. 8). The green leafhopper being density dependent again showed only a close correlation to asynchrony. Its best fit however occurred at 0.6 km. An exponential increase in pest abundance was significantly correlated with greater asynchrony (Fig. 9). We conclude that asynchrony is a determinant of pest abundance independent from the number of rice crops per year as the Nueva Ecija site did not very in this regard.

Management Strategy

Rice production in Asia must increase by 5 million tons per year to keep pace with the rapidly growing human population. Because of limited farm land increases in food production will have to come from multiple rice cropping. The change in plant type from tall photoperiod sensitive varieties that mature only once a year to high yielding semi-dwarfs that are insensitive to day-length has allowed up to three rice crops to be grown per year when irrigated.

The pest outbreaks that occurred soon after the adoption of modern varieties cannot be directly related to the change in plant type but to changes in the rice ecosystem as a result of irrigation. Modern rices have resistance to more insect pests than traditional types (Table 2). Insect pests were not dominant stresses of traditional rices because the dry season fallow acted as an abiotic controlling agent. The long growth cycle of traditional rice during the vulnerable vegetative stage allowed for greater compensation from insect damage. Rice pests changed from oligophagous to monophagous species favored by year-round availability of rice.

Irrigation has brought greater stability from the physical stress of drought, floods, and certain soil problems and thus increased yields. The crop is now at risk from biological stresses, notably insect pests and the diseases they vector. Higher yields have meant greater economic losses from insect pests. The high yield potential has changed rice farming from a subsistence to cash crop. Farmers that grow high yielding varieties can afford to purchase insecticides and fertilizer. The increased insecticide usage however has led to resurgence of rice pests. Year-round rice cropping also favors the multiplication of natural enemies. However, epidemics erupt when their populations are reduced by non-selective insecticides.

Intensified rice cropping will have to be continued in order to feed the increasing human population. The primary management strategy is to lower the carrying capacity of the rice ecosystem through the utilization of insect resistant varieties and cultural practices. A breeding strategy for the immediate future is to cross wild rices with high yielding plant types. Earlier, *Oryza nivara* was crossed giving resistance to grassy stunt I virus. Breeding methods have improved to allow more wide crosses to be made between *Oryza* species and *O. sativa*. Screening the wild rice collection in the IRRI germplasm bank against the major insect pests of rice has identified many accessions with resistance (Table 3).

No more than two rice crops should be grown each year. Short duration varieties 115-125 days should be selected, but should not be so short as to not allow time for compensation from insect damage. The irrigation system and farmers must be organized so as to plant as large an area as possible within the generation time of rice insects -- 3 to 4 weeks. The minimal area to be planted synchronously is the area encompassed by the effective dispersal distance of rice pests and ranges from 0.4 km (50 ha) to 2 km (1256 ha) for yellow stem borer and brown planthopper, respectively. This management strategy will create a rice-free period of 3 to 4 months which should occur during the dry season to mimic the traditional cropping system. A third non-rice crop could be planted with irrigation to encourage plowing under of the rice stubble. This will not only provide further pest control, but the third crop will boost the farmers' income.

Reducing the carrying capacity of rice ecosystems will lower pest pressure and slow the selection of new biotypes on resistant varieties. Wild rices can be used to provide more genes for insect resistance. Greater numbers of genes will provide more durable resistance and resistance genes should be targeted to pests not readily controlled by natural enemies. The level of resistance should be moderate for each pest and allow some to survival so as to maintain natural enemies.

Natural enemies should not only be conserved through moderate levels of resistance but also through the use of selective pesticides. Growing two rice crops per year will increase pest problems over the traditional single crop system. But by managing the double rice crop system to create a break in the rice cycle the times that pests exceed threshold levels should be minimized. A pesticide response will be economical in these cases but selective materials should be used. Over the long run a shift should occur from the synthetic petroleum broad-based chemicals to selective biologically based materials such as microbials, growth inhibitors, and botanicals. Local production of indigenous bacteria, fungi, and viruses specific to certain pest groups is envisioned. In-country production of microbial and botanical pesticides would provide inexpensive products which are safe for small scale farmer usage.

Modern rice culture has to be more intensive than the traditional system. Priority in the management of pests is to develop stable insect resistant varieties and to mimic the traditional system by creating an annual rice free period in the tropics, an effect equivalent to a temperate winter.

LITERATURE CITED

Chandler, R. F., Jr. 1982. An Adventure in Applied Science: A History of the International Rice Research Institute. International Rice Research Institute, Los Banos, Philippines. 233 p.

Chang, T. T. 1976. The origin, evaluation, cultivation, and diversification of Asian and African rices. Euphytica 25: 425-441.

De Datta, S. K. 1981. Principles and Practices of Rice Production. John Wiley and Sons, New York. 618 p.

Dyck, V. A., and B. Thomas. 1979. The brown planthopper problem. pp. 3-17. In Brown Planthopper: Threat to Rice Production in Asia. International Rice Research Institute, Los Banos, Philippines. 369 p.

Heinrichs, E. A., H. R. Rapusas, V. Viajante, F. G. Medrano, C. R. Vega, and E. B. Medina. 1986. Development of insects (Homoptera, Lepidoptera) on traditional and modern rice cultivars. Environ. Entomol. 15: 417-421.

International Rice Research Institute (IRRI). 1985. International Rice Research: 25 years of Partnership. International Rice Research Institute, Los Banos, Philippines. 188 p.

Kenmore, P. E., F. O. Carino, C. A. Perez, V. A. Dyck, and A. P. Gutierrez. 1984. Population regulation of the rice brown planthopper (*Nilaparvata lugens* Stal) within rice fields in the Philippines. J. Pl. Prot. Tropics 1: 19-37.

Litsinger, J. A., B. L. Canapi, J. P. Bandong, C. G. de la Cruz, R. F. Apostol, P. C. Pantua, M. D. Lumaban, A. L. Alviola III, F. Raymundo, E. M. Libetario, and R. C. Joshi. 1987. Rice crop loss from insect pests in wetland and dryland environments of Asia with emphasis on the Philippines. Insect Sci. Appl. (in press).

Sogawa, K. 1976. Rice tungro virus and its vectors in tropical Asia. Rev. Plant Prot. Res. 9: 21-46.

Vergara, B. S., and T. T. Chang. 1976. The flowering response of the rice plant to photoperiod. A review of the literature. International Rice Research Institute, Los Banos, Philippines. 75 p.

Yoshida, S. 1981. Fundamentals of Rice Crop Science. International Rice Research Institute. Los Banos, Philippines. 269 p.

Table 1. Resistance of IR varieties to insect pests.[a] IRRI, 1986.

Variety	Maturity (DAS)	*N. lugens* biotype			*Nephotettix virescens*	*Sogatella furcifera*	*Scirpophaga incertulas*	*Chilo suppressalis*	*Hydrellia philippina*	*Stenchaetothrips biformis*
		1	2	3						
IR5	130	S	S	S	MR	S	S	S	S	S
IR8	125	S	S	S	MR[d]	S	S	S	S	S
IR20	121	S	S	S	MR	S	MR	R	S	S
IR22	119	S	S	S	S	S	S	S	S	S
IR24	118	S	S	S	MR	S	S	S	S	S
IR26	121	R	S	R	MR	S	S	MR	S	S
IR28	104	R	S	R	R	S	S	S	S	S
IR29	112	R	S	R	R	S	S	S	S	S
IR30	105	R	S	R	R	S	S	MR	S	S
IR32	130	R	R	MR[c]	MR	S	S	MR	S	S
IR34	122	R	S	R	R	S	S	MR	S	S
IR36	110	R	R	MR[c]	MR	S	MR	R	S	S
IR38	123	R	R	MR[c]	MR	S	S	MR	S	S

Table 1. Continued.

Variety	Maturity (DAS)	*N. lugens* biotype 1	2	3	*Nephotettix virescens*	*Sogatella furcifera*	*Scirpophaga incertulas*	*Chilo suppressalis*	*Hydrellia philippina*	*Stenchaetothrips biformis*
IR40	130	R	MR	S	MR	S	MR	R	MR	S
IR42	132	R	R	S	MR	S	S	MR	S	S
IR43	120	S	S	S	MR	S	S	MR	S	S
IR44	123	R	R	MR[c]	MR	S	S	R	S	S
IR45	120	R	S_b	R	MR_d	S	S	S	S	S
IR46	112	R	S	R	MR	S	S	S	S	S
IR48	127	R	R	S	MR	MR	S	S	S	S
IR50	107	R	MR	R[c]	R	S	MR	R	S	S
IR52	117	R	R	MR[c]	R	MR	S	MR	S	S
IR54	120	R	R	S	R	S	MR	MR	S	S
IR56	106	R	R	R	R	S	S	MR	S	S
IR58	108	R	R	R	R	S	S	MR	S	MR

Table 1. Continued.

Variety	Maturity (DAS)	*N. lugens* biotype 1	*N. lugens* biotype 2	*N. lugens* biotype 3	*Nephotettix virescens*	*Sogatella furcifera*	*Scirpophaga incertulas*	*Chilo suppressalis*	*Hydrellia philippina*	*Stenchaetothrips biformis*
IR60	110	R	R	R	R	MR	S	MR	S	MR
IR62	110	R	R	R	R	MR	S	MR	S	R
IR64	115	R	MR	R	R	S	S	e	S	e
IR65	115	R	R	R	R	MR	MR	e	S	e

[a] Based on replicated experiments. Hopper resistance based on greenhouse evaluation of seedlings; yellow and striped stem borer resistance based on a screenhouse evaluation of 40-70-day-old plants; leaffolder and caseworm resistance based on the reaction of 30 and 11-day-old plants in the greenhouse; whorl maggot resistance based on field observations at 30 days after transplanting. Varieties with ratings as based on the standard evaluation system of 1-3 are considered resistant (R), 5-7 moderately resistant (MR) and 9 susceptible (s).

[b] IR46 has field resistance to biotype 2.

[c] Reaction to biotype varies, occasionally being susceptible and often resistant.

[d] Occasional susceptible reactions. Least resistant of the IR varieties except for IR22 which is highly susceptible.

[e] Tests still to be conducted.

Table 2. Reaction[a] of modern (IR20, IR36, and IR50) and traditional (Peta and Intan) rice cultivars to six major rice insect species (Heinrichs et al. 1986).

Cultivar	Resistance of rice cultivars to:							
	N. lugens biotypes			*S. furcifera*	*N. virescens*	*C. medinalis*	*N. depunctalis*	*C. suppressalis*
	1	2	3					
IR20	S	S	S	S	S	S	S	S
IR36	R	R	R	S	MR	S	S	R
IR50	R	R	R	S	R	S	S	R
Peta	S	S	S	S	MR	S	MR	S
Intan	S	S	S	S	MR	S	MR	S

[a] S, susceptible; MR, moderately resistant; R, resistant.

Table 3. Evaluation of rice Oryza sativa and wild rice Oryza sp. accessions in the IRRI germplasm collection for resistance against insect pests of rice. IRRI, 1962-84.

Insect	Oryza sativa		Wild rices	
	Screened (no.)	Resistant (%)	Screened (no.)	Resistant (%)
Brown planthopper Nilaparvata lugens				
Biotype 1	45,172	0.9	446	46
Biotype 2	15,068	1.9	445	38
Biotype 3	16,402	1.8	448	40
Green leafhopper Nephotettix virescens	48,961	2.6	239	53
Yellow Stem borer Scirpophaga incertulas	22,920	0.1	322	22
Striped stem borer Chilo suppressalis	15,000	0.2	243	5
Whorl maggot Hydrellia philippina	16,918	0.01	339	2
Leaffolder Cnaphalocrocis medinalis	20,816	0.6	338	2

FIGURE CAPTIONS

Fig. 1. Grain yield response of 4 rices to different levels of nitrogen. Data are average for IRRI and the three experiment stations of the Philippine Bureau of Plant Industry (Maligaya, Bicol, and Visayas), 1967-1985 wet seasons. (S. K. De Data, IRRI-Agronomy Department, Unpublished).

Fig. 2. Twenty land races or traditional varieties from 8 nations are in the genetic ancestry of IR64 rice for irrigated environments.

Fig. 3. Trends in rice area irrigated, area planted to modern varieties (MV), and fertilizer (NPK) use per hectare, South and Southeast Asia. (IRRI 1985).

Fig. 4. Annual light trap collections showing the replacement of dark-headed stem borer *Chilo polychrysus* with yellow stem borer *Scirpophaga incertulas* with the expansion of double rice cropping in Titi Serong, Malaysia, 1964-1975. (Data courtesy of G. S. Lim and K. L. Heong, MARDI).

Fig. 5. Annual light trap collections of green leafhopper *Nephotettix virescens* and yellow stem borer *Scirpophaga incertulas* spanning the period of change from single to double cropped rice with the gradual expansion of the irrigation system in Titi Serong, Malaysia, 1965-75. (Data courtesy of G. S. Lim, MARDI). The carry-over index is the ratio of the insect population at the beginning of the present wet season to the peak of the preceding year's wet season.

Fig. 6. Annual light trap collections of brown planthopper Nilaparvata lugens and yellow stem borer Sciropophaga incertulas from 10 rainfed and irrigated rice sites of varying averages of the number of rice crops per year. Philippines.

Fig. 7. Annual totals of yellow stem borer Scirpophaga incertulas and green leafhopper Nephotettix virescens from 10 rainfed and irrigated rice sites of varying percentages of area planted to rice. Philippines.

Fig. 8. The correlations between seasonal light trap catch of brown planthopper Nilaparvata lugens and yellow stem borer Scirpophaga incertulas and asynchrony calculated for areas of increasing radii. Nueva Ecija, 1981.

Fig. 9. Seasonal totals of yellow stem borer Scirpophaga incertulas and brown planthopper Nilaparvata lugens collected in kerosene light traps in 14 irrigated rice sites in Nueva Ecija in relation to asynchrony of planting within the area of effective dispersal range (radius from each light trap) of each pest.

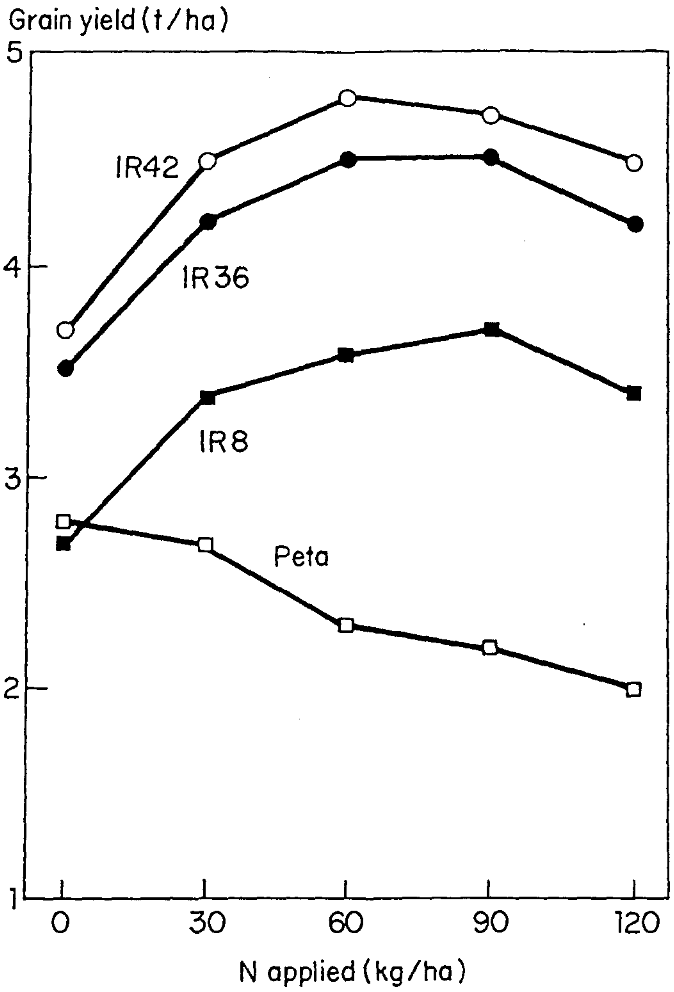


Fig. 1. Grain yield response of 4 rices to different levels of nitrogen. Data are average for IRRI and the three experiment stations of the Philippine Bureau of Plant Industry (Maligaya, Bicol, and Visayas), 1976-1985 wet seasons. (S.K. De Datta, IRRI-Agronomy Department, Unpublished)

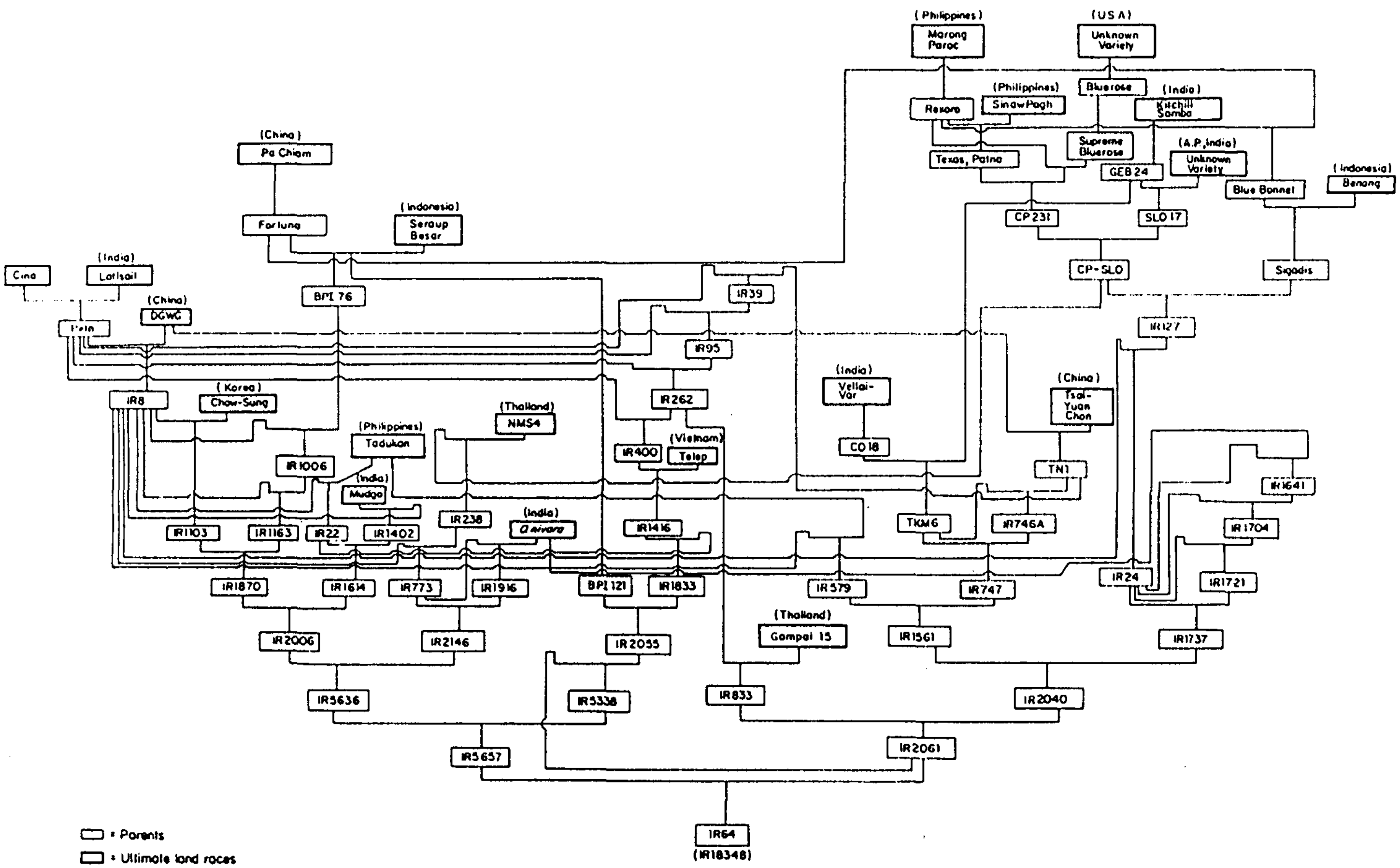
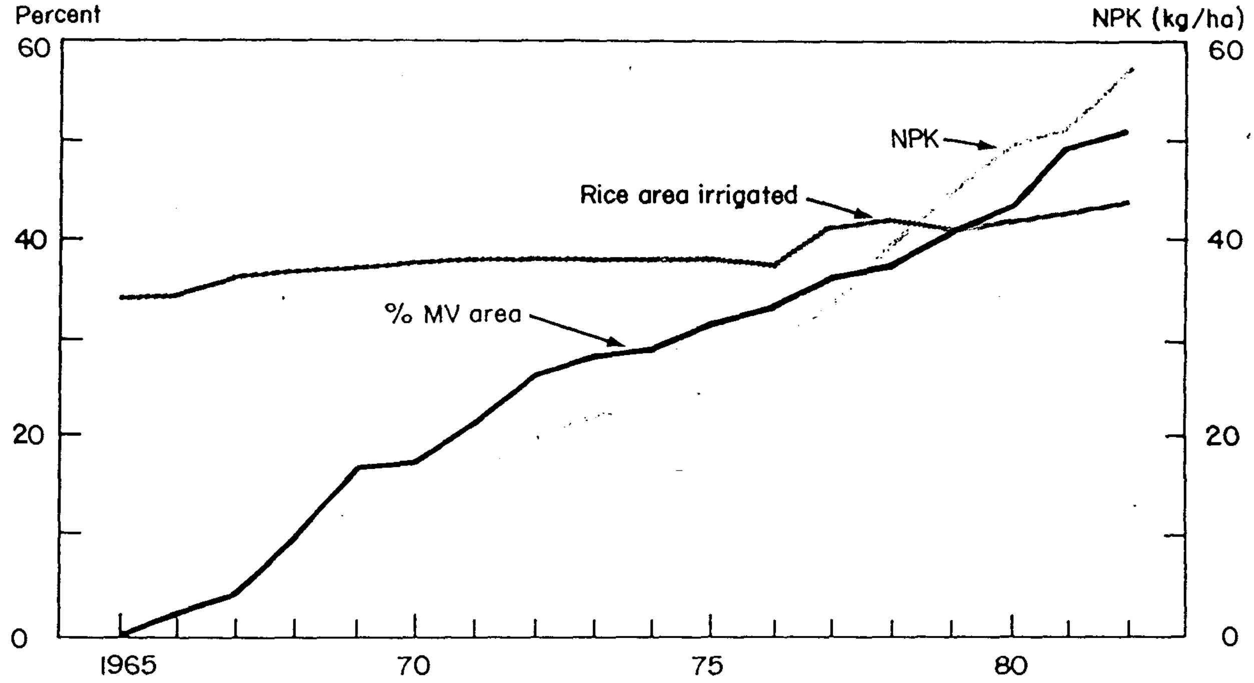


Fig. 2. Twenty land races or traditional varieties from 8 nations are in the genetic ancestry of IR64 rice for irrigated environments.



3. Trends in rice area irrigated, area planted to modern varieties (MV), and fertilizer (NPK) use per hectare, South and Southeast Asia.
(IRRI 1985).

Fig. 3

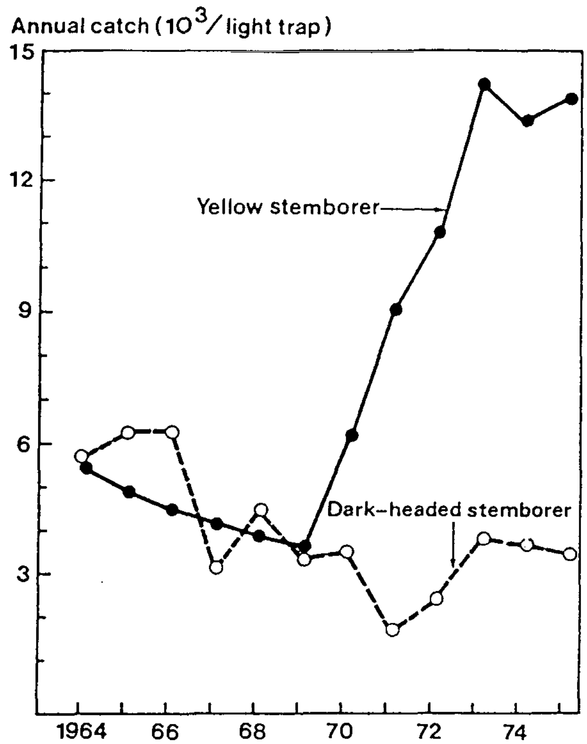


Fig. 4. Annual light trap collections showing the replacement of dark-headed stem borer Chilo polychrysus with yellow stem borer Scirpophaga incertulas with the expansion of double rice cropping in Titi Serong, Malaysia, 1964-1975. (Data courtesy of G.S. Lim and K.L. Heong, MARDI).

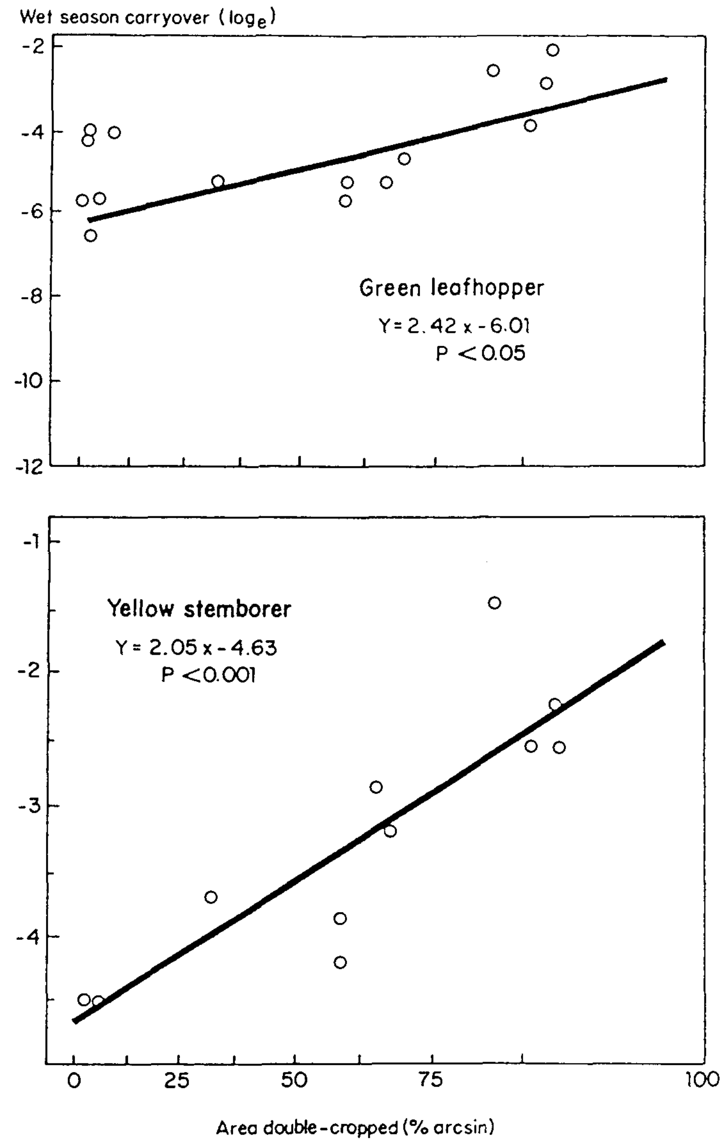


Fig. 5. Annual light trap collections of green leafhopper <u>Nephotettix virescens</u> and yellow stem borer <u>Scirpophaga incertulas</u> spanning the period of change from single to double cropped rice with the gradual expansion of the irrigation system in Titi Serong, Malaysia, 1965-75. (Data courtesy of G.S. Lim, MARDI). The carryover index is the ratio of the insect population at the beginning of the present wet season to the peak of the preceding year's wet season.

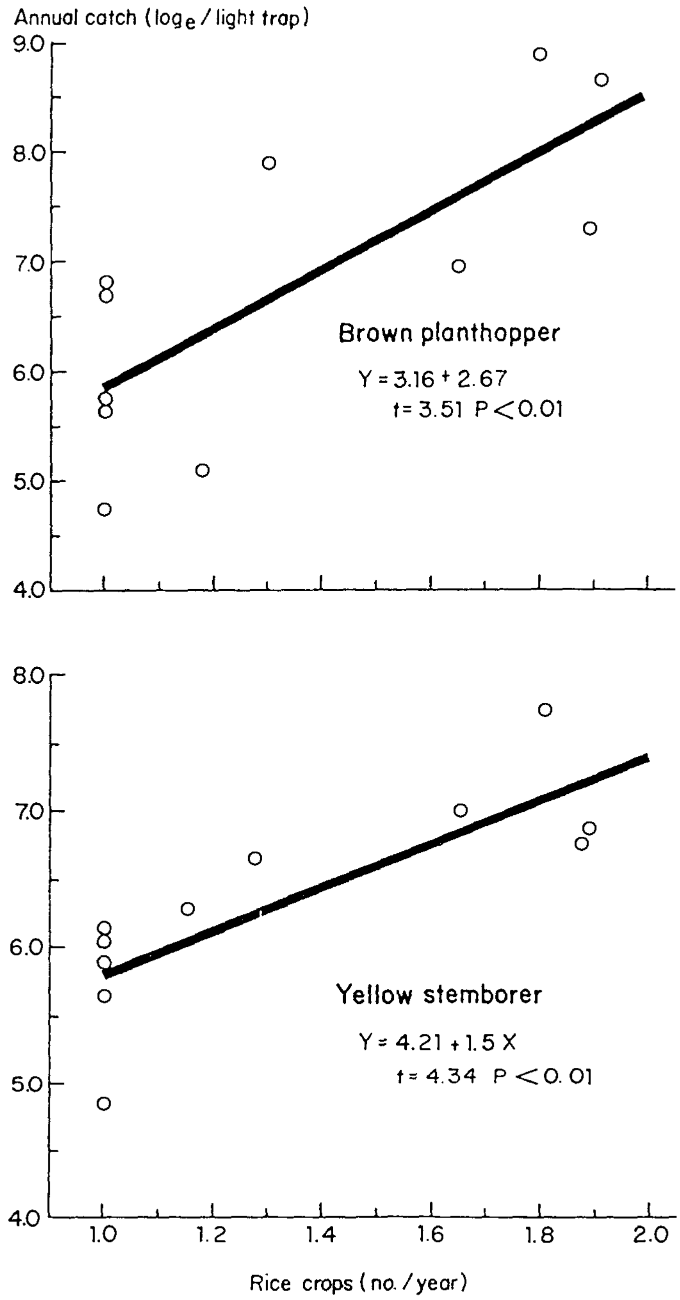


Fig. 5. Annual light trap collections of brown planthopper Nilaparvata lugens and yellow stem borer Scirpophaga incertulas from 10 rainfed and irrigated rice sites of varying averages of the number of rice crops per year. Philippines.

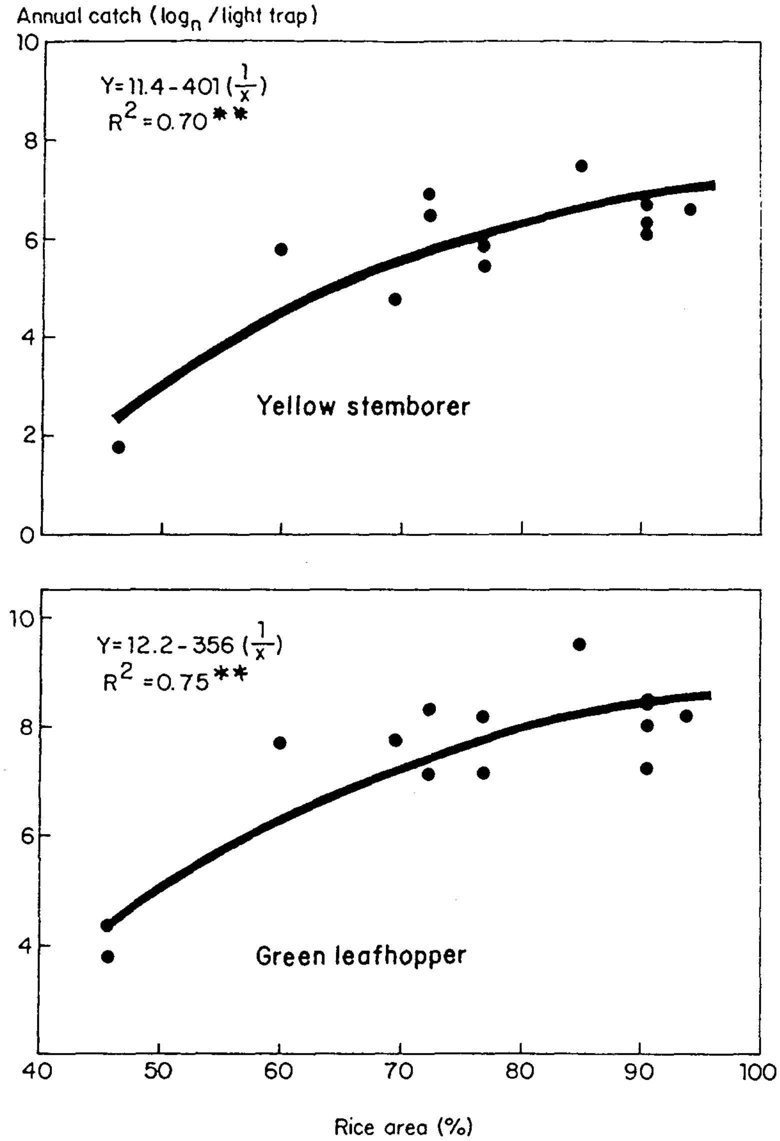


Fig. 7. Annual totals of yellow stem borer *Scirpophaga incertulas* and green leafhopper *Nephotettix virescens* from 10 rainfed and irrigated rice sites of varying percentages of area planted to rice. Philippines.

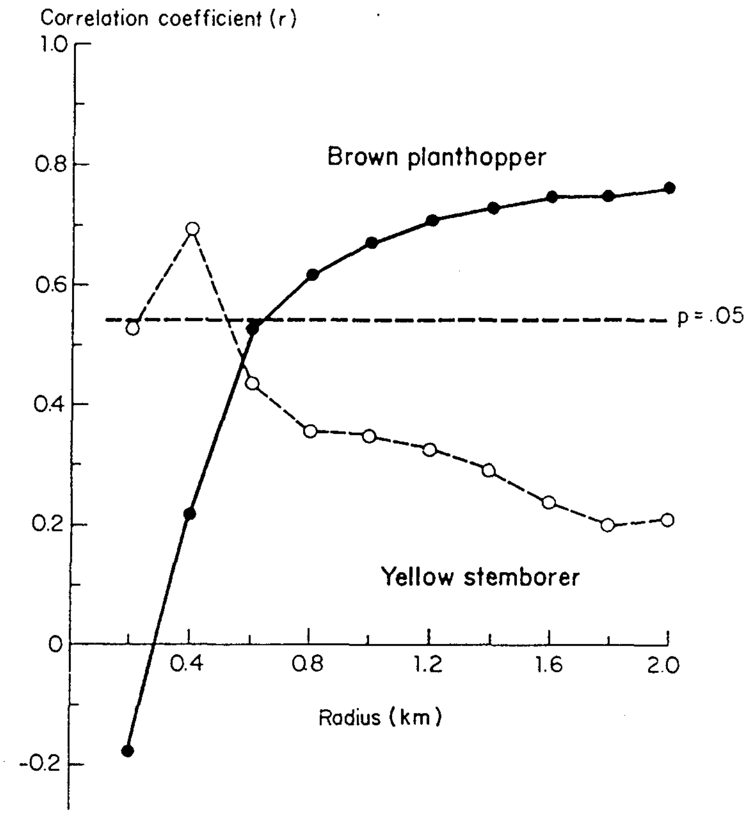


Fig. ¶. .ie correlations between seasonal light trap catch of brown planthopper Nilaparvata lugens and yellow stem borer Scirpophaga incertulas and asynchrony calculated for areas of increasing radii. Nueva Ecija, 1981.

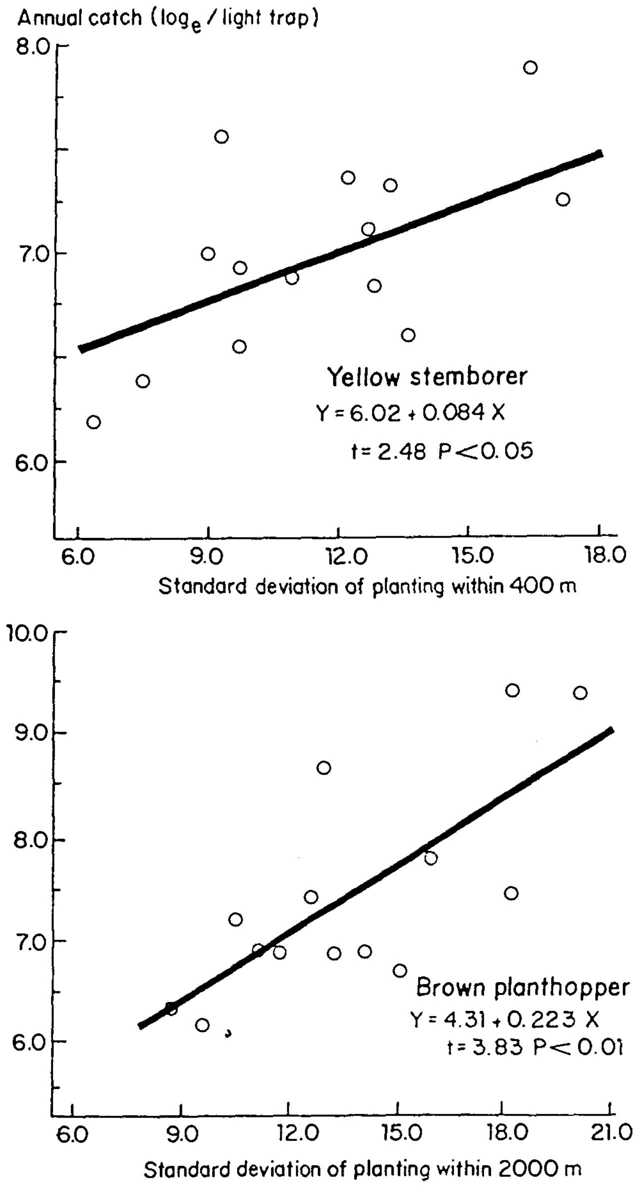


Fig. 8 Seasonal totals of yellow stem borer <u>Scirpophaga incertulas</u> and brown planthopper <u>Nilaparvata lugens</u> collected in kerosene light traps in 14 irrigated rice sites in Nueva Ecija in relation to asynchrony of planting within the area of effective dispersal range (radius from each light trap) of each pest.