Annual Report 1996

Project #3
Improved Rice Germplasm for Latin America and the Caribbean

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and Discussion Only

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Introduction and Overview

In 1996, rice research at CIAT continued its process of transition from the former organization around the Rice program into the new Project structure. Rice research activities are now implemented within the framework of several projects. Project number 3, "Improved Rice Germplasm for Latin America and the Caribbean", gathers the core of rice research, while maintaining strong linkages with other projects where rice topics are also important: public and private linkages (#18), genetic diversity (#15), impact (#17), IPM (#7) and hillside agroecosystems (#20), among others.

The year was characterized by adjustments in the budget as well as in the project structure. Together with Project number 3, we started the year with a separate Project on Integrated Rice Crop Management (Project number 8). Following budget cuts within the plan of the Structural Adjustment, it was decided, by mid-1996, to merge the two projects into Project 3, keeping the focus of our efforts on rice research in pre-breeding activities.

Research on irrigated rice is now centered on the strategic allience with FLAR, the Latin American Fund for Irrigated Rice, jointly financed by public and private organizations in Latin America and the Caribbean. TAC has recently expressed in the CGIAR Priorities and Strategies Paper, April 26, 1996, pages 14-15 that, in face of the universal decline in public sector funding for agricultural research, "partially offsetting these effects are increases in some research fields by the private sector." Then, "perhaps the strongest source of optimism is the emergence of regional groupings of national research capacities...". Rice research in Latin America is now well into that path and is leading a trend into the future. CIAT has played a very active role in this innovative process.

Tapping into IRRI's research, CIAT will focus on prebreeding activities to develop rice germplasm targeted at Latin America production systems. Germplasm acquisition and characterization, including the use of molecular marker techniques, constitutes a central activity of CIAT's rice germplasm work. The project also has a strong focus on overcoming selected major biotic constraints by expanding knowledge on the pest agents as well as on the rice plant and on their interactions.

The main outputs of this Project are:

Output 1: Enhanced Gene Pools
Output 2: Knowledge of Physiological Basis for Yield Enhancement and Adaptation to Acid Soils
Output 3: Rice Blast Pathogen and Genetics of Resistance Characterized
Output 4: Weed Control Enhanced for Competitiveness and Productivity Assesed
Output 5: Rice Lines with Diverse Resistance to Tagosodes and RHBV Developed
Output 6: The Causal Agent of "Entorchamiento" Problem Characterized
Output 7: Priorities and Research Capacity Enhanced

The Project has a total of 8 principal scientists collaborating with an equivalent dedication of 5.5 Senior Staff positions and a total budget of about US$ 1.0 million per year. Our partnership with CIRAD-CA (from France), JIRCAS (from Japan) and FLAR has contributed greatly to strengthen the Project.

A particularly important complement to this Project, have been the activities in Project 18 (Strengthening Private and Public Linkages for Agricultural Research and Development). As many rice research programs in the region have become stronger, there is a clear opportunity for a more effective collaboration among them and with CIAT. Training constitutes, not only an efficient vehicle to advance knowledge and capacity, but it is also a tool to integrate scientists around common themes and share their experiences with colleagues. The development of regional networking and the consolidation of FLAR are key activities that have great impact on our capacity to deliver research products.

During 1996, we also had special strategic linkages with Project 15 (Understanding Species Genetic Diversity for Improving Conservation and Broadening the Genetic Base of Gene Pools) and with Project 17 (Assessment of Past and Expected Impact of Research in Agriculture and Natural Resource Management). While we provide here some cross references to those Projects and activities, reading their reports should be useful to obtain a well rounded vision of rice research activities at CIAT during 1996.

This annual report provides a detailed account for each one of the main outputs of this project. A work breakdown structure has also been included as reference and the logical framework summarizes the main indicators as well as the assumptions for each output.

We have also included annexes with the information on publications, a list of the project staff, trainees and scientific visitors for this year.

Luis R. Sanint
Project Manager

Project #3. Improved Rice Germplasm for Latin America and the Caribbean

Project Goal

To improve the nutritional and economic well-being of rice growers and low income consumers in Latin America and the Caribbean through sustainable increases in rice production and productivity

Project Purpose

To increase genetic diversity and enhance gene pools for higher, more stable yields with lower unit production costs of rice and reduce environmental hazards.

Outputs / Activities

Enhanced Gene Pools

1. Introduce germplasm from different sources.
2. Identify progenitors for crossing.
3. Generate and evaluate gene pools.
4. Seed multiplication and distribution to FLAR and other partners.
5. Identify useful traits in wild germplasm and make interspecific crosses (linked to #15).
6. Use AC/embryo rescue to speed up development of breeding lines.
7. Select for useful traits, with the aid of molecular markers (linked to #15).

Knowledge of the physiological basis for yield enhancement and adaptation to acid soils

1. Characterize new plant type under direct seeding.
2. Improve demand-driven N supply and N uptake for full expression of yield potential.
3. Introgress new plant type into LAC's gene pools.
4. Understanding the physiological mechanism for tolerance to low P and acid soils.

Rice blast pathogen and genetics of resistance characterized

1. Monitoring genetic and virulence diversity of blast pathogen.
2. Testing breeding methods for developing durable blast resistance.
3. Dissecting blast resistance genes in highly resistant cultivars.
4. Training national scientists of Latin America in new blast research technologies.

Weed control enhanced for competitiveness and assess productivity

1. Screen for competitiveness and assess productivity.
2. Make crosses of competitive cultivars with submergence tolerant, and early-vigorous progenitors.
3. Conduct close response tests for *diagnosis of* herbicide resistance and cross resistance, and to monitor management practices.
4. Field evaluation of herbicide resistant transgenic and non- transgenic plants and biosafety measures.

Rice lines with diverse resistance to Tagosodes and RHBV developed

1. Evaluation of rice germplasm for resistance to *Tagosodes orizicolus.*
2. Evaluation of rice germplasm for resistance to RHBV.
3. Studies of RHBV colony vs date vs variety.
4. RHBV surveys in rice fields.
5. Collaboration with FEDEARROZ to transfer Tagosodes and RHBV evaluation technics.
6. RHBV epidemiological studies.
7. Biocontrol of *Tagosodes orizicolus.*
8. Evaluation of transgenic rice for resistance to RHBV.

The causal agent of the "entorchamiento" problem characterized

1. Isolation of the causal agent of "entorchamiento".
2. Isolation of the vector of the "entorchamiento" causal agent.
3. Characterization of the causal agent.
4. Characterization of the vector.
5. Development of *diagnostic* methods.
6. Development of germplasm screening technique.
7. Implementation of "entorchamiento" control measures.

Priorities and research capacity enhanced

1. Coordinate breeding activities with FLAR/other institutions (linked to #18).
2. Organize/support training activities (linked to #18).
3. Exchange information with partners.
4. Characterize rice technologies and costs (irrigated and upland).
5. Apply questionnairies to farmers with national programs.
6. Analyze data and calculate costs, inefficiences, etc.
7. Establish priorities.

LOGICAL FRAMEWORK - PROJECT No. 3

Project Title: Improved Rice Germplasm for Latin America and the Caribbean   Project Manager: Luis R. Sanint

Narrative Summary	Measurable Indicators	Means of Verification	Important Assumptions
Goal To improve the nutritional and economic well-being of rice growers and low income consumers in Latin America and the Caribbean through sustainable increases in rice production and productivity.	Improved access of rice growers and consumers to standard goods and services. Reduction in pesticide use and increase yield average/ha. Increase in the number of ha planted with new cultivars.	National statistics on agriculture and development of LAC. Rice production statistics.	Donors, governments and NARS continued interest in sustainable increase in rice production.
Purpose To increase genetic diversity and enhance gene pools for higher, more stable yields with lower unit production costs of rice and reduce environmental hazards.	Evaluations of yield potential of F2BC2, end 1997. Increased use of improved populations from recurrent selection by NARS at the end of 1997. Rice lines selected with desired gene traits. Potential donors high levels of blast resistance.	Database on seed exchange. Project, CIAT and NARS annual reports.	Improved/diversed populations are adopted/used by NARS; policies favor adoption. Farmers are willing to reduce pesticide use.
Output 1 Enhanced Gene Pools.	Seed of best gene pools distributed to FLAR and 50% of other partners by the end of 1997.	Project progress report for 1997.	Continued demand for these populations. NARS willing to try out/use improved lines.
Activities - Introduce, identify, generate and evaluate germplasm from different sources. Multiply seed to FLAR/ other partners. Use AC/ embryo rescue (CM, MCH, ZL, P-Docs). - Identify and select for useful traits with the aid of molecular markers (linked to #15) (JT, FC, CM).	First evaluation of the yield potential of 3 F2BC2 populations conducted by 1997 in 3 sites. Number of field trials planted. Number of crosses made, DH obtained, hybrid plants recovered by embryo rescue and traits identified. QTLs identified.	Project progress report for 1997. Field visits to testing sites. Budget.	Adequate funding and timely release of budget. Continued support from CIRAD-CA. Useful traits in wild germplasm can be incorporated in improved populations. NARS willing and capable to try out/use new improved populations.
Output 2 Knowledge of the physiological basis for yield enhancement and adaptation to acid soils.	Main 5 agronomic/physiological traits measured beginning 1997.	Project progress report for 1997. Two publications.	Continued demand by NARS for these populations and knowledge.
Activities - Characterize new plant type under direct seeding and N uptake. Introgress new plant type into LAC's gene pools (Post-Docs, CM, HR) - Understand the physiological mechanisms for tolerance to low P and acid soils (P.-Doc)	N-management for new plant type worked out by the end of 1997. First BC to new plant type made by end 1997. Mechanism for tolerance to low P/acid soils proposed.	Project progress report for 1997.	Continued JIRCAS interest and support. Adequate funding and timely released of budget. Rice support staff in plant physiology in place. Post-Doc in place.
Output 3 Rice blast pathogen and genetics of resistance characterized.	Isolates characterized for their virulence and genetic structure.	Project progress reports.	Collection of blast infected samples gives viable isolates. Molecular markers available from BRU.
Activities - Monitoring genetic and virulence diversity of pathogen. Testing breeding methods for durable blast resistance (CM, FC) - Dissecting blast resistance genes in highly resistant cultivars and make new crosses (CM, FC, linked to project #15)	Isolates.	Assigned budget.	Rice crosses and populations developed by rice breeders. Biotechnology unit continues identifying molecular markers associated with resistance.

Output 4 Weed control enhanced by the use of new genotypes and practices.	Weed competitive varieties developed. Herbicide - resistant rice cultivars to control red rice and herbicide resistant weeds developed.	Project reports.	Farmers adopt technology developed. Germplasm adoption is higher and more consistent than of agronomic changes.
Activities - Screen for competitiveness and assess productivity. Make crosses of competitive cultivars with submergence tolerant, and early-vigorous progenitors (P-Doc, CM) - Conduct tests for herbicide and cross resistance, and monitor management practices. Evaluate herbicide resistant transgenic and non-transgenic plants (Post-Doc, ZL, HR linked to project #15)	Transgenic plants. Identified traits for competitiveness.	Workplan. Budget.	CIAT-RP representative will continue to participate in COMALFI herbicide resistance committee, and will link with similar efforts in LAC. Post-doc in weed agronomy in place.
Output 5 Rice lines with diverse resistance to Tagosodes and RHBV developed.	RHBV and vector surveys implemented. Evaluation and biocontrol methods developed.	Project reports.	Existence of diversified resistance to RHBV and Tagosodes.
Activities - Evaluation of rice germplasm including transgenic plants for resistance to *T. orizicolus* and to RHBV (CM, FC, ZL) - Studies of RHBV colony vs date vs variety (LC, CM) - RHBV surveys in rice fields and epidemiological studies. Biocontrol of *T. orizicolus* (LC, CM, FC) - Collaboration with NARS to transfer evaluation technics (LC, CM, FC)	Rice lines with diversified resistance to *Tagosodes orizicolus* and to RHBV. More effective colony management. Baseline information for understanding and prediction RHBV epidemics, crop management. Increased capacity of NARS to screen germplasm. Effective entomopathogens for insect control. Transgenic lines with RHBV-viral genes w/reduced disease symptoms.	Workplan. Budget plan.	Collaboration with FEDEARROZ, FLAR. Depends partially on special project funding.
Output 6 The causal agent of the "entorchamiento"problem characterized.	Identification and characterization of causal agent.	Project reports.	Recommendations issued and adopted by farmers.
Activities - Isolation and characterization of the causal agent and vector of "entorchamiento" (FC, FM). - Development of diagnostic methods and germplasm screening technique to implement control measures (FC, FM).	The causal agent of the entorchamiento"disease of rice and its vector are characterized, managed. Different control strategies are implemented.	Publications and diagnostic kits available. Resistant germplasm selected under artificial conditions. Workplan, budget.	Available infected material can be maintained and propagated by artificial measures. Recommendations issued and adopted by farmers. Special funding by COLCIENCIAS and ODA
Output 7 Priorities and research capacity enhanced	One workshop conducted by 1997 for NARS. 15-20 trained people from NARS. Farmers' surveys in LAC.	Project progress and workshop report for 1997.	NARS continued interest in specialized training and information exchange. Linkages with NARS.
Activities - Coordinate research, training activities with NARS. Establish priorities (LS, MCh, FC, ZL) - Apply questionnaires to rice farmers (LS).	Research plans written. Number of scientists trained Costs of production, production coefficients Budget.	Progress report for 1997.	Adequate funding and timely released of budget.

Executive Summary

I. OUTPUT 1. Enhanced Gene Pools

Ten improved populations for irrigated rice and acid soil conditions developed through recurrent selection were multiplied and maintained; besides, two new populations for acid soil and hillside conditions were formed. A backcrossing program to improved rice cultivars was continued to develop improved populations via interspecific hybridizations; the aim is to selectively transfer QTL's controlling traits of economic importance from wild rice to cultivated via molecular marker-aided selection. Replicated yield trials with F2BC2 families and molecular characterization of those families carrying the desired gene combinations to continue the backcrossing scheme and the development of near-isogenic lines.

Activities developed by the upland savannas conventional breeding project were reduced. Breeding lines were sent to EMBRAPA-CNPAF to be incorporated in their breeding program with which we maintain close collaboration. Visits and exchange of information on the behavior of the CIAT breeding lines are made regularly. Three CIAT upland lines were released in BRAZIL and GUATEMALA. One line developed by the CIAT/CIRAD-CA project was proposed for registration in the rice catalogue of CIRAD-CA.

From 1993, we started, with the "Centro Nacional de Investigaciones del Café" CENICAFE and the Hillsides Program of CIAT, an informal collaboration on the adaptation of rice as a new crop for the highlands ecosystem of Colombia. Results are very encouraging.

The expertise of the collaborative project on recurrent selection is shared with NARS through activity reports, didactic documents, field visits and training courses. The first International course on Rice Recurrent Selection Breeding was held at CIAT in 1996. Fifteen scientists from 13 countries attended the course.

Eleven Gene Pools and Populations (8 from Brazil and 3 from CIRAD-CA/CIAT) were registered in the germplasm catalogue for recurrent selection.

II. OUTPUT 2. Knowledge of the Physiological Basis for Yield Enhancement and Adaptation to Acid Soils

Data on the evaluations of the new plant type suggest that it is not yet ready for use under tropical conditions but that it is a valuable source of genes for breeding purposes to enhance our locally adapted germplasm. A crossing program was started to introgress useful plant traits into improved rice cultivars.

Acid-soil tolerance: tolerant to which soil factor? The difference between two groups of varieties (acid-soil tolerant and susceptible) in terms of their response to calcitic-lime application was confirmed by the 2nd years' field experiment. However, the decreased yield of susceptible varieties at low lime treatment was not accompanied by the known symptoms of Al toxicity like reduction of root length, root mass, or increase of mean root diameter. The summary of the field experiments in the past 4 years indicated that low-Ca rather than the high-Al is the major limiting factor which is differentiating the tolerant and susceptible varieties.

cid-soil tolerance mechanisms of upland rice. Low aluminum uptake at the root tip of Al-tolerant variety can be partly ascribed low cation exchange capacity. The tightly bound Ca on the cell wall which cannot be eluted by the chelator may also be the tolerance mechanism.

Screening of low-P tolerant varieties of upland rice. Basically the same genotypes were chosen as low-P tolerant in the two years field experiment with low and high P application. The usefulness of the experiment is demonstrated. The genotypes which is demonstrated to be low-P tolerant will be used in further mechanistic study as well as in breeding program in collaboration with other advanced institutes.

III. OUTPUT 3. Rice Blast Pathogen and Genetics of Resistance Characterized

Blast is the most widespread and damaging disease of rice. New blast strains render resistant varieties susceptible within 2 or 3 years of release, and sometimes even before the breeding lines reach farmers' fields. The need to continuously produce lines with resistance to blast inflates the cost of rice breeding programs worldwide. Besides, in the presence of susceptible cultivars farmers have to rely in many instances on environmentally damaging and costly fungicides for blast control. An integrated strategy involving the characterization of the genetic structure and virulence diversity studies of the pathogen is providing rice scientists new tools for the development of durable blast resistance. These results will lead to major benefits reducing breeding efforts as well as positive implications in the sustainability of rice production.

Blast samples were collected from different rice germplasm during 1996 and analyzed for their genetic structure using DNA-fingerprinting and virulence diversity in greenhouse inoculations. These studies have shown both, changes in frequency of different genetic families of the blast pathogen as well as changes in virulence spectrum as a response to changes in area planted with new commercial cultivars. We have been able to follow the initial steps of resistance breakdown in the highly resistant blast cultivar Oryzica Llanos 5, demonstrating that its breakdown is being attained by blast isolates of an individual genetic family present in the pathogen population and not by a new family introduced to the system, neither by different pathotypes of different genetic families of the fungus.

The use of complementary blast resistance genes in different crosses is being tested both in the field as well as in the greenhouse to demonstrate the lineage exclusion hypothesis as a strategy for the development of durable blast resistance. Rice lines developed from the cross between the complementary resistance genes Pi-1 and Pi-2, have proved to be resistant to all the blast pathogen population present in the field as it was predicted from the initial greenhouse studies. Other crosses between complementary resistance sources have also yielded resistant lines which are being advanced to F5 generation. Complementary resistance sources to blast have also been identified among different commercial rice cultivars from Latin America to be used by breeders in genetic crosses. These crosses can give origin to excellent lines in a short term as they already have many desired traits. Dissection of blast resistance genes in the highly resistant rice cultivar Oryzica Llanos 5 is being conducted by analyzing the blast reaction of 247 recombinant inbreed lines (RIL) derived from the cross of this cultivar with the highly susceptible Fanny. Evaluation of these lines for their reaction to blast isolates representing six genetic families of the blast fungus in Colombia has been conducted in the greenhouse. Results of this study are being integrated to the molecular analysis of the same RAIL by the Biotechnology Research Unit to identify markers associated with the resistance genes present in Oryzica Llanos 5 using RFLP, AFLP, RAPD, and other molecular markers.

Transfer of new techniques used in the characterization of blast pathogen populations for the development of a more durable blast resistance was achieved by training national scientists from Cuba, Venezuela and Colombia for a period of time up to four months. Several publications as well as presentations at different meetings in different countries were also used for the transfer of these new strategies. Graduate students from Cuba, USA, Germany and Colombia came to CIAT during 1996 for blast research training.

IV. OUTPUT 4. Weed Control Enhanced by the Use of New Genotypes and Practices

Continuous rice cropping in Latin America and the Caribbean (LAC) has resulted in serious weed problems and herbicide overuse. Competitive rice varieties could help reduce herbicide dependence. A study was conducted during 1994 to 1996 at CIAT, Colombia, to: a) Assess the competitiveness of semidwarf irrigated rice plant types adapted to LAC's direct seeding systems, b) identify plant traits responsible for such competitiveness, and c) detect adverse effects of competitiveness on rice yield potential. Pregerminated seed of 10 and 15 semidwarf rice cultivars was sown on drained puddled soil in 1994 and 1995, respectively. Cultivars were grown weed-free or with *Echinochloa colona* (L.) Link (40 viable seeds m^{-2} broadcast immediately after seeding rice), and were intermittenty irrigated to keep the soil near saturation. Rice and *E. colona* biomass, leaf area index, tiller no., and height were recorded at 20, 40, 60, 90, and 120 days after emergence. Rice cultivars differed in their ability to tolerate competition and suppress *E. colona*. Average yield losses ranged from 27 to 62% under saturating *E. colona* infestations of up to 5.9 Mg dry matter ha^{-1}. Leaf area index, tiller no., and canopy light interception recorded in competition, and not much before 40 dae, correlated positively with rice competitiveness. Competitive semidwarf cultivars can substantially reduce the number of herbicide applications in systems where suboptimal water control does not allow weed suppression by flooding. Breeding to enhance rice competitiveness appears as a valid objective, since competitive and also highly productive cultivars were identified in this study.

V. OUTPUT 5. Rice Lines with Diverse Resistance to Tagosodes and RHBV developed

Rice hoja blanca virus (RHBV) is a growing threat throughout Central America, Caribbean and tropical Andean countries. The levels of RHBV are currently increasing in Colombia, Dominican Republic and Ecuador. Costa Rica has been experiencing high levels of RHBV for several years. The research on RHBV is centered around understanding the pathogen, the nature of the host plant resistance, developing novel sources of resistance, and developing strategies for mitigating the effects of a new cycle with high levels of RHBV. In our efforts, CIAT, FEDEARROZ and FLAR have a dynamic partnership, and this collaboration will remain important to accelerate the areas of investigation needed to combat RHBV.

One of the major activities has been to monitor levels of RHBV in plants and quantify the vector populations. It is clear that the level of RHBV in the Llanos and Tolima are increasing and that these are the regions in Colombia that are at greatest risk. It is our recommendation that rice producers grow several varieties in order to reduce losses caused by the epidemic. There are specific recommendations that are tailored to the individual rice growing regions. It is also clear that there are foci of the epidemics. Investigations on the number of insects with the genetic capacity to transmit RHBV has shown that up to 20% of some populations have the ability to be viruliferous vectors. This exceeds the estimates made during the last epidemic and changes the threshold levels for the recommendations. Also measures of the percentage of vectors with the genetic capability to transmit virus are a early warning that an area is at risk from RHBV. More information is needed to have a clear understanding of vector populations and several different activities are currently on going.

The activities for producing varieties with higher levels of resistance both to RHBV and *T. Orizicolus* are continuing with CIAT testing varieties from several sources and Institutions. This is being complemented with efforts to transform rice with parts of the RHBV genome and select resistant plants. There is one line of transformed plants that show a delay and decrease of symptoms when infected with RHBV. These plants are in the second generation and the trait appears to be stably inherited. There still needs some additional testing to determine the degree of resistance in these transgenic rice lines. The strategy is to cross these plants with other resistant varieties. All of the conventional resistant varieties are more susceptible to RHBV when they are young. Therefore the addition of a novel source of resistance should confer a higher degree of resistance and this is still needed to break the recurring cycles of RHBV epidemics.

Another activity started this year is to select biological control agents that attack *T. orizicolus*. There are many insect parasites to the planthopper in the rice fields, but these are often rendered ineffective because of the high use of insecticides. Therefore, our research is concentrating on entomopathogens. Promising entomopathogens are being identified in the greenhouse and should be ready for field trials during 1997.

VI. OUTPUT 6. The Causal Agent of the "Entorchamiento" Problem Characterized

A new production problem of rice in Colombia, known as "entorchamiento", was first observed in the Eastern Plains of Colombia in 1991. The new problem causes early seedling death or severe malformation of the adult rice plant, rendering it unproductive. Research conducted by the national programs and the rice growers' federation, suggested that different abiotic or biotic factors, such as soil compaction, pesticide damage, nutritional problems, aphids and nematodes, could be the causal agent. Despite corrective cultural practices and the intensive use of insecticides and nematicides, the problem continued to spread throughout the Eastern Plains. Last year, the Virology Research Unit, in cooperation with ICA, CORPOICA, and FEDEARROZ, demonstrated that the causal agent of the "entorchamiento" disease of rice is a furovirus transmitted by the fungus Polymyxa sp.. This disease was first observed in West Africa in 1969, and was later shown to be a viral disease called "rice stripe necrosis" in 1983 by ORSTOM virologists working in the region. This disease of rice has been slowly spreading in W. Africa, probably due to the predominantly artesanal rice production systems that prevails in that region. In Colombia, the highly mechanized nature of rice production, has apparently contributed to the rapid dissemination of the disease in the country. To date, the virus and its vector have already been detected in the following rice-growing departments: Cordoba, Cundinamarca, Huila, Meta, and Tolima. Reports form Nicaragua suggest that the disease may also be present in Central America. To date, control measures have been directed toward the search for genetic resistance and the implementation of cultural practices that seem to reduce disease incidence.

VII. OUTPUT 7. Priotities and Research Capacity Enhanced

A. Activitiy 1. The National Rice Sample in Colombia: an application to varietal stability

In the 1980's, Colombia decided to follow a breeding strategy of regionalization. The goal is to release varieties highly adapted to specific environments. As a result, varieties like Llanos 5 and Caribe 8 were developed for very specific environments. But farmers are using them outside their recommended domains. The methodology applied here allows to collect evidence of differences in yields and adaptability associated with different environments. The results clearly show that the eight varieties evaluated here using farmers field data collected from the National Rice Sample over the 1991-94 period present significant varying responses in yields and stability associated with environmental changes. Some varieties that were broadly tested under different environmental conditions and that were released as National Varieties (like Cica 8 and Oryzica 1) exhibit higher plasticity; i.e., have a higher capacity to respond under varying environmental conditions. On the other hand, varieties that were released for specific environments (Caribe 8, Llanos 5, Linea 2), have lower adaptability values and are unable to respond to a wide variety of environmental conditions. Currently, the variety that shows the highest demand by farmers in Colombia is Oryzica 1; besides its adaptability, it has good grain quality and is widely accepted by millers. Looking to the future, a National Rice program, like Fedearroz, seems to be more inclined to resort to the release of National Varieties, leaving to the private sector the strategy of releasing Local Varieties with high yield potential under very specific (and narrow) environmental conditions. Small farmers prefer varieties like Cica 8, with wide adaptability, perhaps due to their lower capacity to offset environmental changes and also given their lower ability to apply specific technological packages in a timely and precise manner. This need to obtain widely adapted varieties highlights the value of participating in a regional breeding program, like the one FLAR offers to Fedearroz.

B. Activity 2. Impact of Rice Research in Latin America and the Caribbean during the past three decades

The past three decades (1967-96) have resulted in strong national rice improvement programs, 275 high yielding rice varieties on farmers' fields, and networks of germplasm improvement and related information linked, via CIAT, to the premier upstream research resource, IRRI. Measuring past benefits and identifying the shares apportioned by main interested parties is a valuable exercise not only to gain an idea of the profitability of past research investments but also to guide future efforts. The model used here measures benefits to producers and to consumers. A further breakdown permits to calculate benefits by major production ecosystems: irrigated, rainfed lowlands, mechanized upland and traditional (or manual) upland; the model also calculates foregone benefits to producers resulting from imports. The main beneficiaries of the technological innovations have been the consumers, with an annualized flow of benefits (discounted at 3% per year) of US$518 million. Producers have received great benefits as a group with US$340 million per year. But it has been the irrigated system the one that has received the benefits of research

(US$437 million per year), while the other ecosystems have been adversely affected by the rapid gains in the irrigated sector. All these ecosystems had net annual losses of US$9 million in rainfed, US$70 million in mechanized upland and US$5 million in manual upland. With productivity gains in irrigated rice, prices have decreased, making upland rice less competitive and reducing the economic incentive to open new rice lands in those upland ecosystems. Productivity gains in irrigated rice have played a role of release valve for the more fragile ecosystems of the forest margins and the savannas. The future of rice research holds exciting challenges and opportunities. Rice research aims to make significant contributions to environmental goals and reduction of agrichemical use, as well as in feeding people through devoting its efforts to the development of improved rice gene pools and integrated crop management. Rice research plays and important role in the development of agropastoral protocols for the savannas adjoining the margins of the rain forest in tropical America. Breeding to develop germplasm adapted to the acid soils savannas and the understanding of rice/pasture associations will lead to a more sustainable rice production in this ecosystem and a more rational use of pesticides. As a result of recent strategic changes in international donors, national organizations of LAC, together with CIAT and IRRI, have created the Latin American Fund for Irrigated Rice (FLAR), which will ensure continuity in irrigated rice research activities at the regional level. This process clearly shows that Latin American rice producers are aware of the value and innovation of new technologies.

I. OUTPUT 1. Enhanced Gene Pools

INTRODUCTION

It is estimated that by the year 2025 some 8.3 billions people will live on earth and that 50% of them will be rice eaters. Therefore, current world rice production (approx. 575 millions tons) must be increased by 70% to meet this demand.

More than 90% of the world's rice is grown and consumed in Asia, while Latin America's rice production represents 3.5% of the total; over 80% of rice production in Latin America comes from irrigated and rainfed lowland ecosystems. Rice production in LAC increased from 9.9 to 20.6 million tons from 1966 to 1995, while modern semidwarf varieties combined with appropriate management practices caused 76% regional average yield increase for the irrigated and rainfed lowland sectors from 2.5 to 4.4 t/ha. However, some studies have shown that rice improvement in LAC has depended on a narrow genetic core of 12 landraces and that yield potential of irrigated rice has reached a plateau. Therefore, there is a need for increased rice production in a sustainable manner.

The main purpose of this project is to increase genetic diversity and enhance gene pools for higher, more sustainable yields.

A. ACTIVITITY 1. GENERATE AND EVALUATE GENE POOLS

Activity 1a. Irrigated and lowlands rice

The especific objective of this activity is to make up and maintain improved populations developed through the use of recurrent selection. Three populations (PCT6, PCT7, and PCT8) and one gene pool (GPCT-9) developed in 1995 for the irrigated and favorable upland conditions were multiplied and maintained in CIAT-Palmira. Seed from male-sterile plants was bulked-harvested while best fertile plants were harvested individually for evaluation in pedigree rows. Seed of these populations was distributed to several national programs.

Six populations (CNA-IRAT5/0/4, CNA-IRAT A/0/2, CNA-IRAT P/1/1, PCT A/0/0/0, PCT 5/0/0, and PCT 4/0/0/1) developed for upland-acid soils were multiplied and maintained in La Libertad Experiment Station, Villavicencio. Two new populations (PCT-11 and PCT-13) were formed; 26 cultivars choosen among best pedigree lines from the upland breeding program and best upland commercial varieties grown in Brazil and Colombia constitute the genetic make up of PCT11. On the contrary, PCT-13 was developed for the hillside region of LAC based on 11 improved breeding lines.

Fertile S0 plants selected in different recurrent selection populations were run through anther culture and doubled-haploids obtained were evaluated for tolerance to several diseases in CIAT-Santa Rosa; out of the 48 doubled-haploid lines evaluated only two (IRAT CT/0/2-CA-39 and IRAT CT/0/2-CA-62) were selected.

Finally, two populations (IRAT CT/0/2 and IRAT CT/0/1F) developed by CIRAD-CA for better response to anther culture were planted and evaluated in CIAT-Palmira; 138 fertile plants were harvested and run through anther culture; 90 doubled-haploids were selected for further evaluation in CIAT-Santa Rosa in 1997. There was good genetic variability in terms of plant type, earliness, tillering, and grain type.

Activity 1b. Upland savannas rices

BACKGROUND INFORMATION

Genetic uniformity, or lack of genetic diversity, is of major concern to breeders, geneticists, and the agricultural community in general. In many crops, genetic improvement is usually accomplished by reducing genetic diversity in the gene pools used to develop new cultivars. But genetic uniformity is now considered as increasing a crop's potential vulnerability to disasters caused by biotic or abiotic constraints.

A way of broadening the genetic base of Latin American rice and assessing the genotype-by-environment interaction is to identify specific potential parents and pool them to develop new, genetically broad-based, breeding material.

CIAT and CIRAD-CA new breeding strategies focus on developing and improving populations to provide sources of potential parents with specific traits required by the national breeding programs. One suitable breeding method to achieve this goal is Recurrent Selection. Started in 1992, the CIRAD-CA/CIAT rice improvement collaborative project introduced from Brazil and French Guyana, gene pool and populations segregating for a male-sterile recessive gene.

The main objectives of the project are:

(a) to understand the performance of the introduced germplasm in the upland acid soils of the Colombian savannas,

(b) to maintain the germplasm by harvesting fecunded male-sterile plants,

(c) to identify adapted fertile genotypes for use in breeding programs for fixed lines,

(d) to start recurrent selection by recombining the best selected genotypes in the introduced germplasm, and

(e) to create new populations by incorporating the best locally adapted lines of CIAT's upland rice breeding program into the best adapted introduced germplasm that provides a good source of male-sterile background.

RECURRENT SELECTION FOR SAVANNAS UPLAND RICE

1. INTRODUCTION

The upland rice recurrent selection project aims at adapting, developing and selecting upland rice gene pools and populations.

The main characteristics of the germplasm we are looking for are:

- Tolerance to soil acidity
- Resistance to diseases, mainly rice blast (*Pyricularia grisea* Sacc.)
- Resistance to pests, mainly *Tagosodes orizicolus*
- Good grain quality (translucent, long-slender grain)
- Earliness (total cycle about 115 days)

The activities reported presented here (1995 off-season and 1996 cropping season) were conducted in two different experimental stations:

Off-season (1995 B): October 1995 to March 1996 at Palmira Experimental Station (EEP) and Cropping season (1996A): April to September 1996 at La Libertad Experimental Station (EELL).

2. LINE DEVELOPMENT FROM RECURRENT POPULATION

During the enhancement of the gene pools and populations using recurrent selection, we selected fertile plants to develop promising fixed lines.

2-1. *Generation S2*

2-1-1. Populations PCT-5\0\0\0, PCT-A\0\0\0 and PCT-4\0\0\1

During 1995 cropping season at La Libertad (1995A EELL) we selected 55, 85 and 18 S0 fertile plants in PCT-5\0\0\0, PCT-A\0\0\0 and PCT-4\0\0\1 respectively, and during 1995 off-season we grow the S1 at Palmira (1995B EEP).

During 1996 cropping season a total of 158 S2 and 3 checks (Oryzica Sabana 6, IAC 165 and Linea 30 = CT 11891-2-2-7-M) were observed at the EELL and selected. We discarded 102 S2 lines (64,5%) mainly for plant type and yield potential.

A total of 56 S2 lines (35.4%) was selected (PCT-5\0\0\0, 21 lines (38.1%) - PCT-A\0\0\0, 26 lines (30.6%) and PCT-4\0\0\1, 9 lines (50%). In the 56 selected lines, we harvested 178 fertile plants, 62, 91 and 25 in PCT-5\0\0\0, PCT-A\0\0\0 and PCT-4\0\0\1 respectively.

In each selected S2 line, were applied a different selection intensity in relation to the phenotipic value of the lines (grain yield potential, plant and grain type). For example, the highest average selection intensity in three PCT-5\0\0\0 S2 lines was 14% and the lowest average was 1.6% in 14 S2 lines.

The S3 generation will be grown during 1996B at EEP and the S4 seeds will be sent to EELL to grow the S4 generation during 1997A.

2-1-2. Population PCT-4\0\0\1

We started the enhancement of this population using the S2 lines method (see 4-1). We decided to take opportunity of the 1996A S2 trial to select S2 lines and individual fertile plants for line development.

From a total of 152 S2 lines evaluated, we selected 19 (12.5%) and 74 individual plants based on plant and grain type, and grain yield potential. The S3 generation will be grown during 1996B at EEP and the S4 seeds will be sent to EELL to grow the S4 generation during 1997A.

2-1-3. Populations PCT-5\PHB\1\0 , PCT-A\PHB\1\0 and PCT-4\PHB\1\1

During 1996A, from the first recurrent selection cycle for leaf blast and Hoja Blanca Virus (see 4-2.) we selected 211 S0 fertile plants:

49 (11.5% of the total number of fertile plants), 48 (12.4% of the total number of fertile plants) and 114 (17.3% of the total number of fertile plants) S0 fertile plants into PCT-5\PHB\1\0, PCT-A\PHB\1\0 and PCT-4\PHB\1\1, respectively. The S1 generation (211 S1 lines) will be grown during 1996B at EEP and the S2 seeds sent to EELL to grow the S2 generation during 1997A.

2-2. *Advanced Generations*

During 1995B at EEP we seed increased 2 and 4 advanced lines selected in CNA-IRAT 5 and CNA-IRAT A (first germplasms we introduced at CIAT in 1992).

We observed these 6 lines during 1996A at EELL. In each of the 6 lines we selected 5 individual plants for seed increase during 1996B at EEP to setup a yield trial during 1997A at EELL. We also selected 20 panicles and a seed bulk in 2 lines for registration in the Rice catalogue of CIRAD. Panicles and bulked seeds were sent to EEP for storage in the cold chamber.

2-3. *Lines Registration*

The two advanced lines, CNA-IRAT 5 \SA\O\3>127-2-M-2-M and CNA-IRAT A\SA\0\3>1-M-2-M-4-M selected from the populations CNA-IRAT 5 and CNA-IRAT A were proposed for registration in the rice catalogue of CIRAD.

This is the first time that rice lines selected from recurrent selection populations apply for registration.

3. POPULATION MAINTENANCE THROUGH RECOMBINATION

Until now the maintenance of the upland populations was made under irrigated conditions at Palmira. But, results obtained in Madagascar under theses conditions show that a possible genetic drift towards more indica plant type frequency in the population can occur.

Such a drift can be explained by a more effective cross polinization of the genotypes with more indica background. We have to remember that the male-sterile line used to buildup the populations is an irrigated indica line (IR 36 mutant).

From this year we decided to maintain and seed increase the upland populations under savannas conditions.

During 1996A season at EELL we maintained 6 populations:

CNA-IRAT 5/0/4, CNA-IRAT A/0/2, CNA-IRAT P/1/1, PCT-A\0\0\0, PCT-5\0\0\0 and PCT-4\0\0\1. Each population, represented by approximately 1500 plants- except CNA-IRAT P with 600 plants- was isolated from the others by fences of Maize and protected against blast. During the vegetative stage, some plants presented symptoms of the Hoja Blanca Virus and we decided to eliminate the infected plants in each population.

Susceptibility of the germplasm to Hoja Blanca was as follow:

CNA-IRAT5/0/4 presented 312 infected plants (20.8 %), PCT-A\0\0\0 247 (16%), PCT-4\0\0\1 242 (15.5 %), CNA-IRAT A/0/2 236 plants (22.3 %), PCT-5\0\0\0 219 plants (14%) and CNA-IRAT P/1/1 86 plants (14.3 %).

The most susceptible populations are the basic germplasm we introduced from Brazil. In that country, there is no incidence of the disease, and the germplasm was never selected against Hoja Blanca. That explains the susceptibility we found in Colombia. The locally developed *populations* show less susceptibility.

All male-sterile plants were identified, harvested individually and their seeds mixed in equal proportion. Fertile plants were also harvested individually and their seeds mixed in equal proportion.

The identification of the resulting populations is:

Harvest of male-sterile plants	**Harvest of fertile plants**
CNA-IRAT 5/0/5	CNA-IRAT 5/0/4F
CNA-IRAT A/0/3	CNA-IRAT A/0/2F
CNA-IRAT P/1/2	CNA-IRAT P/1/1F
PCT-5\0\0\1	PCT-5\0\0\0F
PCT-A\0\0\1	PCT-A\0\0\0F
PCT-4\0\0\2	PCT-4\0\0\1F

The populations were sent to CIAT Palmira and stored in the cold chamber for further use by the program and to attend any request from regional NARS breeding programs.

4. *POPULATION ENHANCEMENT* - RECURRENT SELECTION

The CIAT upland rice activities emphasize the enhancement of populations and is slowing-down the production of fixed lines and the release of cultivars, devolving these activities to the NARS in the region.

The strategy is to develop and enhance gene pools and population for well-targeted trait(s) to be use as source of potential parents by the NARS' breeding programs.

In the first two years of the recurrent selection project, we concentrated on the introduction, characterization, mass selection, and new populations development. From 1995 and forward, we concentrate our activity on the enhancement and development of new populations. Fixed line development has to be considered as a spillover of the project.

4-1. PCT-4\0\0\1 Population. Recurrent Selection based on S2 evaluation

During 1995A at EELL we selected 159 S0 fertile plants. The generation S1 was grown during 1995B off-season at EEP.

152 lines S2 and 2 checks (Oryzica Sabana 6 and Linea 30 =CT 11891-2-2-7-M) were evaluated and *selected in* 1996A at EELL under the "Augmented Blocks" statistical design (6). Outside the experiment we decided to grow 4 of the 7 parental lines of the *population* PCT-4 as a reference for visual evaluation. The statistical analysis was done at CIAT Palmira. From the analysis we selected S2 lines.

The remanent seeds of the S0 plants that originated the best S2 lines were mixed to develop the recombined enhanced population during 1996B at Palmira.The enhanced mixture is identified as PCT-4\SA\0\1 and the enhanced recombined population (harvest of the male-sterile fertilized plants) as PCT-4\SA\1\1. This population will go through a second selection cycle in 1997A at EELL.

Fertile plants were also selected in the best S2 for line development (see 2-1-2.)

4-2. PCT-4\0\0\1,PCT-A\0\0\0 and PCT-5\0\0 Populations. Mass Recurrent selection on both sexes for main agronomic traits, blast and Hoja Blanca virus

During 1995A at EELL we eliminate at the vegetative stage all the plants showing symptoms of leaf blast and VHB. At harvest time we selected male-fertile plants with a good phenotype. Seeds produced by these plants are the result of the fertilization by pollen produced by healthy fertile plants. 102, 99 and 96 male-sterile plants were selected into PCT-5\0\0\0, PCT-A\0\0\0 and PCT-4\0\0\1 respectively and their seeds mixed individually.

The identification of the first mass recurrent selection cycle (selection and recombination) was: PCT-5\PHB\1\0 , PCT-A\PHB\1\0 and PCT-4\PHB\1\1

During 1996A the seed mixture of each population with one mass recurrent selection cycle was grown at EELL .

To do the second recurrent selection cycle the same selection method as during 1995A was applied (elimination during the vegetative stage of all plants with symptoms of leaf blast and Hoja Blanca). 304, 341 and 442 healthy male sterile plants fertilized by pollen of fertile healthy plants were selected into PCT-5\PHB\1\0, PCT-A\PHB\1\0 and PCT-4\PHB\1\1 respectively and their seeds mixed individually.

The identification of the second mass recurrent selection cycle (selection and recombination) is: PCT-5\PHB\1\0,PHB\1 PCT-A\PHB\1\0,PHB\1 and PCT-4\PHB\1\1,PHB\1

Fertile plants were also selected in the first recurrent selection cycle for line development (see 2-1-3.)

5. DEVELOPMENT OF NEW POPULATIONS

Two new japonica populations were buildup in 1996 at Palmira targeting upland savannas and upland hillsides ecosystems. The source of male-sterility background is the best japonica population developed earlier by the project.

5-1. Upland savannas population

The idea in developing this population is to pool together the best lines of the CIAT conventional rice breeding program and the commercial varieties released in Brazil and Colombia. Eighteen (18) lines were selected on their behavior for earliness, blast and acid soil tolerance, and grain quality.

We used the best adapted upland japonica population (PCT-4) as source for male-sterility. Each line was crossed with at least 4 male sterile-plants from PCT-4. Each resulting F1 generation was grown individually, evaluated, and individual plants selected. The F2 seeds of the selected F1 plants were bulked in equal proportion. Each F2 bulk was mixed in equal proportion to buildup the new basic population identified as PCT-11.

5-2. Upland hillside population

The idea is to develop a population for the Andean highlands of Colombia, with earliness and cold tolerance for high altitude, 1300-1600 masl.

Eleven lines - 6 from the CIRAD-CA/FOFIFA hillsides program of Madagascar, 4 from the CIAT upland savannas program and 1 IRAT line - were selected based on their previous evaluation at high altitude for earliness, cold tolerance and spicklet fertility The lines are presented in the table 13. We used the best adapted upland japonica population (PCT-4) as source for male-sterility. Each line was crossed with at least 4 male sterile-plants from PCT-4. Each resulting F1 generation was grown individually, evaluated, and individual plants selected. The F2 seeds of the selected F1 plants were bulked in equal proportion. Each F2 bulk was mixed in equal proportion to buildup the new basic population identified as PCT-13.

6. REGISTRATION OF NEW POPULATIONS

In 1996, seven populations and 1gene pool developed by EMBRAPA-CNPAF (CNA) and by the former collaborative project between CNPAF and IRAT (CNA-IRAT)- Brazil, were registered in the recurrent selection germplasm catalogue and received new identification.

4 upland germplasm:	CNA-IRAT 5GR	= PCNA-14
	CNA 6/0/3	= PCNA-15
	CNA 7/0/3	= PCNA-16
	CNA 10/0/3	= PCNA-17
4 lowland germplasm:	CNA-IRAT 4/0/4	= GPCNA-18
	CNA-IRAT P/0/2	= PCNA-19
	CNA 1/0/1	= PCNA-20
	CNA 5/0/3	= PCNA-21

7. GERMPLASM DISTRIBUTION

A total of 106 breeding lines and 1 recurrent population were sent to EMBRAPA-CNPAF.

Recurrent population: PCT-4\0\0\0

Selected breeding lines:	50 lines from	PCT-4\PHB\1\1
	22 lines from	PCT-5\PHB\0\0
	20 lines from	PCT-A\PHB\0\0
	8 lines from	PCT-4\PHB\0\1
	2 lines from	CNA-IRAT-5\SA\0\3
	4 lines from	CNA-IRAT-A\SA\0\3

8. GERMPLASM IDENTIFICATION

According to the "Nomenclature System for Rice Gene Pools, Populations and Recurrent Selection Breeding: General Use and Catalogue Registration" (4) the meaning of the germplasm identification used in the text is as follow:

Introduced Gene Pool from Brazil **(CNPAF/IRAT): CNA-IRAT 5**

CNA-IRAT 5/0/3	3 recombinations of the Basic Gene Pool
CNA-IRAT5/0/4	4 recombinations of the Basic Gene Pool
CNA-IRAT5/0/4F	Harvest of fertile plants of the 4th recombination of the Basic Gene Pool
CNA-IRAT5/0/5	5 recombinations of the Basic Gene Pool
CNA-IRAT5\SA\0\3	One selection for acid soils in the third cycle of recombination of the Basic Gene Pool

Introduced Population from Brazil **(CNPAF/IRAT): CNA-IRAT A**

CNA-IRAT A/0/1	1 recombination of the Basic Population
CNA-IRAT A/0/2	2 recombinations of the Basic Population
CNA-IRAT A/0/2F	Harvest of fertile plants of the 2d recombination of the Basic Pop.
CNA-IRAT A/0/3	3 recombination of the Basic Population

Introduced Population from Brazil **(EMBRAPA-CNPAF/IRAT):CNA-IRAT P**

CNA-IRAT P/1/1	1 selection followed by 1 recombination
CNA-IRAT P/1/1F	Harvest of fertile plants of the Pop. selected & recombined one time
CNA-IRAT P/1/2	1 selection followed by 2 recombinations

Enhancement of Population CNA-IRAT A for acid soils, after 3 Selection-Recombination Cycles. The new Enhanced Population is **PCT-A**

PCT-A\0\0\0	Basic Population
PCT-A\0\0\0F	Harvest of the fertile plants of the Basic Population
PCT-A\0\0\1	1 recombination of the Basic Population
PCT-A\PHB\1\0	One selection for blast (P) and Hoja Blanca Virus (HB) in the Basic Population followed by one recombination
PCT-A\PHB\1\0,PHB\1	Second round of selection for blast (P) and Hoja Blanca Virus (HB) followed by 1 recombination

Population developed at CIAT: **PCT-4**

PCT-4\0\0\0	Basic Population
PCT-4\0\0\1	1 recombination of the Basic Population
PCT-4\0\0\1F	Harvest of fertile plants of the 1 recombination of the Basic Population
PCT-4\0\0\2	2 recombinations of the Basic Population
PCT-4\PHB\1\1	One selection for blast (P) and Hoja Blanca Virus (HB) in the first recombination of the Basic Population followed by one recombination
PCT-4\PHB\1\1,PHB\1	Second round of selection for blast (P) and Hoja Blanca Virus (HB) followed by 1 recombination
PCT-4\SA\0\1	One selection for acid soils (SA) in the first recombination of the Basic Population
PCT-4\SA\1\1	One selection for acid soils (SA) in the first recombination of the Basic Population followed by one recombination

Enhancement of the Gene Pool CNA-IRAT 5 for acid soils after 3 Selection-Recombination cycles. The new Enhanced Population is **PCT-5**

PCT-5\0\0\0F	Harvest of the fertile plants of the Basic Population
PCT-5\0\0\1	1 recombination of the Basic Population
PCT-5\PHB\1\0	One selection for blast (P) and Hoja Blanca Virus (HB) in the Basic Population followed by one recombination
PCT-5\PHB\1\,PHB\1	Second round of selection for blast (P) and Hoja Blanca Virus (HB) followed by 1 recombination

Population developed at CIAT: **PCT-11 -**	PCT-11\0\0\0	Basic Population
Population developed at CIAT: **PCT-13 -**	PCT-13\0\0\0	Basic Population

9. CONVENTIONAL BREEDING

9-1. Upland line distribution

A total of 537 lines (496 breeding and 41 parental lines) developed by the conventional upland savannas breeding program of CIAT were sent to EMBRAPA-CNPAF.

F4 generation	484 lines and 32 parents
F6 generation	12 lines and 9 parents

9-2. Upland line release

In 1995 and 1996, three (3)upland lines developed by the CIAT/CIRAD-CA conventional upland savannas breeding program were released in Brazil and Guatemala.

BRAZIL (1995)

CANASTRA	CIAT line: CT 7415-6-5-1—2-B	
	Tox 939-107-2-101-1-1B	25%
	IRAT 216	25%
	Tox 1780-2-1-1p-4	50%
MARAVILHA	CIAT line: CT 6516-23-10-1-2-2-B	
	Tox 1010-49-1	25%
	IRAT 121	25%
	IRAT 216	50%

GUATEMALA (1996)

ICTA IZABAL CIAT identification is CT 11615-4-4-M-2-2-M
Genetic constitution:

Tox 1780-2-1-1P-4	31.25%
IRAT 216	25.00%
Tox 1010-45-1-1	18.75%
IAC 47	18.75%
IRAT 122	6.25%

9-3. Use of CIAT's Upland lines in Brazil

We participate to the "XIV reuniao da Comissao Tecnica Regional de Arroz Região II" (regional rice technical reunion) held in Vitoria Espirito Santo State, Brazil, September 26-30. This is the annual opportunity to know about the use and behavior of the CIAT upland rice germplasm. Each state with upland and lowland rice research is represented and trial results discussed.

The 1995-1996 results show that CIAT's upland germplasm participation in the yield trials is very impressive. The upland observation trial was composed of 57.8% CIAT lines.

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Activity 1c. Course on Recurrent Selection on Rice

1. General Information

This course was carried at CIAT. It was sponsored by the General Secretariat of the Organization of American States under the Training Program between developing countries and the Colombian Government, through the ICETEX. These institutions offered 10 scholarships and CIAT, five. The course had a duration of 10 weeks (April 30 - July 6, 1996) and Dr. Cesar P. Martínez coordinated it with the logistic support of David Salgado and Jaime Borrero, from CIAT and Dr. Elcio P. Guimaraes fro EMBRAPA/CNPAF.

2. Objectives

The main objective was to train Latin-American rice researchers in management for breeding populations through the Recurrent Selection method. A second objective was to update participants in the last progresses of CIAT's Rice Program in breeding, biotechnology, pathology, entomology and crop management.

3. Program

The following topics were underlined: a) theoretical description of the several breeding methods used in autogamous and allogamous plants compared to populational breeding; b) criterions to select parents to create a population base; c) population's formation using manual crossing and the sterility gene; d) description of several selection alternatives for the populational breeding; e) genetic parameters' calculations (variances, inheritance, genetic progress etc.); f) breeding plans preparation based on acquired knowledge; g) management of selection index programs; h) projects planning by objectives; I) field practices (parents selection, crossings, sterile plants identification, population's formation, etc.; j) Use of Recurrent Selection in crops different to rice; k) practices on statistical analysis of experimental data; l) libraries' consultation.

Presentations were carried out by researchers of different varietal breeding programs: CIAT, CIMMYT, CENICAÑA and professors of the Facultad de Agronomía of the National University of Palmira. This allowed to transfer to participants, experiences and knowledge on Recurrent Selection in different crops. Relation between theory and practice was 1:1. As a complement, participants made literature revision on Recurrent Selection in their preferred crop and presented a seminar on it. Two observational tours to Tolima and Villavicencio were organized to visit research projects related with the central topic of the course.

4. List of participants

Annex 4 compile names of participants, origin, scholarship source and the initial and final evaluation knowledge of each of them. The 15 selected participants were chosen based on the outlines shown by the OEA/ ICETEX, and CIAT's rice and training programs; 13 countries were represented. Ten of the participants got the benefits of the scholarships granted by the OEA/ ICETEX, while CIAT financed the other five. In this latest case, national institutions paid their air tickets. Received applications show that this type of course has good demand from national institutions.

5. Results and discussion

An individual knowledge evaluation and a final one shows that the proposed objectives were reached and that the course was successful. The initial knowledge evaluation had an average of 66 with a range of 40 to 100, which showed great heterogeneity in the previous knowledge of participants. A final knowledge evaluation had an average of 92 that suggests that the participants significantly improved their knowledge. As for the course, 87% of the participants considered it as excellent and the other 13% as good. According to participants, relation between the course content and their needs was good. All participants considered that the new knowledge will have many applicability in their work, with some variations inherent to each region and to the production limitations to solve.

The course coordination was qualified as good but with very long duration. Same objectives could be achieved in a shorter course.

Participants considered advantages the following: the Rice Program's emphasis in the use of breeding methods different to the traditional ones like the Recurrent Selection; the opportunity of knowing Recurrent Selection works in crops different to rice; the exchange of knowledge and experiences among researchers of other countries and programs, and the conformation of a network. Also, they underlined the excellent friendship environment present during the course. Main disadvantages of the event were its duration, development of rice populations that were not in an optimum state for practices and the heterogeneity of knowledge and experience of participants.

This event was closed with a discussion in which all had the opportunity of giving an opinion on the course and make recommendations. By unanimity it was recommended to the Rice Program to create a network on Recurrent Selection. It was suggested a search for external funding through the preparation of a project endorsed by all countries participating in this course. Additionally, they suggested the formation of populations according to different ecosystems and regions and finally, the organization of a work shop on Recurrent Selection in the International Rice Conference that will be carried out in Venezuela in March of 1997.

B. Activity 2. Identify and select for useful traits with the aid of molecular markers

Much concern and high priority has been given to increasing the yield potential and broadening the genetic base of cultivated rice. Different approaches (hybrid rice, recurrent selection, new plant type, etc) are being used by several groups to address these issues. However, another alternative, already proven to work well in tomato, offers a great potential for rice. This breeding strategy makes use of wild germplasm, a backcrossing scheme, and molecular markers for the genetic improvement of cultivated rice. Molecular markers will allow the identification of "positive" alleles (QTLs) from the wild species in early segregating generations and the introgression of these positive alleles into selected improved cultivars via marker-aided selection. The main goal is to implement a breeding strategy for the systematic discovery and transfer of genes associated with yield and other agronomic traits of economic importance from wild germplasm into cultivated rice.

Starting in 1994, single crosses between seven improved irrigated cultivars (Bg-90-2, *Oryzica Llanos* 5, *Oryzica* 3; *Morelos* A-88, *Lemont, Cypres, and Jupiter)*, five upland cultivars *(Caiapo, Progresso*, CT6196-33-11-1-3, *Oryzica* Sabana 6, and *Oryzica* Turipana 7), and three wild rice species (*O. rufipogon, O. barthii, and O. glaberrima*) were made (Table 1). F_1 plants were backcrossed to the improved rice cultivar and approx. 100-180 F_1BC_1 seeds were produced. Based on field performance and genetic potential three cross combinations, mainly BG90-2/*0 rufipogon, O. Llanos 5/ O. rufipogon*, and *Caiapo / O. rufipogon*, were chosen for the next backcrossing. Best F_1BC_1 plants (40-50) were identified using negative selection against obvious undesirable traits (spreading plant type, excessive shattering, long awn, dark color grains, high sterility) and used for the second backcross to the improved cultivar. Approx. 900-1000 F_1BC_2 seeds were produced per cross combination; the F_1BC_2 generation was evaluated under field conditions early in 1996 and again negative selection against undesirable agronomic traits was applied. Around 300 F_1BC_2 plants were selected per cross combination and harvested individually; F_2 seed was used to plant replicated *yield trials* is four locations (CIAT-Palmira and Santa Rosa, la Libertad Exp. Station in Villavicencio, and Saldaña. Tolima) including the parents, F_1 and commercial standard varieties as checks. These yield trials are under way; however, field observations suggest that in the case of Bg90-2/ *O. rufipogon* there are several F_2BC_2 progenies that look superior to Bg90-2 in terms of yield potential and grain length. In all three cross combinations, all F_2BC_2 families are very similar to the recurrent parent and show very little segregation. Molecular characterization of the parents, F_1, and F_1BC_1 was already done while molecular characterization of the F_2BC_2 families is underway. This molecular analysis together with data on 12 agronomic traits (including yield) will be used to identify F_2BC_2 families carrying positive alleles from the wild parent to continue the backcrossing scheme and the development of near-isogenic lines.

II. OUTPUT 2. Knowledge of the Physiological Basis for Yield Enhancement and Adaptation to Acid Soils

A. ACTIVITY 1. CHARACTERIZATION NEW PLANT TYPE UNDER DIRECT SEEDING AND N UPTAKE

Yield improvement resulting from the green revolution was based on modifications of the plant type, converting a traditional tall, leafy tropical plant type into a high-tillering semidwarf, and input-responsive modern type; this modification improved the harvest index. However, it has been shown that high tillering carries a cost as many tillers bear no grain at all and reduce the harvest index. A new plant type (NPT) has been developed by IRRI characterized by having few but fertile tillers, large panicles, more and heavier grains, dark-green leaves, and high harvest index, ideal for planting under the wet-seeding conditions prevailing in Asia. Will this NPT adapt well and express its higher yield potential under the dry-seeded conditions prevailing in Latin America where poor land preparation and water control lead to stand gaps?. Our main objective has been to evaluate and characterize the NPT under direct-seeding, and transplanting conditions at several plant densities; 100, 175 and 250 kg/ha of pre-germinated seed were used while 10x10, 15x15, and 20x20 cm spacings were used in transplanted rice. This experiment was carried out in CIAT-Palmira using a split-split design with three reps. Based on preliminary data (CIAT Rice Program Annual Report 1995) eleven genotypes of the NPT and four standard varieties (Oryzica1, Oryzica Yacu-9, IRGA 409, and Perla) were evaluated; 60 kg/ha of K_2O and P_2O_5, and 160 kg/ha of N were applied. Data on main agronomic traits, yield components, and grain yield were taken.

Statistical analysis (Table 2) showed that there were significant differences in several characteristics, including grain yield; on the average, and under direct seeding conditions the NPT was taller, had a longer growth duration, heavier grains, and higher sterility than the check varieties; similarly, the NPT did not show greater yield potential and better harvest index than our best varieties. A similar trend was observed in transplanted rice.

In direct-seeded rice, the NPT performed better at lower plant densities (100, and 175 kg/ha of seed) than at higher seed rate (250 kg/ha); at 100 kg/ha the NPT had higher yield, better harvest index and lower sterility; on the contrary, in transplanted rice the NPT performed much better at closer spacings (10x10 cm).

Table 3 shows data on main agronomic traits under direct seeding conditions; among the 11 genotypes of the NPT tested, lines IR65600-96-1-2-2, IR66160-134-1-3-1, IR66158-38-3-2-1, and IR66738-118-1-2 performed better and had greater grain yield and harvest index than the others. Regarding the check varieties, Oryzica Yacú 9 had the highest grain yield; same was true in transplanted rice.

Two-semester evaluations carried out at CIAT-Palmira failed to show any yield advantage of the NPT over our best commercial varieties; this was expected since our germplasm has been extensively bred and selected for adaptation to local conditions. This lower performance of the NPT could be due to some problems related to plant estabisment under direct seeded conditions and the total amount of N applied in our experiments; it has been indicated that in order to get higher yields with the NPT, a constant and high content of N is needed in the leaf tissue; therefore, frequent N applications are required. Experiments are underway using up to 450 kg/ha of N to elucidate this point.

Data suggest that the NPT as it is presently, is not yet ready for use under our tropical conditions, but that is a valuable source of genes for breeding programs. This NPT posses some important plant characteristics such as heavier grains, longer grain filling period, late leaf senescence, sturdy stems and in some cases high harvest index that could be used to enhance our locally adapted germplasm; besides, some lines of the NPT are tolerant to Tagosodes, rice hoja blanca virus, and rice blast. Genes controlling some of these traits may be different from those already present in our genetic material.

A crossing program was initiated in 1996 to introgress these traits into our germplasm and 215 crosses were made. On the other hand, 460 F_3-F_5 lines with long and slender grain type were introduced to CIAT from IRRI.

Table 1. Inter-specific crosses made between several improved irrigated and upland rice cultivars, and three wild species of rice.

	BG90-2 // 2 * BG90-2 (3)
	MORELOS A88 // 2* MORELOS A88 (3)
	ORYZICA 3 // 2* ORYZICA 3 (3)
	ORYZICA LLANOS 5 // 2* ORYZICA LLANOS 5 (3)
	LEMONT // LEMONT (2)
O. rufipogon /	RU94030006 // RU94030006 (2)
	CYPRESS // CYPRESS (2)
	ORYZICA SABANA 6 // 2 * ORYZICA SABANA 6 (3)
	ORYZICA TURIPANA 7 (1)
	PROGRESSO (1)
	CT6196-33-11-1-3 (1)
	CAIAPO // 2* CAIAPO (3)
	BG90-2 // BG90-2 (2)
	MORELOS A88 // 2* MORELOS A88 (3)
	ORYZICA 3 // 2 * ORYZICA 3 (3)
	ORYICA LLANOS 5 // ORYZICA LLANOS 5 (2)
	LEMONT // LEMONT (2)
O. barthii /	RU94030006 // RU94030006 (2)
	CYPRESS // CYPRESS (2)
	ORYZICA SABANA 6 // ORYZICA SABANA 6 (2)
	ORYZICA TURIPANA 7 // ORYZICA TURIPANA 7 (2)
	PROGRESSO (1)
	CT6196-33-11-1-3 // CT6196-33-11-1-3 (2)
	CAIAPO (1)
	BG90-2 // BG90-2 (2)
	MORELOS A88 (1)
	ORYZICA 3 // ORYZICA 3 (2)
	ORYZICA LLANOS 5 (1)
	LEMONT (1)
O. glaberrima /	RU94030006 // RU94030006 (2)
	CYPRESS (1)
	ORYZICA SABANA 6 // ORYZICA SABANA 6 (2)
	ORYZICA TURIPANA 7 // ORYZICA TURIPANA 7 (2)
	PROGRESSO (1)
	CT6196-33-11-1-3 (1)
	CAIAPO (1)

Remarks: (1) = Single cross made
(2) = First backcross made; in some cases second backcross underway
(3) = Second backcross made; in some cases replicated yield trials with F2BC2 progenies underway

Table 2. Comparison between the IRRI-new plant type (NPT) and commercial varieties under direct seeding conditions. CIAT-Palmira. 1996. [1/]

Type of Material	Height (cm)	Flowering (Days)	Panicle Lenght (cm)	1000 Grain Weigth (gr)	Harvest Index	Sterility (%)	Grain Yield Kh/ha)
NPT	97.0 a [2/]	96.6 a	21.9 a	25.1 a	0.33 b	26.3 a	5590 b
Check Var.	88.1 b	81.0 b	21.8 a	22.0 b	0.43 a	13.2 b	7399 a
Stand Dev.	3.5	1.3	0.9	3.7	0.04	9.3	738.0
C.V	3.7	1.4	4.1	13.9	11.80	43.3	11.8

1/ Mean values based on 11 lines of the NPT and four check varieties, three reps. and three seeding rates.
2/ Significant differences based on a contrast analysis.

Table 3. Some agronomic data of the new plant type and check varieties under direct seeding conditions. CIAT-Palmira. 1996.

	Genotypes	Height (cm)	Flowering (Days)	Panicle Lenght (cm)	1000 Grain Weigth (gr)	Harvest Index	Panicle Sterility (%)	Grain Yield (Kh/ha)
1	IR65600-96-1-2-2	100	99	24	29	0.45	19	7862
2	IR66160-134-1-3-1	93	103	22	31	0.39	13	7407
3	IR65600-61-3-1-3	96	104	21	29	0.36	5	5978
4	IR66738-118-1-2	95	99	24	26	0.41	14	6362
5	IR65600-87-2-2-3	97	93	-23	17	0.26	47	3688
6	IR65598-27-3-1	101	86	20	24	0.24	26	4076
7	IR65564-44-2-3	102	101	22	25	0.31	46	5153
8	IR66155-2-1-1-2	86	76	20	23	0.34	35	5607
9	IR66165-24-6-3-2	96	100	22	11	0.16	60	2859
10	IR66600-77-4-2-2	99	113	21	27	0.23	12	4647
11	IR66158-38-3-2-1	102	89	22	32	0.45	14	7849
12	PERLA	96	83	22	26	0.42	13	7746
13	ORYZICA 1	89	83	22	19	0.44	17	6932
14	ORYZICA YACU 9	87	86	22	21	0.47	12	8472
15	BR-IRGA 409	80	71	21	24	0.39	10	6445
	Duncan's	3.14	1.33	0.9	3.76	0.04	7.9	746

B. ACTIVITY 2. UNDERSTANDING THE PHYSIOLOGICAL MECHANISM FOR TOLERANCE TO LOW P AND ACID SOILS

Acid tolerant and susceptible varieties of upland rice: What is the major growth limiting factor of soil which is responsible for the differentiation of the two variety groups?

Upland rice has clear genotypic difference in the tolerance to acid-soil conditions of tropical savannas (Llanos and Cerrados, etc.). Although high input of alkaline materials like lime can correct the soil acidity problem, developing the tolerant varieties by crop improvement is the more strategic measure for the sustainable agricultural development of the region. For the further breeding of the tolerant varieties, understanding the physiological mechanisms behind the tolerance contributes significantly to increase the efficiency of the process.

However, the acid soils of tropical savannas have many problems of soil chemistry. They are deficient in many essential elements, while Al, Fe, Mn are excessive amd reach level of toxicity in many cases. Therefore, first of all, we have to understand what is the major limiting factor related to the tolerance of certain germplasm.

Usually, the major limiting factor in acid soils is considered to be aluminum. There is abundant research conducted on the mechanisms of Al-tolerance for wheat. However, in the case of relatively acid-tolerant species like rice, the other possibilities also should be considered.

Last year report showed that the yield of susceptible varieties (Oryzica 1 and Oryzica Llanos 5) responded to calcitic lime application significantly but that of tolerant varieties (IAC165 and Oryzica Sabana 6) did not. This year, we repeated the same experiment only with the exchange of Oryzica 1 with maize (var. Sicuani). The response of maize was the expected. But the rest of the varieties responded in similar manner as in the last year.

The root samples which were collected by mechanic auger in the experiment of last year as described in the previous report (Rice Program Annual Report for 1995) were washed and the image of the roots was scanned by flat-bed scanner. The image of the roots were analyzed by a analytical program (Delta-T Scan, Delta-T Devices Ltd., Cambridge, England) for length as well as diameter distribution. However, none of these parameters (root dry weight, root length, specific root length, mean root diameter) showed that the susceptible varieties at the low lime treatment suffered from Al toxicity.

On the other hand, the Ca concentration in the leaves of 3 month old plants showed that the two susceptible varieties had significantly lower Ca concentration than the tolerant varieties at low lime treatment.

We could also draw a useful insight in the acid-soil syndrome of upland rice by summarizing the results of the 4 years of field experiments in Llanos Orientales. No significant yield response of susceptible varieties to liming was obtained in the root experiments in La Libertad, CORPOICA Experimental Station in 1993 and 1994 (as reported in Annual Report for 1994). But we obtained the response in liming experiments in Matazul in 1995 and 1996. Typical soil characteristics related to acid-soil stress are summarized in Table1. The comparison of these two experiments suggests that low-Ca status is the major limiting factor for susceptible variety in savanna conditions, rather than the high-Al itself or the Al saturation. It also includes two practical suggestions, 1) the field screening for acid-soil conditions in savannas should be conducted in the field where the exchangeable Ca content is low (like native savanna soils). Even if the Al saturation is high, the field with high Ca content (like continuously cropped La Libertad fields) should not be used. 2) The mechanisms for the tolerance to low-Ca conditions with the existence of a medium level of Al should be pursued.

Physiological mechanisms for Al tolerance

The role of chelating substances in the root exudates as the detoxifier, which was evidenced for some other crops, has been rejected for upland rice by the preliminary experiments conducted in our laboratory as well as by the report of other institutes.

From the circumstantial evidences, another hypothesis that the cell wall is playing the major role in the Al tolerance has been presented in some reports. But so far no report has been presented regarding the preferential retention and/or binding for Al as well as Ca by cell wall. Therefore, we investigated the Al and Ca retention capacity of root surface by using the root tips, which is considered to be the site of Al toxicity.

Materials and methods

Both acid soil tolerant (Oryzica Sabana 6) and acid-soil susceptible (Oryzica 1) varieties were planted between the filter papers with the moisture of deionized water. They were kept for 72 hours at 25 C in dark. Then the seeds with 1.5-2 cm seminal roots were selected and sown in trays which have different concentrations of Al prepared with $AlCl_3$. All the treatment has $CaCl_2$ at the concentration of 5mM but contains no other elements. The solutions were daily adjusted to pH 4.2 with 0.1 HCl or 0.1 NaOH. The growth solution was constantly bubbled with air at the rate of 300 mL min^{-1}. The rice seeds were allowed to grow under the dark condition with constant temperature (25 C) for further 3 days.

The cation retention experiment was conducted based on the method of Tice, et al, 1992. Briefly, the 30 root tips (0-1 cm, and 1-2 cm) of seminal roots were cut and were shaken with 10 mL of one of the following elution solution for 30 min. : (1) 0.5 mM $BaCl_2$, (2) 0.33 mM citric acid, (3) 0.5 mM EDTA (pH was adjusted to 4.2 in all solutions). Then the solution was eluted and collected. The same shake was repeated with another 10 mL of the solution, and this 10 mL was combined with the former 10 mL. The elements in this solution was considered to have existed in the "apoplastic" compartment of the root tips. Then the roots were frozen in freezer and kept there for one night to rapture the cell membrane. In the second day, the de-frozen roots were again washed with the same solution, again 10 mL and two times. These solution was combined. The elements in this solution was considered to have existed in the "symplastic" compartment. Since the element concentration was very low (ppb order) and the interference from the matrix of the solution was anticipated, the measurement of Al and Ca was conducted using ICP (Inductively Coupled Plasma spectrophotometer, sequential type) (Shimadzu ICPS-1000 IV) in collaboration with INGEOMINAS in Cali.

Results

1) The root tips of susceptible variety retained significantly higher amount of Al in the exchangeable site of root surface than the tolerant variety did. This phenomenon maybe ascribed to the cation exchange characteristics of cell wall itself. The same phenomenon was reported for other species, too.

2) The quantity of Al which was bound by cell wall (not eluted by salt but by chelator) is same for both genotypes.

3) For the case of Ca also, the susceptible variety retained more Ca electropotentially than the tolerant one. However, the chelator eluted much more Ca from root surface of susceptible variety than the tolerant one. This suggests that either the root surface of the tolerant variety had not bound Ca or it fixed Ca very tightly so that even the chelators like citric acid or EDTA could not detach it from roots. This point will be clarified by the analysis of Ca in the residual which is undergoing.

4) This experiment showed the possibility of the repulsion capacity of tolerant root cell surface and/or tightly fixation of Ca in the root tissue as the mechanisms of acid-tolerance. If these are true, the screening by the root cell surface characteristics can be established. The further investigation using the isolated cell wall is pending.

Screening for low-P tolerance of upland rice

The experiment comparing 30 genotypes with low and high P application in the savanna field was repeated this year. Although viral diseases interfered the experiment, basically the same results were obtained, which demonstrated the usefulness of this experimental design. The variety WAB99-84 was identified as having good yield potential as well as low-P tolerance in both years. The varieties which had middle yield potential but higher low-P tolerance (Oryzica Sabana 6 and CNA7013B) showed only medium to low-P tolerance with unknown reason.

As a part of the collaboration with other institute, the seeds of these tolerant varieties were sent to Japan and included in the screening test at NARC (National Agricultural Research Center, Tsukuba, Japan) under paddy conditions. The seeds which showed contrasting low-P tolerance were sent to the group at NIAES (National Institute of Agro-Environmental Sciences, Tsukuba, Japan) for the study of physiological mechanisms of the low-P tolerance. The information of this experiments were also sent to WARDA, where another group is interested in the same problem of low-P tolerance.

Reference

Tice, K. R., D.R. Parker and D.A. DeMason 1992. Operationally defined apoplastic and symplastic aluminum fractions in root tips of aluminum-intoxicated wheat. Plant Physiology 100:309-318.

Table 1. Major soil characteristics of La Libertad and Matazul field under acid-soil stress conditions and the yield response of acid-susceptible variety (Oryzica Llanos 5).

	La Libertad 0.3 t/ha lime	Matazul 0 t/ha lime
pH	4.30 ± 0.06	4.78 ± 0.02
Exch-Al (cmol kg^{-1})	2.90 ± 0.15	2.03 ± 0.12
Exch-Ca (cmol kg^{-1})	0.33 ± 0.09	0.21 ± 0.02
Al sat. (%)	83.2 ± 3.9	84.8 ± 0.4
Relative yield compared with non-acid condition	94%	76%
Yield reduction	Non-significant	Significant

III. OUTPUT 3. Rice Blast Pathogen and Genetics of Resistance Characterized

A. ACTIVITY 1. MONITORING THE GENETIC STRUCTURE AND VIRULENCE DIVERSITY OF BLAST PATHOGEN POPULATIONS

Characterization of the genetic structure and virulence spectrum of blast populations is being conducted during 1996 and will continue during 1997. Blast samples have been collected from the highly resistant cultivar Oryzica Llanos 5, commercial rice cultivars released in the last two years, and infected samples from commercial Latin American rice cultivars planted in the Santa Rosa experimental field which exhibited good levels of blast resistance or showed complementary resistance to different genetic lineages of the pathogen in greenhouse inoculations. Analysis of the genetic structure of the blast pathogen as well as its virulence composition helps understanding pathogen shifts leading to resistance breakdown as well as in identifying new sources of resistance to be used in genetic crosses.

Analysis of blast isolates recovered from 26 Latin American rice cultivars exhibiting complementary resistance to lineages of the pathogen yielded 5 genetic lineages using the MGR-586 DNA sequence. Lineages SRL-6, SRL-5, SRL-4, and SRL-2 were recovered from 12, 4, 3, and 2 cultivars, respectively. A possible new lineage, preliminary identified as lineage X, was recovered from 5 of the cultivars. Lineages SRL-1, and SRL-3 reported in the past were not recovered. Average similarity coefficients determined in comparisons of the DNA-fingerprinting profiles of the new lineage and lineages SRL-6, SRL-5, SRL-4, and SRL-2 were 0.76, 0.69, 0.72, and 0.60, respectively. Similarity between lineages SRL-6 and SRL-5 in this test was 0.74 and similarity within lineage SRL-6 was 0.88.

Average virulence frequencies for all these isolates inoculated on a set of 42 rice cultivars were 0.5, 0.38, 0.31, 0.26, and 0.24 for lineages SRL-6, SRL-5, SRL-2, SRL-4, and X, respectively.

Although cluster analysis of the virulence spectrum of all isolates was highly correlated with DNA clusters, lineage X had a narrow spectrum of virulence and low similarity with any of the virulence spectra of the other known lineages. In general, the most virulent isolates belong to lineage SRL-6 recovered from cultivars Oryzica Llanos 4 and Oryzica 3 with the same *virulence frequency* of 0.61. These isolates infected 22 cultivars out of 42. The narrow spectrum of virulence detected in the new lineage could explain its relative low frequency. The high similarity found between this lineage and lineage SRL-6 might suggest that this lineage could have derived from SRL-6, as this is the most frequent lineage in Colombia. More studies reported below were conducted for searching more isolates of the new lineage that could help to define its origin and for determining the potential role that this lineage could play in rice fields.

More than 100 blast isolates were collected from two rice cultivars, the highly resistant Oryzica Llanos 5, and the recently released cultivar Oryzica Caribe 8, reported as susceptible by us in the annual report from last year. Samples were collected in the Departamento Meta at La Libertad, Santa Rosa, Matazul, Granada, La Balsa, and the San Carlos de Guaroa sites. Analysis of the DNA-fingerprinting of 72 isolates yielded lineages SRL-4 (88%), SRL-6 (8%) and SRL-2 (4%).

The spectrum of virulence of these lineages is shown in Table 1. For the first time, infection of the cultivar Oryzica Llanos 5 was observed in artificial inoculations in the greenhouse (Table 1). Compatibility was only observed with lineage SRL-4. In no case a severe infection was observed, but typical susceptible blast lesions developed in at least 20% of the inoculated plants. Most isolates of lineage SRL-4 were compatible with Oryzica Llanos 5 independently of the origin (Oryzica Llanos 5 or Oryzica Caribe 8) or the site of collection. Transplanting of susceptible as well as resistant plants was conducted to harvest seeds of individual plants and repeat inoculations to reconfirm the first observations of resistance breakdown of this cultivar, eliminating possibilities of seed contamination. It is worthy to note here that although lineage SRL-6 had been most frequently isolated from single lesions observed in the field on Oryzica Llanos 5 in the past, a different lineage, in this case SRL-4, is apparently breakingdown the resistance of this cultivar. Epidemics of the disease were not observed however in farmer's fields. M onitoring of commercial fields planted with Oryzica Llanos 5 will be conducted during 1997.

Virulence analysis (Table 1) and DNA-fingerprinting characterization of the isolates collected revealed the presence of two variants of genetic lineage SRL-6. These two variants are shown as lineages SRL-6A and SRL-6B in Table 1. Careful comparisons of these two genotypes/haplotypes with lineage X reported above indicate that lineage X correspond to lineage SRL-6A. More studies are being conducted to determine if lineage SRL-6A was the original lineage known as just SRL-6 which has been replaced largely by SRL-6B. The new variant being then SRL-6B which has a broader spectrum of virulence (Table 1).

Monitoring virulence and lineage changes will continue as a very important component in this project aiming at understanding resistance breakdown and in identifying sources leading to the development of durable blast resistance for Latin America.

B. Activity 2. Testing breeding methods for developing durable blast resistance

An ongoing activity within this project has been testing the lineage exclusion hypothesis for developing stable blast resistance. The hypothesis is based on evidence accumulated to date that there is a high degree of specialization between some resistance genes and all the pathogen isolates of a genetic lineage. Crosses between rice cultivars exhibiting a complementary resistance should generate lines resistant to the whole pathogen population. Table 2 shows the crosses made between several blast susceptible parents exhibiting complementary resistance, number of F4 lines tested and number of selected lines that exhibited a field resistant reaction (CT13432) or still segregating for resistance. Resistance of selected lines of the cross CT 13432 potentially carrying the complementary resistance genes Pi-1 and Pi-2 that exclude all the blast pathogen population in Colombia will be tested in the greenhouse under artificial inoculations as well as in Purdue University by one of our collaborators. Selection for blast resistance in segregating lines of all other crosses will continue under field conditions at Santa Rosa. Eight F4 lines of the same cross CT 13432 advanced at Purdue University by Dr. Morris Levy and selected for resistance against blast lineages of other countries were evaluated against six lineages of the pathogen in Colombia. Line C1x6-12-281-1 exhibited a resistance reaction to all lineages tested and possibly is a double resistant line carrying both Pi-1 and Pi-2 resistance genes derived from the parents C101LAC and C101A51, respectively. All 8 lines were resistance to lineages SRL-1 and SRL-3. Seven lines were intermediate or susceptible to lineage SRL-2; one line (C1x6-12-279-4) was intermediate to susceptible to lineages SRL-4 and SRL-5, and seven lines susceptible to lineage SRL-6. All these lines will be tested with molecular markers associated with the resistance genes Pi-1 and Pi-2 to test for the presence of these genes and correlate their presence/absence with their blast reaction.

Identification of complementary resistance sources to be used in crosses to potentially yield blast resistant lines was carried out between 1995 and 1996. Latin American commercial rice cultivars were initially evaluated under field and greenhouse conditions for their blast reaction. Initial observations on specific interactions between some Latin American rice cultivars and different genetic lineages of the pathogen allowed us to identify potential complementary blast resistance sources. These cultivars were planted during 1996 in the field and blast samples collected from each cultivar. Blast isolates were recovered in the laboratory from as many of these cultivars as possible and used for genetic lineage composition and for inoculating the same cultivars under greenhouse conditions. Table 3 shows the lineage composition of isolates recovered from these cultivars and the complementarity in resistance between the cultivars, including only those whose reactions were consistent in several inoculations with different blast isolates. As it can be seen, there are many possible crosses between complementary resistance sources that could yield segregating lines resistant to the entire pathogen population in Colombia. This information is being made available to breeders of the project as well as breeders from Latin American countries. Several of these parents can be selected for their different genetic background, desired agronomic characteristics they already possess as good yield, plant architecture, Tagosodes and hoja blanca resistance, height, etc., and be used in a recurrent selection program. As an example, the cross between Oryzica Caribe 8 and Oryzica Yacu 9 has been realized by FEDEARROZ and segregting blast resistant lines were selected in 1996.

C. Activity 3. Dissecting blast resistance genes in the highly resistant cultivar Oryzica Llanos 5

Previous studies suggest that earlier pyramiding of resistance genes which gave origin to the rice variety Oryzica Llanos 5 may have resulted in the combination of complementing genes which exclude all the genetic lineages of the pathogen present in Colombia. This hypothesis is supported by the fact that all immediate parents of this cultivar are susceptible under field conditions were Oryzica Llanos 5 is resistant. Table 4 shows the evaluation of 247 F5 recombinant inbred lines of the cross between Oryzica Llanos 5 and the susceptible cultivar Fanny. All lines were inoculated with blast isolates representing six genetic lineages and their spectrum of virulence. The information of these evaluations is used in conjunction with the biotechnology unit in project 15 for the identification of molecular markers (RFLP, RAPD, AFLP) that could be associated with the resistance genes to the different genetic lineages of the pathogen present in Oryzica Llanos 5. As it has been shown above, lineage SRL-4 has initiated to show a compatible reaction with Oryzica Llanos 5, and although this cultivar was resistant to the isolate used in this test, only 33 lines were resistant to this isolate (Table 4). This suggests that these lines can be used in the initial process to identify the resistance genes present in this cultivar. It has been however a difficult task and several alternatives are being carried out, including the evaluation and characterization of all intermediate reactions in a continuous quantitative scale that allows identification of quantitative trait loci (QTL) associated to resistance, and believed to be present in Oryzica Llanos 5.

D. Activity 4. Training of national scientists of Latin America in new blast research technologies

Adoption and implementation of new technologies currently used at CIAT for the characterization of rice blast pathogen populations and resistance by national scientists from different Latin American countries is being done through different kinds of training, including two weeks to a four months training process. During 1996, a rice pathologist from the Instituto de Investigación del Arroz from Cuba was trained during four months on the characterization of virulence diversity of the blast pathogen, as well as on the characterization of the resistance of Cuban rice cultivars to the different genetic lineages of the pathogen in Colombia. From the same country, a researcher from the Centro de Estudios Aplicados de Energía Nuclear, CEADEN, with a molecular biology background was also trained for a period of four months at CIAT on the characterization of the genetic structure of the blast pathogen using molecular markers, as well as the use of molecular tools for the characterization of blast resistance genes in rice. A project to study the blast pathogen population in Cuba was developed and initiated already in Cuba by the two researchers trained. Blast samples are being collected and analyzed from different sites in Cuba. These results should help the breeders in identifying blast resistance sources suitable for the blast prone areas found in the country.

Two rice researchers from Venezuela have been trained for a period of one month on the characterization of the virulence diversity of the blast pathogen and the use of molecular markers for characterizing the genetic structure of the fungus. Both researchers have gone back to their country with a plan for collecting and analyzing the blast pathogen in Venezuela working in close collaboration with rice breeders in the development of blast resistance.

A master student from Germany has finished his work on blast research after one year at CIAT. He was also concentrated on the characterization of the genetic structure and virulence diversity of the blast pathogen for the development of durable blast resistance. A Colombian Ph.D. student from the Universidad Nacional is working on his dissertation on the characterization of blast populations from different hosts in different ecosystems in Colombia and their relation with rice blast. A Ph.D. student from the USA, University of Florida is finishing his third year working in Villavicencio on the use of Silicon for the control of rice diseases and improvement of yields in the acid upland soils of the Colombian Llanos.

Table 1. Genetic lineage and virulence structure of blast isolates collected from cultivars Oryzica Llanos 5 and Oryzica Caribe 8.

Cultivar	Lineage			
	SRL-2	SRL-4	SRL-6(A)	SRL-6(B)
FANNY	+	+	+	+
ORYZICA 1	+	+	+	+
CICA 9	+			+
CICA 8				+
ORYZICA LLANOS 5		(+)(-)		
LINEA 2	+			+
ORYZICA LLANOS 4		(+)(-)		+
ORYZICA CARIBE 8		+		
ORYZICA YACU 9				+
SELECTA 3-20	+	+		+
COLOMBIA 1		+		+
C 101 A51 (Pi-2)	+	+		+
C 101 LAC (Pi-1)				
C 101 PKT (Pi-4a)		+	+	+
C 101 PKT (Pi-3)		+		+
C 105 TTP-4L23 (Pi-4b)		+	+	+

+ = Compatible reaction.
(+)(-) = Some plants exhibiting a compatible reaction.

Table 2. Crosses among complementary resistance sources to rice blast and number of selected segregating lines in Santa Rosa, 1996.

Cross	Parents	Lines (No.)	Selected Lines
CT 13432	C101A51(Pi-2)/C101 LAC (Pi-1)	145	40
CT 13550	LINEA 2/ORYZICA 2	2	2
CT 13551	CICA 8/LINEA 2	6	6
CT 13552	LINEA 2/CICA 6	13	7
CT 13553	LINEA 2/METICA 1	6	5
CT 13554	ORYZICA 2/CICA 8	2	2
CT 13555	ORYZICA 2/CICA 9	1	1
CT 13393	ORYZICA 1/CICA 8	3	1
CT 12670	ORYZICA LLANOS 5/CICA 9	71	50
CT 12670	CICA 9/ORYZICA LLANOS 5	46	33
CT 12693	IR 22/CICA 9	27	9

Table 3. Latin American rice cultivars exhibiting complementary resistance to lineages of *Pyricularia grisea*.

Cultivar	Origin	Lineage SRL-2	SRL-4	SRL-5	SRL-6
MG-1	Brazil		+		
RIO VERDE	Brazil		+		
O. CARIBE 8	Colombia		+		
O. LLANOS 5	Colombia		+/-		
SACIA 2	Bolivia			+	
AMISTAD 82	Cuba			+	
IR 1529 ECIA	Cuba			+	
PERLA	Cuba			+	
JUMA 51	Dom. Republic			+	
BAMOA A75	Mexico			+	
ORYZICA 3	Colombia				+
O. YACU 9	Colombia				+
CAPI 93	Honduras				+
PA-3	Peru				+
LINEA 2	Colombia	+			+
CICA 9	Colombia	+			+
ARAURE 2	Venezuela	+			+
JUMA 61	Dom. Republic	+			+
O. LLANOS 4	Colombia		+		+
IR 65	Philippines		+		+
CUYAMEL 3820	Honduras		+		+
ICTA CRISPO	Guatemala			+	+
JUMA 62	Dom. Republic	+		+	

+ = Compatible reaction.
+/- = At least 20% of plants exhibiting a compatible reaction.

Table 4. Rice Blast evaluation of 247 recombinant imbred lines of the cross Oryzica Llanos 5(R) x Fanny (S) and five known resistance genes to six genetic lineages of *Pyricularia grisea*.

	Number of lines			Resistance gene				
Genetic Lineage	Susceptible	Intermediate	Resistant	Pi-1	Pi-2	Pi-3	Pi-4a	Pi-4b
SRL-6A	86	15	146	-	-	-	+	+
SRL-6b	120	54	73	-	+	+	+	+
SRL5	45	17	185	+	-	+	+	+
SRL-4	183	31	33	-	+	+	+	+
SRL3	34	16	197	-	-	-	-	-
SRL-2	34	2	211	-	+	-	-	-
SRL-1	44	14	189	-	+	-	-	-

+ = Susceptible; - = Resistant.

IV. OUTPUT 4. Weed Control Enhanced by the Use of New Genotypes and Practices

A. ACTIVITY 1. SCREEN FOR COMPETITIVENESS AND ASSESS PRODUCTIVITY

Continuous irrigated rice cropping in LAC has resulted in chronical and difficult-to-control weed problems, such as red rice (*Oryza sativa* L.) and *Echinochloa* spp. Red rice alone is responsible for 20% production losses in the region (De Souza, 1989). Farmers rely heavily on herbicides for weed control, spending annually 218 million US dollars. Often, farms lack adequate soil levelling and water control to suppress weed growth with a permanent flood, thus weeds can emerge in successive flushes throughout the growing season prompting for repeated herbicide applications. Seventy percent of the land under irrigated rice is leased (L.R. Sanint, 1996, pers. comm.), and for these farmers the burden of weed control costs is particularly heavy.

With two or more rice crops a year, herbicides are repeatedly used on the same fields, and the repeated use of propanil to control *E. colona*, has resulted in the spread of propanil-resistant biotypes of this weed (Fischer et al., 1993). Resistance of *E. colona* biotypes to other rice herbicides has also been reported (Caseley et al., 1995).

Enhancing rice competitiveness against weeds would provide a low-cost and safe tool for integrated weed management, allowing to reduce herbicide dependence. Differences in weed suppression among crops or varieties has long been established (Wall, 1982; Wortmann, 1983; Blackshaw, 1994; and Ford and Mt. Pleasant, 1994;), and the need to study the competitiveness of modern rice against weeds has been recognized (De Datta and Llagas, 1984). Although differences in competitiveness among rice varieties exists (Jennings and de Jesús, 1968; Jennings and Herrera, 1968; Jennings and Aquino, 1968; Garrity et al., 1992; and Smith Jr. and Moody, 1979), irrigated rice breeders have not yet made full use of such variability to improve rice competitiveness with weeds. According to Blackshaw (1993), cultivars for sustainable systems should be both, high yielding and competitive with weeds.

Canopy characteristics and light capture have been associated with a crop's ability to suppress weeds, or sustain yields in the presence of weeds (Richards, 1989; Wortmann, 1993; Blackshaw, 1994). Thus tall rice cultivars have proven to be considerably weed suppressive (Jennings and de Jesús, 1968; Jennings and Herrera, 1968; Jennings and Aquino, 1968; Garrity, et al., 1992). However, tall and leafy rice plants, particularly land races or traditional cultivars, tend to have low yield potential, and to lodge more than modern and productive semidwarf cultivars. Therefore, concern for a trade-off between competitiveness and yield potential has deterred the pursuit of competitive ability in rice (Jennings and Aquino, 1968c). However, Garrity, et al., 1992 have recently shown that although the height of upland rice was strongly correlated with weed suppression, other traits such as crop dry matter and leaf area were also associated with high competitive ability. In the case of the modern irrigated semidwarf rice cultivars for LAC, the variability in their competitiveness, and the traits associated with it, still need to be explored. The most appropriate conditions for evaluating such traits, also needs to be established. Traits for competitiveness may be under polygenic control and subject to environmental interactions, thus best exposed for selection when the crop is grown with a competing species (Wall, 1982).

E. colona is the worst weed of tropical rice (Gonzáles et al., 1983), and enhancing the competitive ability of the highly productive semidwarf germplasm of LAC against this weed would be highly relevant to reduce production costs and the spread of herbicide resistance in this and other species (Hoagland et al., 1995). A study was conducted at CIAT with direct-seeded irrigated rice cultivars, grown in monoculture and in competition with *E. colona*, to establish: a) if there is variability in competitiveness among modern irrigated rice semidwarfs; b) what the main traits associated with such competitiveness are; and c) if competitiveness also implies a relevant yield penalty.

MATERIALS AND METHODS

The study was conducted in 1994 to 1996 with 10 and 15 rice cultivars, respectively, that had been released for irrigated systems in LAC. Most of these cultivars corresponded to semidwarf indica types, but there were two japonica cultivars as well, their flowering (50%) dates ranged from 71 to 99 d. Cultivars were the sub-plot treatments in a spit-plot design with four replications. The main plots were two competition levels (Systems): Weed-free and full season competition. On August, 1994 and June 1995, after puddling and draining the soil (Yypic Pellustert) on the day before, 65 kg pregerminated rice seed ha^{-1} (270 viable seed m^{-2}) of each cultivar were broadcast over 4 x 7 m plots; at the same time, *E. colona* was seeded at the rate of 40 viable seeds m^{-2}. Twenty-three kg urea ha^{-1} were applied at 20, 40, and 60 dae. Intermittent irrigation was applied to keep the soil near saturation. Bentazon and quinclorac at 1.2 and 0.35 kg ha^{-1} were applied on the weed-free plots at 10 dae.

Rice and *E. colona* leaf area, height, tiller no. and above-ground biomass was recorded in each plot within a 2 x 0.5 m quadrat at 20, 40, 60, and 90 dae. The leaf area of ten plants was measured with a LI-3100 meter, and extrapolated to the whole quadrat using the leaf area/weight ratio. Height and tiller no. were determined on 10 plants per quadrat. At maturity, grain yield was harvested from a 8 m^2 sampling area.

At anthesis, PAR[1] interception by rice canopies was measured at ground level with a LI-Line Quantum Sensor; in weedy plots, weeds were removed before reading. Two diagonally crossed readings were taken at each of three sites per plot, and averaged. Incident PAR was recorded above the crop at each plot, and readings were taken during cloudless days between 1100 and 1400 h.

Standard analysis of variance was conducted for grain yield and growth parameters. Simple correlation analysis for cultivar means (Wortmann, 1993) was performed to relate plant traits to competitiveness and yield potential. The variance component of significant System (competition or monoculture) x Cultivar interactions was analyzed following Ramalho et al (1993), to establish the relative merit of sreening rice germplasm for competitiveness under weedy vs. weed-free conditions. Thus the variance component due to Cultivar x System interaction was broken down as follows:

$$S^2_{VE} = 0.5[0.5(S_M - S_C)^2 + S_M S_C (1 - r_{MC})]$$

Where s_M and s_C are the genotypic standard deviations in monoculture and competition, respectively, and r_{MC} is the genotypic correlation for both environments; these parameters were estimated using the ANOVA results. The second term of the variance ($s_M s_C(1-r_{MC})$), or complex term, predominates when cultivar performance in monoculture differs from that in competition.

RESULTS AND DISCUSSION

Competition

E. colona competition reduced rice grain yield and biomass (Table 1), and such reductions were positively correlated with *E. colona* growth (Table 2). Rice competed against a maximum of 4.4 and 5.9 Mg weed dry matter ha^{-1} in 1994 and 1995, respectively (Table 1), and competition effects became significant on rice and *E. colona* biomass at about 40 dae (Table 3).. Average yield losses for both years ranged from 27 to 60% , and weed weights for the strongest competitior (CICA 8) were 40 to 43 % lower than for the weakest competitor in 1994 and 1995, respectively (Table 1). Rice cultivars differed in their competitiveness, or ability to supress *E. colona* and sustain yields under competition (Table 1).

Differences in the abilities of upland and rainfed lowland rice cultivars to suppress similar weed infestations as in our experiments have been documented (IRRI, 1992 and 1993), and upland rice cultivars can differ by up to 75 % in their capacity to supress weeds (Garrity et al.,1992). In other experiments, the popular cultivar Oryzica 1 lost 15 to 20% of its weed-free yield against late-emerging weeds (Fischer and Antigua, 1995). Whereas under similar conditions, growing a competitive cultivar like CICA 8 should completely eliminate the need for late weed control, saving farmers 30% of their herbicide expenditures (Fischer and Ramirez, 1993).

Yields and HI

Although there was some correspondence between weed-free yields and yields under competition (Table 1), no negative relationship was found between competitiveness (as yield in competition/yield in monoculture) and yield potential (Table 4). Thus under weedy conditions, the best competitor (CICA 8) yielded 2.4 to 3.0 Mg grain ha^{-1} more than the weakest competitor (IRGA 409), but both varieties yielded similarly in monoculture (Table 1). Also, in 1995, the newly released Yacú 9 was significantly less competitive than CICA 8, but both cultivars had similar weed-free yields. Furthermore, no correlations were observed between rice competitiveness and its HI, either in monoculture or in competition (Table 4). Therefore, an adverse effect of competitiveness on yield potential, and on the efficiency to partition assimilates into grain, was not observed among the cultivars tested, indicating that breeding to increase the competitiveness of current highly productive rice plant types is still possible without significantly compromising yields. Other studies also suggested that ability to suppress weeds can be combined with the high yield potential of intermediate-statured cultivars (Garrity et al., 1992). However, yield potential and competitiveness should not be considered as completely independent, since plant morphology can affect both (Tanaka et al., 1966; Jennings and de Jesús, 1968; Jennings and Herrera, 1968; Jennings and Aquino, 1968).

Traits

The dynamics of rice and *E. colona* growth in competition can be illustrated by the highest, intermediate, and least competitive cultivars (Figure 1). Although not taller than the weed, rice had higher LAI than *E. colona*, and the most competitive cultivar had also considerable advantage in tiller no. (Figure 1). This superiority allowed rice canopies to intercept most of the incoming radiation, and to accumulate twice as much biomass than the weed (Table 1). Light capture by rice, as measured by canopy PAR interception, was relevant in suppressing *E. colona* competition (Table 5), and LAI and tillering were key traits associated with canopy light interception and rice competitiveness (Table 5). According to this, the new semidwarf plant types that are being developed to break the current yield plateau in irrigated rice, having restricted early vegetative expansion and low number of tillers (Dingkun, et al., 1991), may not be as competitive as many current indica semidwarfs adapted to direct seeding conditions in LAC.

Competition effects first modified LAI and tillering at 40 dae (Table 3), and although competitive interactions for light may occur before they visiby affect plant growth (Jennings, 1968c), no rice trait recorded before 40 dae was consistently related to competitiveness (Table 6). As noted by Smith (1974), as the period of vegetative growth increased, so did the cultivar's ability to suppress *E.colona* growth (r = -0.63* and -0.58*, for 1994 and 1995, respectively).

Rice biomass, as an expression of competitive success, was negatively correlated with weed growth at 60 and 90 dae (Tables 5 and 6). Rice height was affected by competition only at late growth stages (Table 3), and no correlations were found between rice height and canopy PAR interception or *E. colona* suppression (Table 5). Modern rice plant types have erect leaves that allow for good light penetration deep into the canopy. With such canopies, variations in plant height should not affect light penetration as much as they would in leafier canopies with droopy leaves. Also, plants in competition elongated, and their heights were similar to those in monoculture (Fig. 2). Therefore to enhance the competitiveness of semidwarf germplasm, height would not be a convenient parameter to select for.

In other studies, involving contrasting plant types, tall, vigorous and leafy cultivars have been more competitive than short ones with erect leaves (Jennings and de Jesús, 1968; Jennings and Herrera, 1968; Jennings and Aquino, 1968). But large and competitive plant types, tend to have low yield potential due to mutual shading, premature leaf senescence, and high respiratory rates (Tanaka, 1966; Jennings and de Jesús, 1968; Jennings and Herrera, 1968; Jennings and Aquino, 1968). Thus yield potential and competitiveness appear as conflicting goals in such comparisons. However, our analysis found no negative correlations between the traits discussed above and rice weed-free yield or harvest index (data not shown). Thus for highly productive, erect-leaved plant types, progress in competitiveness should be possible without greatly compromising yields.

Variance Components of the Genotype x System Interaction

When rice LAI, tillering, biomass and PAR interception at 90 dae were recorded on weed-free rice, they related poorly or inconsistently to *E. colona* suppression and rice competitiveness (Table 7). The analysis of variance for grain yield and sequentially-recorded growth parameters, showed significant System (competition or monoculture) x Cultivar interactions (S x C) for LAI and tiller number at most sampling dates (Table 3), indicating that the expression of those traits in monoculture was different than in competition. When the relative contribution of variance components to the SxC variance was analyzed, the complex term of the variance predominated in all but one case (Table 3), suggesting a lack of correlation between trait expression in monoculture and in competition (Ramalho et al., 1993). According to this analysis, selection for leaf area and tiller number to enhance rice competitiveness for light capture would not be efficient if conducted in monoculture, since the leafiest or mostly tillered cultivars in monoculture, would not be such under competition. Although cultivar expression of height and biomass was similar in either system for both years, these traits were not consistently related to competitiveness when recorded in monoculture (Table 7).

In summary, although a detailed study of pleiotropic effects of vegetative traits on yield potential was beyond the scope of this study, it appears that competitiveness of semidwarf rice germplasm in LAC could be enhanced without major losses in yield potential. With the current high weed control costs and the environmental risks resulting from herbicide overuse, mild compromises in yield potential favoring competitiveness should be acceptable. The upper range of competitiveness observed in our experiments would be adequate to reduce the need for repeated herbicide applications in rice, lowering environmental pollution, and improving farmers economies. Low input farmers, and those who must rent their land, or have suboptimal flood control, would greatly benefit from this approach. Socioeconomic constraints, and infrastructure limitations to water management will still persist for some time in much of the direct seeded areas of LAC, therefore, competitive plant types will be needed in the less favoured agroecosystems to smother weeds in unflooded areas or in the gaps of uneven rice stands. Increasing leaf area, tiller number, and PAR interception will result in more competitive rice cultivars, but plant types with excessive mutual shading and vegetative biomass should be avoided. Therefore, a convenient way of increasing LAI, avoiding excessive foliar biomass and the corresponding respiratory losses, would be by augmenting the canopy's specific leaf area (cm^2/g). Breeding for resistance to weed competition should be conducted under weed pressure, much like breeding for resistance to other pests (Wall, 1983).

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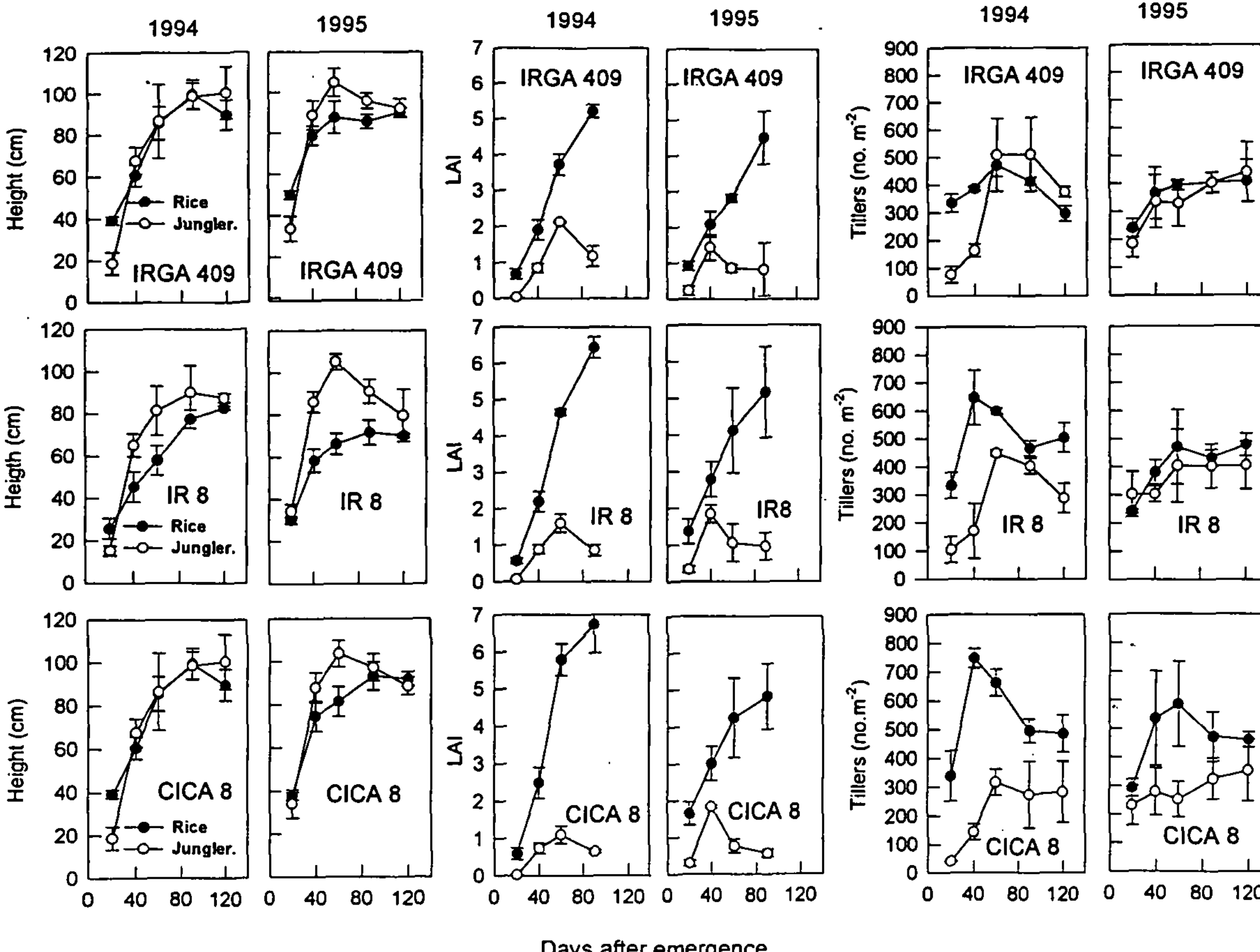

Fig. 1. Height, LAI, and tiller no. of *Echinochloa colona* and of the weakest (IRGA 409), intermediate (IR 8), and strongest (CICA 8) rice competitor, when both species grew in competition in two years.

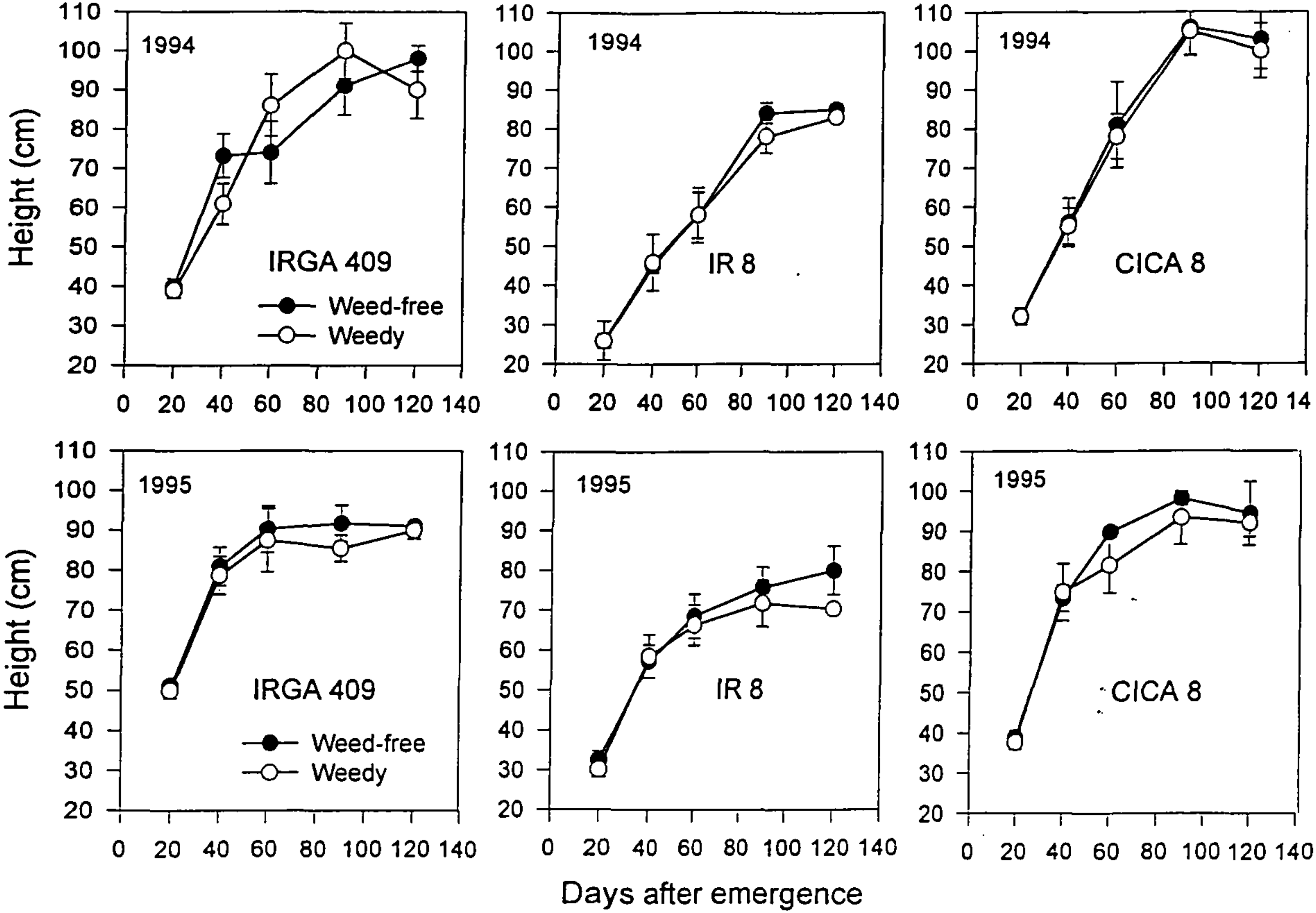

Fig. 2. Heights of the weakest (IRGA 409), intermediate (IR 8), and strongest (CICA 8) rice competition when they grew weed-free or in competition with *Echinochloa colona* in two years.

Table 1. Rice yields, biomass +, canopy light interception + +, weed growth when rice cultivars grew in monoculture, or in competition with junglerice.

	Grain yield weed free		Grain yield in competition		Rice biomass		Rice biomass reduction§		Weed biomass		Rice yield reduction§		PAR¶ Interception	
Rice cultivar	1994	1994	1994	1995	1994	1995	1994	1995	1994	1995	1994	1995	1994	1995
	Kg ha^{-1}		Kg ha^{-1}		gm^{-2}		%		g/m^{-2}		%		%	
Inti	9175	7443	4763	3949	1153	953	31	33	338	396	47	44	94	88
Eloni	4518	6979	3308	3640	1138	864	25	32	270	393	27	48	95	85
Irga 409	8271	8326	3134	3454	780	843	44	38	436	446	62	58	88	84
Cica 4	8589	6227	5224	3460	1075	731	23	46	295	503	39	44	94	84
Cica 8	8250	8025	6111	5835	1260	1122	27	22	275	338	25	28	96	90
Cica 9	8709	7891	5622	4712	995	946	26	28	278	407	33	41	94	87
Oryzica 3	9522	10832	5641	4922	895	770	31	39	303	428	41	54	95	87
Ceysvoni	7031	7411	4410	4010	920	667	23	38	293	435	37	47	94	85
Bluebelle	6052	6208	3097	2806	677	593	42	44	380	586	49	55	87	83
IR 8	8409	6578	4121	3389	795	762	39	41	380	503	49	48	93	85
O. Turipana 7		6618		2894		529		48		545		56		84
O. Caribe 8		7380		3654		872		38		422		50		85
O. Yacu 9		8643		4030		541		49		488		53		85
B.Bonnet 50		6620		3304		913		32		462		49		85
LSD (0.05)	1173	1151	1173	1151	149	224	15	20	84	122	20	13	2	4
CV (%)	10	13	13	17	11	20	33	38	18	18	23	17	1	3

+ Recorded at 90 days after emergence.
+ + Dry matter.
§ Weed-free yield-yield in competition/weed-free yield x 100.
¶ Photosynthetically active radiation.

Table 2. Correlation coefficients (r) between rice yield and biomass reduction, and junglerice biomass at 90 dae + when both species grew in competition.

	r	
	1994	1995
Grain reduction	0.94*	0.65**
Biomass reduction	0.94*	0.83**

*,** Significant at the 0.05 and 0.01 level, respectively.

+ Days after emergence

Table 3. Analysis of variance for grain yield and four growth parameters of rice growing in two systems (monoculture and competition with junglerice), and the complex components of significant cultivar x system interactions.

	Sampling dates									
	20 dae		40 dae		60 dae		90 dae		120 dae	
	1994	1995	1994	1995	1994	1995	1994	1995	1994	1995
<u>Heigth</u>										
System	ns+	ns	ns	ns	ns	*	ns	*	*	*
Cultivar	*	ns	*	*	*	*	*	*	*	*
SxC	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Complex comp. (%)										
<u>Tiller Number</u>										
System	ns	ns	*	*	*	*	*	*	*	*
Cultivar	*	ns	*	*	*	*	*	*	*	*
SxC	ns	ns	ns	*	*	*	*	*	*	*
Complex comp. (%)				80	97	84	96	35	98	93
<u>Leaf Area</u>										
System	ns	ns	*	*	*	*	*	*	nd	nd++
Cultivar	*	ns	*	*	*	*	*	*	nd	nd
SxC	ns	ns	ns	*	*	*	*	*	nd	nd
Complex comp. (%)				80	99	99	81	72		
<u>Biomass</u>										
System	ns	ns	*	*	*	*	*	*	*	*
Cultivar	*	ns	*	*	*	*	*	*	*	*
SxC	ns	ns	*	ns	ns	ns	ns	ns	ns	ns
Complex comp. (%)				97						
<u>Grain Yield</u>										
System									*	*
Cultivar									*	*
SxC									*	*
Complex comp. (%)									93	73

*, ** Significant at the 0.05 and 0.01, repectively.

+ Not significant at the 0.05 level.

+ + No data

Table 4. Correlation coefficients (r) between rice competitiveness (yield in competition/yield weed-free) and rice productivity parameters at 90 dae +, when rice grew weed-free or in competition with junglerice.

	r	
	1994	1995
Grain yield (weed-free)	-0.28ns + +	-0.06 ns
Harvest Index (weed-free)	-0.36 ns	-0.16 ns
Harvest Index (competition)	0.24 ns	0.02 ns

\+ Days after emergence

\+ + Not sifnificant at the 0.05 level.

Table 5. Correlation coefficients (r) among rice and junglerice parameters, recorded at 90 dae +, when both species grew in competition.

	1994		1995	
	Junglerice biomass	PAR+ + interception	Junglerice biomass	PAR interception
PAR interception	-0.81**	-	-0.81*	-
LAI	-0.71*	0.77**	-0.63*	0.54*
Tiller No.	-0.80*	0.58*	-0.70*	0.61*
Height	0.1 ns§	0.43 ns	-0.05 ns	-0.07 ns
Biomass	-0.72*	0.79**	-0.74**	0.74**

*, ** Significant at the 0.05 and 0.01 level, respectively.

\+ Days after emergence.

\+ + Photosynthetically active radiation.

§ Not significant at the 0.05 level.

Table 6. Correlation coefficients (r) between sequentially recorded rice growth parameters and junglerice biomass at 90 dae +, when both species grew in competition.

	Days after emergence					
	20		40		60	
	1994	1995	1994	1995	1994	1995
LAI	0.04ns+ +	-0.49 ns	-0.33 ns	-0.66*	-0.90**	0.61*
Tiller No.	0.09 ns	-0.67**	-0.73*	-0.62*	-0.85**	-0.73**
Height	0.41 ns	-0.22 ns	0.26 ns	-0.17 ns	0.09 ns	0.05 ns
Biomass	0.18 ns	-0.61**	0.08 ns	-0.57*	-0.66*	-0.63*

*, ** Significant at the 0.05 and 0.01 level.

+ Days after emergence

+ + Not significant at the 0.05 level.

Table 7. Correlation coefficients (r) between rice parameters (weed-free) and junglerice biomass at 90 dae + and the relative yield of rice incompetition.

	Weed biomass		Relative rice yield + +	
	1994	1995	1994	1995
LAI	0.20 ns§	0.01 ns	0.05 ns	0.15 ns
Tiller No.	-0.23 ns	-0.11 ns	-0.03 ns	0.16 ns
Height	-0.30 ns	0.02 ns	0.25 ns	-0.05 ns
Biomass	-0.41ns	0.62*	0.36 ns	0.54*

* Significant at the 0.05 level.
+ Days after emergence.
+ + Yield in competition/yield weed-free.
§ Not significant at the 0.05 level.

V. OUTPUT 5. Rice Lines with Diverse Resistance to Tagosodes and RHBV developed

A. ACTIVITY 1. EVALUATE RICE GERMPLASM FOR RESISTANCE TO *TAGOSODES ORIZICOLUS*

The objective of these evaluations are to identify diversified sources of resistance to *T. orizicolus*. While there are studies to determine if field evaluations in hotspots would be as effctive as greenhouse screen, the trials reported here were conducted in the greenhouse under controlled conditions. During 1996, out of the total of 1732 lines evaluated, 36% were classified as highly resistant, while 24% were classified as resistant. The remaining 40% were classified as susceptible. To assure that advanced lines have a good level of resistance only those lines that have a rate of resistant or highly resistant were recommended for further evaluation.

B. ACTIVITY 2. EVALUATE RICE GERMPLASM FOR RESISTANCE TO RHBV

The RHBV evaluations are conducted twice yearly in the field, and when requested in the greenhouse. Since the trials from the second semester are not finished, only the trials from the first semester are being reported. The lines that were evaluated first semester of 1996 were from CIAT, FLAR, FEDEARROZ and several national programs. Out of the total 2137 lines evaluated in the field during the first semester of 1996, 28% were classified resistant and highly resistant to RHBV. The remaining 72% were considered susceptible. To assure that advanced lines have a good level of resistance only those lines that have a rating of ≤ 3 (resistant and highly resistant) were recommended for further evaluation.

C. ACTIVITY 3. RHBV COLONY STUDIES

The objective of these studies is to develop management strategies for more effective RHBV screening. RHBV resistant rice varieties are susceptible during the first 20-25 days after planting. In 1995, a newly established colony with a source of *T. orizicolus* from Tolima was shown to be able to transmit RHBV more efficiently to resistant varieties. Planthoppers from Tolima and Valle were crossed with the planthoppers from the CIAT colony, and a high level of viruliferous planthoppers were selected. These colonies were used during the screening trials for RHBV during 1996.

One of the reasons that the *T. orizicolus* colonies declined in vigor in the past was a decision not to introduce more diversity because of the increased risk of parasite introduction. In August 1996, there was a problem with a parasite in the colonies and several changes have been made to safeguard the colonies. The current view is that a colony that is not aggressive may lead to the development of varieties without the needed level of resistance both to the planthopper and RHBV. Therefore a series of measures including restricted access, duplicate colonies, and a new site for introducing insects from the field into the greenhouse have all been implemented. It is hoped that with these changes, the colonies can be maintained with the aggressive characteristic needed for proper screening but without problems of parasitism.

D. ACTIVITY 4. SURVEYS OF RHBV INCIDENCE AND VECTOR ACTIVITY

The objective of these surveys is to determination of current levels of RHBV and risk for epidemics. These surveys were started in the second half of 1995 and were the result of higher levels of RHBV incidence. There are reports of higher levels of RHBV in central America especially from Costa Rica. The surveys in Colombia are collaborative efforts between CIAT, FEDEARROZ and ICA. The Colombia survey covers the major rice growing areas including the llanos, the central zone (Tolima and Huila) as well as both the Caribbean humid and dry zones. The methodology is to collect *T. orizicolus* and from several fields in each region and to test them using the ELISA to detect the presence of RHBV. Some tests were done using both plant assays and ELISA to confirm that the test does accurately reflect the level of viruliferous vectors. The other part of the survey is to count the number of RHBV infected plants in the field. This is best done in the same field one month after the planthoppers are collected.

Over one hundred samples were collected during 1996 and the sampling is continuing. The llanos is the region with the highest incidence of infected plants and viruliferous vectors. Tolima is the other region with a significant level of RHBV. In general, the levels of RHBV appears to be increasing in both the llanos and Tolima although not enough data was collected during 1995 for the results to be statistically significant. Within these regions there are localities such as Acacias Meta, and Ambalema Tolima that have a higher incidence of RHBV. This corresponds to observations in Costa Rica which has experienced outbreaks of RHBV for several years that there are foci of higher incidence. This contrasts somewhat with the description of epidemics occurring rapidly, being highly destructive for just two or three rice growing seasons, and then receding for a decade or more. It is too early to know if the newer varieties which incorporate higher levels of insect or RHBV resistance will change the character of the epidemics.

In both Central America and Colombia, the incidence of RHBV is increasing. The intensive survey in Colombia has determined that the two zones at greatest risk are the llanos and Tolima. It is recommended to grow varieties with resistance to the planthopper and to RHBV in these zones.

E. ACTIVITY 5. TRANSFER OF TAGOSODES AND RHBV EVALUATION TECHNICS

CIAT and FEDEARROZ are working closely to increase the capacity to screen and evaluate rice germplasm for resistance to RHBV and *T. orizicolus*. FEDEARROZ has maintained at CIAT an Associate Scientist level position to work on RHBV related projects. This partnership has led to expanded activities in the monitoring of RHBV incidence and allowed the epidemiology studies to begin. FEDEARROZ is gaining a scientist with training experience in both entomology and virology who can lead the efforts to mitigate the effects of RHBV. FEDEARROZ has also place an Assisistant Scientist at CIAT who is working on screening biological control agents for *T. orizicolus*.

F. ACTIVITY 6. RHBV EPIDEMIOLOGICAL STUDIES

The objective of epidemiological studies is to develop baseline information needed to effectively manage outbreaks of RHBV. The vector of RHBV is the planthopper, *T. orizicolus* (Muir), and it transmits the virus in a propagative manner. The virus also causes a disease in the planthopper vector and those insects which harbor the virus are less fit compared to those that do not. It is speculated that this phenomenon, coupled with a slow, progressive build-up of plants infected with virus in the field is responsible for the cyclic nature of the RHBV epidemics. At the current time, there is not sufficient information on the relationship between the numbers of vectors with the genetic capacity to transmit RHBV and the percentage of rice plants infected with RHBV to determine what levels result in actual economic crop loss. To address this question a series of field trials will be conducted with a limited number of control varieties using different levels of inoculum pressure. In October, a preliminary field trial was planted using two levels of inoculum pressure and the results of this experiment will guide the future research. This activity is expect to last for two years.

G. Activity 7. Biocontrol of *Tagosodes orizicolus*

The objective of this line of investigation is the identification of entomopathogens for the control of *Tagosodes orizicolus*. This activity started in April 1996 and is a collaboration between CIAT, FEDEARROZ and AGREVO. During this time protocols for the evaluation of isolates of entomopthogens in the genera *Metarrhizium* and *Beauveria* were adapted to screening under greenhouse conditions for pathogencity to *T. orizicolus*. To date, over 50 isolates of *Metarrhizium* and *Beauveria* were tested and several of the isolates of *Metarrhizium* anisopliae appear to be the most efficacious. In experiments more than 80% of the adult planthoppers killed by an application of these entomopathogens compared to less than 10% mortality in the control. Additional entomopathogens are being screened and tested using eggs, nymphs and adults. The promising isolates will be tested extensively first in the greenhouse trials. The most effective isolates will be tested in field trials during 1997.

H. Activity 8. Control of RHBV through coat protein mediated cross protection and anti-sense RNA strategies

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BACKGROUND

The main goal of this project is to provide new source(s) of resistance to minimize the possibility of an outbreak of the disease by (I) transforming rice with novel gene(s) for RHBV resistance; and (ii) incorporating these genes into Latin American commercial varieties or into genotypes to be used as parents in breeding. RHBV is a member of the tenuivirus group. The molecular characterization of RHBV and the preparation of cDNA libraries has led to the design of novel virus-resistant strategies to genetically engineer commercially-grown rice cultivar. Two different strategies are being attempted: a) the nucleocapside (NC) cross protection and b) the antisense-gene down regulation of the major NS4 protein. The NC-mediated cross protection has been successful for the tenuivirus RStV. The strategy for the expression of the RNA4 is to determine the function of the major NS4 protein and study the potential for a different method of producing viral resistant plants. The down regulation of this protein may be a novel method of producing virus-resistant plants by breaking the cycle of transmission.

RESULTS AND DISCUSSION

The direct deliver of genes into immature embryos or immature panicle-derived calli is conducted using DNA-coated gold particles accelerated by the PDS-1000/He system. The tropical irrigated Latin American *indicas* varieties Oryzica 1, Cica 8, and Inti and the tropical upland japonica line CT 6241-17-1-5-1 are used as targets. Constructs containing the RHBV-NC or the antisense RHBV-NS4 genes driven by the 35S CaMV promoter are being used. The 35S CaMV - hph gene is used as the selective marker. The putative transgenic events are recovered using a step-wise selection on culture medium containing 30 mg/l hygromycin B (hyg B) followed by 50 mg/l hyg B throughout plant regeneration. With this system one Hyg ^{r}plant line might be recovered from 2 to 33 explants initially bombarded depending on the genotype. Single or multiple copies of the transgenes are noted. Segregations of 3:1 among offspring of transgenic plants are recovered, indicating Mendelian inheritance from single genetic locus of a functional hph gene. But also some transgenic plants showing skewed segregation patterns are obtained. Similar results had been reported in transgenic rice. Possible interpretation of these results may include the linkage of the transgene with semidominant or dominant lethal mutations, inactivation of the transgene by methylation, and/or excision of the transgene from the genome. The co-transformation rate for two unlinked transgenes is from 30% to 60%. Detailed data on the efficiency of recovering transgenic plants, and the stability of expression and inheritance of the transgenes introduced using this methodology can be found in the Annual Reports of 1994 and 1995.

Antisense RNA 4. After the complete step-wise selection process throughout plant regeneration on 50 mg/l hyg B, a total of 165 plants from the antisense RHBV-NS4 and 187 plants from the RHBV-NC bombardments had been recovered. Southern blot of genomic DNA and Northern blot of the plants recovered from the antisense RHBV-NS4 bombardments indicated that 2 of these plants (1.2 %) contain and express the antisense-RNA4 gene. The identification of transgenic plants that express the RHBV antisense may allow for the analysis of the affect of the major non-structural gene and to determine the down regulation of this viral gene confers resistance to RHBV.

Sense RNA 3. Sixty of the 187 (32%) plants recovered from the RHBV-NC experiments contain the RHBV gene. In all cases, larger NC fragments than the expected length were visualized on the Southern blots suggesting the presence of rearrangements. Apparently, a variety of integration patterns had been obtained in other works specially when circular plasmid is used (Hayakawa et al., 1992). Therefore, currents experiments include the linearization of the expression vector before bombardment.

Nineteen T0 plants showing integration of the RHBV-NC gene as indicated by Southern blots, were analyzed for inheritance of the hph resistance and RHBV-NC genes by genetic and molecular analyses of the transgenic T1 progeny. Genetic analyses were conducted by evaluating the resistance to hygromycin of T1 seeds germinated *in vitro*. Five of the nineteen plants did not inherited the hygromycin resistance (ratio 0:1 resistant: susceptible) in the T1 progeny (Table 1). About 58% of the T0 lines showed a skewed segregation of 1:1 (resistant: susceptible), whereas 16% showed a segregation of 3:1 indicating the inheritance of a single active locus (Table 1). A sample of 9 plants including 1:1 or 3:1 segregations ratios were analyzed by Southern blots. The two lines that showed a 3:1 ratio for hygromycin resistance, also showed a 3:1 ratio for the presence of the hph and RHBV-NC genes in the T1 progeny, confirming the inheritance of a single active locus for the transgenes. However, those lines showing a 1:1 or 0:1 (resistant:susceptible) ratio for hygromycin resistance showed segregations of 1:0 (homozygous) or 3:1 (heterozygous single locus) for the integration of the transgenes in the genome suggesting that the skewed segregations noted for hygromycin resistance are probably due to the inactivation of the hph gene (Table 1).

Based on the inheritance analyses, six plants were chosen of each line (Table 1) and evaluated for RHBV resistance under biosafety greenhouse conditions. Twenty five day-old T1 plants of each T0 line were inoculated using two proven RHBV viruliferous planthoppers per plant. Plants were enclosed within a plastic tube and the insects were allowed to feed on the plants for 5 days. Plants were scored for the presence of the RHBV disease symptoms every two days for 25 days. At 40 day-old, plants were evaluated for the level of the disease reaction with a scale of 1 (dead plant), 2 (diseased, low vigor); 3 (diseased, intermediate vigor); 4 (vigor, some tillers free of disease symptoms); and 5 (healthy plant, no disease symptoms); and leaf tissue was analyzed to detect the presence of RHBV virus particles by ELISA using an antibody specific for the RHBV-RNA4.

This evaluation showed that 8 T1 lines derived from the A3-49 T0 line had with attenuated disease symptoms, and increased performance for various agronomic traits respect to the non-transgenic control infected with RHBV (Table 2). These results are promising, however to clearly determine if these plants are truly resistant, selfed progeny seeds (T2 generation) of each of these T1 lines will be evaluated for RHBV resistance and for expression and integration of the RHBV-transgene to confirm the inheritance and stability of the RHBV transgenes. This contrasted with many of the other transgenic lines that were tested. These either showed the same level or increased susceptibility to RHBV. Since all the plants that showed resistance were derived from the line A3-49, it is probable that these plants have stablely inherented tolerance to RHBV.

Currently, the generation of transgenic plants carrying various versions of the RHBV-NS4 and RHBV-NC sense and antisense to modulate different levels of the RHBV transgene expression is in progress. Future work includes the genetic and molecular characterization of these plants jointly with the RHBV resistance evaluations to determine the efficiency of the different strategies to confer protection to the virus.

Table 1. Inheritance of the hph resistance and RHBV-NC genes by genetic and molecular analyses of the transgenic T1 progeny.

TO line	Hygromycin resistance[1] observed ratio R:S	X^2	p	Southern plot[2] observed ratio Present:absent	X^2	p
A3-49*	1:1	0.34	0.56	1:0	—	—
A3-50	1:1	0.69	0.41	1:0	—	—
A3-57*	3:1	0.13	0.72	3:1	0.01	0.90
A3-58*	1:1	0.29	0.59	3:1	0.05	0.83
A3-59	0:1	—	—	NE		
A3-60	0:1	—	—	NE		
A3-61	0:1	—	—	NE		
A3-64	1:1	0.82	0.37	NE		
A3-72	0:1	—	—	NE		
A3-74	1:1	0.69	0.41	NE		
A3-75	0:1	—	—	3:1	0.00	1.00
A3-76	1:1	0.82	0.37	NE		
A3-77*	3:1	0.05	0.83	NE		
A3-78*	1:1	0.53	0.47	1:0	—	—
A3-81	1:1	0.09	0.76	NE		
A3-83	1:1	0.34	0.56	3:1	0.43	0.52
A3-84	1:1	0.29	0.59	NE		

[1] Twenty T1 seeds analyzed per TO line. [2] Ten plants analyzed per TO line, except for A3-57 where 23 plants were assayed, for the integration of the *hph* and RHBV-NC genes. * Lines choosen for RHBV resistance tests. NE = not evaluated.

Table 2. Evaluations of T1 progeny plants from line A3-49 for RHBV resistance and agronomic traits under greenhouse conditions.

Line A3	Flowering (days)	Height (cm)	Tillers	Flowers/ panicle	Grains/ plant	Fertility (%)	Disease reaction	ELISA (units)
49-34	127	55	44	NE	NE	NE	3	0.153
49-37	124	62	23	56	40	3	5	0.071
49-39	126	57	15	63	287	22	4	0.372
49-56	126	86	12	NE	NE	NE	4	0.558
49-60	133	66	12	114	396	32	4	0.787
49-75	125	78	15	NE	NE	NE	3	0.152
49-101	113	78	14	NE	NE	NE	4	0.432
Controls								
Infected mean	141	66	5	53	0	0	2	0.440
Sd	29	15	4	55	0	0	1	0.111
Not mean	117	83	15	106	1594	87	5	0.005
infected Sd	11	3	8	18	454	8	0	0.001

NE = not evaluated yet.

VI. OUTPUT 6. The Causal Agent of the "Entorchamiento" Problem Characterized

A. Activity 1. Isolation and characterization of the causal agent and vector of "entorchamiento"

A new disease of rice, known as "entorchamiento" (crinkling), was first noticed in the Eastern Plains of Colombia, in 1991. Symptoms include seedling death, foliar striping and severe plant malformation. Tissue extracts and partially purified preparations from diseased rice plants, contained virus-like particles ca. 20 nm in diameter, with a bimodal length of 260 and 360 nm. Particle aggregates were also observed in the cytoplasm of infected leaf cells. Electrophoretic analyses of purified preparations and ds-RNA extracts, revealed a single protein species of M_r 22,500, and four ds-RNA bands ca. 6,300, 4,600, 2,700 and 1,800 bp in size. Cystosori, characteristic of plasmodiophorid fungal vectors of plant viruses, were consistently observed in the roots of diseased rice plants. The crinkling symptoms were reproduced by planting rice in soil collected from affected fields. The "entorchamiento" disease of rice in Colombia, is identical to "rice stripe necrosis" described in West Africa, in 1977. Rice stripe necrosis is caused by a furovirus (RSNV) transmitted by the fungus *Polymyxa graminis*. A serological assay with RSNV antiserum, confirmed the emergence of rice stripe necrosis in the Americas.

B. Activity 2. Development of diagnostic methods and germplasm screening techniques to implement control measures

The virology Research Laboratory has implemented different diagnostic methods for the "entorchamiento"disease of rice: 1) **Electron Microscopy**: this technique allows the observation of virus particles in leaf or root tissue extracts from diseased plants, using rapid (10 min) negative staining techniques. 2) **Light Microscopy:** the resting spores of the fungal vector of the virus, *Polymyxa* sp., can be rapidly observed in rootlets of diseased rice plants using standard staining techniques: 3) **Serology**: an antiserum to the causal virus, produced in West Africa by French scientists, has been used to confirm the etiology of the "entorchamiento"disease caused by rice stripe necrosis furovirus, and 4) **Double-stranded RNA Analysis** , has been used to isolate the viral RNA species (4) of the causal pathogen from systemically infected rice plants. Work in progress aims to produce an antiserum to the Colombian isolate of the causal virus, for general distribution to NARIs and NGOs working on the "entorchamiento"problem.

Main achievements: the causal agent of the "entorchamiento"disease of rice has been identified at CIAT.

CIAT and partner staff contributing to project: F. Morales, J. A. Arroyave, A. C. Velasco, M. Castaño, G. Guzman and F. Correa (CIAT); Francia Varón (ICA), Fabio Montealegre and several agronomists from FEDEARROZ, Darío Leal (CORPOICA), and C. Fauquet (ORSTOM, Francia).

VII. OUTPUT 7. Priorities and Research Capacity Enhanced

A. ACTIVITY 1. THE NATIONAL RICE SAMPLE IN COLOMBIA: AN APPLICATION TO VARIETAL STABILITY

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* Project 17: Impact Assessment

INTRODUCTION

During the past decade, the Colombian rice breeding program has been working to release regional varieties, where the interaction between variety and environment is narrowed down to very specific conditions that should produce varieties with high yield response to those aspects that characterize such environments. In this research, we looked at the performance of the most common varieties grown in Colombia during 1991-94, to see if the regionalization is producing highly adapted varieties and to see the effects of the strategy in rice yields throughout the country.

We start by providing definitions on key parameters of this research: rice environments, stability and adaptability.

Rice environments which, for the purposes of this paper, are defined as the interaction between Zone and Rice Cropping System, have great incidence on the yield potential of rice varieties. For that reason, breeders must evaluate promising lines in several environments and times of the year.

Stability is the variety's capacity to avoid substantial fluctuations in its performance through different environments.

Adaptability is the process through which individuals or part of them, populations or even species change their performance in different environments, in such way that they survive better under given environmental conditions.

The relative value of adaptability of each variety will be determined by the combination, in changing degrees, of stability and of its productivity potential (or yield).

In the last decades, the use of methodologies has been intensified to determine the stability and/or adaptability of varieties in several environments like the ones used by Ebrthart and Russell (1966). Several authors consider that released varieties recommended to farmers should have the combination high yield and good stability or adaptability Amézquita el al (1983).

The purpose of this study is to improve the criterion to evaluate rice yields that generally are bounded to comparison of average yields. The goal is to obtain a value for yield stability through different environments to complement it with the mean yield value. The ideal variety would obviously have a higher mean yield and good stability.

MATERIALS AND METHODS

Information from the Colombian National Rice Survey was used for the statistical analysis (CIAT, 1991). The Survey was carried out during 1991-1994 in each semester (A and B) respectively. An analysis of Variance was conducted to calculate the probable existence of an interaction between the variety and the environment to later on apply the Eberthard and Russell stability and/or adaptability test. Table No. 1 lists the environments and the varieties evaluated in each.

Statistical analysis

a) A combined Analysis of Variance shows the effect of the environment in terms of its productivity, and test the variety/environment interaction according to the following model:

$$Yij = u + Ai + V(A)\,ij + Residual \qquad [1]$$

Where:

Yij= Rice Paddy yields kg/ ha

u= Effect of general environment

Ai= Effect of the Environment i

V(A) ij= Effect of Variety j within the Environment i

b) Estimates of the parameters of stability, allow us to classify varieties according to its sensibility to differences of the environment, through the Eberthart and Russell method (1966), modified by Amézquita (1982) 2/. The method eliminates the dependence between variety yields under study and the general environmental index value (EI), by the exclusion of the studied variety in the EI calculations.

The Environmental Index (EI) was defined as:

$$EI = Y.j - Y.. \qquad [2$$

Deviation from the general average of the Environmental Average j should integrate the diverse factors of production that affect individually the genetic potential of all varieties tested in each environment.

With the calculated values of EI and with the average yields of each variety in each environment the Regression Analysis was done, assuming a lineal relation between yield and EI. The model used was:

$$Yield\ kg/ha = a + b^{*}EI \qquad [3]$$

Where:

Yield kg/ha = Variety average yields

a = Intercept, that represents the variety medium productivity in all the environments.

bi = Regression Coefficient that represents the degree of adaptability (productivity change) of the variety to several environments.

EI = Environmental Index.

c) The location of the varieties in a Cartesian plane (see Fig. No. 1) according to their adaptability grade, b, and according to their productivity in the ecosystem, a, allows us to view the relative productivity and adaptability of ecosystems' varieties in relation to the productivity average of all the varieties considered in the analysis and to an adaptability level of reference of a represented variety b= 1. (Measures of all varieties have by definition an slope b= 1). The following are the various types of response that a variety can have:

b= 1 The variety shows average stability

b<1 The variety is quite sensitive to environmental changes, stands out in good environments.

b>1 The variety is less sensitive to environmental changes and is the most suitable for adverse environments.

d) Finally, an analysis of variance was carried out to compare the varieties in each environment, using the following model:

Yik = u + Vi + Residual [4]

Yi= Variety yield in kg/ha

U= Effect of general medium

Vi= Effect of the Variety i

RESULTS AND DISCUSSION

Table 1 lists the varieties evaluated in each environment.

Table 2 shows the classification of varieties according to their degree of adaptability, b and their productivity potential, a. The results are also illustrated in the Cartesian plane (Figure 2). The eight varieties evaluated here present significant varying responses in yields and stability associated with environmental changes.

For example the variety CICA 8, with a yield average of 5.407 kg/ha, and b=1.66 has a higher response to environmental changes, showing that it is not easily constrained by environmental factors to express its production potential. This is consistent with the observation that, despite being a variety released in Colombia in the early 1970's, CICA 8 is currently found in most countries throughout Latin America and the Caribbean. It is typically a small farmers' variety, given its plasticity to respond to varying environmental and management conditions. The variety Oryzica 1 with a yield of 5.261 —close to the sample average— and with b= 1.2, is also considered a plastic variety with very good productivity potential.

On the other hand, Linea 2, with a yield of 5.188 kg/ha near to the average (5.334 kg/ha), and with a very low slope, b= 0.03, present very little improvement to the environmental changes but it produces well in very specific environments. The variety Caribe 8 presents the more stable behaviors (b= 1); it suggests that this variety is not as specific to any given environment as Linea 2.

Other varieties, like Oryzica 3, Llanos 5 and IR22, although present productivity near or better than the average, have a low b index (0. 5< b< 1), and therefore are unstable varieties with little response capacity to environmental differences.

The results of the combined Analysis of Variance for yields (kg/ha) of different rice varieties are shown in Table 3. We can observe that the environmental effect is highly significant ($p > 0.001$). It shows that there are clear statistical differences for the defined environments in the sample.

The variety effect within the environment resulted not very significant ($p > 0.17$), which shows relatively low varietal responses when they are exposed to different environments.

Table 4 shows the rice yield's averages (kg/ha), for each of the different environments and their respective Duncan's tests to show the means separation. The rice environment "Centro Irrigated" is the environment that presents the highest productivity average 6.599 kg/ha, compared with the rice environment "Humid Caribbean, Mechanized", with a productivity average of only 3.572 kg/ha. Environments are very different in terms of their productivity for hectare.

CONCLUSIONS

The eight varieties evaluated here present significant varying responses in yields and stability due to environmental changes. The results clearly show that the eight varieties evaluated here using farmers field data collected from the National Rice Sample over the 1991-94 period present significant varying responses in yields and stability associated with environmental changes. Some varieties that were broadly tested under different environmental conditions and that were released as National Varieties (like Cica 8 and Oryzica 1) exhibit higher plasticity, i.e., have a higher capacity to respond under varying environmental conditions. On the other hand, varieties that were released for specific environments (Caribe 8, Llanos 5, Linea 2), have lower adaptability values and are unable to respond to a wide variety of environmental conditions. Currently, the variety that shows the highest demand by farmers in Colombia is Oryzica 1; besides its adaptability, it has good grain quality and is widely accepted by millers. Looking to the future, a National Rice program, like Fedearroz, seems to be more inclined to resort to the release of National Varieties, leaving to the private sector the strategy of releasing Local Varieties with high yield potential under very specific (and narrow) environmental conditions. Small farmers prefer varieties like Cica 8, with wide adaptability, perhaps due to their lower capacity to offset environmental changes and also given their lower ability to apply specific technological packages in a timely and precise manner. This need to obtain widely adapted varietieshighlights the value of participating in a regional breeding program, like the one FLAR offers to its members.

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Table 1. Environments and rice varieties considered in the analysis.

Environments		
Zone		Ecosystem
1	Centro	Irrigated
2	Llanos	Irrigated
3	Dry Caribbean	Irrigated
2	Humid Caribbean	Irrigated
5	Llano	Mechanized
6	Humid Caribbean	Mechanized

Varieties
Caribe 8
CICA 4
CICA 8
IR 22
Linea 2
Llano 5
Oryzica 1
Oryzica 3

Source: National Rice Surveys 1991 -1994

Table 2. Stability analysis for rice yields (kg/ha) according to Eberhart y Russell (1966).

Variety	b	Sb	y kg/ha	cv	r2 %
CICA 4	1.013 ns	2.050	5.402	16.3	19.3
CICA 8	1.660**	0.260	5.407	12.38	82.0
IR 22	0.763 ns	0.685	5.279	10.00	55.0
Linea 2	0.031 ns	0.042	5.188	0.96	33.3
Llano 5	0.581 *	0.190	5.333	4.75	75.7
Oryzica 1	1.282 **	0.048	5.261	5.00	94.9
Oryzica 3	0.714*	0.227	5.753	11.0	66.3
Caribe 8	1.001*	0.690	6.105	14.03	67.8

$\bar{Y}$= 5334.14
$\bar{Y}$= General average for all environments
$\bar{y}$= General average for each variety in all environments
* Significantly different from zero to level P < 0.01

Table 3. Variance analysis combined for rice yields in kg/ha.

Sources of variation	Degrees freedom	F value
Environment	5	141.40***
Variety (Environment)	23	1.29 *
Error	606	
Total Modified	634	
Average (kg/ha)	5.688	
C.V. (%)	16.9	

*** Significant effect at 0.0001 < p < =0.0001

* Significant effect at 0.2 < p < = 0.1

Table 4. Average and yields means separation for different environments.

Duncan's Multiple Range Test for variable: YIELDKGHA

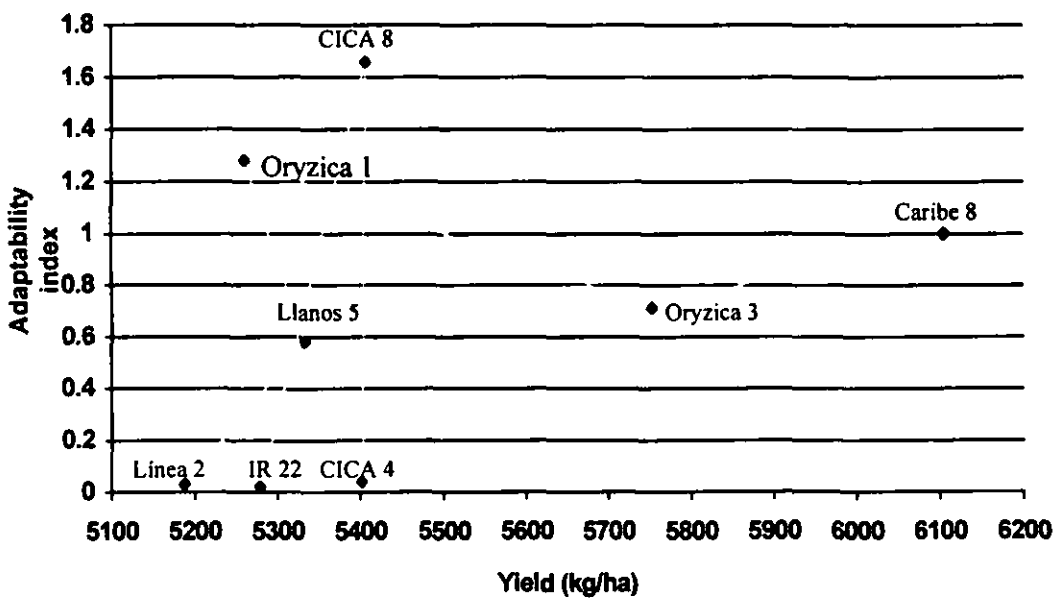
Alpha = 0.05 *df=606* MSE=926114.5
Harmonic Mean of cell sizes= 63.14468

Number of means	2	3	4	5
	6			
Critical Range 336.4	354.1	366.0	374.8	381.7

Means with the same letter are not significantly different

Duncan Grouping	Mean	N	Environment
A	6599.5	296	1
B	5446.5	120	3
B	5414.0	68	2
B	5037.9	39	6
C	4789.2	33	4
D	3572.3	79	8

Figure 1. Relation between yield and adaptability in 8 rice varieties, Colombia, 1991-94.



B. ACTIVITY 2. IMPACT OF RICE RESEARCH IN LATIN AMERICA AND THE CARIBBEAN DURING THE PAST THREE DECADES

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INTRODUCTION

Significant advances in rice production have been made over the past three decades in Latin America and the Caribbean (LAC). Some 275 new rice varieties have been released, the majority of them (90%), targeted to flooded environments. Of the new varieties, 39% came from crosses made at CIAT, 12% at IRRI and several of the rest has parentage from IARC's progenitors (Table 1). Modern semidwarf rice varieties now account for 93 percent of all flooded rice production, itself representing more than 80 percent of total rice production in the Region (Table 2). Average yields in flooded areas have risen from 3.3 tons per hectare in the mid-1960s to 4.6 t/ha in 1995; and total rice production doubled between 1967 and 1995 to reach about 20 million tons of paddy rice (Table 3), making the Region largely self-sufficient in rice. With rice prices falling by about 50 percent in real terms over the period (Table 4), consumers have benefitted greatly, rice is well established as a "wage good", and the crop has become the most important source of calories and proteins for that 20 percent of the Region's population with lowest incomes.

Measuring past benefits and identifying the shares apportioned by main interested parties is a valuable exercise not only to gain an idea of the profitability of past research investments but also to guide future efforts. The model used here measures benefits to producers and to consumers. A further breakdown permits to calculate benefits by major production ecosystems: irrigated, rainfed lowlands, mechanized upland and traditional (or manual) upland; the model also calculates foregone benefits to producers resulting from imports.

RICE IN LATIN AMERICA AND THE CARIBBEAN

Throughout this century, rice gradually became a staple food in the diets of consumers of tropical Latin America. Per capita consumption of white rice went from 10 kilos in the 1920's to about 30 kilos in the 1990's. Rice is the most important grain crop for human consumption across most of the tropics of Latin America and the Caribbean (LAC). It supplies more calories to these people's diet than wheat, maize, cassava, or potatoes. In the rapid process of urbanization of LAC, where 70% of the population now lives in the cities, rice has displaced from the diets traditional, bulky and perishable staples like plantains, cassava, yams, etc.

About half of LAC's population lives below the FAO poverty line, and income is lowest in the tropical parts of LAC. Food purchases account for over 50% of total expenditures for the poor, and rice accounts for about 15% of their total food purchases. For the poorest 20% of the population, it even supplies more protein to the diet than any other food source, including beef, milk and beans.

Evolution of Rice Production in Latin America

Latin America produces some 20 million MT of paddy rice which represents about 3.6% of the world rice output in an area of 6.7 million has. (4.5% of the world rice area). By 1995, the dominant rice environments in this continent are wetland rice (54.5% of the area) and upland rice (45.5% of the area). Wetland rice, with 3.7 million has, is dominated by irrigated cropping which occupies two-thirds of that area; the rest is almost entirely cultivated under rainfed, lowland rice. Upland rice (with 3.0 million has.) is predominantly mechanized (2.1 million has.), while manual rice farming covers almost 1.0 million has. (Table 3). For most of this century, rice has been a pioneer crop in the vast savannas and in the forest margins of Latin America. Mechanized upland rice predominates in the colonization of the savannas while manual, traditional rice cropping has been a key component in the forest margins.

Stages in rice production, 1966-1995

The advent of the new rice technologies has had a sharp impact on the relative shares of the predominant rice production systems. *Different stages can be distinguished.*

Early adoption, 1966-1981. By 1966, the tall traditional varieties covered the entire rice area (5.8 million has). The 1970's witnessed a very rapid adoption of the new semidwarf varieties for irrigated environments, mainly in the tropical countries. By 1981, the region produced 15.7 million MT, an increase of 50% from 1966. About half of this rice came from MSVs and more than 75% of the irrigated rice area was under these new varieties. With the advent of the new semidwarf rice varieties in late 1960's, the irrigated rice systems became more competitive: higher yields resulted in lower unit costs and lower rice prices. As a consequence, upland rice, *confronting a lower relative price* but without yield advances, was also displaced by maize, soybeans, cassava, cotton and other crops as a pioneer crop in the areas of deforestation. The area under manual, traditional upland rice fell from about 1.1 million has. in 1966 to 0.85 million in 1981. In the savannas, the story was a little different. Brazil produces 90% of upland rice in the region. This country made a firm commitment in the 1950's to develop the vast acid savannas (Cerrados); the decision even embodied the removal of the nation's capital from the Coast (Rio de Janeiro) to the Cerrado (Brasilia) in the 1960's. Today, the acid savannas of the Cerrados produce over 40% of the country's total agricultural supply. This aggressive expansion of the Brazilian frontier had a peak during the 1970's and was heavily based on government support. Large, mechanized rice exploitations were favored by several schemes based on price supports, crop insurance, forward contracting by the public sector, etc. As a consequence of the policies, rice area in Brazil peaked in 1976 at 6.7 million has. accompanied by a surge in upland area that reached 6.1 million has. Over this period, mechanized upland area went from 2.8 million has. in 1966 to 4.8 million has. in 1981 (Table 3).

The lost decade: 1981-1989. Throughout the 1980's, economic stagnation was the norm in the Region. Promotional rice policies were phased out in the late 1970's, when the heavy foreign debt and the fiscal burden, coupled with rampant *inflation rates meant* that promoting extensive agriculture became unviable. Mechanized upland rice subsidies were virtually eliminated in Brazil by the mid-1980's.

Total rice area in LAC decreased from 8.3 million has. in 1981 to 7.3 million has. in 1989 but, fortunately, yields increased from 1.9 to 2.5 MT/ha as the adoption of new varieties continued, mainly in Brazil where MSV's became widely adopted in the early 1980's. By

1989, regional paddy rice production reached 18.4 million MT. MSVs accounted for two-thirds of rice production and 44% of the rice area. In irrigated rice, 85% of the area was already under MSV's.

The 1990's. This has been a period of economic growth, open markets and reduced inflation rates in LAC. By 1995, paddy rice production reached 20.6 million MT, or 3.6% of the world rice output. About 98% of the irrigated rice area was under MSV's. Significant growth in production has ocurred in temperate South America (South Brazil, Argentina and Uruguay) as the MSV's have been quickly adopted. Irrigated yields for LAC have reached 5.0 MT/ha while total rice yields are at 3.1 MT/ha due to the low upland yields of 1.3 MT/ha. Since the 1980's, upland rice area in Brazil has continue to decline to its current level of around 3.0 million has. by 1995 (Table 3).

THE ECONOMIC BENEFITS OF PAST RICE R&D INVESTMENTS IN LATIN AMERICA AND THE CARIBBEAN

This section reports some preliminary outputs from an on-going study to develop new databases and analytical tools for generating information on the social returns to R&D investment in Latin America and the Caribbean. This work is being undertaken in an IDB financed collaborative project involving IFPRI, CIAT, and IICA together with sub-regional institutions and NARS. The main goal is to improve the capacity to undertake R&D evaluation, priority setting, and resource allocation in the region, and one of the sub-activities is to systematize the generation of aggregate ex post assessments.

Given the scarcity of consistent historic data on rice technology generation and utilization at the national level in LAC a geographically aggregated approach is being taken to the ex post evaluation. However, an attempt is being made to track the evolution of the four major rice production systems of the region and to calculate separately the impacts of R&D on each. *Irrigated* and *rainfed lowland* represent the anaerobic production systems while *mechanized upland* and *manual* or *traditional upland* represent the aerobic systems. LAC rice production has been allocated proportionately among these systems based on an existing, diverse set of regional and sub-regional studies (Scobie and Posada 1977, Valente Moraes 1977, CIAT 1979, 1992, 1995, Posada 1981, CIAT IRTP 1983, Muchnik de Rubinstein 1984, Dalrymple 1986). The period of analysis is 1966 to 1995, 1966 being chosen to precede the widespread release and adoption of the modern semi-dwarf varieties in the region.

For both ex post and ex ante assessment a multi-market economic surplus model described by Alston, Norton and Pardey (1995, pp 395-410) is being used. The model, *Dream*, is capable of analysing multiple (horizontal) markets, trade in products and technology transfer between market regions, technology adoption and disadoption, exogenous (non-R&D-induced) growth in demand and supply, and tax/subsidy price distortions for both producers and consumers. Analyses are made using a software package based on the model (Wood, Wood-Sichra, Alston, and Pardey 1995, 1996). The approach generates a time stream of R&D benefits to producers and consumers by simulating the expected market level changes induced by the adoption and application of new technologies at the farm level. The basic representation of technical change in such economic surplus models is shown in Figure 1. If we define a pre-research position at point *a* on the supply curve S_0, the equilibrium price and quantity are P_0 and Q_0 respectively, and the associated consumer and producer surpluses are represented by the areas FaP_0 and

P_0aI_0. The application of new technology can be represented as a downward shift in the supply curve up to a maximum amount determined by the effectiveness of the technology (conventionally described as the *potential unit cost reduction*) and the extent to which it is ultimately adopted. This supply curve shift takes place over a period of years determined by the adoption rate. In any given year the new market equilibrium position (P_1, Q_1) may be represented by point *b* on the shifted supply curve S_1. In this year the new consumer and producer surpluses are represented by areas FbP_1 and P_1bI_1 respectively. The effects of R&D in the given year, however, are measured by the *changes* in economic surplus between *a* and *b* - the areas P_0abP_1 (i.e., FbP_1 - FaP_0) and P_1bcd (geometrically equivalent to P_1bI_1 - P_0aI_0). It can be shown that the sum of these two areas - the total economic surplus - is equivalent to the shaded area swept out by the movement of the supply curve (I_0abI_1).

Alston, Norton and Pardey (1995) describe this process and its ramifications in greater detail and present the generic equations for changes in surplus, that is, the economic impacts of R&D. Alston et al set out procedures for the calculation of these prices, quantities and unit price reductions using the parameters listed in Table 5. They also present procedures for calculating transfer benefits through government if producer or consumer taxes or subsidies are applied in any of the regions (although this feature is not implemented in the ex post study described).

The extension of the basic framework to the ex post case described here is shown in Figure 2. In addition to the R&D induced supply shift (S_1 to S_1^R) there are also exogenous shifts in supply (S_0 to S_1) and demand (D_0 to D_1). At the start of the ex post analysis period the equilibrium position, (P_0, Q_0), is found at *a*. During the analysis period the three shifts occur simultaneously resulting in a new observed equilibrium point, *b* (P_1^R, Q_1^R). Without R&D (the counterfactual case) the final equilibrium position would have been *c*. Thus, the shaded area ($I_1cbI_1^R$), represents the economic surplus attributable to R&D. It should be noted that even though the demand shift is assumed to be *independent of research* it generates a significant additional contribution to the total economic surplus attributable to R&D - as represented by the area *cbde*.

Market Regions and their Interaction

Regions can be characterized in ways that describe their capacity to generate new technologies as well as to produce and consume (Table 5). A region may have any individual property or any combination of properties. Where regions are defined as countries they generally have all three properties. However, where important sub-groups of producers or consumers need to be represented in a modeling framework, for example, small traditional producers and large mechanized producers, or rural and urban consumers, appropriate market "regions" of single properties may be constructed.

The analysis proceeds by a simulation through time of the release, adoption and application of new technologies and the consequent changes in prices and in quantities produced and consumed. As new technologies are adopted the supply-curve shifting effects of R&D in each region are transmitted between regions through prices. The model assumes that, in each time period, price levels adjust to ensure that production equals consumption across all regions, that is, an aggregate market clearing condition is imposed.

Model Specification and Parameter Estimation for ex Post Analysis

The ex post rice model has been formulated at a geographical scale of LAC using six analysis regions:

- Irrigated rice production system - anaerobic
- Rainfed rice production system - anaerobic
- Upland mechanized rice production system - aerobic
- Upland manual/traditional rice production system - aerobic
- Rice consumption
- Net trade

The final region was necessary to provide the required balance between LAC rice production and consumption. It is effectively another (external) production region since LAC has been, and is increasingly, a net importer of rice. Rice consumption was assumed to be equivalent to rice supply as defined in FAO's Supply Utilization Accounts, i.e., it is more properly defined as *apparent consumption.*

The modeling strategy adopted was to simulate the evolution of regionally aggregated price and quantity over the 30 year period (1966-95), while fitting the disaggregated production system trends to the limited historic data points available at this level. To reflect several distinct phases of the evolution of rice production in LAC, as well as to coincide with the availability of key calibration datasets at the production system level, the period was split into three sub-periods. The sub-period 1966-81 covered the initial phase of strong growth in the adoption of semi-dwarf varieties as well as major expansion in the mechanized upland area, predominantly in Brazil. The regional overview of the situation with regard to rice production technology at the end of this period was summarized by Muchnik de Rubenstein (1984). The second sub-period 1982-1989 witnessed a major reversal in the growth of the upland mechanized area. A 1989 regional summary of the major rice production systems defines the end of that sub-period (CIAT, 1992). The final sub-period 1989-1995 coincides with strong growth in production from the temperate irrigated areas, but otherwise much instability in both production and prices.

To evaluate the economic consequences of R&D it is necessary to decompose the observed production trends for each of the four rice production systems and for each sub-period. This is done in two stages; firstly into the relative contribution of the area and yield components of production change in each sub-period, and secondly, into the shares of those area and yield changes attributed to R&D and other (exogenous) sources respectively. Shares have been estimated on the basis of the sources used in deriving Table 3, other econometric studies of rice technology impacts (e.g., Evenson and Flores, 1978) and, frequently, expert opinion. This heuristic process provides estimates of the R&D-induced effect (that is, the unit cost reduction as a percentage of the initial price), the exogenous supply growth rate (as an annual percentage rate), and the maximum adoption level (percentage of MSV production in total production).

For each sub-period it was assumed that technology was available to be adopted (R&D time lags were set to zero and the probability of R&D success was 100%) and that adoption was a continuous process (adoption lags were set equal to the sub-period length). Since R&D cost streams were not available only gross benefits have been calculated. Technology spillover was not explicitly modelled in the ex post analysis, but its effects are embodied in the historic data. For example, the 1988 national rice census of

Colombia reports 24.6% of upland producers were using the CIAT/ICA-developed CICA-8 irrigated rice variety (FEDEARROZ 1990). None of the other 75.4% of varieties used in the upland manual systems were identified, but a significant proportion of those are also thought to be MSV's developed for irrigated areas. On this basis we made a nominal R&D contribution of 5% to the *yield gains* in all non-MSV (traditional variety) areas. Within the MSV areas the estimated contribution of R&D to *yield gains* ranged between 30% in the irrigated systems to 50% in the upland systems. We did not attribute any *area changes* to R&D. Table 6 shows the input dataset by production system (that is, by market "region") and by sub-period.

RESULTS

The model tracked the evolution of production and prices very closely (Figure 3). Results indicate that the main beneficiaries of technological innovations have been consumers, with annualized benefits (discounted at a real rate of 3% per year) of US$518 million (Table 7). As a group producers have received annualized benefits of US$340 million per year. But it was the irrigated production systems that generated practically all of the positive R&D benefits (US$437 million per year). The other production systems were adversely affected by the rapid gains in the irrigated sector, although those non-irrigated producers who adopted new technologies (targeted to them or to the irrigated sector) were less affected. In aggregate the non-irrigated production sectors had net annual losses of US$9 million in rainfed, US$70 million in mechanized upland, and US$5 million in manual upland[1]. It is probable that the large productivity gains in irrigated rice have played an important role in releasing pressure on the more fragile ecosystems of the forest margins and the savannas. With productivity gains in irrigated rice, prices have decreased, making upland rice less competitive and reducing the economic incentive to open new rice lands in those upland ecosystems.

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[1] In this context "losses" signify the reduced economic benefits of rice production in the non-irrigated areas *relative to those that would have been generated without R&D*. As a consequence of R&D, relative changes in the cost of production favour expansion of irrigated production and contraction of other systems. Rational producers in the less favoured (that is, relatively higher unit cost of production) systems may opt to switch out of rice and into their next most profitable production activity.

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ACRONYMS

CIAT: Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture)

FEDEARROZ: Federación Nacional de Arroceros de Colombia

FAO: Food and Agriculture Organization of the United Nations

FLAR: Fondo Latinoamericano y del Caribe para Arroz de Riego (Irrigated Rice Fund for Latin America and the Caribbean)

ICA: Instituto Colombiano Agropecuario

IRRI: International Rice Research Institute

IARCs: International Agricultural Research Centers

LAC: Latin America and the Caribbean

MSV: Modern Semidwarf Varieties

NARS: National Agricultural Research Systems

Table 1. Rice varieties released in Latin America and the Caribbean by origin.

Sub-region	1970-1980						1981-1990						1991-1995						TOTAL					
and	Total						Total						Total											
Country	Released	Local	IRRI	CT/P*	Others	%CT	Released	Local	IRRI	CT/P*	Others	%CT	Released	Local	IRRI	CT/P*	Others	%CT	Released	Local	IRRI	CT/P*	Others	%CT
Caribbean																								
Belize							1			1		100%							1			1		100%
Dom.Rep	5	4	1			0%	4	2	1	1		25%							9	6	2	1		11%
French Guyana													1			1		100%	1			1		100%
Guyana	2	1	1			0%							1		1			0%	3	1	2			0%
Suriname	11	11				0%	1	1				0%							12	12				0%
Subtotal	18	16	2			0%	6	3	1	2	0	33%	2	0	1	1		50%	26	19	4	3	0	12%
Cuba	3	1	2			0%	5	4			1	0%	6	6				0%	14	11	2		1	0%
Mexico	22	14	8			0%	11	5	2	2	2	18%	3	2		1		33%	36	21	10	3	2	8%
Central America																								
Costa Rica	3		1	2		67%	2			2		100%	4			4		100%	9		1	8		89%
El Salvador							4			4		100%	1			1		100%	5			5		100%
Guatemala	2			2		100%	5			4	1	80%	1			1		100%	8			7	1	88%
Honduras							4			4		100%	1			1		100%	5			5		100%
Nicaragua	1		1			0%	1			1		100%	5	2		3		60%	7	2	1	4		57%
Panama	2	2				0%	4	1		3		75%	2			2		100%	8	3		5		63%
Subtotal	8	2	2	4		50%	20	1		18	1	90%	14	2		12		86%	42	5	2	34	1	81%
Tropical Brazil	4	4				0%	30	13	2	11	4	37%	18	10		6	2	33%	52	27	2	17	6	33%
Temperate Brazil	11	3	4	4		36%	12	5	1	4	2	33%	7	6		1		14%	30	14	5	9	2	30%
Andean Countries																								
Bolivia							2		1	1		50%	4			3	1	75%	6		1	4	1	67%
Colombia	8		1	6	1	75%	6			6		100%	6			5	1	83%	20		1	17	2	85%
Ecuador	4		2	2		50%	2		1	1		50%	1			1		100%	7		3	4		57%
Perú	4	1	3			0%	9	5	1	3		33%	6	2		4		67%	19	8	4	7		37%
Venezuela	1			1		100%	4			2	2	50%	2			2		100%	7			5	2	71%
Subtotal	17	1	6	9	1	53%	23	5	3	13	2	57%	19	2		15	2	79%	59	8	9	37	5	63%
Temperate South America																								
Argentina							2	2				0%							2	2				0%
Chile	3	3				0%							1			1		100%	4	3		1		25%
Paraguay	1			1		100%	3			1	2	33%							4			2	2	50%
Uruguay							4	4				0%	2	2				0%	6	6				0%
Subtotal	4	3	0	1	0	25%	9	6		1	2	11%	3	2		1		33%	16	11		3	2	19%
TOTAL	87	44	24	18	1	21%	116	42	9	51	14	44%	72	30	1	37	4	51%	275	116	34	106	19	39%

* Varieties resulting from crosses made at CIAT

Table 2. Percent of modern semidwarf varieties (MSV) in production and in area.

	Percent in Production				Percent in Area			
	1966	1981	1989	1995	1966	1981	1989	1995
Irrigated	0.0	79.3	88.1	98.3	0.0	76.4	84.7	97.6
Rainfed	0.0	53.3	69.3	76.7	0.0	50.3	61.8	71.7
Subtotal Wetlands	0.0	73.5	84.2	92.8	0.0	69.7	79.1	89.5
Mechanized Upland	0.0	6.9	13.3	24.7	0.0	5.8	10.3	18.0
Traditional Upland	0.0	30.0	30.0	30.0	0.0	26.0	28.2	31.2
% MSV in Total LAC	0.0	49.9	67.5	80.3	0.0	28.2	43.6	58.8

Table 3. Participation of modern semidwarf varieties (MSV) in production and area and implicit yield, LAC, 1966-95.

	Production (1,000 MT)				Area (1,000 Has)				Yield (MT/Ha)			
	1966	1981	1989	1995	1966	1981	1989	1995	1966	1981	1989	1995
Anaerobic	6,354	9,888	13,863	16,792	1,927	2,630	3,291	3,662	3.3	3.8	4.2	4.6
MSV	0	7,272	11,676	15,587	0	1,832	2,602	3,278				
Irrigated	4,328	7,710	11,022	12,518	1,252	1,952	2,475	2,519	3.5	3.9	4.5	5.0
MSV	0	6,110	9,708	12,310	0	1,491	2,097	2,459				
Rainfed	2,026	2,178	2,840	4,273	674	678	816	1,144	3.0	3.2	3.5	3.7
MSV	0	1,162	1,968	3,277	0	341	505	820				
Aerobic (Upland)	3,799	5,858	4,561	3,879	3,912	5,633	4,050	3,063	1.0	1.0	1.1	1.3
MSV	0	587	752	1,009	0	499	580	675				
Mechanized	2,809	5,070	3,684	2,920	2,812	4,786	3,146	2,123	1.0	1.1	1.2	1.4
MSV	0	350	489	722	0	279	325	381				
Manual	990	788	877	959	1,100	847	904	940	0.9	0.9	1.0	1.0
MSV	0	236	263	288	0	220	255	293				
LAC total	10,153	15,745	18,424	20,670	5,838	8,262	7,341	6,725	1.7	1.9	2.5	3.1
MSV	0	7,858	12,428	16,596	0	2,331	3,181	3,953				

Source: Estimated by the authors on the basis of Muchnik de Rubenstein 1984, Dalrymple 1986, Valente Moraes 1977, CIAT 1979, 1992, 1995, CIAT IRTP 1983, Posada 1981, Dalrymple 1986, Scobie and Posada 1977, Avila 1981, IRRI 1995.

Table 4. International Prices of White Rice, Bangkok, 5% Broken, 1966-95.

Year	US Wholesale Price Index 1995=100	Nominal Price of White Rice, Bangkok 5% Broken	Nominal Price of Paddy Rice (White *0.5)	Real Price of Paddy Rice US$ of 1995
1966	26.7	165.7	82.8	309.7
1967	26.7	221.0	110.5	413.1
1968	27.5	204.7	102.3	372.2
1969	28.5	185.1	92.5	324.5
1970	29.5	143.0	71.5	242.0
1971	30.6	130.3	65.2	213.2
1972	31.9	149.9	75.0	235.2
1973	36.1	296.6	148.3	411.2
1974	42.9	541.5	270.8	631.6
1975	46.9	363.2	181.6	387.4
1976	49.0	254.1	127.0	259.2
1977	52.0	272.4	136.2	261.9
1978	56.1	368.5	184.3	328.4
1979	63.1	334.3	167.2	264.9
1980	72.0	433.7	216.8	301.0
1981	78.6	482.8	241.4	307.3
1982	80.1	293.4	146.7	183.0
1983	81.2	276.8	138.4	170.5
1984	83.1	252.3	126.1	151.7
1985	82.7	217.4	108.7	131.5
1986	80.3	210.2	105.1	130.8
1987	82.4	229.8	114.9	139.4
1988	85.7	301.5	150.8	175.8
1989	90.0	320.3	160.2	177.9
1990	93.2	287.2	143.6	154.1
1991	93.4	312.6	156.3	167.4
1992	93.9	287.4	143.7	153.0
1993	95.3	267.9	134.0	140.5
1994	96.6	294.0	147.0	152.3
1995	100.0	353.0	176.5	176.5

Table 5. Properties of market regions.

Major property	Parameters in the *Dream* model
Capacity to generate technology	R&D research investments R&D lag times Type and expected range of unit cost reductions
Capacity to produce	Adoption lag time Maximum adoption level Disadoption lag Initial production quantity Initial producer (farmgate) price Price elasticity of supply Exogenous (non R&D-induced) growth rate in supply Producer taxes/subsidies
Capacity to consume	Initial consumption Price elasticity of demand Exogenous (non R&D-induced) growth rate in demand Consumer taxes/subsidies

Table 6. Input parameters for ex-post analysis.

Period	Region	R&D			Production						Consumption		
					Adoption								
		Time Lag	Probabilty Success	Shift (Kmax)	Lag	Level	Initial Quantity	Initial Price	Elasticity of supply	Exog. Growth	Initial Quantity	Elasticity of demand	Exog. Growth
		(yrs)	(%)	($/T)	(yrs)	(%)	(1000T)	($/T)		(%/yr)	(1000T)		(%/yr)
	Irrigated	0	100	59.86	15	78.5	4218	288	0.7	4.7			
	Rainfed	0	100	22.72	15	41.6	1925	288	1	4			
1966-81	Upland mechanised	0	100	12.87	15	8	3252	288	1.2	4.8			
	Upland Manual	0	100	8.65	15	8	760	288	1.2	2.7			
	LAC Consumtion										10214	-0.3	3.2
	LAC Net Trade						61	288	0	13			
	Irrigated	0	100	29.76	8	87	7676	208	0.7	5.3			
	Rainfed	0	100	4.53	8	54	2847	208	1	1			
1981-89	Upland Mechanised	0	100	1.27	8	11	5138	208	1.2	-1.7			
	Upland Manual	0	100	0	8	11	854	208	1.2	3			
	LAC Consumption										16854	-0.25	1.3
	LAC Net Trade						339	208	0	8.3			
	Irrigated	0	100	23.39	6	95	1123	180	0.7	1.4			
	Rainfed	0	100	4.72	6	84	2739	180	1	9.2			
1989-95	Upland Mechanised	0	100	4.43	6	19	3770	180	1.2	-4.7			
	Upland Manual	0	100	8.07	6	19	904	180	1.2	2			
	LAC Consumptiom	0	100								19031	-0.2	2.4
	LAC Net Trade	0	100				595	180	0	8.6			

NOTES:

1. In the ex-post setting we consider a timestream of undifferentiated technologies was adopted. Since the starting point is adoption, R&D *lag tie is set to zero and, since* the technology was available, probability of success was set to 100%.
2. Maximum unit cost (Kmax) is the product of the potentital unit cost reduction (kpot), probability of research success, the maximum adoption level, and the producer price.
3. Adoption lags are set equal to the simulation period i.e., adoption is continuous in the ex pot context (up to the maximum adoption level specified for that period.
4. Exogenous demand growth rates were calculated by the authors on the basis of growth in population, real wages and income elasticities.
5. Initial estimates of the exogenous supply growth rates were calculated as described in the text but were subsequently adjusted to fit the equilibrium quantities and price to the available data points.

Table 7. Gross Benefits in LAC of global rice R&D (period of impact 1966-96). All values in 1000 of 1995 US%.

	Gross Annual Research Benetifs									
	Producer Benefits							Value if benefits invested at 3%		
Year	Irrigated	Rainfed Lowland	Upland Mechanised	Upland Manual	Total Producers	Consumers	Total	Producers	Consumers	Total
1967	10,723	113	-1,941	-667	8,229	14,887	23,115	18,826	34,059	52,886
1968	22,368	233	-4,016	-1,351	17,234	30,844	48,078	38,282	68,513	106,794
1969	31,983	360	-6,231	-2,052	27,061	47,928	74,988	58,359	103,360	161,719
1970	48,624	494	-8,594	-2,769	37,755	66,197	103,952	79,051	138,602	217,653
1971	63,346	635	-11,111	-3,503	49,367	86,715	135,082	100,353	174,240	274,593
1972	79,208	784	-13,792	-4,252	61,948	106,545	168,493	122,260	210,276	332,535
1973	96,271	941	-16,643	-5,015	75,553	128,757	204,310	144,768	246,712	391,480
1974	114,600	1,106	-19,674	-5,793	90,240	152,422	242,662	167,873	283,550	451,423
1975	134,263	1,280	-22,891	-6,584	106,069	177,616	283,684	191,672	320,794	512,366
1976	155,331	1,462	-26,303	-7,357	123,103	204,418	327,520	215,861	358,447	574,309
1977	177,877	1,653	-29,920	8,200	141,409	232,911	374,320	240,740	396,515	637,254
1978	201,978	1,853	-33,750	-9,024	161,058	263,182	424,240	266,204	435,000	701,204
1979	227,716	2,062	-37,802	-9,855	182,122	295,325	477,447	292,252	473,910	766,162
1980	255,172	2,281	-42,084	-10,692	204,678	329,436	534,114	318,882	513,250	832,132
1981	284,436	2,510	-46,606	-11,532	228,808	365,617	594,424	346,092	553,028	899,120
1982	304,241	848	-51,684	-12,512	240,894	385,028	625,922	353,760	555,426	919,187
1983	326,065	813	-56,439	-13,522	255,292	405,062	660,354	363,985	577,522	941,507
1984	350,011	-2,469	-60,858	-14,559	272,125	425,747	697,872	376,684	589,334	966,018
1985	376,186	-4,114	-64,929	-15,631	291,513	447,112	738,625	391,769	600,881	992,650
1986	404,704	-5,741	-68,637	-16,707	313,620	469,186	762,806	409,203	612,182	1021,384
1987	435,685	-7,344	-71,968	-17,812	338,561	492,002	830,563	428,879	623,253	1052,132
1988	469,252	-8,915	-74,906	-18,933	366,497	515,591	882,088	450,745	634,112	1084,857
1989	505,536	-10,449	-77,436	-20,066	397,585	539,990	937,575	474,738	644,776	1119,514
1990	528,613	-13,476	-81,783	-20,563	412,792	576,122	988,913	478,539	667,883	1146,421
1991	552,792	-17,090	-85,765	-21,087	428,850	613,952	1042,802	482,675	691,008	1173,683
1992	578,022	-21,360	-89,384	-21,638	445,641	653,571	1099,212	486,964	714,175	1201,138
1993	604,242	-26,363	-92,636	-22,212	463,031	695,076	1158,107	491,230	737,406	1228,636
1994	631,387	-32,185	-95,518	-22,808	480,876	738,569	1219,445	495,302	760,726	1256,028
1995	659,382	-38,921	-98,023	-23,423	499,015	784,158	1283,172	499,015	784,158	1283,172
Annualized flow at 3%	436,651	-8,551	-70,396	-5,454	339,551	518,312	857,863			

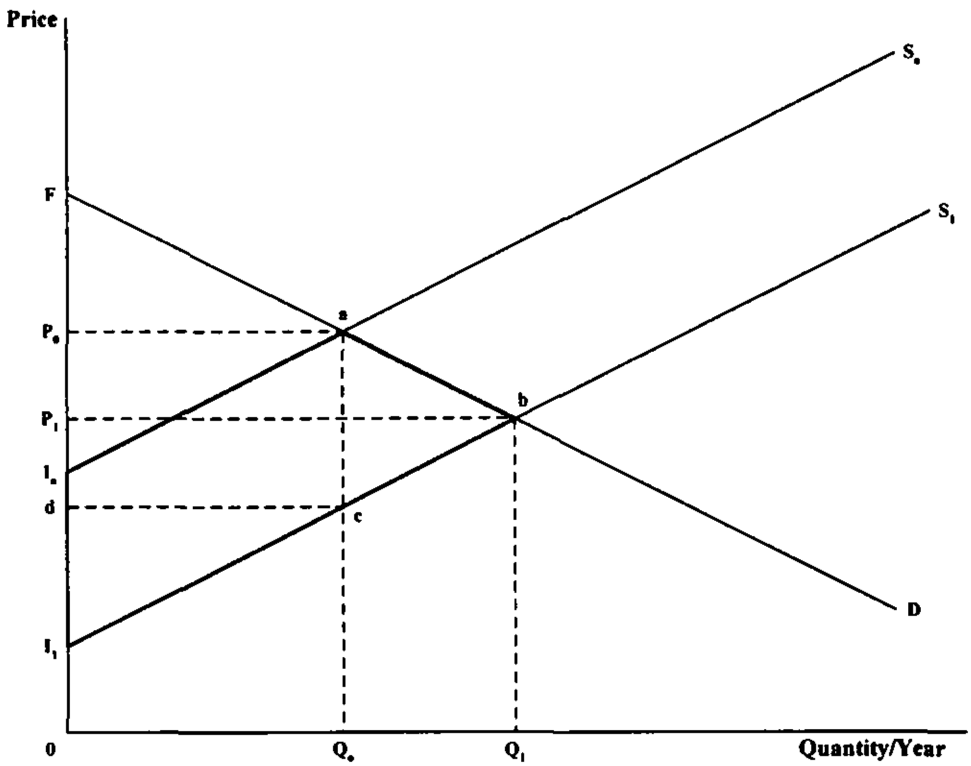
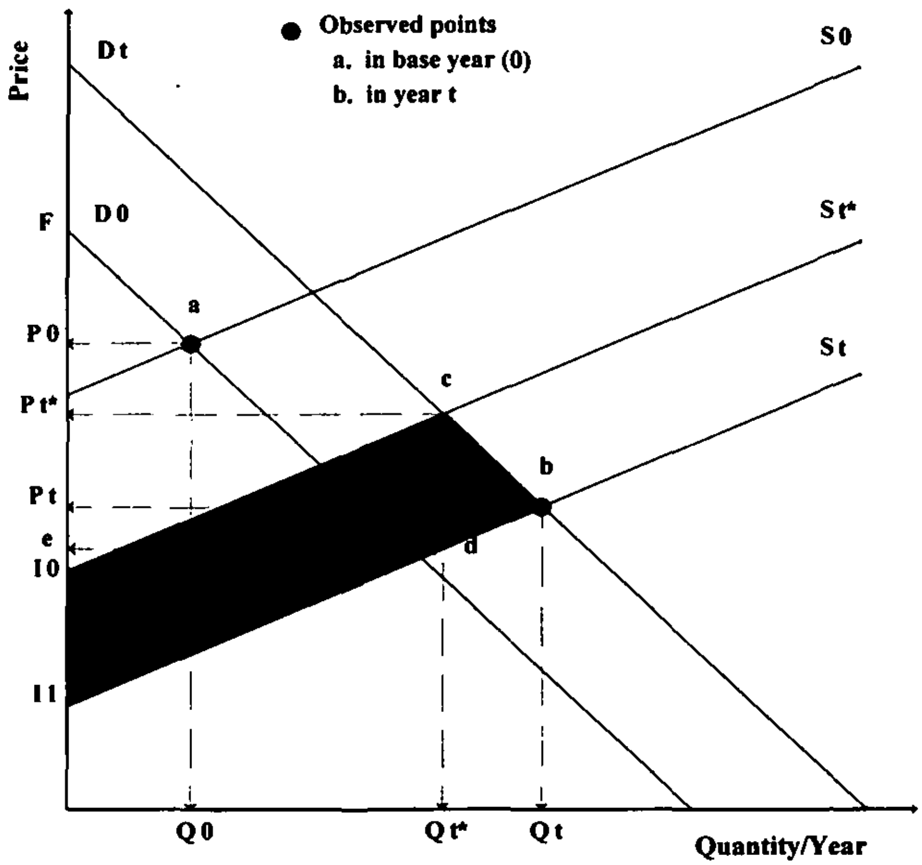


Figure 1. Representing gross annual research benefits in an economic surplus model.

Figure 2. Ex post Representation of Gross Annual Research Benefits in an Economic Surplus Framework



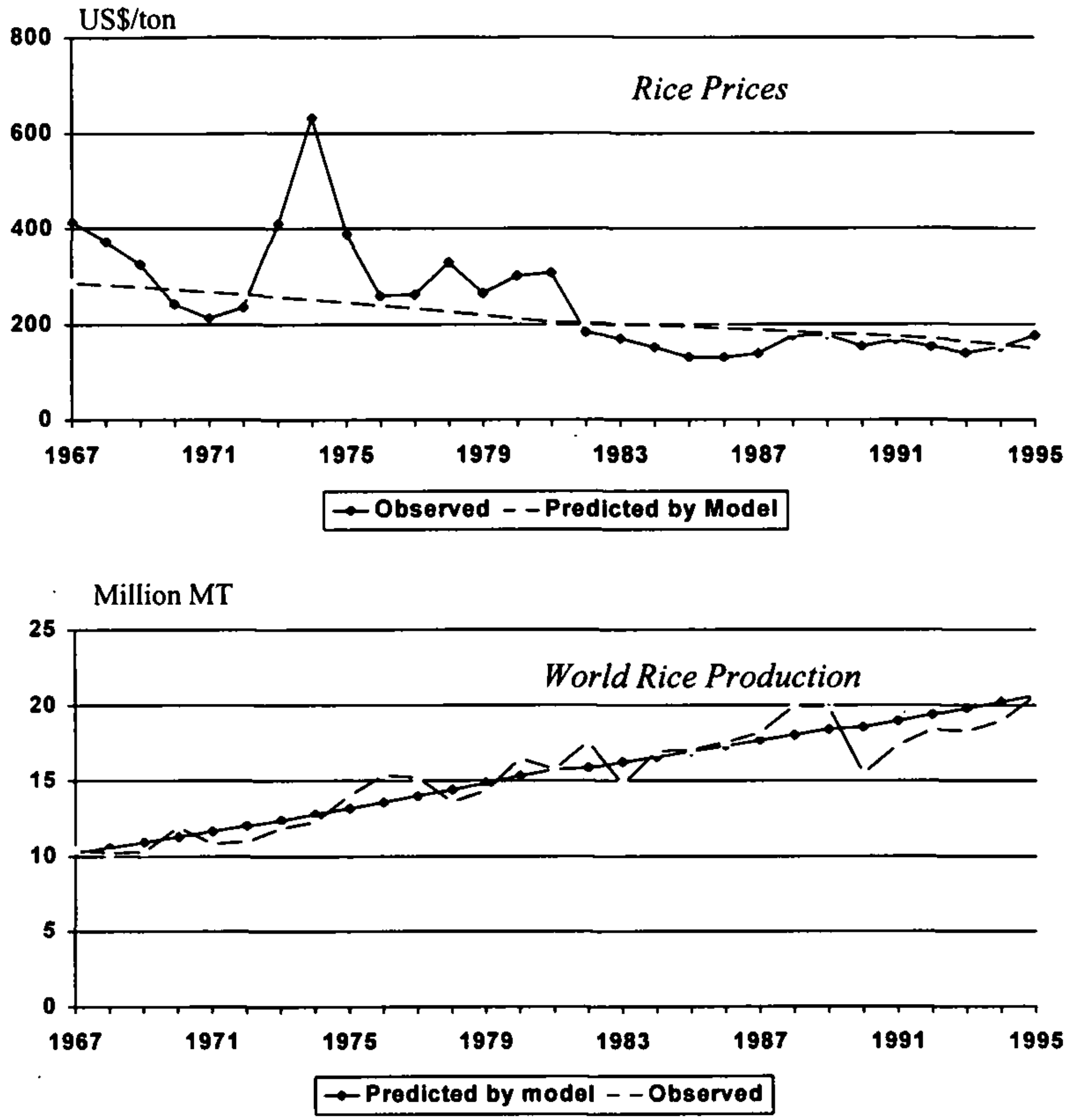


*Figure 3. Paddy Rice Prices (Bangkok 100% *0.5) and World Production*

Annex 1

PUBLICATIONS

In Refereed Journals

Guimaraes, E.P., Amezquita, M.C., Lema, G., and Correa-Victoria, F.J. 1996. Determination of Minimum Number of Growing Seasons for Assessment of Disease Resistance Stability in Rice. Crop Science (accepted for publication).

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Winslow, M.D., K. Okada and F. Correa-Victoria 1996. SIlicon deficiency and tropical rice adaptation. Plant and Soil (accepted)

In Non-refereed Journals

Lentini, Z., Martinez C.P., Sanint L.R. 1996. Se Cultivan Anteras para Mejorar el Arroz. Arroz en Las Americas. 17(1): 2-4.

Lentini Z. 1996. Anther Culture and Genetic Transformation: New Opportunities to Improve Rice with a Broaden Genetic Base. Latinoamerican Rice Forum. 2(2): (In Press).

Morales, F.J., Arroyave, J.A., Velasco, A.C. and Castaño, M. 1995. Caracterización parcial del virus del "entorchamiento" o "necrosis rayada" del arroz en Colombia. Fitopatología Colombiana 1:48-54 (appeared February 1996).

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Okada, K. 1996. Agriculture of South America No.3 Colombia. Agrochemicals(Nouyaku) 43(1):24-27. (in Japanese)

In Books and other types of publications

Chatel, M. 1996. Upland Rice Improvement: Using Gene Pools and Populations with Recessive Male-Sterile Gene. 1994-1995 CIRAD-CA/CIAT Rice Project Report.CIRAD-CIAT document, 31 pages. February, 1996.

Correa-Victoria, F.J. 1996. Diversidad Genetica de *Pyricularia grisea* en Colombia e Implicaciónes en el Desarrollo de Resistencia Durable en Arroz. II Seminario Nacional de Biotecnologia. Universidad del Tolima, 23-25 de Mayo, 1996, *Ibague*, Colombia.

Correa-Victoria, F.J. 1996. Induced Mutations for Developing Sources of Resistance to Rice Blast, *Pyricularia grisea*. Second FAO/IAEA Research Coordination Meeting on Induced Mutations in Connection with Biotechnology for Crop Improvement in Latin America. 21-25 October, 1996, Buenos Aires, Argentina.

Correa-Victoria, F. J., Guimaraes, E.P., and Martinez, C. 1996. Patterns of Genetic Variation in the Rice Blast Pathogen: Breeding for Stable Resistance. 26th Rice Technical Working Group. February 25-28, 1996. San Antonio, Texas.

Lentini Z., Calvert, L., Tabares E., Lozano I., Ramirez B.C., Roca W.M.1996. Genetic transformation of rice with viral genes for novel resistance against rice hoja blanca virus. In Khush G.S. (Ed.). Rice Genetics III. International Rice Research Institute Press. Manila, Philipines. p: 780-784.

Lentini Z., Martinez C.P., Roca W.M. (Eds.). 1996. Rice Anther Culture in Germplasm Development for Latin America and the Caribbean. A handbook. Centro International de Agricultura Tropical(CIAT), Rockefeller Foundation, Fundación Polar. CIAT Press, Cali, Colombia. (In press).

CABI Crop Protection Compendium: Description Rice Hoja Blanca Virus. Ziegler, R. & Calvert, L.A. (In press).

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Sanint, Luis R. 1996. FLAR: Fondo Latinoamericano y del Caribe de Arroz de Riego. En: Arroz Moderno con el Mejor Entorno Ambiental. G. Robayo (ed.). Fedearroz, Bogotá, Colombia.

Pardey, C., Triana, M., Calvert, L.A. Davalos, A. and Reyes, L.A. 1996. Datos preliminares del porcentaje de insectos vectores (*Tagosodes orizicolus* Muir) del virus de la hoja blanca en zonas arroceras de Colombia. SOCOLEM.

Sanint, Luis R. and S. Wood. 1996. Impact of Rice Research in Latin America and the Caribbean during the past three decades. Proceedings of a Conference on Impact of Rice Research. Bangkok, Thailand, June 1996. (In Press).

Sanint, Luis R. Editor, Foro Arrocero Latinoamericano. Twice a year.

Sanint, Luis R. Co-Editor, Arroz en las Américas. Twice a year.

Annex 2

Project #3.
Improved Rice Germplasm for Latin American and the Caribbean
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Annex 3

Investigadores Visitantes
Programa de Arroz - 1996

Funcionario	Empresa	País	Capacitación en:	Fechas
Gabriel Fernando Pardo	Fedearroz	Colombia	Cultivo de tejidos	Enero 28- Feb. 9
Vladimir Cordero	IIA	Cuba	Caracterizaciónde virulencia de patógeno de la pyricularia	Enero 29-abril 29
Jorge Luis Fuentes	Centro de Estudios Aplicados al Desarrollo Nuclear	Cuba	Determinación de la estructura genética de *Pyricularia grisea* por medio de datiloscopia de ADN	Enero 29-abril 29
Luis Guillermo Preciado	Fedearroz	Colombia	Tesis	Abril '96-'97
Olga Lucía Higuera	Fedearroz	Colombia	Evaluación de hongos entomopatógenos para el control de sogata	Abril 30-Dic. 15
Kenneth Seebold	Universidad de Florida	USA	Uso de silicona como alternativa de fungicidas en el control de enfermedades de arroz	Marzo 31-Nov. 30
Vicente Emilio Rey	CORPOICA	Colombia	Evaluación del virus de la hoja blanca	Mayo 27-Junio 7
Martha Jazmín Sánchez	CORPOICA	Colombia	Evaluación del virus de la hoja blanca	Mayo 27-Junio 7
Benjamín Rivera	CORPOICA	Colombia	Evaluación resistencia a hoja blanca	Junio 3-7
Juan Sierra	FEDEARROZ	Colombia	Evaluación resistencia a hoja blanca	Junio 3-7
Julio Holguín	FEDEARROZ	Colombia	Evaluación resistencia a hoja blanca	Junio 3-7
Alberto Dávalos	FEDEARROZ	Colombia	Evaluación resistencia a hoja blanca	Junio 3-7
Roberto Simmonds	CORPOICA	Colombia	Evaluación resistencia a hoja blanca	Junio 3-7
Randolph Campos	Ministerio de Agricultura	Costa Rica	Evaluación resistencia a hoja blanca	Junio 3-7
Edgar Corredor	FEDEARROZ	Colombia	Evaluación resistencia a hoja blanca	Junio 3-7
Oneides Avozani	IRGA	Brasil	Biotecnología de Arroz	Julio 5-20
Liliana Dávalos	Universidad del Valle	Colombia	Tesis de pregrado	Julio '96-'97
Roberto Alvarado	INIA	Chile	Cultivo de anteras y mejoramiento	Agosto 5-17
Rafael Meneses	IIA	Cuba	Programación curso MIP, preparación de materiales y revisión manual	Sept.19-21 y 29 a Oct.4
Luis E. Rivero	IIA	Cuba	Programación curso MIP y preparación de materiales	Sept. 19-21
Andrés Ginarte	IIA	Cuba	Metodologías de evaluación de resistencia a sogata	Sept. 29-Nov. 15
Edis Milena Quintero	Universidad Nacional	Colombia	Aplicación de glifosato	Oct.
María Elena Urdaneta	DANAC	Venezuela	Identificación de razas de *pyricularia grisea* y calidad de arroz	Oct. 1-Nov. 9
Reinaldo Cardona	FONAIAP	Venezuela	Identificación de razas de *pyricularia grisea*	Oct. 1-Nov. 1
María Antonia Marasi	Universidad del Nordeste	Argentina	Transformación genética de arroz	Oct. 10-Nov.
Hernando Delgado	ICA-La Libertad	Colombia	Ejecución y mantenimiento de cruzamientos de arroz	Nov. 18-30
Luis Vega Ramírez	ICA-La Libertad	Colombia	Ejecución y mantenimiento de cruzamientos de arroz	Nov. 18-30

ANNEX 4.

INTERNATIONAL COURSE ON RECURRENT SELECTION
CIAT April 30-July 6, 1996

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