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The Epidemiology and Management of Rice Tungro Virus Disease

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SECTION A

Executive Summary

Rice tungro disease is considered to be one of the most important constraints to rice production in intensively cultivated irrigated areas in South and Southeast Asia. Due to the highly destructive nature of the disease resource poor farmers can incur serious loss of income if their crops are affected. Tungro disease is difficult to control and management strategies have traditionally relied on heavy insecticide usage with adverse effects on human health and the environment. The purpose of this project was to reduce yield losses and to protect farmer income in intensive rice cropping systems by developing and promoting sustainable tungro disease management strategies.

The deployment of varieties with durable resistance to tungro was identified as one of the key disease management options. In the past, varieties with resistance to the leafhopper vector conferred 'field' resistance to tungro but this resistance broke down as leafhoppers adapted to them. In this project advanced breeding lines developed at the International Rice Research Institute (IRRI) were selected and evaluated in the greenhouse and in multi-location field trials in India, Indonesia and the Philippines. Some lines showed strong levels of resistance and a clear demand for the material was shown by farmers in on-farm trials. One advanced breeding line is expected to be released as an approved variety by the Philippine Seedboard in November 1999. Other lines are being utilised by rice breeders in their own resistance breeding programmes. A simple, reliable and relatively low cost prototype diagnostic kit for rice tungro bacilliform virus was developed and this should greatly facilitate the breeding work. Test kits were evaluated by selected participants at an international workshop on tungro management conducted in November 1998. The method was then refined and further field evaluation was done in Bangladesh and Philippines.

A spatial model was developed and was used to evaluate the effects of the deployment of resistant varieties and the closer synchronisation of planting dates on tungro incidence. Model outputs enabled optimum disease reducing strategies to be identified. Surveys of farmers' perceptions of tungro disease and their current control practices were used to develop extension methodologies for improved tungro management. Training courses in tungro identification and management were conducted for both agricultural extension officers and farmers and training manuals were developed. Information obtained from focus group surveys conducted two years after the training showed that farmers retained the main messages promoted during the courses. The spontaneous adoption of virus-resistant lines by farmers before clearance for varietal release indicates the potential for their widespread uptake. Farmers understood the importance of synchronising planting dates to reduce tungro incidence but were constrained by insufficient and irregular water supplies. However, at a workshop held in Midsayap, Philippines in December 1998 a commitment was made by farmers, agricultural extension officers, local government units and the National Irrigation Authority to improve the scheduling of irrigation water in the municipality. If successful, this would serve as a model for other areas. Reports from Midsayap in the 1999 wet season indicate that a tighter scheduling of irrigation water was achieved, resulting in more synchronous planting and low tungro incidence.

The project has contributed to efforts made by IRRI, FAO, national agricultural research systems and others to reduce the dependency on insecticides for the control of rice pests. In identifying and evaluating viable alternative options for tungro management, the project has provided agricultural extension agencies with strategies that can be adopted by rice farmers. In areas where tungro is endemic, these management strategies have the demonstrated potential to protect the incomes of poor rice farmers and to reduce their debt burden.

Background

Rice tungro disease emerged as a serious problem for rice farmers in the 1960's as a result of the intensification of rice production during the 'Green Revolution'. Major outbreaks of tungro occurred in various countries in South and Southeast Asia causing serious production losses over wide areas. Large-scale epidemics have become less frequent but still occur. In 1995 a major tungro outbreak occurred in Central Java, Indonesia affecting an estimated 18,000 hectares of rice and resulting in large economic losses for resource poor farmers and for the country as a whole.

The dynamics of tungro disease are extremely complex and remained poorly understood until very recently. Consequently, there was no clear strategy to manage tungro and many of the control measures implemented were inappropriate and ineffective. The use of varieties with resistance to the leafhopper vector has been successful in reducing tungro incidence but this resistance has not proved to be durable. Farmers were forced into relying on insecticides even though they knew that this approach had limited efficacy (Warburton *et al*., 1997). Many rice farmers depend on credit to purchase inputs. As a result of the lack of effective control measures and the high yield losses they sustained, farmers were caught in a debt cycle from which they could not easily escape.

A DFID-funded project (R5243) was initiated in 1989 to investigate the epidemiology of tungro disease and the ecology of the leafhopper vectors in order to provide a scientific basis for improved tungro management strategies. Results from studies on leafhopper ecology showed that tungro incidence was not directly related to insect abundance and that the widely used threshold-based recommendations for control by insecticides could not be justified. Research on disease dynamics revealed that secondary plant to plant spread by leafhopper vectors played an important role in tungro epidemiology. The utilisation in rice varieties of resistance to rice tungro spherical virus had the potential to dramatically reduce tungro incidence by preventing secondary spread. The most effective way to control tungro was not through the use of tactical measures such as applying insecticides or removing infected rice plants. A strategic approach involving the deployment of virus-resistant varieties and the manipulation of planting dates offered the best prospects for effective tungro management. Research findings from other projects, such as a study on developing a tungro forecasting system in Indonesia, provided further evidence to support such an approach (Suzuki *et al*., 1992).

An international conference on rice tungro disease management was held in Malaysia in November 1993 as part of this earlier project (Chancellor and Thresh, 1996). Participants in the workshop reported that tungro remained an important constraint to rice production in India, Indonesia and the Philippines. Key researchable issues were identified and these formed the basis for the development of this project. The need for continuing research was also demonstrated by the frequent requests that IRRI scientists received from researchers, extension agencies and farmers to help them manage the tungro problem in their respective countries.

Project Purpose

The purpose of this project was to increase and stabilise rice yields in intensive rice cropping systems by developing and promoting sustainable strategies to manage rice tungro disease. These strategies were to be based on sound epidemiological and ecological principles and to involve an integrated approach to disease management with a reduced reliance on pesticides.

This project has identified appropriate methodologies to reduce yield losses due to tungro in endemic areas and to protect farmers' incomes from the drastic loss of income that results from a serious attack of the disease. The key management option is the deployment of new disease-resistant varieties. This offers the most practical and sustainable approach in endemic areas. Farmers have demonstrated that they are keen to adopt resistant varieties. However, they need to be provided with adequate information about such varieties and to have access to reliable sources of seed supply.

Research Activities

The research activities carried out during the project are summarised in this section and are described in detail in Section B. The activities and outputs are presented under three main themes which relate directly to the three outputs (1-3) listed in the original Project Memorandum document. These themes are a) Durable resistance to rice tungro disease b) Evaluation of rice tungro disease management strategies and c) Extension methodologies for rice tungro disease management. Additional outputs (4-7) resulting from subsequent amendments to the Project Memorandum were closely linked to outputs 1-3. Consequently, the additional outputs and their associated activities are also presented under the appropriate theme. This is illustrated below:

Theme	*Output*	*Project document*
Durable resistance to rice tungro disease	2. Rice varieties and advanced breeding lines evaluated for resistance to leafhopper vectors and to tungro viruses at two locations in each of the three countries (India, Indonesia and Philippines) and recommended for deployment in specific localities to provide durable resistance to RTVD. 6. New antisera characterised for specificity and sensitivity and a dip-stick assay developed and field-tested. 7. Tungro screen kit optimised and evaluated under field conditions in three target countries by 30.9.1999.	Project Memorandum Amendment B Amendment D
Evaluation of rice tungro disease management strategies	1. RTVD management recommendations developed and adapted for differing agroecological and socio-economic conditions in accordance with disease risk for two target countries; India and Philippines. 4. Three papers completed and submitted for publication in international journals by 31.3.1998. One conference paper prepared and project outputs disseminated at the IRRI IPMNET meeting in July 1997. 5. End of project workshop held to disseminate project outputs in November 1998.	Project Memorandum Amendment A Amendment C
Extension methodologies for rice tungro disease management	3. Extension methodologies developed to enable farmers to identify RTVD symptoms and leafhopper vectors, to gain a basic understanding of the operation of the disease cycle and to utilise appropriate control measures such as resistant varieties.	Project Memorandum

1. Durable resistance to rice tungro disease (Outputs 2, 6 and 7)

Advanced breeding lines with resistance to rice tungro viruses developed at IRRI were selected and evaluated in the greenhouse and in multi-location field trials in India, Indonesia and the Philippines. Two trial sites were used in each of the three countries. Trials were conducted in the wet season, as tungro disease incidence was generally greatest during this period. At two of the trial sites where disease incidence was high throughout the year, dry season trials were also conducted. Leafhopper vector numbers and tungro disease incidence were recorded and leaf samples were indexed for the presence of tungro viruses using enzyme-linked immunosorbent assay (ELISA). [*Output 2*]

On-farm trials were conducted in North Cotabato, Philippines and in Tamil Nadu, India to assess the performance of promising virus-resistant lines in farmers' fields. Replicated field plots were planted with a virus-resistant or virus-tolerant line, a leafhopper vector-resistant line and a variety chosen by the farmer and grown in the rest of his or her field. Leafhopper vector numbers, tungro disease incidence and grain yield were recorded.

Polyclonal antisera for rice tungro bacilliform virus (RTBV) and rice tungro spherical virus were characterised and purified and used in a tissue-printing procedure for rapid detection of tungro viruses in rice plants. Prototype detection kits for RTBV were developed and evaluated in Bangladesh, India, Indonesia and Philippines. [*Outputs 6 and 7*]

2. Evaluation of rice tungro disease management strategies (Outputs 1, 4 and 5)

Focus group discussions and a formal questionnaire were used to evaluate farmers' perceptions and management practices for rice tungro disease. The study was conducted in nine villages in North Cotabato and six villages in Tamil Nadu. At the end of each cropping season, data on cropping practices and pest and disease management were collected from farmers in each of the nine villages in North Cotabato and in two of the six villages in Tamil Nadu. [*Output 1*]

Modelling studies were carried out to investigate the dynamics of tungro disease spread between rice fields. A lattice model was developed and used to examine how the spatio-temporal deployment of resistant varieties could reduce the incidence of rice tungro disease. The model was also used to assess how changes in the synchrony of planting dates affected the incidence of tungro. [*Outputs 1 and 4*]

An international workshop on rice tungro disease management was held in Los Baños, Philippines on 9-11 November 1999 to disseminate project outputs. [*Output 5*]

3. Extension methodologies for rice tungro disease management (Output 3)

Two training courses in the 'Identification and Management of Rice Tungro Disease' were devised for agricultural extension officers and for rice farmers. Courses were conducted in North Cotabato and in Tamil Nadu. Selected agricultural extension officers subsequently trained groups of *c*. 30 rice farmers in three villages in North Cotabato and two villages in Tamil Nadu. On-farm trials (see para 1 above) were used in the training to demonstrate the advantages of resistant varieties and to enable farmers to identify tungro disease, tungro vectors and their natural enemies.

Focus group discussions were held with agricultural extension officers and farmers two years after the initial training in order to assess the extent to which they retained the main messages disseminated during the courses.

Outputs

Project outputs are summarised below and are presented in detail in Section B.

- *Tungro management strategies* were evaluated at sites in India and the Philippines. The spontaneous adoption of virus-resistant lines by farmers before clearance for varietal release indicates the potential for their widespread uptake. Farmers understood the importance of synchronising planting dates to reduce tungro incidence but were constrained by insufficient and irregular water supplies. However, at a workshop held in Midsayap, North Cotabato, Philippines in December 1998 a commitment was made by farmers, agricultural extension officers, local government units and the National Irrigation Authority to improve the scheduling of irrigation water in the municipality. If successful, this would serve as a model for other areas. Reports from Midsayap in the 1999 wet season indicate that a tighter scheduling of irrigation water was achieved, resulting in more synchronous planting and low tungro incidence. [*Output 1*]

- *Advanced breeding lines with resistance to rice tungro viruses* were identified and seed provided to rice breeders. Some lines showed strong levels of resistance at each of the sites in India, Indonesia and the Philippines. A clear demand for this material was shown by farmers in on-farm trials. Farmers in areas where these trials were conducted are now growing one or more of the resistant lines, although they have not yet been approved for varietal release. One advanced breeding line is expected to be released as an approved variety by the Philippine Seedboard in November 1999. Other lines are being utilised by rice breeders in their own resistance breeding programmes. [*Output 2*]

- *Extension methodologies for tungro management* were developed from the results of the modelling studies and data from surveys of farmers' perceptions of tungro disease and their current control practices. *Training courses* were designed and used to train farmers and agricultural extension officers, respectively, in tungro identification and management. *Training manuals* are now being written using dissemination funds [*Output 3*]

- *A spatial model* was developed and was used to evaluate the effects of the deployment of resistant varieties and the closer synchronisation of planting dates on tungro incidence. Model outputs enabled optimum disease reducing strategies to be identified. Three papers were written and submitted to international journals and one conference presentation was made on tungro disease management [*Outputs 4 and 1*]

- An international workshop on 'Rice Tungro Disease Management' was held on 9-11 November 1998 in which project outputs were disseminated. [*Output 5*]

- *A simple, reliable and relatively low cost prototype diagnostic kit for rice tungro bacilliform virus* was developed and this should greatly facilitate the breeding work. Test kits for evaluation were given to participants at an international workshop on tungro management conducted in November 1998. The method was then refined and further field evaluation was done in Bangladesh and Philippines. [*Outputs 6 and 7*].

Anticipated project outputs were fully achieved.

Contribution of Outputs

Durable resistance to rice tungro disease offers the most practical, cost-effective and environmentally sound way to stabilise yields and protect farmers' income in intensive production systems where the disease is a major problem. By identifying virus-resistant advanced breeding lines appropriate for particular geographical locations the project has laid the basis for the implementation of this approach. Farmers are already growing tungro-resistant lines before they have been officially released as varieties. Promising lines are now being used by rice breeders in India, Indonesia and Philippines in their own tungro resistance breeding programmes and one line is expected to be released as a variety in Philippines in November 1999. The development of a simple and reliable diagnostic kit has provided rice breeders with a valuable tool to utilise this resistant material in their own breeding programmes. There is strong demand for the kit and researchers and agricultural extension officers from Bangladesh, India, Indonesia and Philippines have been trained to use it. The project has contributed to a new emphasis on strategic measures for tungro management in recommendations promoted by national agricultural extension agencies. This has led to a reduced emphasis on insecticide-based tungro control strategies with consequent benefits for human health and the environment.

SECTION B

1. Durable Resistance to Rice Tungro Disease

Collaborators

India: Indian Council for Agricultural Research (ICAR), Tamil Nadu Agricultural University (TNAU), Tamil Nadu Department of Agriculture, Bidhan Chandra Krishi Viswavidyalaya (BCKV).
Indonesia: Agency for Agricultural Research and Development (AARD), Balai Proteksi Tanaman Pangan (BPTP), Maros Institute for Maize and other Cereal Crops (Maros), Research Institute for Rice (SURIF).
Philippines: Philippine Rice Research Institute (PhilRice), Department of Agriculture, International Rice Research Institute (IRRI).
UK: Natural Resources Institute, University of Greenwich.

Background

The deployment of varieties with resistance to the major vector of rice tungro disease, *Nephotettix virescens*, has been the cornerstone of tungro management strategies for more than two decades. However, adaptation by populations of *N. virescens* has led to a breakdown of the 'field' resistance of these varieties to tungro and they have succumbed to the disease (Dahal *et al*., 1990). Rice breeders are now incorporating virus resistance into elite lines in an attempt to produce varieties with more durable resistance to tungro. However, recent studies have shown that there are different strains of tungro virus which have the potential to infect varieties which carry certain resistance genes (Dahal *et al*., 1992; Cabauatan *et al*., 1995). Therefore, information on the performance at a given locality of advanced breeding lines with specific resistance genes is a prerequisite to a varietal deployment programme.

In an earlier study (R5243), advanced breeding lines with resistance to rice tungro viruses were evaluated in the greenhouse and the most promising lines were selected for field testing. A method was developed for assessing the performance of these elite lines in replicated field trials with plots which were sufficiently large to enable any secondary plant to plant spread to be analysed (Chancellor and Thresh, 1996). Field testing was conducted using the resistant donors, most of which were unimproved varieties, and some of their earlier progeny from crosses with agronomically superior lines. The results showed that the resistance derived from some donors was effective at all locations. However, in the case of other donors high infection with tungro viruses was recorded at certain sites (Chancellor and Thresh, 1996).

Sensitive and reliable methods for detecting plant viruses in their hosts can be essential tools in host breeding and researching resistance mechanisms and virus epidemiology. At IRRI, enzyme-linked immunosorbent assays (ELISA) based on 96-well microtitre plates and using polyclonal antisera (PAb) produced on site has been used for many years for detecting the two viruses responsible for rice tungro disease; rice tungro bacilliform badnavirus (RTBV, *Badnaviridae*), and rice tungro spherical virus (RTSV, *Sequiviridae*). The procedure is relatively simple, but does require access to a relatively advanced laboratory with reliable electricity and water and an ELISA plate reader (also a mechanical sap extractor if large numbers of samples are to be tested).

Researchers had commented that they thought a cheap, easy to use kit for confirming tungro infections would be a useful tool for rice breeders and extension agents working in the field. In 1995, a small-scale survey of Filipino rice growers, agricultural extension officers and researchers was conducted under project R5243 (C. Foot, unpublished report). It was found that there was considerable interest in the availability of such a kit among all these groups. Previous attempts at IRRI to develop simpler diagnostic tools for tungro viruses based on polyclonal antisera were not successful, partly due to the insufficient titre of the antisera. However, preliminary analysis of antisera produced by an IRRI scholar, Mr Palash Deb Nath, using a multiple immunisation procedure revealed a significantly increased titre. The objective of the present study was to further characterise the new batches of antisera and to assess their potential for use in simple diagnostic tests.

Activities

A) Multi-location testing of advanced breeding lines with resistance to rice tungro viruses

[Output 2: Rice varieties and advanced breeding lines evaluated for resistance to leafhopper vectors and to tungro viruses at two locations in each of the three countries (India, Indonesia and Philippines) and recommended for deployment in specific localities to provide durable resistance to RTVD.]

In the present project, multi-location testing of advanced breeding lines with resistance to rice tungro viruses was continued at six sites covering three countries in 1996-1998, as indicated in Table 3. In each test location a randomized complete block design was used with four replications. The plot size was 8m x 8m with a 2m separation distance between plots. Two to three seedlings per hill were transplanted at 21 days after sowing at a spacing of 20 cm x 20 cm and exposed to natural infection by tungro viruses. At some trial sites, spreader rows of a susceptible variety were planted between the blocks to enhance disease spread. Variety IR64 was used as a leafhopper- and tungro-susceptible check. IR62 was used as a leafhopper-resistant check.

Plants were assessed for disease symptoms and leaves sampled for detection of tungro viruses by ELISA at 30-35 and 55-60 days after transplanting (DAT). Disease assessment was conducted in six quadrats of 4 x 4 hills arranged in a ‘W’ pattern in each plot. In one replication of each treatment, each hill in the plot was assessed for tungro incidence in order to provide information about the spatial distribution of the disease. Vector leafhoppers were collected from each plot using 10 sweeps of a 30 cm diameter insect net at 30-35 and 55-60 DAT. In selected trials, data on grain yield were collected from a 5m x 5m area in the centre of each plot.

Field trials conducted in 1994-95 showed that Utri Merah was the most promising resistant donor for use in the tungro resistance breeding programme as it showed strong resistance at all locations (Chancellor & Thresh, 1996). Utri Merah has resistance to RTSV and resistance to multiplication of RTBV; in this report, resistance to multiplication of tungro virus is classified as a form of tolerance. The resistance characteristics of all the donors for the advanced breeding lines evaluated during the present project are shown in Table 1. The background of the advanced breeding lines is shown in Table 2.

Table 1. Resistance characteristics of the varieties used as tungro virus-resistant donors for the advanced breeding lines evaluated in multi-location trials.

Variety	Resistance characteristics			
	Resistant to:			Tolerant to:
	GLH	RTBV	RTSV	RTBV
ARC11554	√	√	√	
Balimau Putih				√
Habiganj DW8				√
Oryza longistaminata	√			√
Oryza rufipogon				√
Utri Merah			√	√
Utri Rajapan			√	√

Table 2. Advanced breeding lines with resistance or tolerance to rice tungro viruses evaluated in multi-location trials in India, Indonesia and the Philippines in 1996-98.

Breeding line	Cross
IR68305-18-1	IR64 *4 / Balimau Putih
IR69704-4-4-8-1-1	IR1561-228-3-3 *2 / Utri Rajapan
IR69705-1-1-3-2-1	IR1561-228-3-3 *2 / Utri Merah
IR73890-1-3-1-4-1	IR1561-228-3-3 *2 / Utri Merah // IR24
IR69726-16-3-2	IR61009-37-2-1-2 /// IR1561 / Utri Merah // IR24
IR69726-116-1-3	IR61009-37-2-1-2 /// IR1561 / Utri Merah // IR24
IR71030-2-3-2-1	IR1561-228-3-3 *6 / ARC11554
IR71031-4-5-5-1	IR1561-228-3-3 *6 / ARC11554
IR71605-2-1-5-3	IR1561-228-3-3 *3 / Habiganj DW8 // 4* IR64
IR71026-3-24-3-5-2	IR1561-228-3-3 *2 / *Oryza longistaminata*
IR72928-1-2-1-2-4-1	IR1561-228-3-3 *2 / *Oryza longistaminata* // 3* IR24
IR73891-2-1-5-1	IR64 / *Oryza rufipogon* // 3* IR64

B) On-farm tungro management trials

[Output 2: Rice varieties and advanced breeding lines evaluated for resistance to leafhopper vectors and to tungro viruses at two locations in each of the three countries (India, Indonesia and Philippines) and recommended for deployment in specific localities to provide durable resistance to RTVD.]

Promising advanced breeding lines with resistance to rice tungro viruses were evaluated in on-farm wet season trials in North Cotabato, Philippines and Tamil Nadu, India in 1996-1998. The performance of a leafhopper-resistant variety (T_1) and a virus-resistant or virus-tolerant line (T_2) was compared with a variety chosen by the farmer (T_3) which was also planted in the rest of his field. The plot size was 10m x 10m with a 2m border row of the leafhopper-resistant variety between plots and surrounding the whole trial area. There were three replicates of each treatment and the trial was laid out in a randomized complete block design. The farmer was requested not to spray T_1 or T_2 plots against leafhoppers or tungro, but was free to apply the pest management practices of his choice to T_3 plots. Tungro incidence was assessed by counting the proportion of diseased hills (transplanted crops) or plants (direct-seeded crops) within five 1m x 1m quadrats. Leafhopper numbers were estimated by ten sweeps of a 30 cm diameter insect net. Yield data were collected from a 5m x 5m area in the centre of each plot. These trials were also used for training and demonstration purposes (see Section B).

C) Evaluation of antisera produced at IRRI against rice tungro viruses, and development of rapid diagnostic kits for the viruses

[Output 5: New antisera characterised for specificity and sensitivity and a dip-stick assay developed and field-tested. Output 6: Tungro screen kit optimised and evaluated under field conditions in three target countries by 30.9.1999]

Antiserum production: P. Dab-Nath immunised two rabbits separately by three subcutaneous injection (at fortnightly intervals) with purified RTSV and RTBV virions respectively in Freunds adjuvant, followed by 6 booster inoculations at 6 week intervals. Test bleeds (*c.* 1 ml) were taken from the rabbits one week after the first two immunisations. Bleeds of *c.* 20 ml were taken one week after each subsequent injection. Serum was separated from blood cells by standard methods. IgGs were purified from serum by ammonium sulphate precipitation and DEAE-cellulose chromatography. Glutaraldehyde treatment was used to conjugate alkaline phosphatase to the immunoglobulins. A rough measure of the titre of each batch of crude antisera was made by the ring-interface precipitation test with purified virions.

Antisera characterisation: L. Kenyon made a visit to IRRI in February 1998 to set up a mini polyacrylamide gel electrophoresis (PAGE) and Western blot apparatus, and used these to start to characterise the new antisera batches. Sap extracts from screen-house-grown rice plants were denatured by boiling in electrophoresis sample buffer and were then electrophoresed in 12.5% PAGE gels. Following electrophoresis, proteins were transferred (electroblotted) to nitrocellulose membranes. Membranes were probed with different batches of the RTSV or RTBV antisera to observe differences in specificity between the different batches. During a subsequent visit in June-July 1999, comparative tests were made with other batches of antiserum.

Cross-absorption (purification) to remove non-virus-specific antibodies: Initial attempts to remove healthy plant cross-reacting antibodies involved simply incubating the diluted test antiserum with sap extract from uninfected plants for one hour (= direct cross-absorption) before using the mixture to probe nitrocellulose membranes. Subsequently, healthy sap proteins were immobilised on small pieces of nitrocellulose membrane and then the diluted test antisera were incubated with these membranes prior to being used to probe Western blots or tissue prints.

In order to scale up the antiserum purification (removal of healthy plant-reacting antibodies), healthy sap proteins were bound to sepharose beads (by the cyanogen-bromide method), and these were used to form affinity columns. Relatively concentrated IgGs were then passed through these columns; only those IgGs specific for non-plant proteins (e.g. virus) passed straight through the columns, the plant-specific IgGs binding to the plant proteins in the matrix. The resulting solution was then incubated with a piece of nitrocellulose membrane previously saturated with healthy rice plant homogenate in order to mop up any remaining antibodies with affinity to plant proteins.

Tissue-printing and development of a prototype diagnostic kit for RTBV: During the antisera characterisation and purification (see above), trials were made on a tissue-printing procedure. Rice plants grown in the screen-house and infected with either RTBV, RTSV, both viruses or uninfected were used. Individual plant stems were cut (transverse or oblique cuts) with a clean, sharp razor blade and the cut surface gently pressed (printed) onto a protein-binding membrane. Nitrocellulose and PVDF membranes were tested, as were different antibody preparations/purifications, membrane blocking techniques and antibody detection protocols.

Testing of systems for improved sensitivity: Two alternative systems for amplifying the signals were compared with the original reporter system. These systems involved the use of a protein-A-alkaline phosphatase conjugate and an anti-rabbit Ig-biotin conjugate followed by Exravidin-alkaline phosphatase and BCIP, respectively.

Evaluation of prototype kits: Prototype kits were given to collaborators for initial evaluation in November 1998. Further evaluation of kits was conducted in Bangladesh and Philippines in July-September 1999.

Outputs

A) Multi-location testing of advanced breeding lines with resistance to rice tungro viruses

[Output 2: Rice varieties and advanced breeding lines evaluated for resistance to leafhopper vectors and to tungro viruses at two locations in each of the three countries (India, Indonesia and Philippines) and recommended for deployment in specific localities to provide durable resistance to RTVD.]

In the majority of the trials tungro disease incidence, as measured by the reaction of the susceptible check variety IR64, was sufficiently high to enable the performance of the advanced lines to be effectively evaluated (Table 3). In Bali and in North Cotabato, the incidence of tungro was consistently very high and this provided ideal conditions for the trials.

The reaction of some of the most promising test lines is shown in Fig. 1. These data constitute mean tungro incidence and infection with tungro viruses from the most recent set of trials for which data were available at the time of writing . The data are from 1998 dry season trials in North Cotabato and Central Luzon and a 1998 wet season trial in Bali. Infection with tungro viruses and tungro disease in lines IR69705-1-1-3-2-1 and IR69726-116-1-3 (both derived from Utri Merah) and in line IR71031 (derived from ARC11554) was extremely low and there was little variation between sites (data not shown). Infection with RTSV in line IR71605-2-1-5-3 (derived from Habiganj-DW8) was high but this line is still considered to be useful because of its tolerance to RTBV.

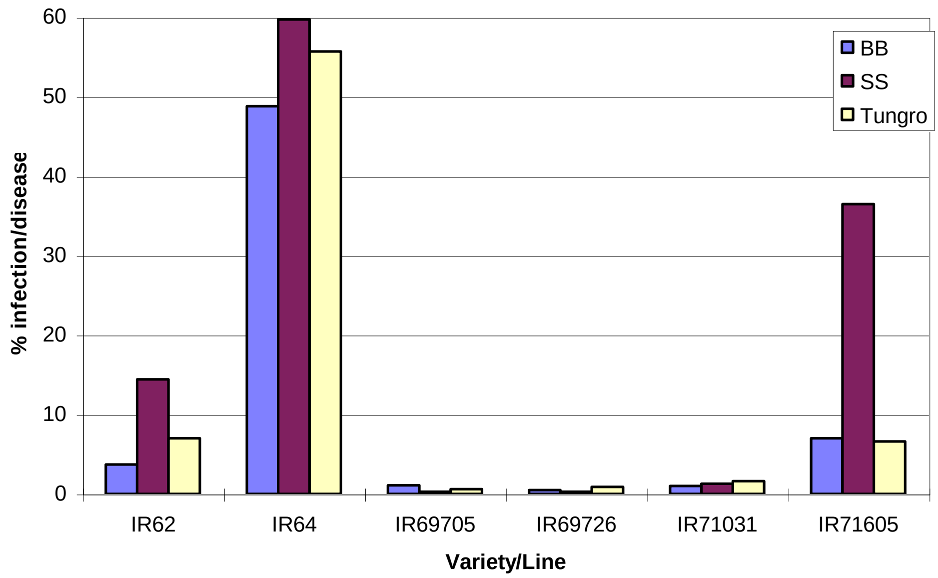

Figure 1. Mean tungro incidence and infection with rice tungro bacilliform (BB) and spherical (SS) viruses in advanced breeding lines and varieties at two sites in the Philippines and one in Indonesia in replicated field trials in 1998.

Table 3. Seasonal and locational differences in the incidence of rice tungro disease and the abundance of the green leafhopper (GLH) based on the reaction of the susceptible variety IR64.

Location	Season/Year	Infection (%)[b]				GLH no.[c]
		BS	B	S	Visual	
India						
Tamil Nadu	DS96	26.5	2.3	39.5	37.3	nd[d]
Tamil Nadu	WS96	0.3	0.3	5.8	17.0	9.3
Tamil Nadu	WS97	21.3	5.0	20.3	70.5	12.8
Tamil Nadu	WS98	0	0	1.5	0	4.0
West Bengal	WS96	4.8	1.5	10.5	32.5	9.8
West Bengal	WS97	27.0	5.5	37.5	64.3	35.8
West Bengal	WS98	0	0	1.5	nd	nd
Indonesia						
Bali	WS96	41.0	0.8	29.0	60.3	8.8
Bali	WS97	67.8	2.0	20.0	99.8	60.3
Bali	WS98	59.8	4.0	28.0	87.5	30.3
South Sulawesi	WS96	10.3	6.0	19.5	11.0	18.3
South Sulawesi	WS98	44.5	1.5	44.3	100	26.0
Philippines						
North Cotabato	DS96	63.8	20.0	8.3	99.3	179.5
North Cotabato	WS96	80.0	2.3	14.5	100.0	117.5
North Cotabato	DS97	53.8	15.0	14.5	91.0	49.8
North Cotabato	WS97	54.5	3.8	33.3	100.0	38.5
North Cotabato	DS98	84.3	3.5	8.8	99.3	85.0
North Cotabato	WS98	78.0	6.0	12.8	97.3	172.5
Central Luzon	WS96	25.0	7.3	9.0	26.5	78.8
Central Luzon	DS97	3.0	8.3	6.8	3.5	48.8
Central Luzon	WS97	26.5	1.3	60.3	46.3	28.8
Central Luzon	DS98	0.5	0.0	3.5	0.5	60.0
Central Luzon	WS98	0	1.5	2.3	0	17.8

[a] Average of two recordings at 30-35 and 55-60 days after transplanting.
[b] B = infection with rice tungro bacilliform virus alone, S = infection with rice tungro spherical virus alone, BS = infection with both viruses.
[c] Numbers per ten sweeps of a 30-cm diameter insect net.
[d] nd = no data.

The overall results from the full set of trials may be summarised as follows:

- Utri Merah progenies IR69705-1-1-3-2-1 and IR69726-116-1-3 had low infection with RTBV and RTSV and low tungro incidence at all locations.

- Advanced lines derived from ARC11554, IR71030-2-3-2-1 and IR71031-4-5-5-1 had low infection with RTBV and RTSV and low tungro incidence in Indonesia and the Philippines. However, these lines showed susceptibility to RTSV in West Bengal and Tamil Nadu, India and tungro incidence was relatively high at these locations.

- Progenies of Balimau Putih (IR68305-18-1), Utri Rajapan (IR69704-4-8-4-1-1), *O. longistaminata* (IR71026-3-2-4-3-5-2 and IR72928-1-2-1-2-4-1), *O. rufipogon* (IR73891-2-1-5-1) and Habiganj DW8 (IR71605-2-1-5-3) had high levels of RTSV infection. Infection with RTBV in these lines was low compared with IR64 and, based on symptom expression, lines from Balimau Putih and Habiganj DW8 showed tolerance to tungro.

- The vector-resistant variety IR62 supported relatively small populations of leafhoppers and incidence of tungro disease was generally low in spite of high levels of infection with RTSV.

- Data from the WS98 trial in Bali show that under conditions of high tungro incidence lines from ARC11554 (IR71031-4-5-5-1) and Utri Merah (IR69705-1-1-3-2-1 and IR69726-116-1-3) produced yields ranging from 4.7 to 5.2 t/ha.

B) On-farm tungro management trials

[Output 2: Rice varieties and advanced breeding lines evaluated for resistance to leafhopper vectors and to tungro viruses at two locations in each of the three countries (India, Indonesia and Philippines) and recommended for deployment in specific localities to provide durable resistance to RTVD.]

Tungro incidence was low in most of the on-farm trials in North Cotabato and Tamil Nadu. However, there was one trial at each site where tungro incidence was high enough to provide a good test of the performance of the test lines. In the trial conducted in the 1996 wet season in San Pedro, North Cotabato, the highly susceptible variety Masipag which was chosen by the farmer, was severely affected by tungro by 42 DAT and only yielded 0.5 t/ha (Table 4). By contrast, IR62 and IR69705-1-1-3-2-1 had a much lower incidence of tungro in spite of the strong sources of inoculum in the Masipag plots and the surrounding areas. In the case of IR69705-1-1-3-2-1, the result is particularly striking as leafhopper numbers were very high but only 2% of hills were affected by 56 DAT. The lower than expected yields in the IR62 and IR69705-1-1-3-2-1 plots were mainly attributable to damage caused by a late attack of the rice black bug, *Scotinophara coarctata*.

Table 4. Tungro disease incidence, green leafhopper (GLH) numbers and yield in different lines and varieties in on-farm trials in the barangays of Central Bulanan, San Pedro and Villarica, Midsayap, North Cotabato in the 1996 wet season.

Site	Line/variety	GLH no.'s	Tungro incidence (%)	Yield (t/ha)
Central Bulanan	IR62	64.0±7.5	2.4±0.7	3.22±0.5
	IR68305-18-1	318.7±77.3	4.7±0.9	2.58±0.2
	PSBRc10	287.8±18.7	4.1±0.9	2.94±0.2
San Pedro	IR62	33.7±2.2	16.3±5.7	1.47±0.2
	IR69705-1-1-3-2-1	230.5±28.9	3.7±0.4	1.29±0.1
	Masipag	494.8±41.7	95.0±5.0	0.52±0.1
Villarica	IR62	25.1±2.1	9.6±3.2	2.99±0.1
	IR68305-18-1	183.0±3.5	18.7±2.2	2.11±0.1
	Line 601	68.9±18.4	0.5±0.5	3.49±0.1

[a] Number of tungro-diseased hills at 56 days after transplanting (DAT) or seeding (DAS). Mean of three replications.
[b] Average numbers of adults and nymphs of *Nephotettix virescens* per ten sweeps of a 30 cm diameter insect net collected over three sampling dates at 28, 42 and 56 DAT or DAS (42 and 56 DAT only for Central Bulanan). Mean of three replications.

An on-farm trial conducted in Vishar, Tamil Nadu was located in an area of high tungro incidence. The majority of varieties affected in the epidemic were the highly susceptible ADT36 and ADT42. ADT36 was the variety chosen by the farmer collaborator, Mr Radha Krishnan and tungro incidence reached 32% by 56 DAT. Incidence in the locally-recommended vector-resistant variety, ADT37, was 17% at the same date and less than 3% in the virus-tolerant IR68305-18-1. This trial stimulated considerable interest among farmers from both Vishar and from other villages who were brought to view the trials. As a result farmers from Vishar and Pudumavilangai grew IR68305-18-1 from seed saved from the on-farm trials and which was distributed among them without intervention from researchers.

Table 5. Tungro disease incidence, green leafhopper (GLH) numbers and yield in different lines and varieties in an on-farm trial in the village of Vishar, Tamil Nadu, India in the 1997 wet season.

Line/variety	GLH no.'s	Tungro incidence (%)	Yield (t/ha)
ADT37	3.8±0.23	17.4±10.2	4.87±0.1
IR68305-18-1	1.7±0.3	2.6±3.3	6.20±0.4
ADT36	6.1±0.6	31.8±13.3	2.54±0.1

[a] Number of tungro-diseased hills at 56 days after transplanting (DAT). Mean of three replications.
[b] Average numbers of adults and nymphs of *Nephotettix virescens* per ten sweeps of a 30 cm diameter insect net collected over three sampling dates at 28, 42 and 56 DAT. Mean of three replications.

C) Evaluation of antisera produced at IRRI against rice tungro viruses, and development of rapid diagnostic kits for the viruses

[Output 5: New antisera characterised for specificity and sensitivity and a dip-stick assay developed and field-tested. Output 6: Tungro screen kit optimised and evaluated under field conditions in three target countries by 30.9.1999]

Repeatedly injecting the rabbits with antigen (virus particles) resulted in antisera with apparently improved titre when tested against purified virions in the ring-interface precipitation test. However, when the batches with the greatest titre were used as probe for Western blots, they hybridised to protein bands of plant as well as virus origin (Figure 2A).

- Pre-incubating the dilute RTBV antisera with sap from healthy plants (direct cross-absorption) reduced the signal from the plant protein bands in the Western blots (Figures 2B). This cross-absorption worked reasonably well for tissue-printing with RTBV antisera, but presence of plant proteins (probably mainly proteolytic enzymes) with the antisera resulted in a very short antibody shelf life. To overcome this, the healthy plant proteins were immobilised either on nitrocellulose membranes or sepharose beads in an affinity column. The healthy-plant-proteins affinity column was an efficient method of removing the cross-reacting immunoglobulins. Results with cross-absorption of RTSV antisera were less consistent. For RTSV antisera batches, cross-absorption to healthy plant proteins resulted in reduced signal from virus proteins though the signal from healthy plant components was not reduced as much as it was for the RTBV antisera.
- PVDF membrane was found to have better protein binding characteristics for RTBV, resulting in less plant (background) signal in tissue printing than was observed when nitrocellulose membrane was used. PVDF membrane and affinity-purified RTBV IgGs (batch 4 or 6) were the basis for a prototype diagnostic kit for RTBV (Figures 3A and 4).
- Attempts to increase the sensitivity of the method for RTBV detection using two alternative systems for amplifying the signals did not result in an improvement over the initial method.
- The signal to noise ratio when affinity purified RTSV IgGs were used with PVDF membrane in tissue printing was too low (too much healthy background and insufficient virus detection) for this to be used in a diagnostic kit (Figure 3B). This may have been due to a) not enough of the healthy plant reacting IgGs were removed in the cross-absorption, b) too many of the virus-reacting IgGs were removed in the cross-absorption, c) the RTSV coat protein binding to the membrane was inefficient, d) there was insufficient release of the virus particles from the cut plant surface, or e) the virions that were released from the cut surface and bound to the membrane were not sufficiently denatured to be recognised by the IgGs.
- Favourable reactions were expressed by initial evaluators of the RTBV screen kit. Some evaluators indicated that the sensitivity of the method should be increased. One respondent suggested reducing the number of steps involved in the procedure. Further evaluation of the kit in June-July 1999 in the Philippines showed that, with experienced operators, the kit was capable of a high level of accuracy. Two out of three operators scored as positive for RTBV 89% of those samples which were confirmed as positive in DAS ELISA. The third operator scored 83% as positive.

Figure 2 Western blots of tungro-infected rice plant sap electrophoresed in 12.5% polyacrylamide-SDS gels and probed with (A) crude RTBV antiserum (batch 4), and (B) RTBV IgG (batch 4) cross-absorbed to sap from uninfected plants. RTBV = virus-specific protein bands.

Figure 3 Rice-stem tissue prints. (A) probed with cross-absorbed RTBV-IgGs, (B) probed with cross-absorbed RTSV IgGs. H = Healthy, S = infected with RTSV, B&S = infected with both RTSV and RTBV

Figure 4 "Tungro Screen B" prototype diagnostic kit instruction card

Conclusions

The most promising advanced breeding lines derived from Utri Merah and ARC11554 had strong resistance to tungro viruses and produced acceptable yields. However, ARC11554 lines did not perform well in India. This underscores the value of the multi-location testing approach. The best Utri Merah line (IR69726-116-1-3) has been fast-tracked through the National Co-operative Testing trials in the Philippines. This is primarily due to the presentation of data from our own field trials. It is expected that it will be cleared for regional release in the Philippines before the end of 1999 and that it will make a major impact in reducing tungro incidence in endemic areas. The line is also expected to be utilised in Indonesia, where it scored highly in a consumer test for eating quality.

Results from on-farm trials showed that selected lines performed well under farm conditions and that farmers were keen to test them. In Bali, where an agricultural extension officer tested line IR68305-18-1 on his own farm, local farmers adopted the line rapidly. By August 1998, approximately 200 ha. of rice was grown to this line and tungro incidence was reported to be extremely low (IGN Astika, personal communication).

It is noteworthy that the vector-resistant IR62 performed well at most of the trial sites. IR62 has been widely grown in North Cotabato for many years and this illustrates that leafhopper resistance can be durable and has a continuing role to play in tungro disease management.

The antisera produced against RTBV, when purified of activity against host plant proteins using the affinity chromatography column, were found to work well in a simple tissue-printing format with a PVDF membrane. This was the basis for a prototype diagnostic kit for RTBV which was evaluated by groups from Bangladesh, India, Indonesia and the Philippines. Based on the field evaluation, the kit has good potential although a further increase in the sensitivity of the method would simplify scoring of samples by operators. The kit was able to detect RTBV infection in leafhopper-resistant varieties where the titre was expected to be relatively low. Virus could be detected in rice plants at the reproductive stage of growth, but the method is much more efficient for testing plants at the tillering stage when symptoms usually become visible under field conditions. Attempts to develop a tissue-printing method for RTSV antisera were not successful. However, since transmission of RTBV requires the presence of a helper factor from RTSV (i.e. for transmission of RTBV, RTSV must also be present), the need for a test specifically for RTSV is not so great.

2. Evaluation of Rice Tungro Disease Management Strategies

Collaborators

India: Indian Council for Agricultural Research (ICAR), Tamil Nadu Agricultural University (TNAU), Tamil Nadu Department of Agriculture.
Philippines: Philippine Rice Research Institute (PhilRice), Department of Agriculture, International Rice Research Institute (IRRI).
UK: Natural Resources Institute, University of Greenwich.

Background

Research outputs from a previous project (R5243) indicated that a strategic approach involving the deployment of virus-resistant varieties and the manipulation of planting dates offered the best prospects for effective tungro management. In the present study we used a modelling approach to investigate some of the principles involved in tungro dynamics on a supra-field scale. Model outputs were designed to provide a guide to how changes in the degree of planting synchrony and in the proportion of resistant varieties deployed might affect tungro incidence. We also investigated farmers' perceptions and practices related to tungro management with a view to ensuring that control recommendations are consistent with their overall needs.

It has been suggested that the existence of a mosaic of fields at different stages of growth promotes the carry-over between crops of both pests and diseases (Zadoks & Schein, 1979; Loevinsohn, 1984), as well as of beneficial organisms, such as the natural enemies of the pests (Way & Heong, 1994). Changes in the degree of planting synchrony may therefore have both positive and negative effects on pests in the rice system. In certain locations in the Philippines, described as 'hot spots', tungro occurs in most seasons and these 'endemic' areas tend to be characterised to various degrees by asynchronous patterns of planting (Savary *et al*., 1993).

Results from some studies have indicated that the greater the variability in planting time between individual crops within a locality (i.e. the greater the asynchrony), the greater the opportunity for spread of inoculum by movement of the leafhopper vectors between fields (Bottenberg *et al*., 1990; Loevinsohn *et al*., 1988; Widiarta *et al*., 1990). Clear evidence, however, is difficult to obtain because experimentation on the scale required is not usually possible and survey results are often confounded by other factors, or lack comparable controls. Nevertheless, surveys do provide some evidence for the impact of asynchrony. Loevinsohn (1984), Suzuki *et al*. (1992), and Chancellor *et al*. (1997) all conclude that, in a particular cropping season, crops planted at a later date than average suffer a greater incidence of tungro. In parts of both Indonesia and Malaysia where overlapping cropping patterns were considered to be a major cause of tungro, more synchronous planting has been promoted as an important component of the tungro management strategy (Chen & Jatil, 1997; Sama *et al*., 1991) but there has been little quantitative understanding of the potential impact of changes in cropping synchrony on tungro.

New resistant genotypes are usually deployed within a cropping system of currently susceptible varieties. Whether resistant variety deployment can be promulgated as a strategic control measure or whether the effects are largely restricted to those fields in which the resistant variety is grown is an important general question in plant virus disease management. Using the model, several key questions have been addressed:

- How extensive does the deployment of the resistant variety need to be to have a useful effect in reducing overall disease incidence in the locality generally?
- What is the most effective spatial pattern of deployment of fields of a resistant variety, a) to minimise incidence in those fields planted with the variety, and b) to have a strategic, area-wide impact on disease in the cropping system?
- When two crops are grown per year and disease tends to be more severe in one season than the other, what is the optimum approach to resistant variety deployment in time and space?

Both empirical and theoretical studies have helped to quantify understanding of the effects of genotype mixtures on disease progress. The rate of disease increase in oat stem rust was found to have a linear relationship with the logarithm of proportion of susceptible plants in a mixture of resistant and susceptible oat varieties (Leonard, 1969). Van den Bosch *et al*. (1990) examined theoretically the expansion of disease foci in 'ideal' (infinitesimally fine-grained) mixtures of a resistant and a susceptible host. They found that the radial velocity of focus expansion increased linearly with the logarithm of the proportion of susceptible plants. Thus, measures of both disease progress and spatial spread have been shown to be linearly related to the logarithm of the fraction of susceptible plants in a mixture.

Much has been written about farmers' indigenous knowledge and there are many examples of farmers' detailed knowledge of pests and crop protection methods (for example, Boef *et al*. 1993, Brammer 1980, Brokensha *et al*. 1980, Fairhead 1994, Richards 1985). However, virus diseases such as tungro might pose problems for farmers because the causal agent (virus) cannot be seen. Bentley (1991) points out that farmers often know more about conspicuous and important pests (for example, weeds, grasshoppers, beetles) but less about the inconspicuous pests. With a disease like tungro which is difficult to observe, but important in the damage that it does, farmers' understanding may differ considerably from that of scientists. If researchers are to develop better ways of managing tungro which are acceptable to farmers, they need to find out what farmers already know about the disease and build on from there.

Activities

A) Modelling rice tungro disease dynamics

[Output 1: RTVD management recommendations developed and adapated for differing agroecological and socio-economic conditions in accordance with disease risk for two target countries; India and Philippines. Output 4: Three papers completed and submitted for publication in international journals by 31.3.1998. One conference paper prepared and project outputs disseminated at the IRRI IPMNET meeting in July 1997]

The epidemiological model was used as a means of investigating some of the principles involved in the area-wide dynamics of tungro. The mathematical model described the dynamics of a plant virus disease within a spatially-referenced lattice of fields of a host crop. The model represents disease dynamics both within and between fields and allows manipulation of the degree of cropping asynchrony. Within a mosaic of fields, infected crops can be regarded as sub-populations of the pathogen, linked to each other by inoculum dispersal. The spatially-referenced lattice is an approach which has been used for complex simulations of disease systems (Kampmeijer & Zadoks, 1977). In our work, the spatial unit required is the field, and epidemiological processes have been simplified such that they are represented by only two parameters: an infection rate and a dispersal gradient. Thus, a simple conceptual framework has been developed with a general structure of more complex simulators.

The model can be applied to crops in continuous, contiguous cultivation such as tropical irrigated rice. Disease progress in each field of the host crop was assumed to be logistic and determined by incidence within the field itself as well as incidence in neighbouring fields, depending on the gradient of disease spread. The frequency distribution of planting dates (represented by the proportion of the total number of fields planted in successive months) was assumed to follow a normal distribution and the variance of planting date was used as a measure of cropping asynchrony. A dynamic cropping system was therefore represented in which crops were successively harvested and replanted. A spectrum of crop ages existed at any one time and virus disease persisted by spread of inoculum between crops.

B) Farmers' rice tungro management practices in India and Philippines

[Output 1: RTVD management recommendations developed and adapated for differing agroecological and socio-economic conditions in accordance with disease risk for two target countries; India and Philippines.]

Rice tungro disease is a very problematic disease for farmers because it is difficult to forecast, difficult to control and can cause high yield losses. In this study, the perceptions and practices of rice farmers from two areas where tungro is reported as endemic in India and the Philippines were compared. The aim was to find out what farmers knew about tungro and how they coped with it. We also investigated what factors influenced their knowledge and management practices.

The two areas studied were Chengalpattu District, Tamil Nadu, India, and Midsayap, North Cotabato, Mindanao, Philippines. Both these areas were said to be tungro-endemic areas by the local agricultural research institutes. Focus group and semi-structured interviews were held initially with farmers to discuss their perceptions and practices relating to tungro disease and gain insights into how farmers viewed the disease. This was followed by a series of structured questionnaire surveys of randomly selected farmers. These consisted of a baseline survey including questions on farming practices, pest and disease problems, knowledge and management of tungro disease, plus follow-up surveys to record actual farming practices for several seasons after the baseline survey (Table 6). In North Cotabato, actual tungro disease incidence was monitored by researchers on 180 farms of the total sample farms. Consequently, farmers' and researchers' observations of the disease could be compared.

Table 6. Data collected on farmers' perceptions and practices and on tungro incidence in Tamil Nadu, India and North Cotabato, Philippines in 1996-98.

India **Chengalpattu District, Tamil Nadu**	**Philippines** **Midsayap, North Cotabato, Mindanao**
Group interviews in 6 villages	Group interviews in 9 villages
Questionnaire surveys of 90 farmers in 2 villages: baseline plus follow-up surveys for 6 seasons, 1996-1998	Questionnaire surveys of 226 farmers in 9 villages: baseline plus follow-up surveys for 4 seasons, 1996-1997
	Tungro incidence in 3 villages for 4 seasons

C) International Tungro Management Workshop

[Output 5: End of project workshop held to disseminate project outputs in November 1998]

An International Workshop on Rice Tungro Disease Management was held at IRRI on 9-11 November 1998. The Workshop was supported by DFID and the IRRI Integrated Pest Management Network. Forty representatives from agricultural research institutes and extension agencies in Bangladesh, India, Indonesia, Malaysia, Philippines and UK participated in the Workshop. Many of the participants were collaborators in this project.

The objectives of the workshop were as follows:

- To critically examine recent research developments in the areas of rice tungro disease epidemiology and management and to assess the relevance of these findings for sustainable production in intensively-cultivated rice ecosystems.
- To review current recommendations and farmer practices in South and Southeast Asia in the light of recent research results.
- To identify future research opportunities and to develop plans to promote the wider adoption of cost-effective and environmentally-sensitive tungro management strategies.

Outputs

A) Modelling rice tungro disease dynamics

[Output 1: RTVD management recommendations developed and adapated for differing agroecological and socio-economic conditions in accordance with disease risk for two target countries; India and Philippines. Output 4: Three papers completed and submitted for publication in international journals by 31.3.1998. One conference paper prepared and project outputs disseminated at the IRRI IPMNET meeting in July 1997]

Analysis of the multi-field model revealed that:

- *Disease incidence* within the lattice (i.e. mean incidence over all fields) depended upon the infection efficiency, the slope of the dispersal gradient, and the variance in planting date.
- *Disease endemicity* depended mainly on planting date variance and disease persisted in the lattice if this variance exceeded a certain threshold.
- Above the threshold for persistence, the response of mean disease incidence to planting date variance was non-linear and the region of greatest sensitivity was closest to the threshold.
- The region of sensitivity depended also on the mean interval between successive rice crops in the same field. Fig. 5 indicates the type of cropping system, defined in terms of its planting date variance and mean fallow period, in which tungro incidence would be expected to decline in response to increases in synchrony.

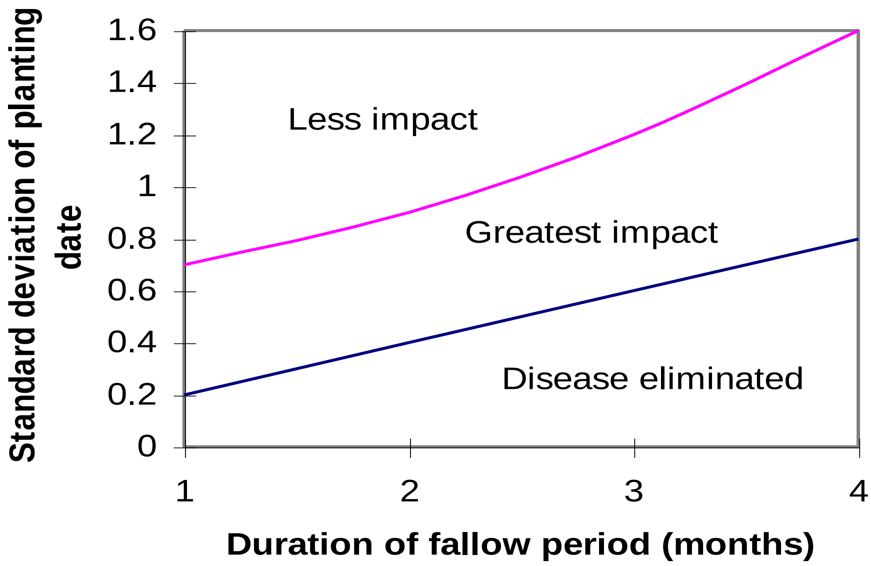

Figure 5 The impact on rice tungro disease of changes in planting date synchrony depends on the current level of planting synchrony (standard deviation in planting date) and the fallow period between successive rice crops. The appropriateness of recommending synchrony changes can thus be evaluated for specific cases.

Previous studies on the effect of genotype mixtures on disease progress within a single crop have shown that both the rate of disease increase and the rate of focus expansion were proportional to the logarithm of the fraction of susceptible plants in the mixture. Using the mathematical model, the deployment of fields of a genotype expressing some resistance to the disease was investigated. Here, looking at long-term disease incidence in a dynamic cropping system, it was found that this same 'logarithmic rule' applied, provided that resistant crop deployment was spatially random.

Full details of the model outputs are given in ***two journal papers*** which resulted from this work (Holt and Chancellor, 1997; Holt and Chancellor, 1999). Assumptions in the model about rates of tungro spread in different varieties were derived from data presented in a ***paper*** by Satapathy *et al*. (submitted to Crop

Protection). ***These three papers constitute part of output 4 of the project as specified under Amendment A***.

B) Farmers' rice tungro management practices in India and Philippines

[Output 1: RTVD management recommendations developed and adapated for differing agroecological and socio-economic conditions in accordance with disease risk for two target countries; India and Philippines.]

(i) Farming system: At both the Indian and Philippine sites, rice was the major staple crop, and multiple crops of rice were grown per year (Table 7). However, there was a more mixed cropping system in Tamil Nadu than in North Cotabato, with other crops such as sugarcane and groundnut grown in rotation with rice. The irrigation system also differed, with North Cotabato farmers relying on a large-scale gravity system whilst the Indian farmers used tanks or wells. In Tamil Nadu there are 3 distinct seasons (s*ornavari*, s*amba* and n*avarai*) whilst in the Philippines there are 2 main seasons, dry and wet, but farmers may plant rice all the year round. The majority of farmers had small farm sizes with 87% of Tamil Nadu farmers and 99% of North Cotabato farmers having 5 ha. or less.

Table 7. Rice-based farming systems in the study areas in Tamil Nadu, India and North Cotabato, Philippines.

	India	Philippines
Crops	Rice, sugarcane, groundnut	Rice
Ave. no. rice crops/year	2.26	2.00
Irrigation system	Tank, tube well	Gravity
Farm size (ha.)	2.78 (std. 3.22)	1.31 (std 0.98)
Main planting method	Transplant	Direct seeded

(ii) Experience of tungro: Although both areas were identified as tungro-endemic, there was a higher incidence of the disease reported by North Cotabato farmers, where 85% of farmers had experienced tungro at least once, and over 40% had experienced it 2 or more times. Almost 75% of Tamil Nadu farmers had experienced tungro at least once, but very few could recall more than one disease attack (Table 8). In the 1996-97 seasons that were monitored, the incidence of tungro in the North Cotabato villages was again much higher, with some incidence found in every season (Table 9). In the Tamil Nadu villages tungro only occurred in one village in one season (s*amba* 1997) where 8% of farmers reported the disease. Although the data is based on researchers' measurements in the North Cotabato case and farmers' reports in the Tamil Nadu case, there is little doubt that incidence is much higher at the North Cotabato site.

Table 8. Percentage of farmers at the Tamil Nadu and North Cotabato study sites who reported experiencing tungro prior to 1996.

No. of tungro attacks experienced	Chengalpattu, Tamil Nadu	Midsayap, North Cotabato
0	25.6	14.2

1	66.7	43.4
2	7.8	20.4
>2	0	22.0

[1] India n=90, Philippines n=226

Table 9. Percentage of farms where incidence of tungro was recorded by researchers in Midsayap, North Cotabato, Philippines in 1996-97.

Tungro incidence (%)	WS 1996 (n = 225)	WS/DS 1996/7 (n = 229)	DS 1997 (n = 172)	WS 1997 (n = 239)
0	18.7	31.0	28.5	42.7
=<5	59.1	58.1	64.5	50.6
=<50	20.4	9.6	5.2	5.4
>50	1.8	1.3	1.7	1.3

(iii) Farmers' ranking of importance of tungro: North Cotabato farmers rated tungro as a far more important pest or disease than did Tamil Nadu farmers. North Cotabato farmers ranked tungro second behind stemborer in both wet and dry seasons, whereas Indian farmers only considered the disease to be a major problem in the s*amba* season.

(iv) Farmers' knowledge of tungro symptoms, causes and mode of spread: All farmers in North Cotabato knew of tungro, but 21% of Tamil Nadu farmers had no idea what it was. Other farmers were able to give a reasonable description of the disease with 37% and 50% of farmers describing both the yellowing leaves and stunted appearance in Tamil Nadu and North Cotabato, respectively. Farmers described tungro as like cancer or AIDS as they were aware that the plant would not recover once infected.

Farmers were more uncertain over the causes and mode of spread of tungro (Table 10). Half the farmers in Tamil Nadu and 14% of North Cotabato farmers said they had no idea. Insects were identified most often as the cause of spread of tungro, and over a third of North Cotabato farmers knew that tungro was spread by green leafhoppers. Only 6% of Tamil Nadu farmers knew this. However, other modes of spread such as through water, air and soil were also identified. Farmers may identify several different modes of spread, for example, believing that tungro is spread by green leafhoppers and through water. North Cotabato farmers were more aware of the effects of varietal selection on tungro incidence. Through their own observations they had noticed that some varieties were more susceptible than others to tungro disease.

Table 10. Percentage of farmers reporting causes of tungro and its mode of spread

Factor	India (n = 90)	Philippines (n = 90)
Green leafhoppers	5.6	36.3
Other insects	36.7	25.2
Virus/germ	3.3	15.9
Water	0	17.3
Wind/air	2.2	7.1
Susceptible variety	0	20.3

Other means	0	14.9
No idea	50.0	14.2

Note: Farmers can specify more than one cause or mode of spread

(v) Farmers' reported tungro management practices: The lack of experience of tungro in Tamil Nadu meant that a significant number of the Indian farmers (43%) had no idea how to manage tungro. However, over half (52%) of the farmers suggested leaving a fallow period. Only 2% suggested the use of insecticides. In Midsayap, use of insecticides was more popular, particularly at the early stages of the crop. Farmers realised that spraying was not effective at late stages once the crop was already infected. In fact many farmers also said that insecticide spraying was not very effective at any stage, but they used it in the absence of other effective measures.

Almost 50% of Philippine farmers said they used resistant varieties or changed varieties to prevent reoccurrence of tungro. Cultural controls such as roguing (removing) infected plants, fallow periods and synchronous planting were not commonly used. However, 24% of Philippine farmers said they would plough under an infected crop and replant if tungro occurred at the early stages of crop growth.

(vi) Farmers' actual tungro management practices: Data collected during four seasons in 1996-98 suggests that resistance to tungro is a more important criterion for varietal selection in North Cotabato than in Tamil Nadu. In Tamil Nadu farmers chose varieties they consider as suitable for the particular season, in terms of characteristics such as duration, tolerance to cold, tolerance to pests. For example IR50 is very popular in the dry, warm *sornavari* season when there are relatively few pests, but is not considered so suitable in the wetter or colder seasons (Table 11).

In the *samba* season of 1997 when there was an outbreak of tungro in the village of Vishar, 7 out of the 10 farmers affected were growing the highly susceptible ADT42; the others were growing IR36 or the highly susceptible ADT36. In the following *navarai* season, farmers switched away from ADT42, and many planted ADT37 which has 'field' resistance to tungro. The disease did not reoccur. In the 1998 *samba* season, many farmers planted ADT37 even though it is not recommended for use in the *samba* season.

In North Cotabato, most farmers grew "Selection" in both wet and dry seasons (Table 12). This name covers a wide range of lines and varieties selected by farmers themselves and it is often not possible to identify them. However, farmers are aware of which varieties are susceptible to tungro. Many farmers grew IR62, which is 'field' resistant to tungro and which is also preferred because of its short duration. Few farmers grew highly susceptible varieties such as Masipag and 7-Tonner (IR64) but some were prepared to take the risk, attracted by the higher market price.

Table 11. Percentage of rice varieties grown by farmers at the study site in different cropping seasons in Tamil Nadu, India in 1996-98.

Variety	Season		
	Sornavari	***Samba***	***Navarai***
IR50	75.5	5.2	5.6

IR36	5.5	10.4	10.4
ADT36+	4.6	11.8	23.3
ADT37*	2.1	8.1	13.3
ADT42+	1.8	7.8	4.4
IET1444	0.9	0	6.7
White Ponni	0.3	12.2	1.5
Others	1.2	13.7	10.4
No rice crop	10.9	34.4	29.6

+ Highly susceptible to tungro. * Resistant to GLH and 'field' resistant to tungro.

Table 12. Percentage of rice varieties grown by farmers at the study site in different cropping seasons in Midsayap, Philippines in 1996-98.

Variety	Dry season	Wet season
Selection	27.1	23.8
IR62*	11.5	8.9
IR36	9.9	6.0
Bordagol	7.3	8.5
7 Tonner (IR64) +	4.7	2.4
IR78	4.2	6.9
IR60	4.2	4.8
PSBRc10	4.2	4.0
Korean	4.2	3.2
IR66	4.2	2.4
Masipag+	2.1	3.6
Others	16.6	24.5

+ Highly susceptible to tungro. * Resistant to GLH and 'field' resistant to tungro.

The level of insecticide use was far lower in Tamil Nadu than in North Cotabato, (Tables 13 and 14). However, up to 70% of the insecticide applications in North Cotabato were targeted at a newly-arrived and highly destructive pest, the rice black bug . Tungro accounted for less than 5% of the total sprays. There was no correlation between the number of insecticide sprays and incidence of tungro.

Table 13. Mean number (standard deviation) of insecticide applications applied over 6 seasons in Tamil Nadu, India

Samba 1996	Navarai 1997	Sornavari 1997	Samba 1997	Navarai 1998	Sornavari 1998
0.98 (0.74)	1.02 (0.89)	0.92 (0.79)	1.63 (1.03)	1.41 (0.90)	1.56 (0.94)

Table 14. Mean number (standard deviation) of insecticide applications applied over 4 seasons in North Cotabato, Philippines.

WS 1996	WS/DS 1996/97	DS 1887	WS 1997

4.58 (2.52)	4.47 (2.91)	5.01 (2.96)	4.2 (2.36)

At the Tamil Nadu site, the greater variation in topography and soil types has resulted in the wide use of rice-based systems involving crops such as groundnut and sugar cane. Rotations are not utilised specifically for tungro management, but undoubtedly contribute to reduced incidence of the disease. In Vishar village, where the tungro outbreak occurred in the 1997 *samba* season there is a large area of land which is cropped with rice throughout the year. The district agricultural service encouraged farmers to grow a break crop of *Sesbania rostratum* between the *sornavari* and *samba* seasons in 1998, but none followed this advice.

Few non-rice crops were planted in the North Cotabato site during the period in which monitoring was done. Overwhelmingly, the major constraint to rice production stated by farmers was a shortage of water in the dry season. The supply of irrigation water to different areas in the municipality is scheduled by the National Irrigation Authority (NIA) and one third of the area is supposed to receive no water in the dry season on a rotational basis. However, the actual delivery of water is irregular and some farmers who are close to the main irrigation canal extract water illegally in the designated 'closure' zone. As a result, planting dates are highly staggered and this is recognised as one of the major factors contributing to the persistent tungro problem.

Preliminary results from this work were presented in ***a paper on 'Rice tungro management in the Philippines'*** at the 3rd Review and Planning Meeting of the Integrated Pest Management Network of the International Rice Research Institute in Hangzhou, China on 14-18 July 1997 (Chnacellor *et al*., 1997). This paper constituted part of output 4 of the project as specified under Amendment A.

A ***Workshop*** was held in Midsayap, North Cotabato, Philippines on 10th December 1998 to disseminate project outputs and to develop tungro management recommendations for the municipality. Fifty participants attended the Workshop with representation from the following communities and organizations:

- Rice farmers from 6 villages
- Members of village councils
- Local government units
- Municipal Department of Agriculture office
- Regional office of NIA
- PhilRice
- Agricultural Training Institute
- IRRI
- NRI

Resolution of the following issues was identified as being the key to solving the tungro problem in Midsayap:

- Asynchronous planting.
- Poor water management.

- Lack of availability of resistant varieties.
- Financial constraints of farmers.
- Absence of appropriate policies and lack of political will.
- Need for monitoring and surveillance.

Participants advocated that the following strategies should be pursued:

- Deploy resistant varieties and maintain up to date varietal recommendations.
- Disseminate information on synchronous planting through training courses and seminars, 'Techno-demos', assembly meetings to agree planting calendars and modules in the IPM Kasakalikasan programme.
- Co-ordination between NIA, the Department of Agriculture and village councils regarding cropping patterns and the release and closure of water.
- Formulate a Memorandum of Agreement (MOA) between NIA, local government units, farmers' leaders and PhilRice.

The following recommendations were made to promote the transfer of tungro management technology to farmers:

- Conduct farmer training courses, especially Farmer Field Schools (FFS). Incorporate a module on tungro management into the FFS. Ensure that trainees have access to testimony from trained farmers and research scientists.
- Conduct a techno-demo on the on-farm varietal trial.
- Broadcast information on radio and the television.
- Submit articles to local newspapers such as the 'Mindanao Cross', and to magazines such as the CEMARRDEC newsletter.
- Reproduce and distribute posters and leaflets at the village level and, if possible, by *purok* (sub-division within a village); preferably in the local dialect or in the Filipino language.
- Invite a resource person to discuss tungro management at village council meetings.
- Continue the collaborative research project on rice tungro disease management.
- Department of Agriculture extension officers should have a specific time and date for field visits in their respective villages.
- Farmers need 'an additional technician for closer supervision on technology transfer'.
- PhilRice and IRRI must maintain tungro resistant varieties to ensure a continuous source of seeds.

Representatives from the farming community, village councils, local government, Department of Agriculture, NIA, and PhilRice agreed to formulate a Memorandum of Agreement to regulate the distribution of water (see under 'Dissemination Outputs' below). If implemented, this would make a major contribution to managing the tungro problem in the municipality. Reports from the area in 1999 suggest that the water supply was more effectively regulated and that planting dates were more synchronised. Tungro incidence in the area was low.

Notes: a 'techno-demo' is a demonstration trial co-ordinated by the Department of Agriculture. The Philippine government's 'Kasakalikasan' programme utilises the

FAO Farmer Field School approach to promote integrated pest management for rice production.

C) International Tungro Management Workshop

[Output 5: End of project workshop held to disseminate project outputs in November 1998]

Review of Recent Research Activities

An examination of the recommendations for future research made at the last International Workshop on Rice Tungro Disease Management held in Malaysia in 1993 showed that considerable progress had been made in addressing many of the issues.

1. A major effort has been undertaken at IRRI to develop ***elite lines with resistance to tungro disease***. These lines have been evaluated in the greenhouse and in the field as part of the IRRI-NRI project. The most promising lines from each of the resistant donors have been evaluated in multi-locational trials in India, Indonesia and the Philippines. One of these lines, with resistance from Utri Merah, has now been cleared for entry into phase 2 of the National Co-operative Testing program in the Philippines. It is hoped that it will be cleared for regional release in the Philippines as it has high yield potential and good eating quality. Encouraging progress was also recorded in breeding for tungro resistance by national programs in the Philippines and in Indonesia.

- ***Seed*** of elite virus-resistant lines is being distributed to interested participants so that they can evaluate it in their own localities and, if appropriate, utilise it in resistance breeding programs.
- Funding would be sought to publish a ***Handbook*** for evaluating resistance to tungro disease.

2. A ***screen kit for rice tungro bacilliform virus*** has been developed by IRRI and NRI researchers. The method is a modification of the standard serological method which is used for routine indexing of leaf samples for tungro viruses. The modified method is much quicker and simpler to conduct and does not require costly equipment for sap extraction.

- ***Five screen kits*** are being given to collaborators in different countries for evaluation. Refinements will be made to the kit based on feedback from the evaluators.

3. Separate ***training courses*** in the 'Identification and Management of Rice Tungro Disease' have been developed in the IRRI-NRI project for agricultural extension officers and for farmers, respectively.

- Funding would be sought to publish ***manuals*** for the training courses.

4. Research results were presented from India and the Philippines indicating that there was a relationship between tungro incidence and numbers of ***viruliferous vectors*** caught in light traps. There was no relationship between tungro incidence and leafhopper vector abundance *per se*. Nevertheless, consensus was not reached

among the participants about the validity of leafhopper control by insecticides in areas where tungro was not endemic.

- It was agreed by participants that ***category 1 insecticides should not be used*** for leafhopper vector control under any circumstances.
- It was agreed that ***seedbed protection*** was appropriate in tungro-endemic areas where older seedlings are used, but not in other situations.

5. Understanding of ***farmer perceptions and practices*** relating to tungro disease has increased considerably through recent studies in India and in the Philippines. Farmers' varietal preferences and the constraints they face in changing cultural practices were recognised as being particularly important in implementing tungro management strategies. An important study currently being conducted by PhilRice in Midsayap, North Cotabato emphasises that tungro management should be considered as one component of an overall pest management strategy.

6. Reviews of tungro disease management strategies employed in India, Indonesia, Malaysia and the Philippines emphasised the increasing importance attached to ***preventive*** measures such as varietal resistance and cultural control. In Malaysia, a large effort has been devoted to surveillance using mobile seed trays as indicators of the presence of virus carriers among leafhopper populations. This approach has been refined since 1995 with the use of serology to detect the presence of leafhoppers carrying RTSV and RTBV.

- An ***analysis*** of the tungro disease surveillance program in Malaysia will be conducted in collaboration with the Department of Agricultural Extension, subject to the availability of funding.

Workshop Proceedings

- It was agreed that funding would be sought to publish a Workshop Proceedings. This has now been approved and ***a book is due to be printed in November 1999***.

Recommendations for Future Research

The following areas were identified as priorities for future research:

1) Continuation of the research on the development of simple and reliable diagnostics for tungro viruses.
2) The advancement of breeding programs for tungro resistance incorporating resistance to RTSV, RTBV and to the leafhopper vector in individual varieties.
3) Mapping tungro resistance genes and utilising marker-aided selection to incorporate them into elite breeding lines.
4) Further research on virus variability linked to the deployment of tungro-resistant varieties.
5) Socio-economic studies on the adoption of tungro-resistant varieties by farmers.
6) The development of more accurate predictions of tungro outbreaks and an analysis of the role of risk assessment by farmers in their tungro management practices.
7) A cost-benefit analysis of tungro disease in relation to the use of different control measures.

Opportunities for Future Research Collaboration

The following areas were identified for future collaboration on tungro management between IRRI, NRI, NARS and other potential research partners.

- Funding would be sought from DFID to support further work on the development of the screen kits for both RTBV and RTSV.
- NRI would examine the prospects for developing a project proposal for funding by DFID on the improved delivery to NARS of IRRI's virus-resistant germplasm and its more effective utilisation. This was designed to enhance the impact of work conducted during the last three years.
- Opportunities would be explored for developing work on mapping and marker-aided selection and linking this to molecular epidemiology and resistance deployment strategies. A multi-disciplinary project linking DFID's Plant Sciences and Crop Protection Programmes is one possibility.

Conclusions

Model outputs showed that disease systems which show moderate rather than high cropping asynchrony, are more likely to be influenced by changes in the variance of planting date. A relatively large proportion of fields has to be planted with resistant varieties in order to have sufficient area-wide impact on inoculum levels to reduce disease incidence in fields of susceptible varieties. In many rice cropping systems there are two growing seasons per year and the modelling indicated that the best strategy was to concentrate deployment of resistant varieties in the season of greatest disease spread. Attempts to minimise inoculum carry-over to the 'high spread' season by concentrating resistant varieties in the previous season had little effect over a range of simulated conditions. In considering recommendations for the management of tungro, a conflict existed between the reduction of disease incidence strategically and in the individual fields of a newly deployed variety. To maximise area-wide strategic impact, small genotype units and random patterns were best, but to protect individual fields, large units and concentrated deployment were best.

In North Cotabato, where farmers experienced tungro relatively often, knowledge of tungro symptoms and how the disease is spread was quite good. However, some farmers thought that tungro was spread by means other than infective leafhoppers and the importance of inoculum sources was not generally recognised. In Tamil Nadu, farmers had limited knowledge of tungro, at least in part because the disease did not occur very often. Farmers integrated resistant varieties into their crop management systems where these varieties satisfied other criteria such as seasonal suitability and yield potential.

In Tamil Nadu, insecticide application based on a threshold number of green leafhoppers is recommended for tungro management. Based on our research, this recommendation cannot be justified given the low incidence of tungro in those areas classified as endemic. However, it is also apparent that, as in North Cotabato, few farmers apply insecticides for green leafhopper control.

In North Cotabato, where there are few break crops or fallows, synchronising planting dates more closely would reduce tungro incidence. After participating in training courses (see next section) some farmers were prepared to co-operate with the irrigation authority in implementing more synchronous planting. In order for this approach to be successful, co-ordination between various groups and agencies is needed. A commitment was made in a Workshop held in December 1998 to pursue this through formal agreements between these parties.

3. Extension Methodologies for Rice Tungro Disease Management

Collaborators

India: Indian Council for Agricultural Research (ICAR), Tamil Nadu Agricultural University (TNAU), Tamil Nadu Department of Agriculture.
Philippines: Philippine Rice Research Institute (PhilRice), Department of Agriculture, International Rice Research Institute (IRRI).
UK: Natural Resources Institute, University of Greenwich.

Background

Studies conducted in the Philippines on farmers' perceptions of rice tungro disease and on their tungro management practises indicated that there were key gaps in farmer knowledge about the nature of the disease and how it is spread (Warburton *et al*., 1997). Many farmers were not aware that the disease is caused by a pathogenic organism or that it is only transmitted by specific leafhopper vectors. Most farmers were not aware of the threat posed by nearby inoculum sources to new rice plantings. As a result, they were not able to develop appropriate tungro management strategies. On the other hand, the survey revealed that many farmers were receptive to the idea of deploying resistant varieties to combat the disease and were enthusiastic about attending training courses to learn more about tungro and its management.

In tandem with the studies on the evaluation of tungro-resistant lines and of tungro management strategies, we devised training courses for agricultural extension officers and farmers on tungro identification and management. The purpose of the training was to explore the most effective ways to communicate information to farmers in order to address the knowledge gaps that were identified. Further, the courses were used to promote messages about the strategic management of tungro. The response of farmers to these messages would provide a guide to the likely adoption by farmers of recommended tungro management practices. In India, where no information was available about farmers' perceptions of tungro the courses were modified after taking into account information collected during focus group interviews (see above).

Activities

[Output 3: Extension methodologies developed to enable farmers to identify RTVD symptoms and leafhopper vectors, to gain a basic understanding of the operation of the disease cycle and to utilise appropriate control measures such as resistant varieties]

In Midsayap, North Cotabato, Philippines a group of 30 farmers was randomly selected from each of three villages for training in tungro identification and management, using lists provided by the Department of Agriculture. These villages were Central Bulanan, San Pedro and Villarica. Another group of 30 farmers was randomly selected from the remaining farmers on the lists. These farmers served as control groups within the villages. In addition, six farmers were randomly selected from each of six other villages. These farmers served as controls for comparing differences in perceptions and practices between villages. Villages were randomly selected from a list of villages which were identified as meeting two basic criteria; frequent incidence of tungro and stable security situation. The latter criterion was needed because there were areas within the municipality, which were the sites of regular conflict between the military and armed rebels.

A similar procedure was adopted for studies conducted in Chengalpattu District, Tamil Nadu, India except that training was only done in two villages; Vishar and Pudumavilangai. In North Cotabato, training courses were run at the end of the study for farmers in the control groups in Central Bulanan, San Pedro and Villarica. These courses were provided in response to requests from the farmers involved. All farmer training courses were conducted by agricultural extension officers who had themselves participated in a week-long training course at the beginning of the study. The content of the two-day farmer training courses was drawn up during the courses for extension officers which also involved farm visits in which they discussed with farmers their problems and needs.

The following training courses were run:

<u>Midsayap, North Cotabato</u>:

- May 1996: Agricultural extension officers from Midsayap (10), Pigcawayan (3) and Libungan (1)
- August 1996: 32 farmers from Central Bulanan
- August 1996: 45 farmers from San Pedro
- September 1996: 37 farmers from Villarica
- November 1998: *c*. 35 farmers from Villarica and 'control' villages
- November 1998: *c*. 35 farmers from Central Bulanan and San Pedro.

<u>Chengalpattu, Tamil Nadu</u>:

- June 1996: 17 Agricultural extension officers from localities throughout the district.
- February 1997: *c*. 30 farmers from Pudumavilangai
- March 1997: *c*. 30 farmers from Vishar

The main messages communicated to farmers during the training were:

- Tungro is a *virus* which causes disease in rice plants
- Tungro can *only* be spread by GLH and zigzag leafhoppers. These insects do not cause damage to rice plants if they are not carrying tungro viruses.
- Insecticide spraying is often *not effective* in reducing tungro.
- *Preventive* measures are better than curative ones and these require group action by farmers to work.
- The key preventive measures are: planting resistant varieties, avoiding very late or very early planting, ploughing under infective stubbles after harvest.

Training involved mainly practical field activities related to disease, arthropod and natural enemy identification and group representatives among the farmers were asked to present their findings. On-farm tungro management trials were used for this purpose and also to demonstrate to farmers the beneficial effects of growing tungro-resistant varieties. A discussion session on tungro management was held to allow farmers to present their views and to enable trainers to explain the rationale behind different management approaches.

- Farmers from Central Bulanan and San Pedro, who received training in tungro identification and management, visited the varietal resistance trial at the PhilRice research station in September 1996.

- Trained farmers from Central Bulanan, San Pedro and Villarica, attended a Field Day at the PhilRice research station in November 1997.

- A Workshop was held at the PhilRice research station in December 1998 (see section on 'Dissemination of Outputs' below).

- In Tamil Nadu, trained farmers from Pudumavilangai and Vishar attended a Field Day in Vishar in October 1997 and visited the on-farm trial in that village.

- A meeting was held with trained farmers from Vishar in November 1998, during which project outputs were reviewed.

Outputs

[Output 3: Extension methodologies developed to enable farmers to identify RTVD symptoms and leafhopper vectors, to gain a basic understanding of the operation of the disease cycle and to utilise appropriate control measures such as resistant varieties]

Training course notes were given to agricultural extension officers and to farmers after their respective courses. These were favourably received and participants requested a more detailed package of information. Consequently, ***training manuals*** are currently being developed for the two target groups using dissemination funds provided through the Crop Protection Programme.

The results of the focus group discussions and the questionnaires in North Cotabato indicated that farmers considered that they had benefited from the training courses. Farmers stated that they now understood that tungro is incurable, but preventable. They also said they had learned that staggered planting, which resulted from a shortage of water, favoured tungro spread. Previously, they had believed that lack of water had a direct effect in increasing tungro incidence. Some farmers learned for the first time that not all insects are pests and that some are beneficial to farmers.

Most of the farmers interviewed still retained the main messages of the training two years after the course was held. In particular, farmers recalled the focus on resistant varieties and synchronous planting. However, the lack of seed and uneven access to irrigation water prevented them from practising their newly-acquired knowledge. Nevertheless, farmer representatives were prepared to commit themselves to closely regulated planting dates based on revised water schedules.

Most farmers appeared not to fully understand the rationale behind ploughing in infected crops or stubbles. Their main concern was to replant as quickly as possible, rather than to remove sources of inoculum which might pose a threat to young rice crops.

There was little evidence to suggest that farmers reduced their insecticide applications as a result of the training. However, few farmers in North Cotabato targeted sprays specifically against leafhoppers or tungro. Most insecticides were used against rice black bug, which farmers believed could not be controlled by other means. In Tamil Nadu, the number of spray applications was low and most were targeted against stemborers, leaffolders or rice bug.

Farmers demonstrated a willingness to experiment with seed of promising virus-resistant advanced lines. This may be illustrated by the case of Vicente Cacindin, our farmer co-operator in San Pedro for the on-farm trial in the 1996 wet season trial. Mr Cacindin selected large panicles with heavy grains from line IR69705 and bulked it up in subsequent seasons. He sold some seed to a rice breeder who marketed it in a neighbouring province under a new name, ‘Line 386’.

In Tamil Nadu, farmers experimented with line IR68305-18-1. Our farmer co-operators grew some of the seed they saved from the on-farm trials and sold or bartered the remainder to neighbouring farmers. Farmers were satisfied with the yield, tungro resistance and eating quality of this line. A disadvantage they pointed out was its low milling recovery. Rice breeders at TNAU are currently back-crossing line IR68305-18-1 with local high yielding varieties and this is expected to increase the milling recovery.

Although seed of virus-resistant lines was exchanged among farmers with close personal contact, there was little transfer of knowledge or information from trained to non-trained farmers in North Cotabato. Existing extension mechanisms were weak in Midsayap. This was partly due to reduced funding following the devolution of government extension services to local agencies. One non-government organisation, the Archdiocese of Cotabato Development Co-operatives, was active in the locality and closer links need to be developed with this group in the future.

Local radio was identified as having good potential to disseminate information about tungro management quickly to a large number of farmers. The two most popular radio stations, DXMY and DXMS, broadcast farming programmes in the local dialects. Farmers involved in the focus group discussions listened to these programmes regularly. Radio could be used to broadcast messages about newly developed tungro management technology, to provide an outlet for farmers to express their needs and concerns and to facilitate horizontal transfer of information between farmers.

Farmers showed interest in the idea of developing a poster calendar on rice pests and their natural enemies which they would use themselves.

Conclusions

Short training courses for farmers on tungro identification and management were well received and many participants retained the main extension messages two years after the training. The deployment of virus-resistant varieties was the tungro control measure that most interested farmers. Greater efforts are needed to further develop and promote suitable varieties and to ensure that up-to-date varietal recommendations are available to farmers.

In order to promote tungro management recommendations over larger areas in endemic regions in the Philippines and India, training courses could be included as modules in the government sponsored IPM farmer field school programmes. In addition, in the Philippines local radio has the potential to allow extension information on tungro management to reach a large number of farmers in a short period of time.

4. Dissemination Outputs

A) Peer reviewed publications

Chancellor T.C.B., Cook A.G. and Heong K.L. (1996) The within-field dynamics of rice tungro disease in relation to the abundance of its major leafhopper vectors. *Crop Protection* **15,** 439-449.

Chancellor, T.C.B, Cook, A.G. , Heong, K.L. & Villareal S. (1997) The flight activity and infectivity of the major leafhopper vectors (Hemiptera: Cicadellidae) of rice tungro viruses in an irrigated rice area in the Philippines. Bulletin of *Entomological Research* **87,** 247-258.

Holt, J. & Chancellor, T.C.B (1997) A model of plant virus disease epidemics in asynchronously-planted cropping systems. *Plant Pathology* **46,** 490-501.

Holt, J. & Chancellor, T.C.B (1999) Modelling the spatio-temporal deployment of resistant varieties to reduce the incidence of rice tungro disease in a dynamic cropping system. *Plant Pathology* **48,** 453-461.

Tiongco, E.R., Chancellor, T.C.B., Villareal, S., Magbanua, M. & Teng, P.S. (1998) Roguing as a tactical control for rice tungro virus disease. *Journal of Plant Protection in the Tropics* **11,** 45-52.

Cooter, R.J., Winder, D. & Chancellor, T.C.B. Tethered flight activity of *Nephotettix virescens* (Distant) in the Philippines. Submitted to the *Bulletin of Entomological Research*.

Nath, P.D., Kenyon, L., Bartolome, V.I. & Azzam, O. Simple serological assays for detecting rice tungro viruses. Submitted to the *Journal of Food and Agricultural Immunology*.

Satapathy, M.K., Chancellor, T.C.B., Teng, P.S., Thresh, J.M. & Tiongco, E.R. The epidemiology of rice tungro virus disease: spread in different IR varieties with and without introduced sources of inoculum. Submitted to *Crop Protection*.

B) Other publications

Angeles, E., Cabunagan, R.C., Tiongco, E.R., Azzam, O., Teng, P.S., Khush, G.S. & Chancellor, T.C.B. (1998) Advanced breeding lines with resistance to rice tungro viruses. *International Rice Research Notes* **23** (1), 17-18.

Cabunagan, R.C., Angeles, E., Tiongco, E.R., Villareal, S., Azzam, O., Teng, P.S., Khush, G.S., Chancellor, T.C.B., Truong, X.H., Mancao, S., Astika, I.G.N., Muis, A., Chowdhury, A.K., Ganapathy, T. & Subramanian, N. (1998) Multilocational evaluation of promising advanced breeding lines for resistance to rice tungro viruses. *International Rice Research Notes* **23** (1), 15-17.

Chancellor T.C.B., Teng P.S. and Heong K.L. eds (1997) Rice Tungro Disease Epidemiology and Vector Ecology: the Development of Sustainable and Cost Effective Pest Management Practices to Reduce Yield Losses in Intensive Rice Cropping Systems. *IRRI Discussion Paper Series no. 19,* International Rice Research Institute, Philippines.

Chancellor, T.C.B., Heong, K.L. & Cook, A.G. (1997) The role of vector control in the management of rice tungro disease. In: *Epidemiology and Management of*

Rice Tungro Disease (T.C.B. Chancellor and J.M. Thresh eds). Chatham, UK: Natural Resources Institute.
Chancellor, T.C.B & Thresh, J.M. (eds) (1996) Epidemiology and Management of Rice Tungro Disease. Chatham, UK: Natural Resources Institute.
Chancellor, T.C.B., Azzam, O. & Heong, K.L. (eds) Management of Rice Tungro Disease. Los Baños, Philippines: International Rice Research Institute (in press).
Satapathy, M.K., Chancellor. T.C.B., Teng, P.S., Tiongco, E.R. & Thresh, J.M. (1997) The effect of introduced sources of inoculum on tungro disease spread in different rice varieties. In: *Epidemiology and Management of Rice Tungro Disease* (T.C.B. Chancellor and J.M. Thresh eds). Chatham, UK: Natural Resources Institute.
Warburton, H., Palis, F.L. & Villareal, S. (1997) Farmers' perceptions of rice tungro disease in the Philippines. In: *Pest Management of Rice Farmers in Asia* (K.L. Heong and M.M. Escalada eds). International Rice Research Institute, Los Baños, Philippines.

C) Papers presented

Batay-an, E. & Villareal, S. 'Technological advances in controlling the rice black bug, rice tungro disease and white stem borer'. Paper presented at the 6th techno-forum of the Central Mindanao Agriculture and Resources Research and Development Consortium, University of Southern Mindanao Agricultural Research Centre, Philippines, 21-23 July 1997. (Winner of 2nd prize in the Best Paper award.)
Cabunagan, R.C., Angeles, E., Tiongco E.R., Villareal S., Teng, P.S., Khush G.S., Chancellor, T.C.B., Truong X.H., Astika, I.G.N., Muis, A., Chowdhury, A.K. & Ganapathy, T. 'Evaluation of advanced breeding lines for resistance to rice tungro disease'. Paper presented at the annual meeting of the Pest Management Council of the Philippines, 19-23 May 1997, Iloilo City, Philippines.
Cabunagan, R.C. Angeles, E.R., Khush, G.S.,Tiongco, E.R. & Chancellor, T.C.B. (1999) Evaluation of elite breeding lines having resistance to rice tungro viruses. VIIth International Plant Virus Epidemiology Symposium, Aguadulce, Spain, April 11-16, 1999 (Abstract).
Chancellor, T.C.B., Cook, A.G., Heong, K.L. & Villareal, S. (1996) The ecology of *Nephotettix virescens* (Distant) (Hemiptera: Cicadellidae) in relation to its role as a vector of rice tungro viruses. Paper presented at the XX International Congress of Entomology, 25-31 August, Firenze, Italy.
Chancellor, T.C.B, Truong, X.H., Cabunagan, R.C. & Villareal, S. 'Rice tungro disease management in the Philippines'. Paper presented at the 3rd Review and Planning Meeting of the Integrated Pest Management Network of the International Rice Research Institute, Hangzhou, China, 14-18 July 1997.
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List of acronyms

AARD	Agency for Agricultural Research and Development
BCKV	Bidhan Chandra Krishi Viswavidyalaya
DFID	Department for International Development, UK
FAO	Food and Agriculture Organisation of the United Nations
FFS	Farmer Field School
ICAR	Indian Council for Agricultural Research
IPM	Integrated Pest Management
IRRI	International Rice Research Institute
NIA	National Irrigation Authority, Philippines
NRI	Natural Resources Institute, UK
PhilRice	Philippine Rice Research Institute
RTSV	Rice tungro spherical virus
RTBV	Rice tungro bacilliform virus
TNAU	Tamil Nadu Agricultural University