SARP Research Proceedings

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- CNRRI - China National Rice Research Institute, Hangzhou, Zhejiang Province
- JAU - Jiangxi Agricultural University, Nanchang, Jiangxi Province
- ZAU - Zhejiang Agricultural University, Hangzhou, Zhejiang Province

India

- CRRI - Central Rice Research Institute, Cuttack, Orissa
- DRR - Directorate of Rice Research, Hyderabad
- IARI-WTC - Indian Agricultural Research Institute, Water Technology Center, New Delhi
- PUAT - G.B. Pant University of Agriculture and Technology, Pantnagar, Uttar Pradesh
- TNAU-TNRRI - Tamil Nadu Agric. Univ., Tamil Nadu Rice Research Institute, Aduthurai, Tamil Nadu
- TNAU-WTC - Tamil Nadu Agric. Univ., Water Technology Center, Coimbatore, Tamil Nadu

Indonesia

- BORIF - Bogor Research Institute for Food Crops, Bogor
- SURIF - Sukamandi Research Institute for Food Crops, Sukamandi, Subang

Korea

- CES - Crop Experimental Station, Suweon

Malaysia

- MARDI - Malaysian Agric. Research and Development Institute, Kuala Lumpur
- UPM - Universiti Pertanian Malaysia, Serdang, Selangor

The Netherlands

- AB-DLO - Research Institute for Agrobiology and Soil Fertility, Agric. Res. Department, Wageningen
- TPE-WAU - Dept of Theoretical Production Ecology, Wageningen Agricultural University

Philippines

- IRRI - International Rice Research Institute, Los Baños
- PhilRice - Philippine Rice Research Institute, Muñoz, Nueva Ecija
- UPLB - University of the Philippines at Los Baños, College, Laguna

Thailand

- DA - Department of Agriculture, Bangkok
- KKU - Khon Kaen University, Khon Kaen

SARP Research Proceedings

Agro-ecological zonation, characterization and optimization of rice-based cropping systems

Proceedings of the 'SARP Applications Workshop' on the
Application Programs 'Agro-ecological Zonation and Characterization'
and 'Crop Rotation Optimization', held at the
International Rice Research Institute (IRRI), Los Baños, Philippines,
18 April - 6 May, 1994

F.P. Lansigan, B.A.M. Bouman & H.H. van Laar (Editors)

SARP Research Proceedings - December 1994

DLO-Research Institute for Agrobiology and Soil Fertility, Wageningen
WAU-Department of Theoretical Production Ecology, Wageningen
International Rice Research Institute, Los Baños

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Preface

Simulation and Systems Analysis (SSA) are useful tools in agricultural research, development, and extension. These tools are now being used by research collaborators of the SARP (Simulation and Systems Analysis for Rice Production) Project in several Asian national agricultural research centers. Near the end of the third phase of SARP, a 'SARP Applications Workshop' was organized from April 18 to May 6, 1994, at the International Rice Research Institute (IRRI) at Los Baños, the Philippines. At this workshop, emphasis was put on the application of SSA tools by introducing the so-called 'Application Programs' Under the Agro-ecosystems research theme of SARP, two Application Programs were formulated: 'Agro-ecological Zonation and Characterization', and 'Crop Rotation Optimization' (in total, six Application Programs were formulated). This book introduces these two Application Programs (Bouman & Lansigan, Lansigan & Bouman) and documents the relevant presentations given at the workshop. Five papers are presented under 'Agro-ecological Zonation and Characterization', and nine papers under 'Crop Rotation Optimization'. The number of papers on zonation is comparatively small because most research results on this topic were already presented at the International Workshop on Agro-ecological Zonation of Rice at Hangzhou, China (published as SARP Research Proceedings by Bouman et al., 1993). The papers included here address diverse topics such as rainfall mapping (Jeyaraman et al.), Geographic Information System (Pascual & Cablayan), soil data base investigation (Kalra et al.) and economic risk analysis (Pandey). Under 'Crop Rotation Optimization', four papers deal specifically with the modelling of rice-wheat cropping (Singh & Timsina, Timsina et al., Pandey, Sattar). Two papers deal with other specific crop rotations: rice-peanut in the Philippines (Orno & Lansigan), and barley-interplanted corn-rice in Zhejiang, China (Yang Jingping). The last two papers investigate more general crop rotations and include an economic analysis of the whole farming system (Pan Jun, Labios et al.).

The SARP Applications Workshop also see the overlap and transfer of coordinatorship of the Theme Agro-ecosystems from B.A.M. Bouman of AB-DLO (Wageningen, The Netherlands) to F.P. Lansigan of UPLB (Los Baños, Philippines) during the last two years of the SARP project. This volume also demonstrates the working research collaboration between the advanced research institutions (IRRI, AB-DLO and TPE-WAU) and the participating national agricultural research centers (NARCs) in Asia.

We would like to acknowledge the assistance provided by many colleagues and friends in the preparation of this book. Mrs Say Calubiran-Badrina (IRRI) helped in reproducing good quality figures.

Los Baños, Wageningen
December 1994

The Editors

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Part I 'Agro-ecological Zonation and Characterization'

Part II 'Crop Rotation Optimization'

The Application Program 'Agro-ecological Zonation and Characterization'

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Introduction

The Application Program 'Agro-ecological Zonation and Characterization' is part of the SARP-III research theme 'Agro-ecosystems'. The term 'characterization' means the quantification of e.g. potential yield level, climatic yield variation, yield risk, irrigation water needs and growth duration. The term 'zonation' means that this characterization is done on regional to (supra-)national scales. Another way to describe this Application Program is that it entails the application of Simulation and Systems Analysis (SSA) tools in the extrapolation of experimental research on field-level to other spatial and/or temporal domains.

Ideas and methods of using SSA tools in agro-ecological zonation were coordinated at three workshops:

1. SARP Research Planning Workshop, 19 - 21 March, 1992, at IRRI, Los Baños, the Philippines.
2. International Workshop on Agro-ecological Zonation of Rice, 14 - 17 April 1993, Hangzhou, China.
3. SARP Applications Workshop, 18 April - 6 May 1994, at IRRI, Los Baños, the Philippines.

The SARP Research Planning Workshop, 1992

At this workshop, agro-ecological zonation was identified as the main topic of the research theme 'Agro-ecosystems' of SARP-III. The line was set to use crop growth simulation modelling in mapping crop yields (potential, water-limited) on regional scales as function of environmental characteristics, i.e. weather, soil and management practices. Emphasis was put on applied research. The output of the simulation models was to be used for optimizing timing of the crop, crop selection, analysis of temporal variation due to weather, and risk analysis for inputs.

From the discussions, it was concluded that uncertainty and spatial variation in input parameters are important aspects in the application of crop growth models on regional scales. So far in most zonation studies, some representative parameter values are estimated for each land unit under consideration that is considered homogeneous in weather, soil and management practices. These single representative parameter values are then used in the simulation model to produce single, representative yield simulations. Thus, the simulated output does not take into account any uncertainty or spatial variation that might be present in the input data. It was decided at the Planning Meeting that this problem needed to be addressed in SARP-III. Another problem identified for further study was that of data scarcity. Most SARP teams mentioned the lack of input data, especially weather and soil, as a major constraint in applying crop growth models for zonation. Thirdly, the combined use of crop modelling and Geographic Information Systems (GIS) in data base management and mapping of simulation results (and of primary data) was mentioned. It was decided that the SARP project would look for possibilities to provide the teams with a simple GIS package plus training.

At this Planning Workshop, SARP teams presented zonation case-study proposals and work plans for the period 1992-1995 (ten Berge et al., 1994a). SARP staff would focus on the three main issues raised above: uncertainty and spatial variation, data scarcity, and GIS.

The Agro-ecology Workshop, 1993

In April 1993, the Agro-ecology Institute of the Zhejiang Agricultural University in Hangzhou, Zhejiang, China, hosted the International Workshop on Agro-ecological Zonation of Rice. SARP teams presented results of zonation studies in which crop growth models were used to quantify yield potentials on regional scales and to optimize rice-based cropping systems. Some teams presented results by graphs and tables, some teams by manually drawn maps, and some teams by using GIS. The first progress made on the special research issues formulated at the Research Planning Workshop in 1992 was presented and discussed. A method based on Monte Carlo simulation was presented to deal with uncertainty and spatial variation in input data. This method can also be used in case of soil and management input data scarcity, and to guide the set-up of cost- and time-efficient measurement strategies. A new soil water balance model, LOWBAL, was presented for puddled rice soils, especially designed to be used for zonation studies (Bouman, 1993). LOWBAL has a low soil data input requirement that agrees with the scarcity of soil information on regional scales. The Interactive Meteorological data Simulation Program (IMSP) was presented to alleviate weather data scarcity. The link between crop modelling and GIS was addressed by a number of researchers that used similar concepts of integrating the two techniques. Generally, GIS was used as a sophisticated means to store and manipulate data that are required as input by the crop growth models. Data were extracted from GIS per 'mapping unit', the crop model was run, and the simulation results were returned to the GIS for mapping. The same data manipulation can be done manually, though it is more cumbersome. Unfortunately, it had to be concluded at this Workshop that the provision of a simple GIS package to all SARP teams fell outside the scope of the SARP-III project. However, SARP teams that had access to GIS of their own could be supported by IRRI.

The results of the work presented at this Workshop, and of other SARP work done on the topic of Agro-ecology of rice, were published as SARP Research Proceedings (Bouman et al., 1993).

The SARP Applications Workshop, 1994

The first week of this workshop was dedicated to updating of all SARP team members with newly developed models and tools. Especially relevant for the Zonation Application Program were the SARP Shell, the program RIGAUS (Random Input Generator for the Analysis of Uncertainty in Simulation), IMSP (Interactive Meteorological data Simulation Program), and the rice growth models ORYZA1 and ORYZA_W. Exercises were made to get familiar with these new tools. A general procedure to use crop growth modelling in zonation studies was presented and adopted as Common Framework (see below: a Common Framework for Zonation). An introduction was given to methods of linking crop growth simulation results (on regional scale) with tools of economic (risk) analysis.

In the second week, short zonation case-studies were performed by 'country' groups using the developed Common Framework: Bangladesh, China, India and the Philippines. The emphasis of these case-studies was to quantify the effect of uncertainty and spatial variation in model input parameters on simulation results (yield probability distribution; risk analysis). The results of the case-studies were compared and discussed among the country groups. Based on the new experiences and insights gained, new team workplans and case-study proposals were developed and old ones updated. The link of simulation results with economic analysis was picked-up as new topic for the next two years.

The third week was spent on further exercises with the new tools and models and on preliminary work on team case-studies. The results of this Workshop (case-study results, team workplans, AP program plan) were plenary reported.

A Common Framework for Zonation

Figure 1 is explained as follows. Any regional study is characterized by some overall objectives, e.g. 'optimizing rice cropping systems'. From this overall objective(s), one or more 'specific' zonation objectives can be formulated that can be addressed with SSA tools, e.g. the quantification of potential yield level, of yield gap, or of irrigation water needs. Based on these specific objective(s), a suitable crop growth model and appropriate tools can be selected. For example, the 'quantification of potential yield level and irrigation water needs' requires a crop growth model for irrigated situations with a water balance component, i.e. ORYZA_W. The choice of the crop growth model puts requirements on the input data that should be available. In the example of ORYZA_W, soil data should be available for the water balance model, next to weather, crop and management data. When no soil data are available, either these data should be collected, or another model should be selected that

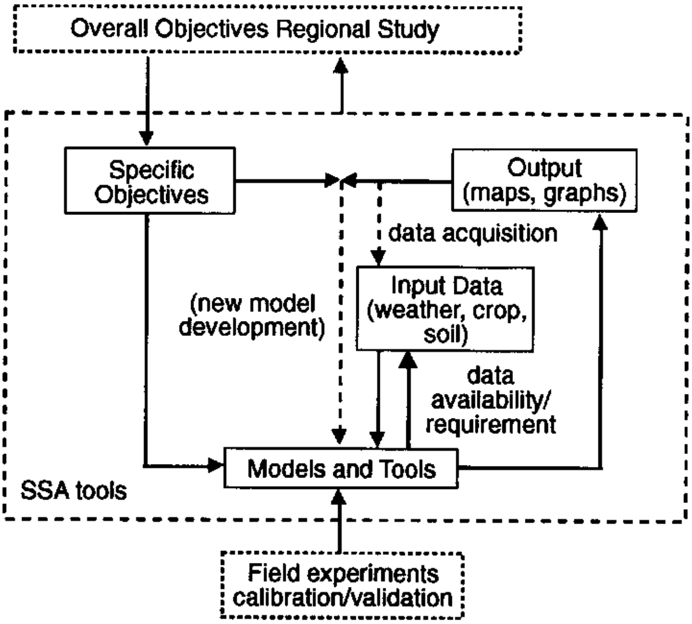

Figure 1. Diagram of the Common Framework for the use of SSA tools in agro-ecological zonation.

can be run with the data that are available. In the first option (data collection), simple sensitivity analysis with the model can help to select the type of parameters and the accuracy with which they need to be collected to satisfy the specific objectives of the zonation study. The second option, when there is no possibility to collect new data, will usually mean that part of the specific objectives can not be satisfied. For instance, when no soil data are available, the model ORYZA1 for potential production (but without water balance) has to be used instead of ORYZA_W, which means that the 'potential yield levels' can be quantified but not the 'irrigation water needs'. When a suitable model has been selected, and input data gathered, simulation runs can be made and output produced in the form of graphs, tables and maps. With the program RIGAUS (see below), the effect of uncertainty or spatial variation in input parameter values (soil, management) on simulated output can be quantified. Simulation output then takes the shape of probability distributions that can be used for risk analysis. The produced output has to be compared with the specific objectives of the study. When these objectives are met, the results can be used to satisfy part of the overall objectives of the case-study. When the specific objectives are not met, e.g. the accuracy of the simulation results does not satisfy pre-set accuracy levels, two possibilities exist. First, it can be concluded that additional data acquisition needs to take place (e.g. to enhance the simulation accuracy, or to be able to use a more suitable model). Second, it may be concluded that none of the available models and tools are satisfactory and that additional model development needs to be done.

Stepwise, the Common Framework consists of the following activities:

1. Define the overall objectives of the zonation study.
2. Derive the specific objectives to tackle with SSA tools.
3. Select an appropriate model based on the specific objectives and on the available (or collected) input data; compilation of input data (use IMSP or SIMMETEO to generate additional weather data if necessary, e.g. 25 years).
4. Run the model using all years of available weather data; the input data are single parameter values that are representative for each of the basic land-units of the zonation study; the simulated output quantifies the effect of variation in weather.
5. Select the best, an average and the worst year (in terms of e.g. yield) and perform Monte Carlo simulation for each of these three years: estimate probability distributions for the soil and management input parameters (instead of single representative values); use RIGAUS to generate a large number of rerun sets (about 100); run the model. The output is a probability distribution that quantifies the uncertainty and/or spatial variation in the input parameter values. If necessary, repeat this procedure for some more years.
6. Summarize the outputs of steps 4 and 5 in the form of maps, graphs and tables; analyse the output (e.g. risk-analysis). The output of step 5 is especially useful to explore and optimize management options under different environmental conditions (soil, weather).
7. Compare the output with the specific objectives stated in step 2. Decide whether the results are satisfactory or whether the simulations need to be repeated with additional input data or with improved models.

Step 4 is carried out for each identified land-unit of the zonation study. Step 5 can be limited to a small number of land-units that are representative for different agro-ecological zones in the study area. When the area of the zonation study is relatively small and all land-units fall in comparable agro-ecological zones, step 5 may even be limited to only one land-unit.

The models currently available in SARP for zonation of rice are:

- ORYZA1 for potential production (Kropff et al., 1994). Input data requirements are weather data (daily values of minimum and maximum temperature and of solar radiation), crop data and management data.
- ORYZA_W for irrigated and rainfed lowland and for rainfed upland (ORYZA_W description, 1994). For lowland (puddled soil), the above-ground crop growth model is linked with the soil water balance LOWBAL; for upland, with SAHEL. Input data requirements are weather data (daily values of minimum and maximum temperature and of solar radiation, wind speed, vapour pressure and rainfall), crop data, management data and soil data.
- ORYZA_0 for nitrogen-limited production (ten Berge et al., 1994b). Input data requirements are weather data (daily values of minimum and maximum temperature and of solar radiation), crop data, management data and soil data [crop, management and soil data are less extensive than for ORYZA1 and ORYZA_W].

The following tools are available:

- SARP-Shell (Riethoven, 1994). This Shell is a user-friendly menu system that facilitates model selection, model running, input data handling, and output manipulation and presentation (tables, graphics, simple statistics).
- RIGAUS (Random Input Generator for the Analysis of Uncertainty in Simulation; Bouman & Jansen, 1993). This program enables the user to study the effects of uncertainty and/or spatial variation in input parameter values on simulated model output. For each model parameter, a statistical probability distribution can be chosen instead of a single value. A model rerun set is generated that can be used for Monte Carlo analysis. The output of this Monte Carlo simulation is a probability distribution of the simulated variables, e.g. yield, that quantifies the effect of uncertainty and/or spatial variation in the input parameter values. RIGAUS and Monte Carlo simulation are options under the SARP-Shell.
- IMSP (Interactive Meteorological data Simulation Program; Lansigan & Casumpang, 1993), a user-friendly and enhanced version of the weather generator software SIMMETEO (Simulation of Meteorological Variables) by Geng et al. (1988). This weather generator is also menu driven, but not yet an option under the SARP Shell.

Input data need partly be collected for each case-study separately, and have partly been collected during the course of the SARP project. Weather data need to be collected for each environment separately. To use the data in the simulation models, they should be put in the WEATHER format (van Kraalingen et al., 1990). Currently at IRRI, a large weather data base is stored in the CLICOM system and conversion software is available to convert the data in the correct format. Soil data should also be collected for each area specifically. When no actual field measurements can be carried out, parameter values may be estimated from information on soil maps. For the soil data for the SAHEL water balance (upland), empirical relations have been derived between some model input parameters and soil texture classes (derived from Dutch soil types). For 18 soil texture classes, ranging from coarse sand to silty clay, standard input data sets are available (Bouman et al., 1994). For the water balance LOWBAL, no data base is yet available. Management parameters have to be estimated from expert-knowledge, or may be obtained by field-inquiries. Crop data have been collected for a number of rice varieties from field-experiments by various SARP teams in the 'Potential Production' and 'Crop and Soil Management' research themes.

Workplan 1994-1995

At the SARP Applications Workshop, nearly all SARP teams proposed a case-study on agro-ecological zonation of rice or of another crop of rice-based cropping systems. The emphasis is on the application of the developed software. The Common Framework as described above will be used as main methodology. A new topic that will be pursued by a number of teams is the link between the simulation output of zonation studies and economic

Table 1. Summary of planned SARP activities in the 'Agro-ecological zonation and characterization' Application Program, 1994 - 1995. For description of the acronyms see the introductory pages of this volume (participating organizations in SARP).

1. Comparative analysis of Agro-ecological Zones
Lead teams: TNRRI, CRRI, CNRRI, ZAU, BRRI, UPLB, PhilRice, BORIF, SURIF

2. Yield gap analysis and evaluation of yield potential and yield variation
Lead teams: TNRRI, TNAU-WTC, CRRI, UPLB, PhilRice, BRRI, ZAU

3. Linking simulation results with economic analysis tools
Lead teams: TNAU-WTC, IARI, CNRRI, ZAU, UPLB, PhilRice

(risk) analysis. Table 1 summarizes the major planned activities in agro-ecological zonation of the SARP teams. SARP staff will support team case-studies where necessary, and perform own case-studies for further methodology development (namely the link with economic analysis tools). Further software development will take place, e.g. improvement of ORYZA_W, incorporating IMSP/SIMMETEO under the SARP Shell, economic analysis tools. Moreover, links will be made between the SARP simulation software and international standardized data base structures, such as DSSAT.

The output aimed for by the end of SARP-III (December 1995) is:

- Software of SSA tools in agro-ecological zonation of rice, i.e. zonation-dedicated rice growth models (ORYZA series), weather data generator (IMSP), RIGAUS, zonation-dedicated SARP-Shell options, interfaces with international standardized data bases.
- Manual on 'Crop growth modelling in agro-ecological zonation of rice' (SARP Research Proceedings).
- Description of ORYZA_W (together with Crop and Soil Management theme; SARP Research Proceedings).
- Methodologies to link simulation output on regional scales with economic analyses tools (Manual; case-study descriptions).
- Finished case-studies (SARP teams, SARP staff); reports, scientific papers.

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Rainfall mapping and cropping strategy in dry farming tract of Tiruchirapalli District, Tamil Nadu, India

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Abstract

Monthly rainfall data of 21 locations in Tiruchirapalli district, Tamil Nadu, India of the period 1961 - 1974 were used to stratify the district into so-called 'rainfall zones'. These rainfall zones and current cropping systems in the district are discussed. New crops and cropping patterns are proposed for the dry farming tracts, based on soil type, rainfall zone and cropping systems research.

Introduction

Tiruchirapalli is one of the 22 districts of the state of Tamil Nadu, India, located between 10° 15' N and 11° 39' N latitudes and 77° 32' E and 79° 45' E longitudes. The 'dry farming tract' constitutes nearly 69% of the total area of 1.113 million hectares, and occurs in almost all of the 10 taluks (administrative divisions) of the district, namely: Karur, Manaparai, Kulithalai, Musiri, Thuraiyur, Tiruchi, Lalgudi, Udaiyarpalayam, Ariyalur and Perambalur (Figure 1).

The major soil groups found in Tiruchirapalli are light textured red soils (70%), heavy textured black soils (23%), and medium textured alluvial soils (7%). Saline and alkaline (sodic) soils occur in about 4000 hectares in a few pockets (Ramu et al., 1988). The red soils mainly occur in Karur, Kulithalai, Udaiyarpalayam, Manaparai, Ariyalur and Musiri taluks, and the black soils in Perambalur, Ariyalur, Thuraiyur, Lalgudi and Musiri taluks. These red and black soils occur predominantly in dry farming tracts. The black soils are more productive than the red soils. Black soils have a capacity to store as much as 300 mm water in one meter depth, whereas light textured red soils can only store 100 - 150 mm water (Singh & Reddy, 1988). Alluvial soils are found in Tiruchi, Lalgudi, Ariyalur, Kulithalai, Musiri and Karur taluks adjoining the Cauvery river.

Tiruchirapalli district receives rainfall mainly from the Northeast monsoon (NEM), and to a lesser extent from the Southwest monsoon (SWM). The mean annual rainfall for the district is 842 mm and ranges between 650 - 1022 mm (Ramu et al., 1988). The normal onset of the SWM is during the second fortnight of June, and withdrawal is at the end of September. The onset of the NEM is during the first week of October, and withdrawal is during the last week of November. Rainfall from the SWM (June - September) averages

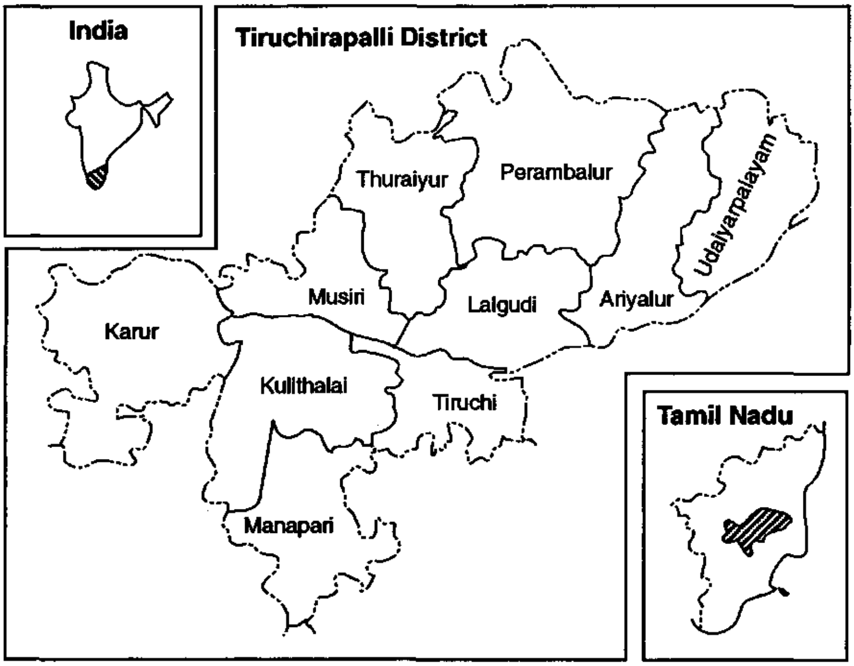

Figure 1. Location map of Tiruchirapalli district with its 10 taluks, Tamil Nadu, India.

273 mm, and that from the NEM (October - December) 395 mm. Average rainfall during winter (January - February) is 41 mm, and during summer (March - May), 134 mm. The weekly rainfall distribution suggests that a possible growing season for this district is from July to December. The effective cropping season in Karur, Manaparai, Kulithalai, Musiri, Thuraiyur taluks ranges from the first fortnight of September to the first fortnight of December, whereas it ranges from the second fortnight of August to the first fortnight of December in the other taluks of the district (Jeyaraman et al., 1987).

Rainfall zone mapping will be helpful in identifying the potentials and constraints for crop production in rainfed areas. The objective of this paper is to determine the rainfall zones of Tiruchirapalli district and to find the suitability of these zones for rainfed cropping systems.

Material and methods

Historical records of monthly rainfall from 1961 - 1974 for 21 locations in Tiruchirapalli district were collected from the Department of Statistics, Government of Tamil Nadu, Madras. These data were used to draw maps of monthly and annual rainfall zones using the Geographic Information System (GIS) facilities at IRRI (International Rice Research Institute). A GIS permits the digital storage, processing and display of geo-referenced data.

Digital maps can be stored and displayed that give thematic information such as soil, land-use, or rainfall maps (Rajan, 1991).

Suitable crops for the different rainfall zones of the district were determined from published information on cropping systems. For example, Oldeman & Frère (1982) found that the water requirements for dryland crops (e.g. rainfed rice) are satisfied when the monthly precipitation is at least 92 mm. These values are comparable to the definition of a dry month (less than 100 mm) as proposed by IRRI (1974) and Oldeman (1980). Values of 75 mm cumulative rainfall correspond to the approximate amount of rainfall necessary for emergence and early growth of rainfed rice (Oldeman & Frère, 1982). Monthly precipitation should be at least 200 mm for three consecutive months to allow cultivation of rainfed rice. A wet period of five to six months is considered sufficient to grow two crops of rice, provided that the first crop is sown directly prior to the onset of the wet period (Oldeman & Frère, 1982). If the dry season lasts for four to six months, a fallow period is unavoidable but two crops in sequence are possible. A dry season of seven to nine months, or a growing period of three to five months, allows the cultivation of only one crop. If the dry period lasts more than nine consecutive months, the area is not suitable for growing crops without an additional source of water (Oldeman & Frère, 1982).

Results and discussion

Rainfall zones

The mean monthly and annual rainfall of the 21 locations in Tiruchirapalli are presented in Table 1.

The monthly rainfall data show that January to July are dry months with rainfall less than 92 mm. The monthly and annual rainfall maps show distinct rainfall zones in Tiruchirapalli district. In July, the taluks of Udaiyarpalayam, Lalgudi, Tiruchirapalli and part of Thuraiyur and Manaparai receive, on the average, more than 70 mm rainfall. In August, the taluks of Ariyalur, Udaiyarpalayam, and part (Marungapuri) of Manaparai receive more than 100 mm of monthly rainfall. During September to November, all taluks receive at least 100 mm rainfall per month. In December, only Tiruchirapalli, Lalgudi, Ariyalur, and Udaiyarpalayam receive rainfall of more than 100 mm while the other taluks receive 48 - 90 mm. Based on the historical annual rainfall pattern, the whole district may be divided into three rainfall zones (Table 2).

According to Oldeman & Frère (1982), Tiruchirapalli district has been further classified into three divisions based on the distribution of wet and dry months (Table 3).

Cropping systems in dry farming regions

Diversity in crops and cropping systems helps to overcome the risks involved in dry farming under erratic climatic conditions and with incidence of pests and diseases. It also can help to effectively utilize the available resources.

Table 1. Average monthly and annual rainfall (1961 - 1974) in mm at different locations in Tiruchirapalli district, Tamil Nadu.

Location	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Tiruchirapalli	21	23	11	18	52	21	78	80	177	206	160	110	957
Lalgudi	20	22	18	33	65	37	73	80	198	165	177	119	1006
Pullambadi	18	20	20	24	38	29	69	74	163	192	170	114	930
Musiri	13	13	13	29	53	30	50	62	141	202	129	75	808
Thathaiyangarpettai	9	13	14	33	35	17	45	68	110	174	113	78	708
Thuraiyur	9	16	13	28	45	37	71	88	166	229	127	73	901
Uppiliyapuram	20	24	19	35	54	35	53	85	162	157	112.	78	836
Perambalur	24	22	19	34	49	37	62	85	170	206	107	79	893
Chettikulam	20	17	16	21	31	24	43	66	168	183	102	70	761
Ariyalur	17	19	22	20	62	53	52	141	174	169	167	120	956
Thirumanur	23	18	10	32	43	38	63	62	148	203	152	107	898
Jeyankondacholapuram	23	21	11	19	64	40	61	129	131	216	176	124	1016
Karur	11	11	15	32	55	20	50	52	151	158	115	56	725
Aravakurichi	13	15	10	27	36	10	39	40	125	187	124	62	688
Kulithalai	12	17	27	28	53	32	61	61	156	186	123	67	823
Kadavur	14	18	8	34	47	19	29	47	113	148	119	54	650
Panchappatti	15	13	7	21	41	24	31	52	133	170	104	55	667
Palaviduthi	17	16	8	21	25	30	26	52	160	139	107	49	648
Manaparai	20	20	10	30	52	46	58	73	174	159	124	80	850
Marungapuri	19	12	17	41	66	54	77	101	168	228	134	89	1006
Udaiyarpalayam	23	24	14	20	64	35	99	118	162	152	186	126	1023

Table 2. Division of the taluks of Tiruchirapalli district into rainfall zones based on average annual rainfall.

Zone	Rainfall (mm)	Taluks in the district
I	> 900	Udaiyarpalayam, Ariyalur, Lalgudi, Marungapuri, part of Manaparai
II	700 - 900	Perambalur, Tiruchirapalli, Thuraiyur, part of Kulithalai, Musiri
III	< 700	Part of Kulithalai, Musiri, and Karu

Existing Cropping Systems

Mixed cropping of sorghum, pearl millet and groundnut with pulses like red gram, cowpea, green gram, black gram and field lab-lab is practiced in the red soil areas. Besides rainfed rice, little millet (samai), foxtail millet (tenai), and horse gram are grown as single crop in some pockets. In black soil areas, mixed cropping of cotton, sorghum and pearl millet with minor millets, coriander and pulses is practiced. Single crops of cotton, chillies, coriander

Table 3. Division of taluks of Tiruchirapalli district based on wet and dry months.

Number of wet months (>100 mm rainfall)	Number of dry months (<100 mm rainfall)	Taluks in the district
5	7	Udaiyarpalayam, Ariyalur
4	8	Tiruchirapalli, Lalgudi, Marungapuri, part of Manaparai
3	9	Kulithalai, Manaparai, Karur, Musiri, Thuraiyur, Perambalur

and horse gram are found in some areas. The traditional long duration sorghum varieties Makkatti, Thalaivirichan and Chencholam are still grown under rainfed conditions. In Udaiyarpalayam and Ariyalur taluks, rainfed rice is grown using the local varieties Kalayan Samba and Kattasamba (Anon., 1988; Jeyaraman et al., 1987). Double cropping of pulses or sesame followed by coriander or horse gram, and pulses followed by sunflower is also practiced (Anon., 1988).

Proposed Crops and Cropping Systems

Improved drought-tolerant crops and varieties can be grown instead of the traditional ones for better utilization of the available resources, particularly rainfall and stored soil moisture. For instance, pearl millet is more drought tolerant than sorghum, and sunflower is more water-use efficient than groundnut and pigeon pea (Venkateswaralu, 1990). Water melon can also be grown in black soil areas under rainfed conditions.

The rainfall pattern, soil depth and soil type together determine the moisture availability period, and thereby the choice of crops and cropping systems. In shallow and medium deep red soils, only single cropping is possible. Single cropping can be taken up in areas with 600 mm rainfall during the rainy season where the average length of the growing season does not exceed 20 weeks, and with 100 mm water holding capacity of the soil (Venkateswaralu, 1990). Inter cropping is generally suitable in regions with annual rainfall ranging between 625 - 800 mm on soils with a water holding capacity of 150 - 200 mm (Venkateswaralu, 1985). Inter cropping in drylands avoids the difficulty of having to establish a second crop after the first crop as in sequential cropping. Therefore, where there are risks associated with establishing a second crop, intercropping is usually a good alternative, and is certainly much more stable in terms of production. Double cropping is possible in areas that receive more than 800 mm of rainfall with a soil moisture storage capacity of more than 250 mm (Venkateswaralu, 1990). The amount of pre-monsoon rainfall determines the possibility for double cropping on deep red and black soils. The success of a sequential cropping system depends on the duration of the first crop. Chillies or pulses followed by

Table 4. Cropping pattern in drylands based on rainfall distribution as suggested by Singh & Reddy (1988). WHC = water holding capacity.

Zone	Annual rainfall (mm)	Effective growing season (months)	WHC of soil (mm)	Cropping pattern
I	350-600	< 4.6	100	Single or mixed cropping of pearl millet and pulses
II	600-750	4.6-7.0	200	Intercropping of sorghum, pearl millet, castor or groundnut with pigeon pea
III	750-900	> 7.0	250	Double cropping with monitoring sorghum-coriander/horsegram
IV	> 900	> 7.0	250-300	Double cropping assured groundnut -sorghum ; cotton - blackgram/ foxtail millet Sorghum-cowpea/clusterbean

coriander or sunflower is one such popular crop sequence in dryland areas. Singh & Reddy (1988) suggested the following cropping patterns for drylands based on rainfall distribution (Table 4).

Here, a new dryland cropping pattern is proposed for Tiruchirapalli district, based on the suggestions in Table 4, to optimally benefit from rainfall received during the Southwest and Northeast monsoons as well as from residual moisture available at the end of the monsoons (Table 5). In general, sowing can be done during July - August for better utilization of the available rainfall. With normal (average) rainfall during July - August, intercropping of sorghum or pearl millet with pulses, or single cropping of sesame, can be practiced in both red and black soil areas. Groundnut plus red gram combinations can be grown in red soils. Intercropping of cotton with pulses, or single cropping of chillies, rainfed rice or watermelon can be practiced in black soil regions. On these soils, the broad-bed cum furrow method can be adopted for growing two rows of sorghum, pearl millet or cotton with one row of cowpea or black gram. In double cropping areas, the first crop can be grown up to July - August, while the second crop can be grown in October - November. Alternative cropping patterns can be adopted to utilize rainfall received during August to November as well as the residual moisture available up to December. The suggested crops and new cropping systems in Table 5 may be effectively practiced to improve the socio-economic conditions of the farmers in Tiruchirapalli district.

Table 5. Proposed dryland cropping pattern for Tiruchirapalli district. WHC = water holding capacity.

Zone	Annual rainfall (mm)	WHC of soil (mm)	Soils	Cropping pattern	Area in Taluks
I	>900	200-300	Black soil	Single cropping of Rainfed rice, Finger millet, Vegetables, Sesamum. Intercropping of Cotton + Blackgram Sorghum + cowpea/Lab lab Double cropping of Pulses/ Chillies - Coriander Sunflower - Coriander	Lalgudi
		100-200	Red soil Laterite soil	Intercropping of Groundnut + Redgram/ Lab lab Sorghum/pearl millet + Redgram	Udaiyarplayam Ariyalur
		100	Hilly areas	Grasses + fodder trees	Marungapuri (area of Manaparai)
II	700-900	200-300	Black soil	Intercropping of Sorghum + Pulses Cotton + Blackgram Groundnut + Sunflower Single cropping of Chillies, Sunflower Coriander, Sesamum, Sorghum	Perambalur Tiruchirapalli Thuraiyur
		100-200	Red soil Laterite soil	Intercropping of Groundnut + redgram Sorghum/Pearl millet + redgram/cowpea/lab lab	Musiri Thuraiyur Kulithalai Tiruchirapalli
		100	Hilly areas	Grasses + fodder trees	Thuraiyur
III	<700	100-200	Red soil	Single or mixed cropping of Sorghum/Pearl millet + redgram/cowpea/lab lab	Karur, Musiri Manaparai Kulithalai
		100	Hilly areas	Grasses + fodder trees	Kadavur area of Manaparai

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Computer Aided Mapping Program (CAMP): A Geographic Information System for identifying areas under irrigation that are suitable for diversified crops

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Abstract

This paper presents a computerized methodology to identify areas suitable for irrigated diversified crops under the service area of an irrigation system. The methodology uses techniques developed for Geographical Information Systems (GIS) for the digital capture of spatially related data (maps). The developed methodology called *Computer Aided Mapping Program* (CAMP) was developed for the ADB funded project *Irrigation Management for Crop Diversification (TA 859 PHI)*. CAMP has the capability to superimpose line maps with thematic maps, and to derive new thematic maps by overlaying existing maps. It can be used for efficient storage, retrieval, output analysis and editing of maps. In a case-study for the Allah River Irrigation Project-1 (ARIP-1) on Mindanao, Philippines, CAMP was successfully used to identify areas with different suitabilities to irrigated diversified crop land. CAMP could be linked with crop simulation models to conduct agro-ecological analyses of rice-based cropping systems.

Introduction

Most irrigation systems in the Philippines and in Southeast Asia are run-of-the-river type. Such systems consist of dams to raise water in rivers or creeks for diversion to the canal network. These systems were mostly designed to serve irrigated lowland rice. In the wet season, these irrigation systems have reliable water supply for the entire service area for lowland rice planting. In the dry season, water is limited and only a part of the system, mostly lowland rice, can be served. Cultivation of upland crops, that use less water than lowland rice, could increase the irrigated area in the dry season. Recently, plans to include irrigation of diversified crops were considered in the construction of irrigation systems in the Philippines. Therefore, a methodology is needed to identify areas that are suitable for upland crops. Identifying potentially suitable areas for diversified cropping using computers is relatively new in irrigation systems design and management. Gines & Kaida (1982) have developed a methodology which is macro in scope for classifying land suitability in relation to its potential for multiple cropping system in some areas in Central Luzon.

Computer Aided Mapping Program (CAMP)

Computer software designed to handle spatial data is called a Geographical Information System (GIS). It is concerned with the digital capture of spatially related data and their linkages relative to one another (Tomlin, 1980). Specifically, GIS deals with the query, analysis, reporting and output of these data (Archibald, 1986). A GIS is a set of computer programs which provides encoding, storage, analysis and output of spatially related information (Figure 1). Maps on soil types, land use, topography, and other spatial and physical data are inputs to the GIS. Using these map inputs and a set of classification rules, the suitability of areas to upland crops can be determined. The outputs of a GIS are then maps showing the suitability of different areas in the irrigation system for diversified crops. There are two kind of maps in a GIS: graphics or line maps, and thematic maps. A graphics map consists of lines representing for instance roads, rivers or creeks. In a thematic map, areas that are enclosed by polygons are (colour-)coded to represent certain themes, e.g. soil types, land suitability class.

CAMP (Computer Aided Mapping Program) is a menu-driven GIS package developed and written in BASIC. First, relevant source line-maps need to be digitized to serve as input in the computer. Source maps may be contour maps, soil maps or maps showing the hydrology of the area (rivers, creeks, canals, drains). The maps are divided into grids of 1.0 mm width. This is easily done by re-drawing the source map on an appropriate sized cross-section paper. After source maps have been entered, sub-programs enable the user to convert these line maps into thematic maps (rasterization). The thematic maps are then overlaid to produce interactions of different map attributes. Output of CAMP are new line or thematic maps, showing e.g. a suitability classification of the area for upland crop. The resolution

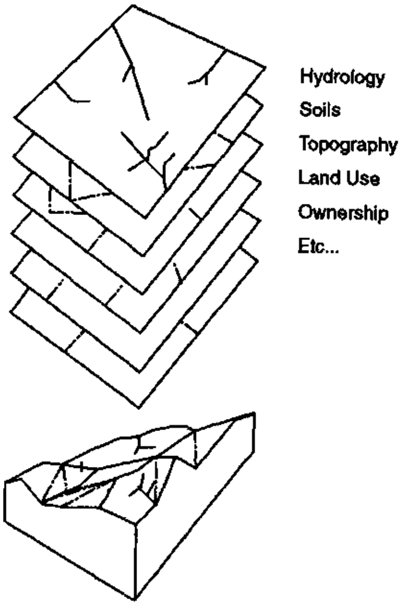

Figure 1. Conceptual framework of spatially related information 'layers' in a Geographic Information System. Source: Cablayan & Pascual, 1989.

(lowest measurable distance between lines) of output line maps is 0.1 mm, and that of output thematic maps 1.0 mm. The output map of CAMP has a maximum dimension of 34 x 25 cm. The scale of the output maps can be determined from the scale of the source maps. The input medium is the key board and the output medium is a Roland DG DXY 880A Plotter (equivalent to the Hewlett Packard series 3000 Plotter). The microcomputer should be an IBM PC-AT or equivalent.

Allah River case study on Mindanao

The Allah River Irrigation Project-1 (ARIP-1) of the Philippine National Irrigation Administration involved the construction of two diversion dams across the Allah River to provide irrigation water to 18812 ha of rice and corn lands in the provinces of South Cotabato and Sultan Kudarat in Mindanao. The dams became fully operational in 1990. The whole service area can be supplied with sufficient irrigation water for rice in the wet season, but in the dry season, there is only sufficient water for about one-third of the area. The irrigated area in the dry season may be increased through the introduction of diversified (upland) crops. In this paper, land use suitability for diversified crops in the dry season is considered for the ARIP Dam No. 1 area. CAMP was used to digitize source maps (soil type, topography and pre-project land-use) and to overlay these maps to arrive at a suitability map for diversified crops.

Pre-project land use

The ARIP Dam No. 1 area had four general land use classes before the project for diversified crops started (Figure 2). Residential areas comprised 101 ha, coconut areas 145 ha, corn areas 3948 ha and rice areas 4376 ha. Regardless of soil type, areas planted to corn

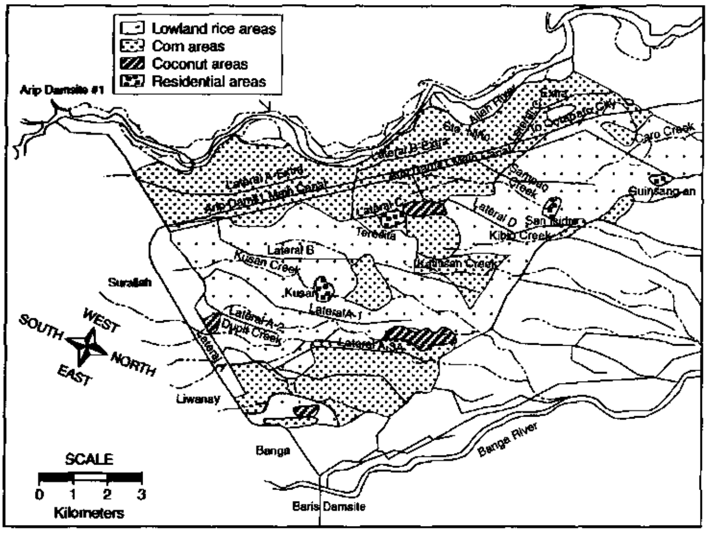

Figure 2. Pre-project land use map of the Allah River Irrigation Project-1 (ARIP-1). Source: Cablayan & Pascual, 1989.

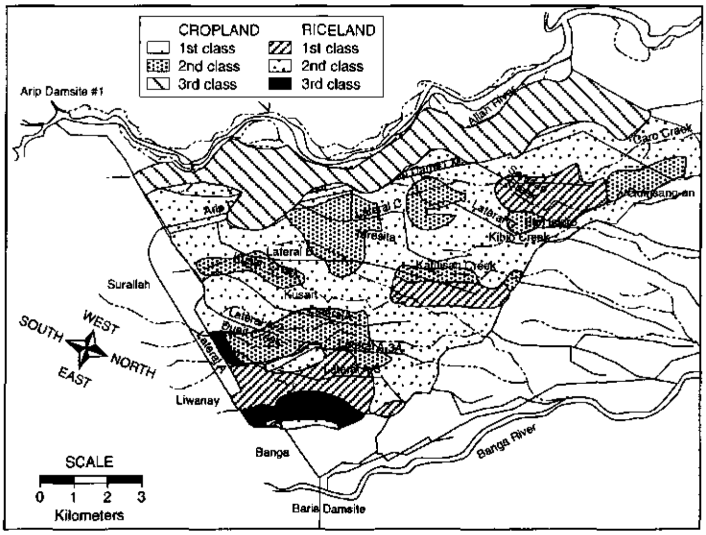

Figure 3. 'Intermediate' land suitability classification map for irrigated Rice Land (RL) and non-irrigated Diversified Crop Land (DCL). Allah River Irrigation Project-1 (ARIP-1). Source: Cablayan & Pascual, 1989.

and coconut were characterized as having good drainage, whereas areas planted to rice had good to poor drainage.

'Intermediate' land use suitability

Based on the (digitized) soil and topography maps an 'intermediate' land suitability map was obtained for rice land (RL) and for non-irrigated diversified crop land (DCL) (Figure 3). Each of these two land use types was classified as highly, moderately, and marginally suitable (Table 1).

Non-irrigated Diversified Crop Lands (DCL) Marginally suitable DCLs were found near the banks of the Allah River. They had very light textured soil (sandy loam) with slopes of 0 - 2%. With adequate irrigation, they can become highly suitable DCLs during the dry season, and moderately suitable RLs during the wet season. Moderately suitable DCLs had sandy clay loam soil with slopes of 0 - 1%. With sufficient irrigation, they can become highly suitable DCLs during the dry season and highly suitable RLs during the wet season. Highly suitable DCLs had a clay loam soil with slopes of 0 - 1%, and will have the same suitability classification under irrigated conditions.

Rice Lands (RL) Marginally suitable RLs had clay to clay loam soil and were either low-lying, flat lands near drainage waterways, or had very steep slopes which need to be leveled before they can be planted to (lowland) rice. Moderately suitable RLs had clay loam to sandy clay loam soil, and were relatively flat lands with poor to good drainage and high water tables during the wet season. Highly suitable RLs had clay to clay loam soil with good drainage.

Table 1. 'Intermediate' land use suitability classification in the area of Allah River Irrigation Project Dam No. 1.

Land use Type	Area (ha)
Ricelands (RL)	5300
Highly suitable ricelands	1080
Moderately suitable ricelands	3980
Marginally suitable ricelands	240
Diversified croplands (DCL)	3260
Highly suitable ricelands	40
Moderately suitable ricelands	1470
Marginally suitable ricelands	1750
Total Service Area	8560*

*Includes areas occupied by roads, irrigation canals and creeks.

Land use suitability for irrigated Diversified Crop Land in the dry season

The final suitability map for irrigated Diversified Crop Land was obtained by combining the pre-project land use map, Figure 2, with the (intermediate) suitability map derived from soil and topography, Figure 3 (Figure 4). Existing corn and coconut areas were classified as highly suitable for irrigated crop diversification in the dry season, regardless of soil type. Highly suitable rice land were well drained and were classified as moderately suitable. Marginally and moderately suitable rice lands had good to poor drainage, and were classified as marginally suitable. Areas classified as (non-irrigated) diversified crop land were also classified as highly suitable, regardless of pre-project land use.

The total area classified as highly suitable for irrigated crop diversification in the dry season was 5274 ha, that as moderately suitable 587 ha, and that as marginally suitable 2601 ha. For a more accurate classification, drainage characteristics should be well defined and used in the classification procedure.

Linking CAMP and crop simulation modelling

Regional application of models requires a means to extend point-information over wider geographic areas and to combine data sets from different disciplines. Combining GIS and crop growth simulation modelling offers possibilities for the interpretation of extensive data sets derived from various disciplines to answer questions at the regional level (Wopereis,

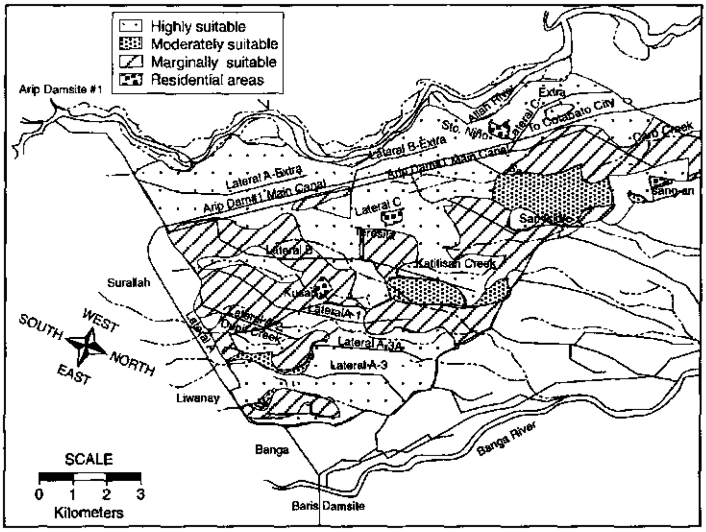

Figure 4. Land suitability classification map for irrigated Diversified Crop Land in the dry season. Allah River Irrigation Project-1 (ARIP-1). Source: Cablayan & Pascual, 1989.

1993). It can help in the extrapolation of research results and in the identification of research priorities. Crop growth models need to be tested at carefully selected key sites. These key sites should represent the full range of situations for water-limited, nitrogen-limited and pest/diseases-limited production. Testing implies improvement of the models and often a better specification of the data input (Wopereis, 1993).

The main pre-requisites for linking a GIS such as CAMP and crop simulation models include the following:

1. A set of spatial databases of soil, weather, and land use attributes, and a relational database management system,
2. Crop growth models such as MACROS (Penning de Vries et al, 1989) or POLYCROP (Garcia, 1993),
3. A facility that allows the production of thematic maps from the model simulation results,
4. A strategy evaluation system that uses the crop models and soil and weather database for extrapolations and predictions,
5. A friendly, menu-driven interface designed to facilitate the interaction of users with the combined systems.

Conclusions and recommendations

CAMP was successfully used to identify areas with different suitabilities to diversified crop land in the case study conducted. It can produce thematic maps overlaid with line features, like roads, canals and creeks for easier identification of canal networks serving the different areas. CAMP output can be readily used by irrigation managers for planning. There are other uses of CAMP. It could be used to store maps for future references. Storage of maps in computer files provides easy access, retrieval, and addition of new features and output. With efficient file management, maps could be protected from deterioration.

To improve CAMP, a digitizer should be included with the hardware set-up. A program to use the digitizer as the input medium should then be developed. Additional programs for contour line drawing and three-dimensional analysis should also be added to the CAMP. Three-dimensional analysis will be useful in identifying location of canals and other irrigation structures and the computation of earthwork volumes for cost estimation. Linking CAMP with crop growth simulation models will provide an innovative expansion of the system for future research into the development of rice-based cropping systems.

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Prediction of moisture retention and transmission characteristics from soil texture of Indian soils

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Abstract

Characterization of moisture retention and transmission behaviour on the basis of soil texture (i.e. proportion of sand, silt and clay) was carried out using a database of 250 measurements that cover major agroclimatic zones and soils of India. Soil moisture retained at 33 kPa (field capacity) and at 1500 kPa (permanent wilting point) was linearly related with total silt and clay (SiC) content. A linear regression accounted for 87% of the variation in both cases. Total available water, i.e. the amount of water between field capacity and permanent wilting point, showed a hyperbolic trend with SiC content. The moisture retention characteristics (pF curve) of various soil types could be differentiated on the basis of soil texture class. The coefficients A and B of the equation $h = B \bullet O^A$ that describes the relationship between soil moisture suction h and soil moisture content O (pF curve), showed a dependency on the SiC content of the soil. Saturated hydraulic conductivity, Ks, decreased sharply from about 90 mm h^{-1} to 10 mm h^{-1} as the SiC content increased from 10 to 30%. With SiC contents higher than 30%, Ks slowly declined to values of about 1 mm h^{-1} at nearly 100% SiC content. A power function between Ks and SiC content accounted for about 80% of the variation.

Introduction

Soil moisture retention and transmission properties are necessary for many soil water related investigations such as water conservation, irrigation scheduling, drainage, solute migration, plant water stress and crop growth modelling. Methods of determining soil moisture characteristics are tedious, time consuming and expensive. In general, data regarding these characteristics for practical applications are not readily available. However, textural classes of major soils are already known, can be easily determined and are known to be related to soil moisture characteristics (Gupta & Larson, 1979; Rawls & Brakensiek, 1982). Work has been initiated at the Indian Agric. Res. Inst. (IARI), New Delhi, to characterize Indian soils with regard to moisture retention and transmission behaviour, as well as to estimate these parameters from soil texture. In this paper, results are reported of a preliminary attempt to relate soil moisture retention and transmission properties to texture classes of Indian soils.

Material and methods

The data used in this study were collected from 250 soil profiles in different agroclimatic zones of India by researchers of the Indian Council for Agricultural Research (ICAR) coordinated research groups, ICAR Institutes and State Universities (Ali et al., 1966; Velayutham & Raj, 1971; Talati et al., 1975; Gupta et al., 1983; Gupta et al., 1984; Bharambe et al., 1990; Datta et al., 1990; Rudra et al. 1991; Gupta, 1992). This database holds, among others, information on soil texture (% sand, silt and clay), bulk density, Ks, and moisture retention characteristics at soil water suction values of 0, 10, 33, 100, 300, 500, 1000 and 1500 kPa. Some statistics of the data set (range, mean, standard deviation) are given in Table 1.

Results and discussion

Moisture retention at 33 kPa

The following relationship was derived between gravimetric soil moisture content at 33 kPa (FC) and percentage sand, silt and clay:

$$\text{Moisture content at FC } (\%) = 0.17 \text{ sand}(\%) + 0.51 \text{ silt}(\%) + 0.56 \text{ clay}(\%) - 13.17 \quad (1)$$

Eqn 1 accounted for 87% of the variation. The regression coefficients for silt and clay were similar, suggesting equal importance of these fractions in determining the moisture content at FC. The coefficient for sand was about 3 - 3.5 times smaller than that for silt and clay.

Table 1. Number of samples, and ranges, mean of values and standard deviation of hydrophysical measurements of soils in different agroclimatic zones of India. CEC = cation exchange capacity; Ks = saturated hydraulic conductivity.

Parameter	Number of samples	Range	Mean	Standard deviation
Sand (%)	240	3.2 - 92.7	47.66	23.81
Silt (%)	240	1.0 - 71.0	21.80	11.94
Clay (%)	240	2.5 - 79.8	30.72	18.09
Organic Carbon (%)	114	0.01 - 3.58	0.61	0.573
Bulk density (mg m^{-3})	240	1.0 - 1.75	1.43	0.16
CEC (meq 100 g^{-1} soil)	95	0.32 - 64.5	18.08	17.09
Ks (mm h^{-1})	180	0.1 - 123.2	23.70	28.64
Moisture content at field capacity (g g^{-1})	159	3.8 - 46.0	23.62	10.80
Moisture content at wilting point (g g^{-1})	159	1.1 - 89.4	11.11	9.05

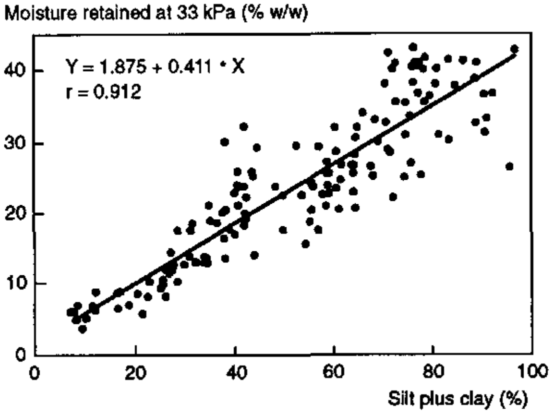

Figure 1. Moisture content retained at 33 kPa (field capacity) versus percentage silt plus clay, SiC. The linear regression is also plotted.

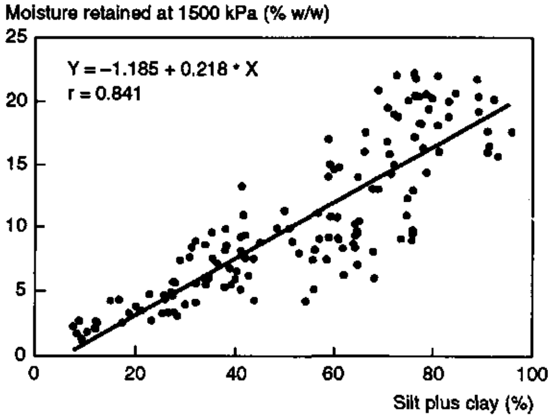

Figure 2. Moisture content retained at 1500 kPa (permanent wilting point) versus percentage silt plus clay, SiC. The linear regression is also plotted.

Next, the moisture content at FC was plotted against the percentage silt and clay taken together, SiC, (Figure 1). A good linear relationship was observed:

$$\text{Moisture content at FC (\%)} = 1.875 + 0.411\ \text{SiC(\%)} \quad (r = 0.912) \qquad (2)$$

Moisture retention at 1500 kPa

The following relationship was derived between gravimetric soil moisture content at 1500 kPa (PWP) and percentage sand, silt and clay:

$$\text{Moisture content at PWP(\%)} = 0.16\ \text{sand(\%)} + 0.29\ \text{silt(\%)} + 0.41\ \text{clay(\%)} - 15.65 \quad (3)$$

Eqn 3 accounted for 87% of the variation. Also, the moisture content at PWP was plotted against the percentage silt and clay taken together, SiC, (Figure 2). The following linear relationship was derived:

$$\text{Moisture content at PWP(\%)} = -1.185 + 0.218\ \text{SiC(\%)} \qquad (r = 0.841) \qquad (4)$$

Available Water

The amount of available water (AW) is plotted against SiC% in Figure 3. A quadratic fit accounted for about 71% of the variation:

$$\text{Amount of available water AW}(\%) = -1.15 + 0.41\ \text{SiC}(\%) - 0.00221\ \text{SiC}(\%)^2 \qquad (5)$$

As SiC(%) increased, AW increased till about 80% of SiC and thereafter gradually decreased. The increase in finer size fraction (SiC) increased both the moisture contents at FC and PWP, but the latter increased relatively more so that the AW finally decreased after 80% SiC%. The AW, when expressed on a volume basis by using measured values of bulk density, was predicted with less accuracy from SiC(%) than AW expressed on a gravimetric basis. This was due to uncertainties and errors associated with the bulk density determinations.

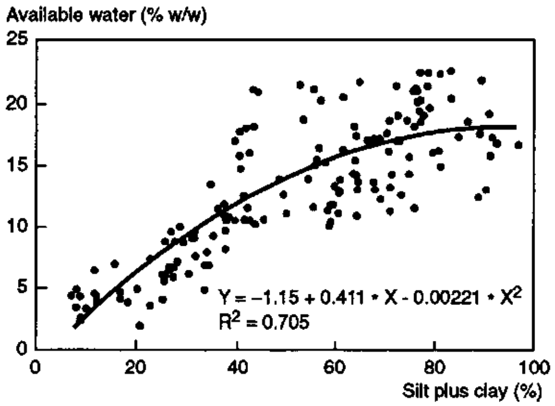

Figure 3. Available water versus percentage silt plus clay, SiC. The quadratic regression is also plotted.

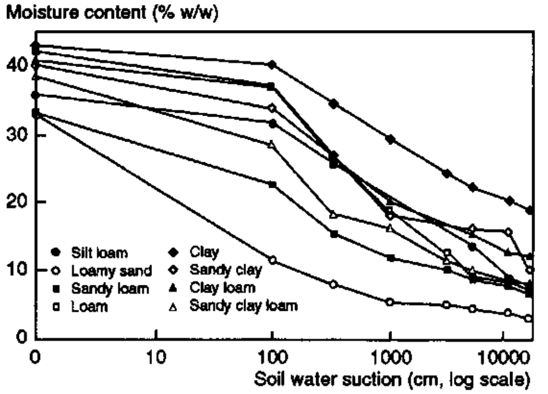

Figure 4. Average moisture retention characteristics (pF curve) for various soil texture classes.

General moisture retention characteristics

Relationship between soil water potential and water content can be described as follows (Brooks & Corey, 1964):

$$h = h_e \, [(O - O_r) \, / \, (O_s - O_r)]^B \qquad (6)$$

where h is soil water suction (kPa), h_e is soil water suction at air entry (kPa), O is actual soil water content ($m^3 \, m^{-3}$), O_s is saturated soil water content ($m^3 \, m^{-3}$), O_r is an empirical value called residual soil water content ($m^3 \, m^{-3}$), and B is a (fitted) empirical value. Eqn 6 can be simplified to the form:

$$h = B \bullet O^A \qquad (7)$$

by setting $O_r = 0$ and $A = h_e \, O_s^{-B}$. This equation has been used successfully in several studies (e.g. Campbell, 1974; Clapp & Hornberger, 1978; Gardner et al., 1970). The higher the value of A, the more the ease with which soil moisture is transmitted at low suction values.

Figure 4 shows that the average moisture retention characteristics, so-called pF curves, of the whole data base for different soil texture classes. Soil water suction is expressed in cm of water on log scale to enhance the representation at lower suction levels. The pF curves were distinctly different for the different texture classes. With increasing clay content of the soil, the moisture content at all suction values increased. Loamy sandy contained the least soil moisture at all suction values, whereas loam contained the most.

Eqn 7 was fitted to the pF curves, and for each soil profile, the coefficients A and B were empirically derived. Table 2 gives the average values of A and B per soil texture class.

Table 2. Values of the coefficients A and B of Eqn 7 ($h = B \bullet O^A$) averaged per soil texture class.

Texture	Coefficient		Correlation coefficient
	A	B	
Sand	−3.220	12.816	−0.985
Loamy sand	−4.378	16.674	−0.993
Sandy loam	−5.960	24.218	−0.932
Loam	−4.148	19.254	−0.893
Silt loam	−4.958	22.495	−0.881
Sandy clay loam	−5.504	23.695	−0.925
Sandy clay	−5.856	25.054	−0.939
Clay loam	−6.018	25.856	−0.958
Clay	−8.446	36.045	−0.952
Silty clay	−12.233	50.137	−0.955

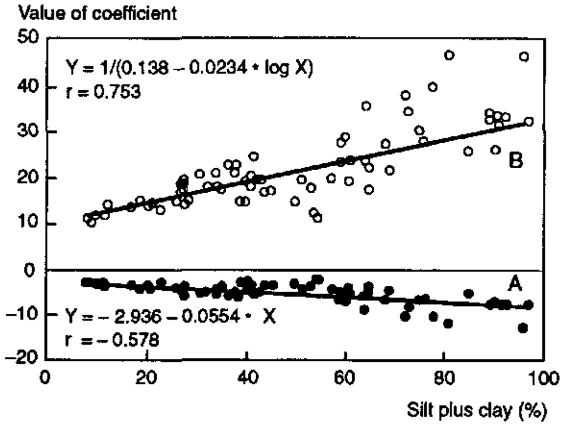

Figure 5. The values of the coefficients A and B of the equation $h = B \bullet O^A$, where h is the soil moisture suction (cm) and O is the soil moisture content (g g^{-1}) versus percentage silt plus clay, SiC. The regression lines are also plotted.

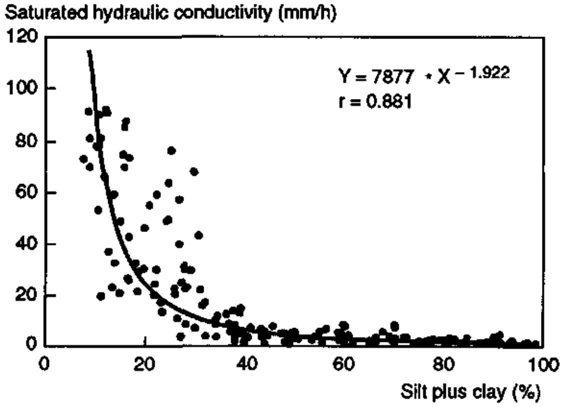

Figure 6. Saturated hydraulic conductivity versus percentage silt plus clay, SiC. The regression line is also plotted.

The values of A and B were different per soil texture class. Figure 5 shows the relationship of the coefficients A and B of each soil profile with the percentage SiC of the soils. The value of A decreased slightly with increasing SiC content, whereas the value of B increased more pronouncedly with increasing SiC content.

Moisture transmission characteristics

The saturated hydraulic conductivity, Ks (in mm h^{-1}) is plotted against percentage SiC in Figure 6. Ks decreased sharply from about 90 mm h^{-1} to 10 mm h^{-1} as the SiC content increased from 10 to 30%. With SiC contents higher than 30%, Ks only slowly declined to values of about 1 mm h^{-1} at nearly 100% SiC content. Ks value averaged 3 - 4 mm h^{-1} with SiC in the range of 50 - 100%. A power fit accounted for about 80% of the variation:

$$Ks\ (\text{mm h}^{-1}) = 7877\ SiC(\%)^{-1.922} \qquad (r = 0.88) \qquad (8)$$

The scatter of the data points was higher at low values of SiC than at high values of SiC content.

Conclusions

Soil texture, as expressed by percentages sand, silt and clay, successfully characterized soil moisture retention and transmission behaviour. Moisture retained at 33 kPa (Field Capacity) and at 1500 kPa (Permanent Wilting Point) showed a linear behaviour with total silt and clay content (SiC). With a linear regression, 75 - 80% of the variation was explained. A quadratic fit relating the available water for plant uptake to SiC accounted for 71% of the variation. Available water increased with increasing SiC, but at SiC values above 80%, available water decreased slowly. The coefficients A and B of the equation $h = B \bullet O^A$, characterizing the pF curves of the data sets, related well with SiC content. The derived relations can be used to estimate pF curves from observed soil texture. Saturated hydraulic conductivities, Ks, were related with SiC content through a power function which accounted for about 80% of the variation. Ks values sharply decreased to values less than 10 mm h^{-1} as the SiC content increased above 30%.

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Risk analysis and crop growth modelling

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Abstract
Farming is an intrinsically risky activity. Farmers have to deal not only with climatic variability but also with the variability in prices of inputs and outputs. Economic assessment of alternative technological and management options in a risky situation requires simultaneous accounting for both the income and risk consequences. The paper provides an overview of the tools useful for such an assessment. The role and limitations of crop growth models in facilitating risk analysis are highlighted.

Introduction

Agricultural production is an intrinsically risky activity. Risk arises due to uncertainty regarding the future consequences of an action. Farmers are continuously faced with the challenge of choosing efficient management practices in the face of uncertain outcomes resulting from such choices. Agricultural researchers, likewise, face the challenge of designing improved technologies in an uncertain environment. In risky situations, a particular choice may appear to be better in some situations but not so in others. Given that situations that are likely to eventuate are imperfectly known at the time the choice has to be made, risk imparts some fuzziness in the decision making process.

The pertinent question is how to assess the performance of various alternatives in the presence of risk so that rational choices can be made. On this, we can draw on decision theory models. Although it may not be possible to fully account for risk (because risk analysis itself is risky), the use of decision theoretic approaches assumes that a systematic treatment of risk is better than ignoring it altogether. The paper is written in this spirit with the aim of demonstrating the potential use of methods of risk analysis in the process of technology development.

Decision making under risk

One of the most widely applied models for studying decision making under uncertainty is the expected utility model (Anderson et al., 1977). Under risky situations, decision makers are assumed to select options which maximize expected utility of probabilistic consequences. For implementing the model, it is essential to know the decision makers' attitudes towards risk and the probability of various outcomes resulting from an action.

Attitudes to risk are captured in the utility function which transforms monetary gains or losses to utility. Attitudes to risk are classified as risk-neutral, risk-averse and risk-preferring. By definition, a risk-neutral decision maker is not concerned about by the risk associated with a choice. Maximization of expected value of the performance measure is the relevant criteria for such a decision maker. The measure of performance could be monetary, non-monetary or a combination of these two attributes. The risk-averse decision maker, on the other hand, simultaneously considers both the risk as well as the expected gain associated with the option and is willing to trade-off some expected gain for reducing the risk. In other words, the risk-averse decision maker is willing to pay a price or premium (in terms of lower expected income) to reduce risk. The size of the premium increases with an increase in the degree of risk aversion.

In the context of decision making, subjective probability distribution is the relevant concept. Whatever the 'objective' probability of an event may be, decision makers are guided by their perception of the likelihood of incurring losses. The risk profile associated with an action is reflected by the subjective probability distribution of outcomes.

Thus, if the utility function of a decision maker and the probability distribution of outcomes associated with each of the options are known, the expected utility maximizing decision could be identified. Even if the utility function is not known, stochastic dominance analysis could be used to identify risk-efficient choices if some assumption on the risk attitudes could be made.

Sources of risk at the farm level

Climatic variability is one of the major sources of risk in agricultural production. Climatic uncertainty manifests itself in the form of variation in yield. Fluctuations in rainfall, temperature and solar radiation are major climatic variables contributing to yield risk. Yield risk is also accentuated by pest and disease incidence which may be partly induced by climatic events. All other factors which can not be predicted with certainty but affect crop growth processes also contribute to yield risk.

Yield risk, although an important one in most cases, is only one of the sources of risk. If farmers are concerned about unpredictable fluctuations in income (or income risk), other sources of risk that are relevant are the risk of output price, input price and input supply. In commercial farming, output price risk can be a major source of risk. When farmers decide to commit certain amount of input to a crop, output price may not be known. Even though yield risk may be reduced by altering the environmental variables (such as provision of irrigation and prophylactic application of pesticides), price risk is generally beyond the control of farmers.

The extent to which input price and input supply risks are important depends on whether

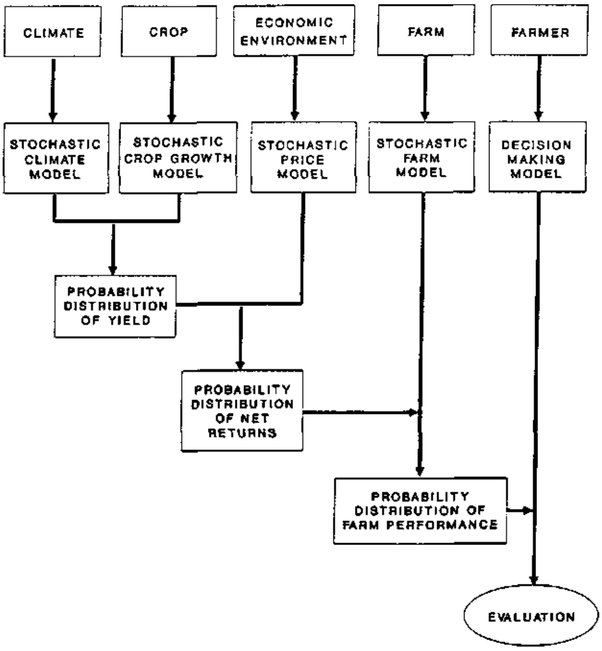

Figure 1. A model for technology evaluation from a farmer's perspective. Source: Pandey & Anderson, 1991.

the risks are embedded or unembedded. If all decisions are made initially and then the uncertainty unfolds, the risk is unembedded. At the time initial decisions on input use are made, both the input price and input supply are known and hence these sources of risk are non-existent. However, if input use decisions are sequential and the later stage decisions are conditioned by both the initial choices and the revealed uncertain outcome, the risk is said to be embedded. If risks are embedded which is the case in most situations, uncertainty about the input price and input supply at later stages becomes relevant in determining income risks.

A framework for risk analysis

A basic model for the evaluation of technology from the farmers' point of view consists of submodels of five broadly-defined sub-systems viz., climate, crop, economic environment, farm and the farmer (Figure 1). Stochastic inputs of climatic variables such as rainfall, temperature and radiation are provided by a climate model. The response of crop to climatic and management inputs is represented in the crop growth model. The level of complexity may vary from a simple production function to a mechanistic crop growth model. A model of economic environment is required to obtain economic variables. Integration of interactions between various farm enterprises is achieved in the farm model. This enables assessment of technological options in a whole farm context. The decision making behaviour of the farmer is incorporated in the farmer model. Evaluation is conducted by comparing probability distributions of various attributes of farm performance associated with various technologies. The framework provides a mechanism of combining multiple types of risk that influence the operation of real farm systems. Other than the sources of risk discussed earlier, an additional source in the context of modelling is parameter uncertainty. Parameters used in models are not fixed but are stochastic with their own probability distributions. Parameter uncertainty arises due to imperfect understanding of the functioning of the system by modellers. Following Mihram's Uncertainty Principle of Modelling (Mihram, 1972), such parameter uncertainty should also be incorporated in risk analysis.

Models as extrapolative devices

To test the performance of a technology such as a new cultivar, an experimental approach involving multi-locational testing over a number of years is generally employed. As such experimental work can be very expensive and time consuming, validated models of production systems can be used to extrapolate the performance of a newly designed technique over time and across space. Mechanistic crop growth models are ideally suited for such extrapolation. Crop yields under a range of management regimes can be predicted by using stochastic climate data to drive the crop growth model.

Risk analysis and crop growth models

From the point of view of risk analysis, crop growth models can be viewed as devices which generate yield data conditional on the environmental variables and the management treatment imposed. The resulting yield data are then fed into a farm model, as outlined in Figure 1, to conduct risk analysis.

There are two major roles of risk analysis in the process of technology generation and evaluation. First, risk analysis can be used to identify technological interventions which are risk-efficient from the point of view of the end-user - the farmer. Second, where possibilities exist for seeking additional information to reduce risk, strategies more appropriate to the predicted scenario could be employed. In essence, the risk associated with the choice will be reduced by using forecasts. For example, the optimal nitrogen dose may differ depending on the likely rainfall scenario. If probabilistic predictions of rainfall are available a nitrogen dose more appropriate to the predicted rainfall could be used.

Stochastic dominance analysis

The expected utility model provides the theoretical basis for risk analysis. The probability distribution of yield (or income) required for risk analysis is obtained from the crop growth model. If the utility function of the farmer is known, the optimal management practice that maximizes the expected utility can be identified. If the utility function is unknown but some reasonable assumptions could be made regarding its nature, the method of stochastic dominance could be used to identify risk-efficient (not necessarily the optimal) practices.

To conduct stochastic dominance analysis, probability distributions are expressed in the form of cumulative distribution functions (CDF) which measure the probability of an outcome being less than or equal to a given value of the random variable under consideration. If CDFs associated with various options are plotted, the distribution which is entirely to the left is said to be first degree stochastically dominated by the distribution which is entirely to the right. For example, in Figure 2, the CDF denoted by X is entirely to the left of the CDF denoted by Y. Thus Y is said to dominate X in the sense of first degree stochastic dominance (FSD). The option which generated X can be dropped out from the choice set as no rational decision maker would prefer X to Y. It is evident that for each probability level, Y yields more than X.

If we compare the distributions Z and Y, both distributions are risk-efficient in the sense of FSD. The CDFs of Z and Y intersect and hence, neither of them is dominated by the other. Assumptions on the nature of the unknown utility function need to be made to discriminate between these two distributions. The relevant concept is that of second-degree stochastic dominance (SSD). If farmers are assumed to be risk-averse, the distribution Y dominates Z in the sense of SSD as the total area between Y and Z to the left of the crossover point is more than the area to the right. Intuitively, Z is more to the left than Y in the lower range and hence has a higher chance of generating small values of income than Y. In this situation, a risk-averse farmer would always prefer Y to Z. In this case Z can be dropped out of the choice set and Y is the risk-efficient choice.

In Figure 3, different CDFs M and N are compared. A risk-averse farmer would be indifferent between M and N in the sense of SSD. The CDF of N is on the right side on the lower range but the area between N and M to the left of the crossover point is smaller than the one to the right. Under this situation, SSD criterion can not discriminate between the two CDFs. The choices representing both CDFs are risk-efficient in the sense of SSD.

In applying the SSD criterion, the only assumption made is that the farmer is risk-averse. If it is possible to be more precise and find out the degree of risk aversion, it would

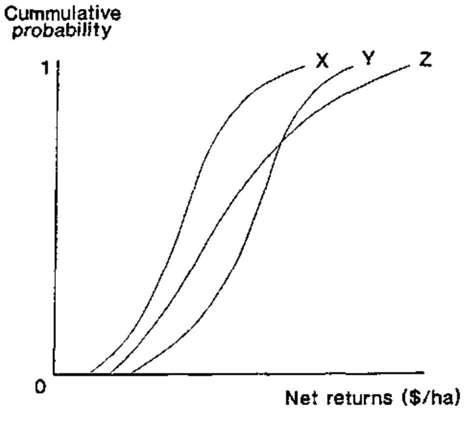

Figure 2. Hypothetical first and second degree stochastic dominance.

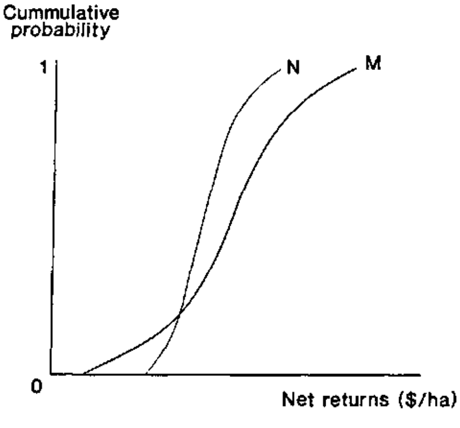

Figure 3. Hypothetical second degree stochastic dominant set.

be possible to discriminate between distributions which are SSD-efficient. If it is not possible to estimate precisely the degree of risk-aversion, but estimate a range within which it is likely to fall, risk efficient choices could still be identified by using the concept of stochastic dominance with respect to a function (SDWRF). The discriminatory power of the technique increases as the range of risk-aversion coefficient is narrowed down. Methods of measuring the range of risk-aversion coefficient have been discussed by King & Robison (1981).

The stochastic dominance criteria in their various forms have been widely used to identify risk-efficient cultivars and management practices (Smith et al., 1978; Pandey, 1990). The method basically consists of pairwise comparison of discrete alternatives and the elimination of dominated alternatives from the choice set. One of the problems with the application of FSD and SSD rules have been their relatively poor discriminatory power such that a large number of choices are left as risk-efficient. The concept of SDWRF has helped narrow down the efficient choice set, although at the cost of a greater information requirement about the value of risk-aversion coefficient.

Mean variance analysis

If net returns can be assumed to be approximately normally distributed, mean-variance rules can be used to simplify the choice of risk-efficient options. The choice set is illustrated in Figure 4 with the example of dry-seeded versus transplanted rice. Mean returns and variance of returns for these two methods of establishing rice are shown in the figure. If the comparison is between the points A and C, dry-sowing is risk-efficient as it yields a greater mean return for a given level of variance (or risk). The transplanting method represented by point C is risk-inefficient in comparison to the dry sowing method represented by point A. Similarly, the dry-sowing method is risk-efficient compared to transplanting method represented by point B as the latter has a higher variance for a given mean. Using the same logic, the transplanting method represented by point E is superior to the dry-sowing method. A comparison between the points A and D is, however, not so easy as the transplanting

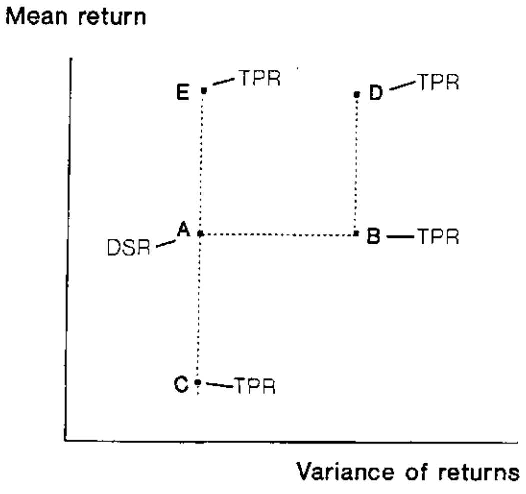

Figure 4. Hypothetical mean-variance space for choice between transplanted (TPR) and dry-sown (DSR) rice.

method represented by point D has a higher mean but also a higher variance. Information on risk attitude is required to discriminate between the points A and D. A highly risk-averse farmer is likely to choose point A as it has a lower but a more stable return than the transplanting method represented by point E.

Programming models

Other methods that have been used to identify risk-efficient choices are programming models in one form or the other (Hardaker et al., 1991). Programming models are capable of taking into account resource availability constraints and interactions with other farm activities in determining risk-efficient choices. For example, a farmer choice of fertilizer doses may depend not only on the riskiness of fertilizer use but also on cash availability to purchase fertilizers. Similarly, the optimal dose of chemical fertilizer may depend on the quantity of farm yard manure applied which in turn depends on the number of livestocks. Programming methods are more suitable when interactions among resource constraints and activity choices are strong. Linear programming using minimization of total absolute deviation (MOTAD) and quadratic programming in its various forms are the two popular programming approaches. These two approaches are more appropriate for non-embedded risks.

Where risks are embedded, sequential decision-making processes need to be modelled to derive risk-efficient choices. Methods available are discrete stochastic programming and dynamic programming. These methods allow farmers to update their decisions throughout the crop growth season based on the most recent information. Decisions on the use of inputs such as pesticides, irrigation and fertilizers could be made on the basis of the state of the crop growth and the anticipated stochastic events. For example, a farmer may decide not to apply insecticide, if the pest density is below the threshold level and the climatic conditions are not favourable to a rapid build-up of the infestation.

Some practical problems

Although crop growth models are very useful devices for generating yield data required for risk analysis, problems in conducting a more complete risk analysis remain. Some of the problems relate to the nature of crop growth model while others pertain to the tools used for risk analysis.

The cost of developing and validating a mechanistic crop growth model could be substantial. A multidisciplinary approach involving scientists from all disciplines from soil science to crop science to agro-meteorology is required. The process is very data intensive. Once a model has been developed and validated, site specific parameters are required for proper calibration. Uncertainty regarding values of various parameters used in the model is an additional problem.

By definition, models represent abstractions from reality. Not all real-world factors can be build into a model - otherwise the model itself would be as complex as the reality. The potential value of modelling for economic analysis depends not only on the adequacy of representing plant growth processes, but also on how well effects of management are incorporated in the model. Many current generation crop growth models mimic the effects of solar radiation, temperature and moisture availability to plants reasonably well (e.g. Kropff et al., 1994; Wopereis, 1993). Such models assume that crop growth occurs in an environment where nutrients are non-limiting and pests and diseases are non-existent. Models based on such assumptions may not be very useful for economic analyses because in most farming systems, especially in developing countries, crops grow under nutrient limitation. When nutrients are limiting, production risk is inaccurately represented by models which do not account for the effect of nutrient limitations.

Dealing with correlations is one of the major problems in conducting risk analysis. For example, price and quantity of output generally tend to be negatively correlated. In years when yields are high, prices tend to be lower and in years when yields are low, prices tend to be higher. Similarly, returns from one crop may be correlated to that of other crops or activities. Since farmers are primarily concerned with the total income risk, and not so much with the risk of individual components of the system, correlation needs to be adequately handled so as not to distort the risk profile of total income. Historically derived correlations may be of limited use since such correlations may not be applicable to newly-devised systems.

Other problems relate to information requirement and actual solution procedure for identifying risk-efficient options in real-world context. Where systems-level interactions can be ignored, fairly simple models could be used. However, most real-world decisions are complex, and are characterized by many activities with uncertain outcomes, interactions among activities, correlation among outcomes and temporal dependence of decisions. Multistage decision models required to solve such problems will have very high informational requirement and could be computationally burdensome. Simplifications which capture the basic essentials are required.

Concluding remarks

Crop growth models are useful tools for extrapolating experimental data over time and across space. Such data are important inputs into economic analysis of alternative management interventions. Ex-ante analysis of technological options is facilitated by linking crop growth models with models of farming systems.

Like any other tool, the practical usefulness of linkage between crop growth models and economic models depends on how these tools are applied. It is not only necessary to recognize the limitations imposed by the need to simplify relationships but also the fact that model building to a large extent is an art. Accordingly, the usefulness of the modelling approach depends largely on the skill of modellers in developing and linking crop growth models and decision-making models.

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The Application Program 'Crop Rotation Optimization'

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Introduction

The Application Program 'Crop Rotation Optimization' is part of the SARP-III research theme 'Agro-ecosystems'. The study of crop rotations was initiated at the 'International Workshop on Agro-ecological Zonation of Rice', hosted by the Agro-ecology Institute of the Zhejiang Agricultural University in Hangzhou, China, in April 1993. The need was felt to study not only single rice cropping, but whole crop rotations as they occur in rice-based cropping systems (e.g. Sattar, 1993; Yang Jingping & Zhang Xigu, 1993). After preliminary inventories among the Workshop participants it was decided to make a start with the rice-wheat rotation. Rice-wheat cropping is a major system in the 'SARP countries' such as India, Bangladesh and China. Moreover, the existence of the Rice-Wheat Project by IRRI/CIMMYT offered possibilities for cooperation.

After the Workshop in China, modelling of rice-wheat rotations was started in Wageningen. Together with SARP team members from Asia, a framework was developed that could serve for further development of the rice-wheat rotation, and that could also be a basis to simulate rotations of other crops (Figure 1; Bouman et al., 1994; Timsina et al., 1994). The rice model ORYZA_W (ORYZA_W Description, 1994) was combined with a growth model for wheat, SUCROS2 (van Laar et al., 1992), and both were linked to a continuous water balance model called WATBAL (Wopereis, 1993). SUCROS2 was calibrated and validated for tropical wheat on data collected from field-experiments in the Philippines. The water balance model can handle puddled lowland conditions for the rice crop and non-puddled conditions for a subsequent (upland) crop. A subroutine was developed that contains the so-called decision rules that govern the fallow period and land-preparations between the two crops, and the start of the second (wheat) crop. The prototype rice-wheat rotation model is called ROTAT_RW. In principle, the crop growth models for the single crops rice and wheat can be replaced by growth models for any other crop, provided that they are programmed in the FORTRAN-FSE system (van Kraalingen, 1991).

Developments at the SARP Applications Workshop

At the SARP Applications Workshop at IRRI, 18 April - 6 May 1994, in-depth inventories

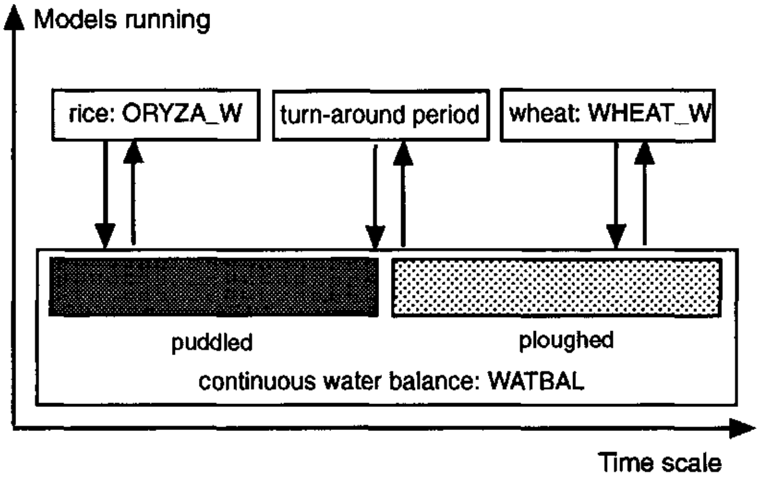

Figure 1. Schematic illustration of the prototype rotation model ROTAT_RW. The crop model for rice is ORYZA_W and for wheat SUCROS2, the water balance model is WATBAL.

were made of crop rotations relevant to the various SARP teams, of (agronomic) problems related to these rotations and of possible topics that could be studied with crop rotation models. The possibilities of linking agronomic models of crop rotations with tools of economic (risk) analysis on farm level were also discussed. The prototype ROTAT_RW model was presented for rice-wheat, and as framework for other crop rotations as well.

The following conclusions and results were obtained at the Workshop. The crops that are grown in rotation with rice in the 'SARP' countries are mainly wheat (Bangladesh, India, China), corn (Malaysia, Philippines), peanut (Philippines, Thailand) and pulses (India, Philippines). A common set of major problems, considered to be suitable to tackle with crop modelling, concerns timing of the crops and soil-water related issues, mainly during the 'interface' period between harvesting of the first and sowing of the second crop. Figure 2 summarizes major problems of especially rice-wheat rotations, and puts them on a time-scale ranging from one year (short-term) to several years (long-term).

A delay in the establishment of a second crop in a rotation system can be caused by several factors: prolonged growth duration of the previous crop due to adverse weather or to the use of long-duration varieties, delayed rainfall, long turn-around time, unfavourable soil conditions for land preparation, unavailability of labour for land preparation. A delay in sowing can result in a decrease of yields because of an unfavourable shift in the growth cycle of the crop in relation to prevailing weather conditions, e.g. too high or too low temperatures during flowering. Unfavourable soil structure and/or soil water conditions between the first and the second crop can result in a delay in sowing or in poor germination. A compacted layer in the soil as caused by the puddling of rice fields can hinder root growth of a subsequent upland crop and cause drought stress under adverse weather conditions. On

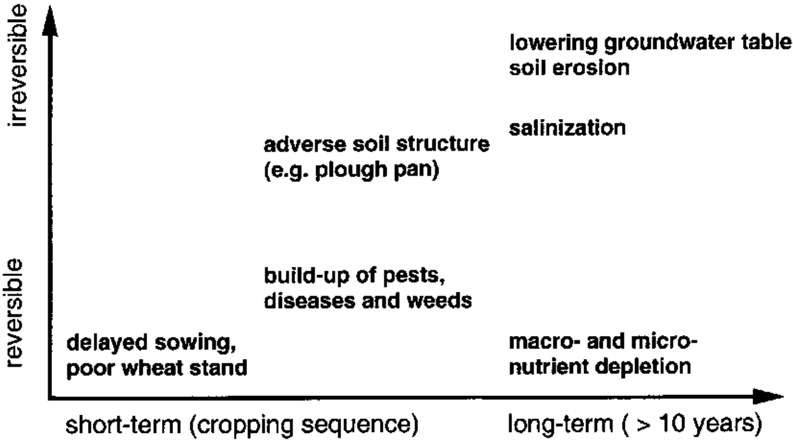

Figure 2. Main problems occurring in rice-wheat rotations. The horizontal axis indicates the time-frame over which the problems manifest themselves and, the vertical axis indicates the degree of 'reversibility' of the effects of the problems.

the other hand, the compacted layer may also cause water-logging during the interface period and thus result in delayed land preparation and poor wheat germination.

It was decided to work further along the lines of the developed rice-wheat model ROTAT_RW, and to explore the usefulness of other crop rotation models such as POLYCROP (Garcia, 1993). In any rotation model, individual crop models will only be incorporated when they have been well validated on field experiments. For wheat, it will be tried to incorporate the model WTGROWS as developed by Aggarwal (1993) in the rotation model. WTGROWS has been extensively validated for wheat grown in semi-dry areas in India. For corn, the model SUCORN was developed by Wan Sulaiman and Rushidah (1991) in Malaysia, but may need further testing in other environments. For peanut and pulses, some basic models exist (e.g. SOYCROS, Penning de Vries et al., 1992; COWPEA, Timsina et al., 1993a/b) but they need further development and validation (field experiments). Modelling the soil water balance (and possibly soil structure) during the interface period between the two crops is of major importance. Therefore, emphasis needs to be given in field experiments to observations of soil water and soil structure.

The modelling activities of rice-wheat were linked with the Rice-Wheat Program of IRRI/CIMMYT. It was agreed that one or more common field experiments would be carried out on rice-wheat rotations by SARP collaborators.

Workplan 1994-1995

For the last phase of SARP-III (1994 - 1995), a number of teams will work on the modelling of crop rotations. In general, the emphasis in this Application Program will be on model development: development and validation of single crop growth models (wheat,

Table 1. Summary of planned SARP activities in the 'Crop Rotation Optimization' Application Program, 1994 - 1995. For description of the acronyms see the introductory pages of this volume (participating organizations in SARP).

1 'Interface' model development linking rice with second crop

Rotation type	Lead teams
Rice-wheat	PUAT, BRRI, IARI
Rice-corn	UPLB, UPM, PhilRice
Rice-peanut	UPLB, PhilRice

2 Modelling of second crop (after rice)

Second crop	Lead teams
Wheat	PUAT, IARI
Corn	UPM, UPLB, PhilRice, ZAU
Peanut	UPLB, PhilRice

3 Linking crop rotation model output with tools of economic analyses (farm level).
Lead teams: TNAU-WTC, IARI, CNRRI, ZAU, UPLB, PhilRice

corn, peanut, pulses) and of a module that simulates the state of the soil (soil water, structure) during the interface period. The possibilities of linking agronomic models of crop rotations with tools of economic analysis at the farm level will also be explored. For rice-wheat rotations, the prototype ROTAT_RW will be further developed into an operational model to study and optimize the crop rotation under different environmental conditions (soil, weather). ROTAT_RW will also be brought under the SARP Shell. A summary of planned activities by the SARP teams is given in Table 1.

The output aimed for by the end of SARP-III (December 1995) is:

- Operational rotation model of rice-wheat for optimization studies (software + manual).
- General framework for a rotation model for other crops in rotation with rice (corn, peanut, pulses), including an interface module for lowland rice - upland crop.
- Design of field experiments for further development of rotation models (for testing of single crop models, and for development of interface module).
- Improved single crop models (e.g. corn, peanut, pulses).
- Inventory of methodologies for linking the simulation output of agronomic rotation models with tools of economic analysis at the farm level.
- Documented case-studies and scientific papers.

Because of the complexity of crop rotation modelling, it is foreseen that the main thrust that can be given in the last phase of SARP-III is the development of a general framework and of a methodology for further elaboration. This will require a well-coordinated research efforts by SARP collaborators.

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Rice-wheat systems: problems, constraints and modelling issues

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Abstract

The complexity of problems and causal relationships facing the rice-wheat rotation in South Asia are described as found by a collaborative research effort by some National Agricultural Research Systems (NARS) of Bangladesh, India, Nepal, and Pakistan, the International Rice Research Institute (IRRI) and the International Maize and Wheat Improvement Center (CIMMYT). Major near-term and long-term problems identified by diagnostic field surveys in the participating countries are summarized. Ideas are presented as to how systems analysis and simulation modelling can help to identify management strategies to improve the rice-wheat system.

Introduction

Rice and wheat are staple crops in most of the countries of South Asia. Roughly one billion people in that area rely on rice and wheat for a large portion of their daily caloric intake. Rice and wheat are cereal crops that require substantial amounts of fertilizers to maintain productivity and fertility of the soil, especially when they are grown in rotation. Productivity of these crops in rotation may decline over time if nutrients are not efficiently and optimally used. For example, in Bangladesh and Pakistan, average yields of wheat and rice, respectively, have been reported to decline (Woodhead et al., 1993). There is a growing concern among scientists and farmers regarding the sustainability of the rice-wheat systems. Sustainability aspects may be assessed and quantified by long-term field experiments. Some long-term field experiments on rice-wheat rotations exist in India, Nepal, Bangladesh (e.g. Bishta, 1990; Garg, 1991; Bhatta, 1993 for Pantnagar, India; Hobbs, 1993; Hobbs et al., 1993 for Bhairahawa, Nepal; Bhuiyan et al., 1993 for Bangladesh). These experiments give valuable quantitative insight into soil fertility issues and the sustainability of rice-wheat cropping. However, such experiments, although useful, are expensive and, in some cases, impracticable, given the allocation of scarce research resources for short-term results. Other information concerning problems facing the rice-wheat rotation can be derived from diagnostic field surveys and from tools of systems analysis and simulation modelling, which are the topic of this paper.

The rice-wheat collaborative project in South Asia

To address issues of productivity and sustainability of rice-wheat cropping in South Asia, some National Agricultural Research Systems (NARS) of Bangladesh, India, Nepal, and Pakistan have determined together with the International Rice Research Institute (IRRI) and the International Maize and Wheat Improvement Center (CIMMYT) priorities and methods of collaboration. This collaborative effort should result in the identification of improved technologies for rice-wheat systems that the NARS could extend to the farmers. The Rice-wheat project started in June 1991, initially for two years with funding from the Asian Development Bank (ADB) to supplement resources provided by the NARS, IRRI and CIMMYT (through their core budgets) and by USAID (for Nepal via CIMMYT). Nine sites (lead centers) were selected for the collaboration: three in India and two each in Nepal, Bangladesh and Pakistan. These sites vary in soil and climatic characteristics (Table 1). The major activities of the project were: diagnostic surveys of the sites using 'rapid rural appraisal' and 'participatory rural appraisal', organizing international traveling workshops, training and advanced workshops, and field and laboratory studies. So far, the results of the diagnostic surveys in the four participating countries and rice-wheat atlases of five countries (the four participating countries plus China) are the major outputs of the project. Here, some major conclusions of the diagnostic survey are summarized.

Diagnostic surveys

Surveys of farmers' practices and constraints and opportunities in rice-wheat systems have been conducted in Rupandehi district (Nepal terai), Naldung (Nepal mid-hills), Faizabad (rainfed Uttar Pradesh, India), Pantnagar (irrigated terai, Uttar Pradesh, India), Karnal and Kurukshetra (irrigated, Haryana, India), Dinajpur district (irrigated, Northwest Bangladesh), Khustia district (irrigated, dry region, Central-West Bangladesh). Each survey was conducted by a multidisciplinary team involving up to 20 members representing NARS, IRRI and CIMMYT. Farmers' responses with regard to farming practices, problems and constraints were collated and presented in tables and (causal) diagrams (Ahmed et al., 1993 (for Khustia, Bangladesh); Saunders, 1990 (for Dinajpur, Bangladesh); Hobbs et al., 1991 (for Faizabad, India); Harrington et al., 1992a (for Karnal and Kurukshetra, Haryana, India); Fujisaka et al., 1990 (for Pantnagar, India); Fujisaka & Harrington, 1989 and Harrington et al., 1990 (for Rupendehi, Nepal Terai); and Harrington et al., 1992b (for Naldung, mid-hills, Nepal)).

Problems and constraints

The diagnostic surveys led to the identification of various problems in the rice-wheat system. The relative importance of problems was estimated by scoring each farmer- and researcher-identified problem in terms of percentage area affected by the problem, relative-frequency of occurrence, and percentage productivity loss. Details of these scoring techniques are given by Fujisaka et al. (1990, 1994) and Ahmed et al. (1993). Consequently, opportunities for research and extension were identified by defining and diagramming

Table 1. Sites of rice-wheat diagnostic surveys conducted under the rice-wheat project in India, Nepal and Bangladesh, with a short characterization of climate, land use and soil.

Countries Sites	Climate	Land types (Texture)	Soil class
1. INDIA			
a. Pantnagar 28° N 78°50' E	Humid; Subtropical; Warm and humid summer and cold and dry winter; 1224 mm annual rainfall; 234-300 m asl	1. Wetlands (clay loam) 2. Lowlands (clay loam to silty clay loam) 3. Medium lands (clay loam to silty clay loam) 4. Uplands (sandy loam)	Mollisols
b. Faizabad 26°32' N 82° E	Semi-arid; subtropical; 1200 mm annual rainfall	1. Uplands (15%) 2. Medium lands (77%) 3. Lowlands (8%)	Incetisols and Alfisols
c. Karnal and Kurukshetra 29°11' E 76°11' E	Semi-arid; Tropical to subtropical; 704 mm annual rainfall; 240 m asl	1. Uplands 2. Medium lands 3. Low lands	Typic and Udic Ustochrepts
2. NEPAL			
a. Rupandehi 27°05' N 83°25' E	Subtropical; Warm and humid summer and cold and dry winter; 1600 mm annual rainfall; 100-200 m asl	1. Upper terraces (sandy) 2. Middle terraces (sandy clay) 3. Lower terraces (heavy clay)	
b. Naldung (hills) 27°20' N 85°24' E	Humid; Warm temperate to subtropical; 1300 mm annual rainfall; 850-2150 m asl	1. Mild sloped lower terraces (silty loam to clay loam) 2. Moderately sloped middle terraces (sandy loam to loam) 3. Highly sloped higher terraces (sandy loam to sandy)	
3. BANGLADESH			
a. Chaudanga 23°7' N 89°0' E	Tropical; Hot and dry throughout year; 1206 mm annual rainfall	1. Highland (sandy loam) 2. Medium highland (sandy loam to loam) 3. Medium lowland (clay loam)	
b. Dinajpur 26°00' N 88°50' E	Subtropical; Hot and humid during summer; Relatively cooler during winter; 1998 mm annual rainfall	1. Highland (brown sandy loam to silty loam) 2. Medium to lowland (grey heavy silt loam) 3. Depressions (Silty clay loam)	

Table 2. Near-term and long-term problems on rice and wheat in rice-wheat cropping systems as derived from diagnostic surveys at various sites of the rice-wheat project.

	INDIA			NEPAL		BANGLADESH	
	Pant-nagar	Faiza-bad	Kernal & Kuruk-shetra	Rupan-dehi	Nal-dung	Dinaj-pur	Chau-danga
			Near - term problems				
Rice							
1. Low yield	x	x	x	x	x	x	x
2. Poor plant stand	x	x		x	x		
3. Inadequate water/Poor water	x	x		x		x	x
management	x	x		x			
4. Unavailability of drought	x	x		x			
resistant varieties						x	x
5. Zinc deficiency	x					x	x
6. Low water holding capacity of							
soils	x	x				x	x
7. Delayed rice transplanting	x	x		x		x	x
8. Pests and diseases attack	x	x		x			
- Brown plant hopper (BPH)	x	x		x		x	x
- Bacterial leaf blight (BLB)	x	x					
- Rats	x	x		x		x	x
- Weeds	x						
- Army worms	x	x		x			
- Rice bugs							
- Case worms							
- Nematodes							
Wheat							
1. Low yield		x	x	x	x	x	x
2. Late wheat planting	x	x	x	x	x	x	x
3. Drought/Inadequate water	x	x		x	x	x	x
4. Water logging/Excess moisture	x	x	x	x	x	x	x
5. Ground water depletion/quality			x				
6. Nutrient deficiencies	x	x	x	x	x	x	x
7. Poor plant stand	x	x	x	x	x	x	x
8. Pests and diseases attack							
- Leaf blight	x	x		x			
- Leaf rust	x	x		x	x		
- Rats	x	x		x	x	x	
- Weeds	x	x		x	x		
- Storage losses (due to rodents, weevils and moisture)	x	x	x	x	x	x	x
9. Delayed wheat harvest	x				x	x	x
10. Expensive tillage smetices			x				
			Long - term (sustainability) problems				
1. Depletion of soil fertility (nutrient	x	x	x	x	x	x	x
mining)	x	x		x	x		
2. Pests and diseases build-up					x		
3. Soil erosion							

the causes of major problems, which helped in suggesting alternative ways to address major problems. The problems were divided into near-term (within one year) and long-term (over the years) problems (Table 2).

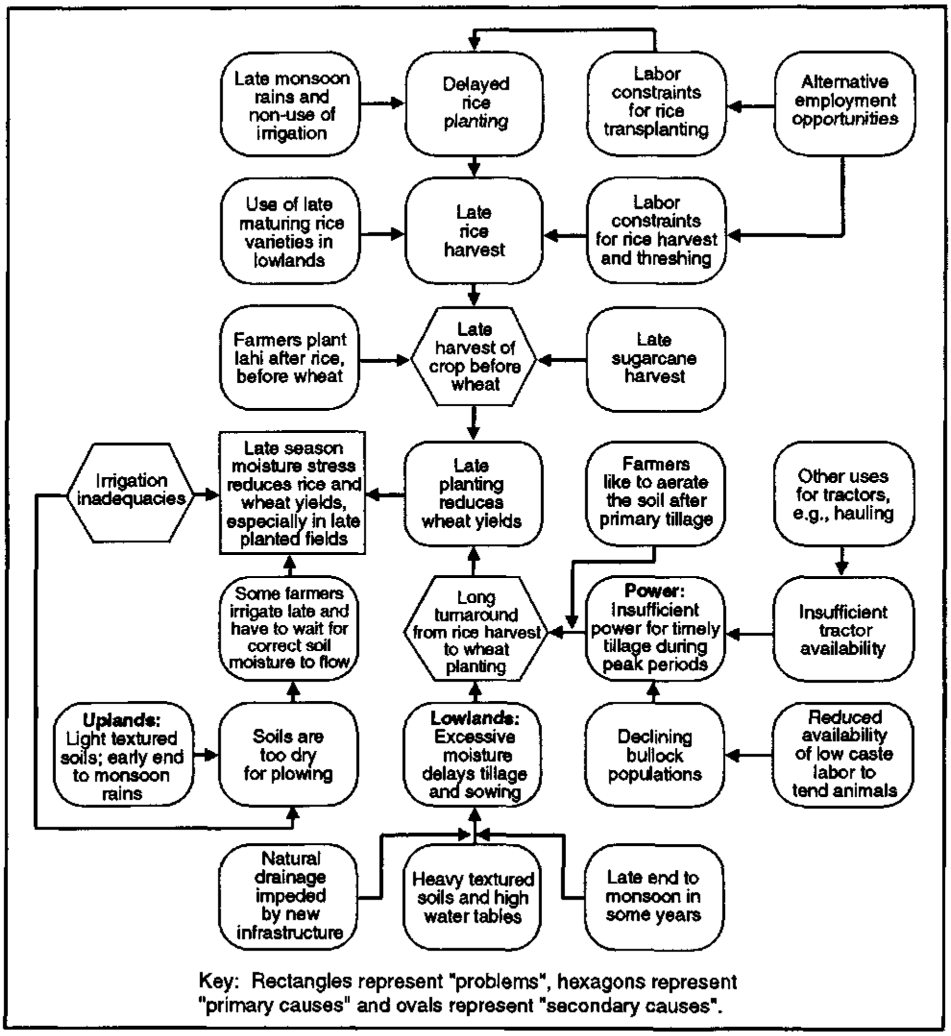
Near-term problems include (1) factors that directly reduce yields, (2) factors where resource use is inefficient, and (3) inefficient cropping patterns or enterprise selection. Some problems are specific for rice, others are specific for wheat, and still others are associated with the whole rice-wheat system. Some problems are common to all sites, while others are site-specific. Pests (insects, weeds, diseases and rats) are the most important problem affecting rice and wheat at almost all sites (except Karnal and Kurukshetra in India). Brown plant hopper (BPH), bacterial leaf blight (BLB) and rats are major rice pest problems in Pantnagar; weeds and rats are major problems and army worm, rice bug, BLB, sheath blight, and brown spot are minor problems in Faizabad; weeds, BLB, rice bug, case worm, nematodes and rats are major problems in Nepal. Nutrient deficiencies are common problems in rice and wheat at most sites. Other major near-term problems are: poor plant stand in both rice and wheat, low rice and wheat yields (except in Pantnagar areas where rice yields are surprisingly high), and drought and poor water management.

Long-term problems affect the sustainability of rice-wheat systems. The surveys identified three major long-term (sustainability) problems. Depletion of soil nutrients and increasing incidence of pests and diseases were major problems at all sites. Only in Bangladesh, these problems were only perceived by the researchers as 'major', and not by the farmers themselves. The third major long-term problem is soil erosion in Naldung, a mid-hill site in Nepal.

Possible causes of the problems

Each problem has several causes. An understanding of causes is important because it can suggest avenues of action (research, extension, policy) useful in attempting to solve these problems. Various 'causal diagrams' are presented in the diagnostic survey reports. As illustration, the causal diagrams for two near-term problems (late planting of wheat in Faizabad; low yield of wheat in triple cropping patterns in Bangladesh), and one long-term problem (soil nutrient depletion in Pantnagar) are presented and discussed.

Late planting of wheat in Faizabad Late harvesting of rice and a long turn-around time between harvest of rice and sowing of wheat are major causes for late planting of wheat in Faizabad. Main causes for long turn-around time are: insufficient power for tillage at peak periods, late termination of the monsoon in some years and excessive moisture in the top soil. For each of these causes there could be sub-causes. The causes and sub-causes for late sowing of wheat are shown in Figure 1 (Hobbs et al., 1991). It should be noted that late sowing of wheat is a common problem at all sites in the participating countries. However, its relative ranking as a problem by farmers is different.



Key: Rectangles represent "problems", hexagons represent "primary causes" and ovals represent "secondary causes".

Figure 1. Problems and causes of late wheat sowing in Faizabad, India. Source: Hobbs et al., 1991.

Low wheat yield in triple cropping systems in Bangladesh Many farmers in Bangladesh follow the triple cropping pattern 'transplanted Aman rice - wheat - Aus rice'. Low wheat yields could be due to either poor growth of wheat or to high temperatures leading to sterility at the reproductive stage. Poor growth of wheat could result from unfavourable soil conditions (soil compaction) as a result of puddling of the soil for rice. High temperatures at the reproductive stage can result from late sowing of wheat or from non-availability of heat-tolerant wheat varieties. Late sowing of wheat could result from late harvesting of transplanted Aman rice and from long turn-around times (as above for Faizabad). Again, each of these causes could have sub-causes (Figure 2; Ahmed et al., 1993).

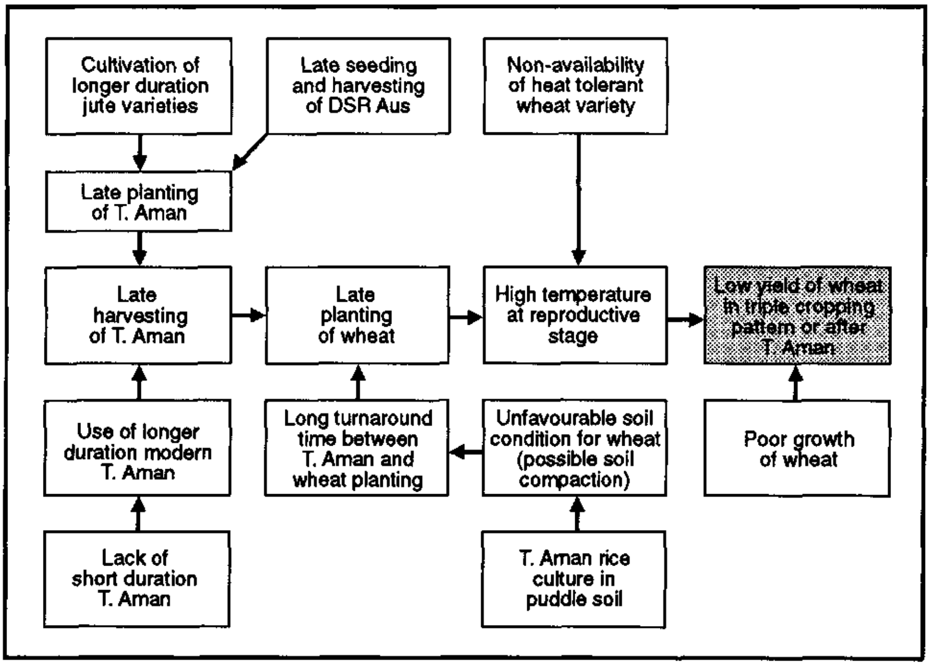


Figure 2. Problems and causes of low wheat yield in triple rice - wheat - rice cropping at Garadob, Hatikata and Garamara areas in Bangladesh. Source: Ahmed et al., 1993.

Soil nutrient depletion in Pantnagar Data from long-term trials at Pantnagar University indicate gradual declines in rice yield for all treatments, and stagnant wheat yields irrespective of fertilizer use (Figure 3). Rice yield decline could be due to increases in soil pH (from 7.1 to 7.8), soilborne pathogens, declines in soil organic matter, and degraded soil physical properties (Fujisaka et al., 1990). Pantnagar scientists believe that wheat yields did not decline in light-textured soil whereas they did decline in heavy-textured soil (personal communication with Y. Singh and Dheer Singh, Pantnagar University, 1994). Wheat yields declined by 50% in 10 years in heavy-textured soils with shallow water tables in long-term experiments in Bhairahawa, Nepal (Hobbs, 1993; Hobbs et al., 1993). Farmers reported several causes and sub-causes for problems related to soil nutrient depletion in rice-wheat systems (Figure 4).

Identifying management strategies through crop simulation modelling

Productivity and sustainability issues can be addressed by the use of simulation models (Monteith, 1990). Up to now, there is still no widespread perception that modelling is a viable framework for such research. Modelling is complementary to, and not a replacement for, field research. One of the greatest contribution of modelling lies in its integrative role by which complex and interactive processes can be studied together. Recent experience shows

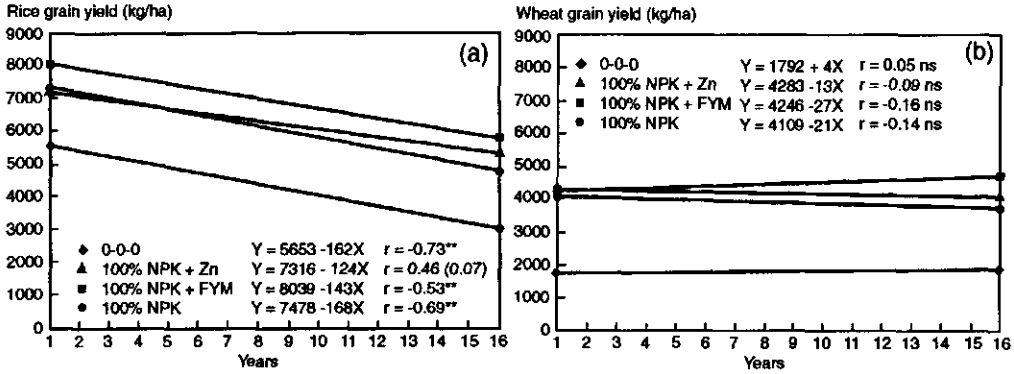


Figure 3. Trends in rice (a) and wheat (b) yield in a long-term rice-wheat trial at Pantnagar University for different fertilizer treatments, Pantnagar, India. Source: Fujisaka et al., 1990.

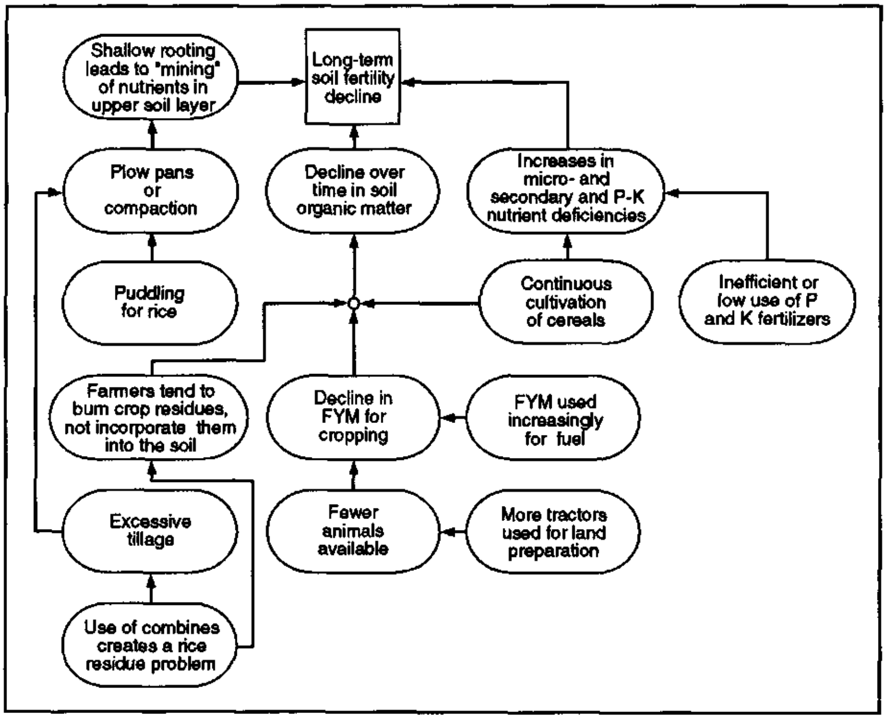


Figure 4. Causes and their interrelationships of soil nutrient depletion at Pantnagar, India. Source: Fujisaka et al., 1990.

that there is considerable potential for integrating computer-based decision support tools into the research and development process. Computer-based decision support tools can be used to provide timely and effective information for use by researchers, extension agents, farmers and policy makers. The benefits of using simulation models include the following:

- A much wider variety of production possibilities can be screened than is possible with field trials only,
- Production alternatives can be screened with direct reference to the resource base of farmers,
- Production alternatives can be screened over many soil types and over many seasons, allowing production stability and sustainability over time to be investigated explicitly.

Simulation experiments can be carried out using historical or synthetically generated weather sequences over many seasons. Fifty 10-year strategies can be simulated in a couple of minutes on a personal computer, facilitating rapid evaluation of strategies in terms of the distribution of outcomes that can arise over time. Risks arising from weather variability can thus be made explicit and quantified. For example, based on long-term weather and site-specific soil data, the selection of suitable rice and wheat cultivars and of management strategies can be optimized. Since late flowering of wheat generally results in low yields, the identification of early to medium maturing rice varieties (for timely sowing of wheat), or the identification of early to medium maturing wheat varieties (under late-sown conditions) through simulation modelling could result in yield gains of the rice-wheat system. Likewise, wheat varieties and dates of wheat sowing can be optimized with respect to risk of water logging and drought, using simulation models and long-term weather data (rainfall events and probabilities) and soil properties (water retention and drainage).

Soil erosion is a major problem in hilly areas. Watershed modelling and soil water balance modelling could help to understand and quantify the magnitude of soil erosion. Based on ex-ante analyses, appropriate management strategies can be devised to tackle this problem.

Inefficient use of nutrients, soil fertility depletion and nutrient deficiencies are some of the major problems in rice-wheat systems. Since farmers apply either insufficient or improper nutrients, and since rice and wheat are both nutrient exhausting/depleting crops, the cultivation of rice-wheat generally results into nutrient deficiencies or nutrient depletion of the soil. Optimization of fertilizer use is necessary, and this requires an understanding of the nutrient cycle and of soil nutrient balances. Again, using long-term weather data, soil properties, rice, wheat and fertilizer prices, recommendations can be made regarding fertilizer inputs and management practices required to achieve maximum economic (and sustainable) yields.

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Modelling tropical rice-wheat systems

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Abstract

Rice-wheat is the most important crop rotation in South and East Asia. After increased production volumes of total grain from the mid-sixties, declining rates of growth have been reported starting from the mid-eighties. The complex short- and long-term constraints facing rice-wheat cropping warrant a modelling approach to better understand the system and to optimize system parameters. A prototype rice-wheat rotation model, ROTAT_RW, was developed to study the effects of delayed sowing of wheat and of adverse soil conditions between harvest of rice to emergence of wheat. The wheat sub-model was parameterized for irrigated tropical wheat on data found in literature and experimental data collected at Los Baños, Philippines. Simulation results were in fair agreement with observed data. Potential wheat yields at Los Baños varied between 2 - 3 t ha^{-1}. Simulation results with ROTAT_RW confirm the sensitivity of wheat production in the post-rice environment to water logging after sowing.

Introduction

Rice-wheat is an important crop rotation in South and East Asia. This rotation is practiced on approximately 14 million ha in South Asia: 11.2 million ha in India, 1.6 million ha in Pakistan, 0.5 million ha in Bangladesh, and 0.4 million ha in Nepal. In addition, about 9.4 million ha are planted with rice-wheat in China. In most of these countries, total grain production (of both rice and wheat) has increased spectacularly since the mid-sixties. These production increases resulted from both increases in cropped area and increased yield levels. Yield increases were mainly due to the introduction of high yielding varieties, better crop management, irrigation, and, in some cases, by supportive governmental price and subsidy policies. However, there is still no significant commercial production of wheat in Southeast Asia and most of the regional demand is met by importing wheat and wheat flour at a huge cost (CIMMYT, 1985). To reduce the large drain of limited foreign exchange and to increase self-reliance, the governments of most South and East Asian countries have a growing interest in cultivating wheat. From the mid-eighties, the rate of increase in total grain production has declined in a number of countries. In Bangladesh and Pakistan, average yields of wheat and rice respectively have even been reported to decline (Woodhead et al., 1993b). Although there is no general consensus, there is a growing concern among some scientists (and farmers) that the sustainability of the rice-wheat system is threatened (Hobbs et al., 1993).

The importance of the rice-wheat rotation, and possible threats to its sustainability have been recognized by the CGIAR (Consultative Group on International Agricultural Research) Centres IRRI (International Rice Research Institute) and CIMMYT (International Maize and Wheat Improvement Center), which started a collaborative Rice-wheat program with a number of Asian National Agricultural Research Systems (NARS) in 1991. Its goals were to quantify global rice-wheat areas, to identify on-farm constraints (in terms of productivity and profitability) and to develop management procedures and technologies to overcome these constraints (IRRI, 1992). Under this program, statistics on yield and areal extent of the rice-wheat rotation have been mapped for China (Huke et al., 1993a), India (Woodhead et al., 1994), Nepal (Huke et al., 1993b), Pakistan (Woodhead et al., 1993a), and Bangladesh (Huke et al., 1993c). On-farm constraints to rice-wheat productivity and profitability have been identified from a number of diagnostic field surveys (e.g. Ahmed et al., 1993; Harrington et al., 1992a; Harrington et al., 1992b; Woodhead et al., 1993a; Fujisaka et al., 1994). Problems identified were listed as long-term, i.e. over the years, and short-term, i.e. within one rotation season. Major long-term problems are depletion of soil macro- and/or micro-nutrient status, depletion of irrigation water reserves, soil erosion, deterioration of soil structure, and increased weed, pest and disease pressures. Short-term problems focus on the period between harvesting of rice and sowing of wheat. Major problems concern delayed sowing of wheat and adverse soil structure. A delay in the establishment of the rice crop in a rotation can be caused by several factors: prolonged growth duration of the previous crop due to adverse weather or to the use of long-duration varieties, delayed rainfall, long turn-around time, unfavourable soil conditions for land preparation and unavailability of labour for land preparation. A delay in sowing can result in yield decline because of an unfavourable shift in the growth cycle of the crop in relation to prevailing weather conditions, e.g. too high or too low temperatures during flowering. Unfavourable soil structure and/or soil water conditions during the interface period can result in a delay in sowing or in poor germination. A compacted layer in the soil as caused by puddling rice fields can hinder root growth of a subsequent upland crop and therefore cause drought stress under adverse weather conditions. Conversely, the compacted layer may also cause water logging during the interface and thus result in delayed land preparation and poor wheat germination.

The problems and constraints facing the rice-wheat rotation system are manifold and complex. Tools of Simulation and Systems Analysis (SSA) are ideally suited to study complex systems in which various forces interact and may either enhance or counteract each other. Therefore, it was decided in 1993 in the Agro-ecosystems theme of the SARP project (Simulation and Systems Analysis for Rice Production) to start building a rice-wheat simulation model to better understand the system and to use it in optimizing system parameters. It was decided to develop a rotation model that would first focus on the short-term problems of delayed wheat sowing on wheat yield and of the effects of an adverse soil water balance. This paper reports some early results of the development of this rotation model: the parameterization and validation of the wheat model component for tropical conditions, the general structure of the rotation model, and some preliminary model runs. Some suggestions are given as to further developing the model.

Material and methods

The rotation model, called ROTAT_RW, was based on three already existing models: WHEAT_W for wheat, ORYZA_W for rice and WATBAL for the soil water balance. WHEAT_W simulates irrigated and rainfed production of wheat on freely draining soils with a deep ground water table. The above-ground part of the model is a FORTRAN version of the growth model SUCROS2 (van Laar et al., 1992), and the water balance subroutine is based on the model SAHEL (van Keulen, 1975; van Keulen & Wolf, 1986). SUCROS2 was developed for temperate (Dutch) environments and needed to be parameterized and tested under tropical conditions. ORYZA_W simulates irrigated and rainfed production of rice in tropical lowland (puddled) and upland (non-puddled) environments (Kropff et al., 1993; ORYZA_W description, 1994). WATBAL is a water balance model that can simulate both puddled and non-puddled soil conditions (Wopereis, 1993). All models are programmed in FORTRAN using the FORTRAN Simulation Environment (FSE, van Kraalingen, 1991).

The WHEAT_W model was parameterized and validated for tropical conditions on data found in literature and on data from field experiments at IRRI by Thein (1988) and Mann (1990). The Philippines is an example of a non-traditional rice-wheat area with interest to explore the possibilities of the system. The experimental data were the best that were immediately available for model parameterization/validation (data from other, more traditional rice-wheat growing countries will be collected in later stages; see also section 'Future work').

Results

Parameterization of the WHEAT_W model

The WHEAT_W model was parameterized on data of irrigated field experiments. This means that only the potential production component of the model was parameterized as no water stress occurred.

1. Crop development rate In the original SUCROS2 model, the development rate as function of average day temperature is (first number is daily average temperature in °C, second number is development rate in (°C d)$^{-1}$):

DVRVT = −10.,0., 0.,0., 30.,0.027
DVRRT = −10.,0., 0.,0., 30.,0.031

where DVRVT is the table of development rates for the vegetative phase, and DVRRT for the reproductive phase. For tropical conditions (Philippines), the functions were redefined based on the field experiments conducted at IRRI as follows:

DVRVT = −10.,0., 0.0,0., 30.,0.023, 40.,0.031
DVRRT = −10.,0., 0.0,0., 30.,0.035, 40.,0.046

Compared with temperate conditions, the development rate at 30 °C was somewhat slower during the vegetative phase, and somewhat faster during the reproductive phase. The functions given here are averages derived from several field experiments using different cultivars.

2. Dry matter partitioning In the original SUCROS2 model, the dry matter partitioning as function of development stage are (first number is development stage (-), second number is partitioning factor in fraction):

FSHTB = 0.0,0.50, 0.1,0.50, 0.2,0.60, 0.35,0.78,
0.4,0.83, 0.5,0.87, 0.6,0.90, 0.7,0.93,
0.8,0.95, 0.9,0.97, 1.0,0.98, 1.1,0.99,
1.2,1.00, 2.5,1.00

FLVTB = 0.0,0.65, 0.1,0.65, 0.25,0.7, 0.5,0.5,
0.7,0.15, 0.95,0.0, 2.5,0.00

FSTTB = 0.0,0.35, 0.1,0.35, 0.25,0.3, 0.5,0.5,
0.7,0.85, 0.95,1.0, 1.05,0.0, 2.5,0.0

where FSHTB is the table of fraction of assimilates partitioned to the shoot, FLVTB is fraction of assimilates partitioned to the leaves, and FSTTB is fraction of assimilates partitioned to the stems. For tropical (Philippines) conditions, these tables were adapted according to van Keulen & Seligman (1987). These new tables were also used by Aggarwal & Penning de Vries (1989) to parameterize the MACROS model for wheat for tropical Southeast Asia, including the Philippines. The new tables are:

Table 1. Changes in model parameter value in the calibration of WHEAT_W.

Parameter		From	To
FRTRL	(fraction of stem weight eventually translocated to storage organs)	0.20	0.35
NPL	(number of plants m^{-2})	210.	300.
WCWET	(volumetric water content where water logging begins)	0.35	0.60
EFF	(light use efficiency in kg CO_2 ha^{-1} leaf h^{-1} per (J m^{-2} leaf s^{-1}))	0.45	0.50

FSHTB = 0.,0.5, 0.1,0.5, 0.2,0.6, 0.35,0.78, 0.4,0.83, ...
0.5,0.87, 0.6,0.9, 0.7,0.93, 0.8,0.95, ...
0.9,0.97, 1.0,0.99, 1.1,1.0, 2.1,1.0

FLVTB = 0.,0.95, 0.1,0.95, 0.2,0.96, 0.35,0.96, ...
0.4,0.86, 0.5,0.5, 0.6,0.27, 0.7,0.16, ...
0.8,0.12, 0.9,0.1, 1.0,0.0, 2.1,0.0

FSTTB = 0.,0.05, 0.1,0.05, 0.2,0.04, 0.35,0.04, ...
0.4,0.14, 0.5,0.5, 0.6,0.73, 0.7,0.84,...
0.8,0.88, 0.9,0.9, 1.0,1.0, 1.1,0., 2.1,0.0

3. Other changes to the original SUCROS2 model are given in Table 1.
These changes were based on literature (van Keulen & Seligman, 1987; Aggarwal & Penning de Vries, 1989). The number of plants m^{-2} was estimated from general practices since it could not be retrieved from published data on the actual field experiments at IRRI.

Validation of the WHEAT_W model

Validation of the model was done at two levels: first, on LAI and total above-ground dry matter (TDM) throughout the growing season, and second on final grain yield. Simulated time courses of LAI and TDM were compared with experimental data of Mann (1990) at the IRRI farm in Los Baños. An example is given for experiments Mann2 and Mann3b in Figure 1. In both experiments, simulated LAI underestimated observed LAI. Simulated TDM slightly underestimated observed values in Mann2, but overestimated observed values in Mann3b. When LAI was used as a forcing function, both the simulated LAI and the TDM were generally in better agreement with observed values for most experiments. If actual data

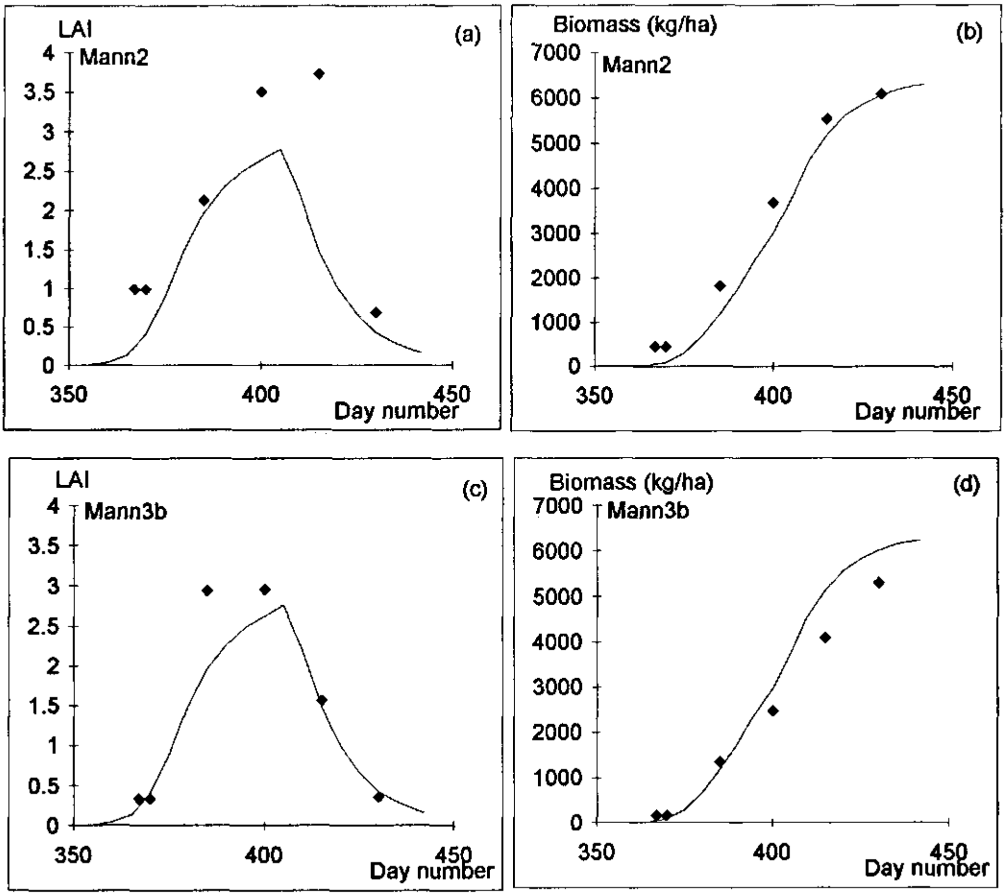

Figure 1. Simulated and observed LAI (Leaf Area Index) and above-ground biomass TDM (Total Dry Matter) of wheat in experiments of Mann (1990). Figures a and b: Mann2 (sowing on Day 355, 1988); Figures c and d: Mann3b (sowing on Day 355, 1988). Simulated values are drawn lines, observed values are black symbols.

on dry matter partitioning and LAI for the Philippines conditions would be available for calibration of the model, LAI and TDM might be more correctly simulated.

Final simulated grain yields were compared with observed grain yields from a number of (irrigated) experiments at the IRRI farm in Los Baños during the eighties (Aggarwal et al., 1987; Thein, 1988; Mann, 1990). Simulated yields were obtained by running the model using the actual weather data for the years in which the experiments were conducted. In general, simulated values were in reasonable agreement with observed yields (Figure 2), indicating that the model's performance was satisfactory. Mostly, yield values varied between 2 - 3 t ha^{-1}. The largest discrepancy between simulated and observed yields occurred for two experiments in which simulated yields were significantly higher than observed yields. When the number of plants m^{-2}, NPL, used in the simulation was 200 (as

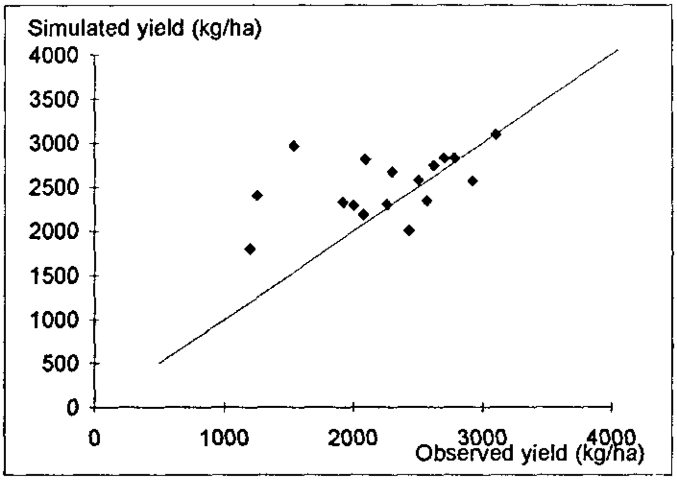

Figure 2. Simulated versus observed wheat grain yields from experiments at Los Baños, 1982 - 1989.

commonly used in temperate environments such as The Netherlands), simulated yields were lower than observed values. When NPL was 400, simulated yields were higher than observed values. In literature, it has been suggested that NPL in tropical environments, such as the Philippines, should exceed 400 plants m^{-2} to obtain yields higher than 2 t ha^{-1} (IRRI, 1990; Jiabao, 1990). This relatively high plant density 'reflects the shortness and high temperature of the tropical wheat-growing season, and the corresponding need for dense populations to intercept efficiently the season's solar irradiance' (IRRI, 1990).

Figure 3 shows the year-to-year variation in simulated wheat grain yields under irrigated and rainfed conditions at Los Baños. The irrigated yields were generally higher and less variable than the rainfed yields.

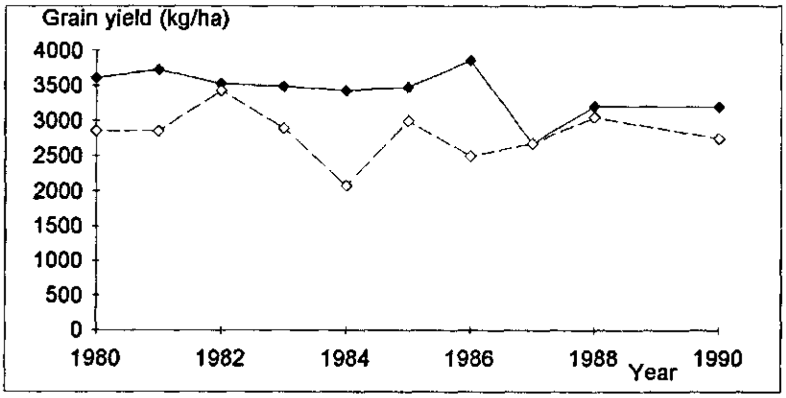

Figure 3. Simulated irrigated (solid line) and rainfed (dashed line) wheat yields at Los Baños. The soil type was loam, and sowing took place on Day 349 (15 December).

Sensitivity analysis with the WHEAT_W model

The sensitivity of WHEAT_W was calculated for potential CO_2 assimilation rate at light saturation for individual leaves (AMX), initial light use efficiency for individual leaves (EFF), fraction of stem weight eventually translocated to storage organs (FRTRL), and number of plants m^{-2} (NPL). Simulated wheat yields were most sensitive to AMX, EFF and NPL, and less sensitive to FRTRL (Figure 4). For an AMX of 20 kg CO_2 ha^{-1} h^{-1}, simulated grain yield was 1.1 t ha^{-1}, whereas for an AMX of 60, it was 3 t ha^{-1}. For an EFF of 0.3, the grain yield was 1.5 t ha^{-1}, whereas for an EFF of 0.6, it was about 3 t ha^{-1}. For a fraction of stem weight (FRTRL) of 0.20, the grain yield was 2.4 t ha^{-1}, whereas for an FRTRL of 0.5, it was about 2.7 t ha^{-1}. Likewise, for an NPL of 100, the simulated grain yield was 1.3 t ha^{-1}, whereas for NPL of 500, it was 3.1 t ha^{-1}.

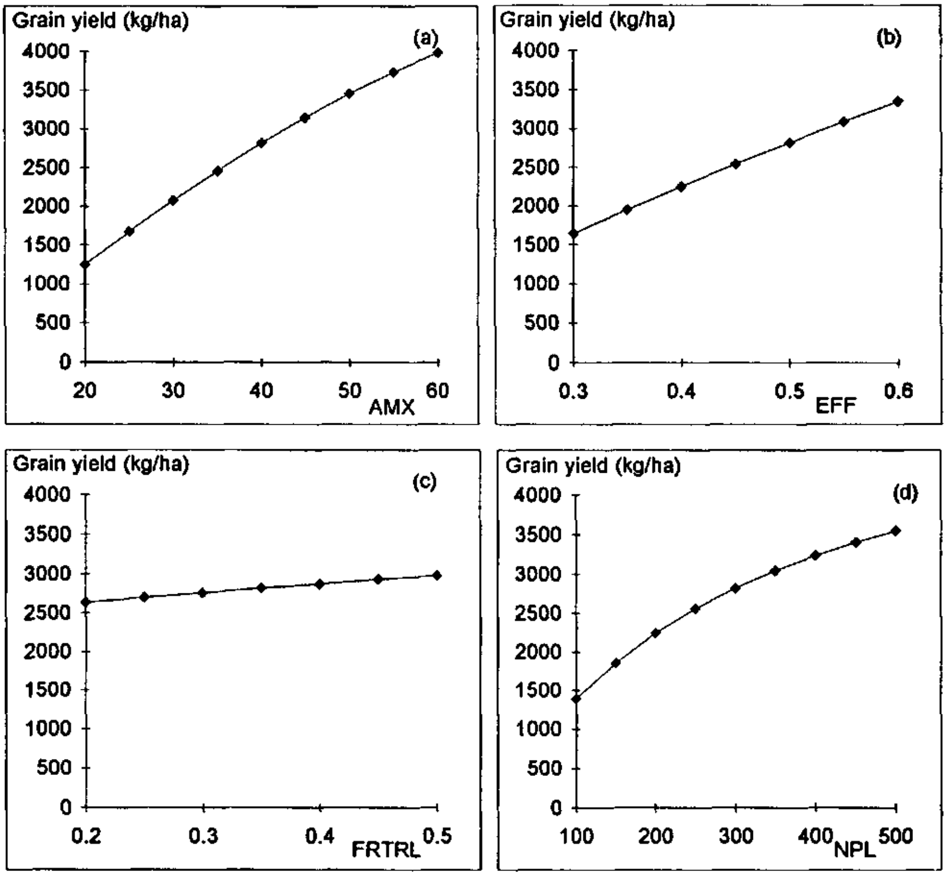

Figure 4. Simulated wheat grain yield as a function of (a) potential CO_2 assimilation rate for individual leaves (AMX, kg CO_2 ha^{-1} h^{-1}), (b) initial light use efficiency for individual leaves (EFF, kg CO_2 ha^{-1} leaf h^{-1}), (c) fraction of stem weight eventually translocated to storage organs (FRTRL, -), and (d) number of plants (NPL, m^{-2}). Simulations were carried out in 1989, with sowing on Day 349 (December 15), Los Baños.

Current state of art of the ROTAT_RW model

The prototype rotation model, ROTAT_RW, for rice-wheat was developed from the models ORYZA_W for rice, WHEAT_W for wheat and WATBAL for the water balance (Figure 5). WATBAL runs continuously 'under' the rice model, during the interface period and 'under' the wheat model. In ROTAT_RW, when the simulation of rice growth is started, WATBAL simulates the soil water balance of a puddled soil. When the rice crop is mature, the model ORYZA_W stops but WATBAL is continued. This period is the fallow period between harvest of rice and sowing of wheat. Land preparation (soil tillage) is assumed to begin when the average water content in the plow layer (set at 0.20 m, comprising the first three soil layers of WATBAL) is between the sticky point and the lower plastic limit. A switch is reset and WATBAL is re-initialized to simulate an upland (non-puddled) soil. The water contents at sticky point and at the lower plastic limit are taken as 50% and 110% of the field capacity, respectively. When a user-defined number of days have elapsed after land preparation (i.e. the changing from a puddled to a non-puddled condition, and re-initialization of WATBAL), sowing of wheat takes place. For the simulation of germination of wheat, a similar criterion is used as applied by Penning de Vries et al. (1992) for soybean in the SOYCROS model. When the conditions for emergence are favourable (i.e. soil water content in the uppermost soil layer is between 70% of field capacity and 90% of saturation) germination proceeds with a constant speed of 1/GMDR (with GMDR = germination rate ≈ 5 d^{-1}). Wheat seedlings emerge when the germination status reaches the value of 1.0. The model WHEAT_W is then started and runs parallel with the water balance model until the wheat crop is ripe.

As illustration, ROTAT_RW was run using different years for a certain transplanting date, and using different dates of transplanting for rice in a certain year. Long term weather data from IRRI, Los Baños, the Philippines were used. For the rice crop, the model data used were for variety IR72, and for the wheat crop data as derived from the parameterization procedure (see above). The data for the soil water balance were from a Tarlac clay loam as measured by Wopereis (1993).

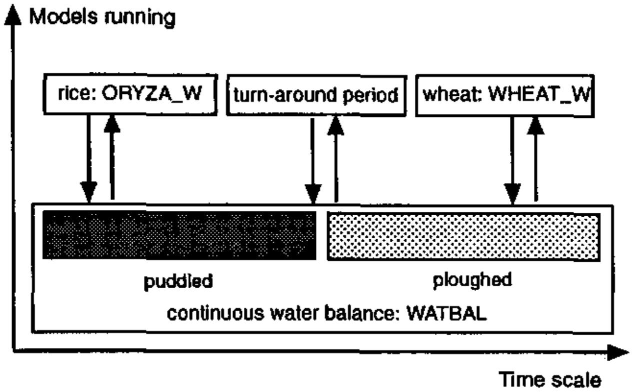

Figure 5. Schematic illustration of the prototype rotation model ROTAT_RW.

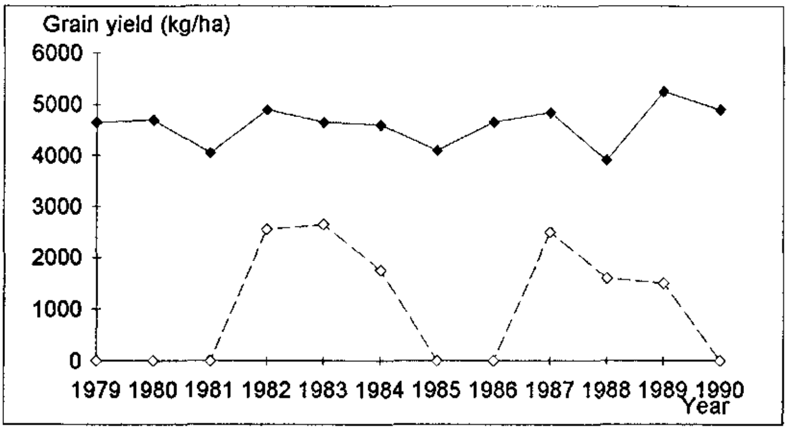

Figure 6. Simulated yields of rainfed rice (solid line) and wheat (dashed line) in a rice-wheat rotation system at Los Baños, using the prototype ROTAT_RW model. Transplanting of rice took place on Day 248 (September 5). See text for further information.

Year-to-year variation in simulated yields of rainfed rice and wheat between 1979 - 1990 at Los Baños is shown in Figure 6. Rainfed rice yields ranged from 3.8 to 5.2 t ha^{-1} when it was transplanted on September 5. Wheat yields were highly variable between the years, varying between 0 and 3 t ha^{-1}. Simulated yields were 0 in 1979, 1980, 1981, 1985, 1986, and 1990 as the seeds did not emerge due to water logging in the first 10 days after sowing.

Future work

ROTAT_RW is a prototype model that needs to be further developed on a number of points:

- Irrigation options need to be elaborated along the lines of the individual ORYZA_W and WHEAT_W models (i.e. irrigation simulated as dynamic variable, with type of irrigation specific for puddled rice and non-puddled upland wheat).
- Re-initialization of WATBAL after the soil turns from puddled to non-puddled needs to be improved: redistribution of soil water, creation of new soil compartments as function of tillage, re-initialization of physical properties (as yet, these options are not fully implemented).
- The simulation of wheat emergence after sowing should be improved. The effects of low or high temperature on germination are not included in the current version. It has been found by Jiabao (1990) that the emergence time (for aggregate sizes with geometric mean diameter of 1 - 8 mm) under wet regime is a function of temperature: (daily average temperature in °C, emergence days) = 20.,6.0, 25.,5.0, 30.,7.0, 40.,10. The maximum time for 100% germination at 30 - 35 °C is 10 days. Also, it has been found that emergence percentage is a function of temperature: (daily average temperature in °C,

emergence %) =0.,0., 10.,50., 15.,72., 20.,93., 25.,95., 30.,72., 35.,50., 40.,0.

- Simulation of the effect of different tillage and sowing practices (e.g. deep/shallow/no tillage, seed drilling) on the structure of the soil, on the water balance and on wheat emergence should be incorporated.
- Since the WHEAT_W (SUCROS2) model was originally developed for temperate environments, some processes that are important in tropical environments are not incorporated (e.g. effect of high temperature on spikelet fertility). Replacement of WHEAT by a wheat growth model for sub-tropical conditions, such as WTGROWTHS (Aggarwal & Penning de Vries, 1988) should be considered.
- The separate components of ROTAT_RW have been parameterized and validated with field experiments in tropical environments (Kropff et al., 1993; Wopereis, 1993; this paper). However, with further development of ROTAT_RW, design and testing should preferably be based on dedicated rice-wheat system experiments.

ROTAT_RW is programmed in a modular way so that other crop rotations can also be simulated by simply exchanging the separate crop models for rice or wheat by models for other crops.

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Rice-wheat cropping and related problems in Western Uttar Pradesh, India

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Abstract
The agro-ecology of rice-wheat cropping is described for the Western districts of Uttar Pradesh, India. Constraints and problems associated with the rice-wheat rotation as derived from diagnostic field surveys, carried-out in the framework of the Rice-Wheat project, are presented. Wheat yields are often low because of poor soil aeration and soil structure, resulting from poor tillage of puddled rice soils and from poor water management, and because of late sowing. Late sowing is caused by late harvest of rice and long turn-around time between rice and wheat.

Introduction

Rice and wheat form the core of Indian food grain crops, with rice occupying 42 million hectares and producing 75 million tons per year, and wheat being cultivated on over 24 million hectares with a production now exceeding 54 million tons annually. Thus, out of 176 million tons of total food grain produced in India in 1990 - 1991, 73% was contributed by these two principal food grains crop. The largest area under rice-wheat rotation of all Indian states is found in Uttar Pradesh (UP), where rice and wheat have been grown in sequence for a long time. UP lies between 23° 52' and 31° 28' N latitude, and between 73° 04' and 84° 38' E longitude. It has a surface of 294 km^2, which is about 9% of the total area of the country, and consists of 63 districts. Rice and wheat in U.P. occupy 5.5 and 8.5 million hectares, respectively, and contribute 14% of total rice production and 35% of total wheat production of the country. Around 4.8 million hectares are under rice-wheat rotation cropping.

The University at Pantnagar, India has its mandated area spread over 21 districts of UP. In these 21 districts, rice is cultivated in 1 to 2 million ha, and wheat in 2.4 million ha. Approximately 1.0 million ha are under rice-wheat cropping. This paper describes the most important features and related problems of rice-wheat cropping in Western UP.

Environmental description of Western Uttar Pradesh

The climate towards the North of the area (Tarai) is sub-humid tropical. Towards the South, it is semi-arid having three distinct seasons: summer, summer monsoon (Kharif) and winter (Rabi). Rainfall is highest in the North (mean annual rainfall of 1380 mm at Pantnagar) and declines towards the South. Thus, rice-wheat cropping is mostly concentrated in the North. Most of that area receives some 1000 - 1200 mm rainfall annually, of which 80 - 85% falls between mid-June to September.

There are two major soil types in the rice-wheat rotation areas: well-drained loamy soils, and poorly drained, heavy loam or silty loam soils (low lands).

The common rice and wheat crop rotations are:

1. Rice-wheat
2. Rice-wheat-rice-sugarcane-ratoon-wheat
3. Rice-toria (*Brassica compestris* var., toria)-sugarcane-ratoon-wheat
4. Rice-toria-wheat
5. Rice-wheat-cowpea/maize fodder

The average productivity of rough rice is about 3.0 t ha^{-1}, and of wheat about 2.5 t ha^{-1}. In some areas, farmers are getting 7.8 t ha^{-1} rough rice yield.

Constraints to rice-wheat productivity

In rice-wheat cropping, the wheat crop is often regarded as secondary and undergoes multiple stresses associated with adverse soil and water management. It is important, therefore, to eliminate or to minimize these stresses to sustain (wheat) production in these areas. In the lowlands of UP, wheat usually follows puddled rice. Yields are low, mainly because of poor soil aeration that results from poor tillage and water management, and because of late sowing. Both poor soil aeration and late sowing result in poor wheat establishment. Another problem is excess soil moisture. Some farmers (necessarily) till their fields under wet conditions, which results in a cloddy seedbed for wheat. Other farmers postpone tillage until the fields are sufficiently dry, which results in late wheat sowing. Late wheat sowing may also result from late harvesting of rice, and then the field may be too dry for good tillage. As a result, wheat is sown in a cloddy seedbed. Fields are often irrigated after about two weeks from sowing to get better germination. However, growth of wheat plants may then be hampered due to poor soil aeration and low soil temperatures. Most often, this period coincides with the winter rainfall which further aggravates the problem (Anonymous 1985, 1986, 1992; Modgal 1989; Pandey & Modgal, 1993).

Diagnostic survey of rice-wheat problems

A diagnostic survey was conducted in the framework of the Rice-wheat project (see also U.

Singh & Timsina, this volume) by a team of multi-disciplinary scientists in the districts Pilibhit, Nainital and Rampur (Hobbs et al., 1991). Some of the problems and their causes in rice-wheat rotation identified in this survey are summarized below in short-term (within a growing season) and long-term (over the years) issues.

Short-term issues

Problems in rice

a. Delayed rice transplanting Rice transplanting in Western UP starts from mid-June, 'peaks' in July, and continues until mid-August. However, transplanting after mid-July causes reduced rice yield. Late transplanting also results in late wheat sowing, reduced fertilizer efficiency and increased stem borer infestation (due to an additional pest cycle). Rice transplanting may be delayed because of shortage of irrigation water, labour and farm power for tillage.

b. Rice establishment Rice is transplanted into puddled soils and requires a relatively large amount of labour in a short period. Alternative methods for rice transplanting, such as direct drilling, have not been developed. Puddling adversely affects the soil properties for the following wheat crop. High yielding cultivars suitable for direct seeding have not been developed, nor has the appropriate production technology.

Problems in wheat

a. Late wheat sowing Wheat sown after November (i.e. in December and January) is considered to be late. Observations made during the survey indicate that this problem exists on both the well-drained and the poorly-drained soil types. Between 1980 - 1990, only 15 - 20% of the wheat crop was sown on time, 70% was sown in December, and 5 - 10% was sown in January. Evidence suggests that delayed wheat sowing after November 20 results in an average yield loss of 1% per hectare per day. Causes of late wheat sowing can be attributed to 1) poor soil physical conditions after puddled rice that require tillage (=> turn-around time); 2) residues of the rice crop create tillage problem, thus increasing the turnaround time; and 3) excess soil moisture during rice harvesting which is a problem particularly in low-lying areas.

b. Water logging and excess moisture This is mainly a problem in the low-lying areas with heavier textured and poorly-drained soils where rice-wheat is continuously grown. In addition to a delay in wheat sowing, this factor probably results in poor rooting with subsequent detrimental effects on yield through inefficient nutrient uptake and water use. Poor aeration also results in reduced tillering of wheat, affecting its productivity.

Excess soil moisture may result from poor drainage as caused by poor soil physical conditions. Puddling the soil for rice results in soils with poor structure, especially in heavy soils, and the formation of a plow pan. This plow pan reduces water percolation for rice culture, but is also a physical barrier for the roots of the subsequent wheat crop. The poor soil structure caused by puddling means that the farmer must till the soil intensely to get a good seedbed and soil structure for wheat. Intensive tillage by tractor-drawn harrows may cause subsurface soil compaction, leading to further reduced drainage. In low-lying Tarai areas, high water tables also cause excessive soil moisture.

c. Poor plant stands This problem is also related to the poor physical condition of the soil following puddled rice, and to the difficulty of preparing a good seedbed after puddled rice (especially when rice crop residues are present). In addition, plant stands can be reduced by water logging after the first irrigation for improved germination. These situations occur more frequently in the low-lying, heavier soils.

Long-term issues

The following long-term problems were identified by the survey teams:

- Observations by farmers show that more inputs are required to attain similar yields over the year, i.e. decreasing input efficiency. Nutrient deficiencies are increasing under high productivity situations.
- Declining trends in rice yield in rice-wheat rotations at constant fertilizer level in long-term field experiments.
- Increasing incidence of pests and diseases with increasing fertilizer use.
- Decline in groundwater table (which has implications for water management).

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Simulation of the productivity of rice-wheat cropping system under rainfed conditions in Bangladesh

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Abstract

Rainfed grain yields of transplanted rice and wheat in rice-wheat rotation in six regions of Bangladesh were simulated with the MACROS crop growth model. Rainfed rice yields varied from 3 to 3.5 t ha^{-1} in areas with a shallow groundwater table, and from 3 to 4 t ha^{-1} in areas with a deep groundwater table. Rainfed rice yield suffered not much from water stress due to the timely onset of the monsoon in the years of simulation, and there was only a yield difference of 0.5 - 1 t ha^{-1} with potential (irrigated) yields. There was no significant variation in the regional yields of rice under water limited conditions. Simulated rainfed wheat yields ranged from 0 to 3.5 t ha^{-1}, depending on sowing date and location, compared to 1.2 - 7 t ha^{-1} under irrigated conditions. Under irrigated condition, highest wheat yields were obtained in the North and North-western regions, while under rainfed situations, wheat yields in these region were relatively the lowest because of severe water stress, particularly in areas with a deep groundwater table.

Introduction

A case study on the potential production of rice and wheat in Bangladesh was conducted earlier using the L1D crop growth model from the MACROS series (Sattar, 1993). Under potential production situations, crop growth is only determined by solar radiation and temperature, and the crop is supposed to be grown under optimal water and nutrient supply and free from pests and diseases. This previous simulation study showed that potential rice yield varied with transplanting date, location and the degree of photoperiod-sensitivity of the used cultivars. At the optimum transplanting period, mid-August, simulated potential rice yields were quite stable and varied between 4 and 5 t ha^{-1}. Simulated potential wheat yields, however, varied considerably from 1.2 to 7 t ha^{-1} from one location to another (due to climatic variation). The optimum sowing time for wheat was between mid-November and mid-December, depending on location. It was also simulated that when rice (cultivars BR14, BR11, and BR22) was transplanted in mid-August, wheat could be sown in mid-December in almost all areas after rice.

In this paper, a follow-up case study is presented to simulate the productivity of rice-wheat cropping under rainfed conditions (i.e. 'water-limited' production situation). The rationale of this work was discussed at length by Sattar (1993). In most regions under rainfed conditions, transplanted *Aman* rice is grown in the wet season as a second rice crop, followed by wheat. The farmer's choice for growing wheat after rice primarily depends on whether the Aman rice crop is harvested early enough. Delayed sowing of wheat reduces yields considerably. Wheat in Bangladesh is grown in various toposequences, and the productivity varies according to the climatic conditions and the availability of water. In order to delineate productivity of rice-wheat crop rotation in the different agroecological zones of Bangladesh, crop growth simulation is applied.

Material and methods

From the MACROS growth simulator series (Penning de Vries et al., 1989), the crop growth model L1D was linked with L2C and the water balance model L2SU for freely draining soils, and with L2C and L2SS for soils with a shallow groundwater table. For rice, the cultivar BR14 was used, and for wheat the cultivar Kanchan. The rice crop data used were mainly those for IR36, and the wheat crop data those for an Israeli spring wheat variety Arminda, as given by Penning de Vries et al. (1989). For rice, the development rates for BR14 were derived from field experiments (DRCV=0.01, DRCR=0.04). For the wheat variety Kanchan, both development rates (DRCV=0.028; DRCR=0.027) and carbohydrate partitioning coefficients were derived from field experiments.

Soil data used were the (standard) data appropriate for the soil water balance models SAHEL (L2SU) and SAWAH (L2SS) for sandy loam soil as given by Penning de Vries et al. (1989). This is because most of the areas under rice-wheat cropping in Bangladesh have sandy loam in the top soil layer (15 - 30 cm). The groundwater table depth was set to approximate most part of the country except for some pockets in the Northern and central regions of the country. Groundwater table depths in these areas fluctuate between 3 and 4 m in the dry season, and between 0.75 and 1.0 m during the monsoon seasons.

The rainfed (water-limited) yields of rice and wheat with ample supply of nutrients and with no pests and diseases were simulated for six locations covering most of the areas of the 30 major agroecological zones of Bangladesh as described by FAO/UNDP (1988) (Figure 1). Rice yield was simulated for August 15 transplanting only, while wheat yields were simulated for four sowing dates: November 15, December 1 and 19, and January 4. Transplanting of rice seedling was done after 20 days in seed bed. The simulation of both rice and wheat growth was conducted for only one year, 1992, in all six locations. Wheat growth was also simulated for four years, 1989 - 1992, at Joydebpur to investigate the annual variation in soil moisture and its effect on yields. For the simulated years, daily values of weather data were obtained from meteorological stations at the sites. Although transplanted Aman rice is usually grown in areas with shallow water table, simulations were also conducted for areas with deep water table to study the effect of water stress. Simulations for wheat were started with the soil moisture at field capacity, and for puddled rice with 10 cm ponded water initially.

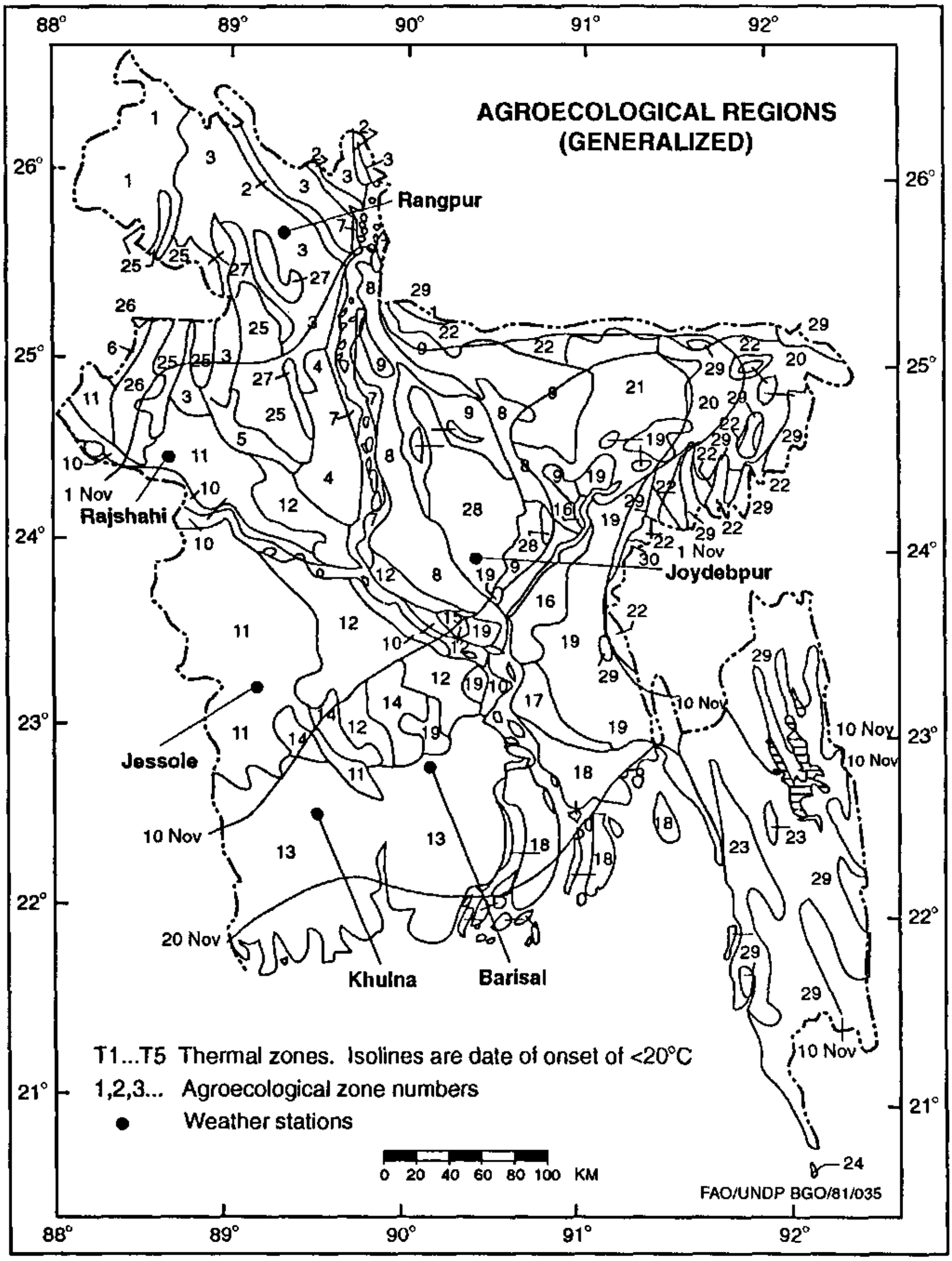

Figure 1. Agro-ecological and thermal zones of Bangladesh. Source: FAO/UNDP, 1988.

Results

Validation

Validation results of the model L1D under irrigated (potential) conditions have been reported elsewhere (Sattar & Roy, 1991; Sattar, 1993). Under rainfed conditions, simulation results were only 'roughly' compared with some field observations. For both rice and wheat, the simulated phenological development was compared with observations from a field experiment conducted at Joydebpur in 1993 and 1992, respectively (Table 1). Although the models were calibrated under irrigated conditions only, the crop phenological developments under rainfed conditions were simulated quite satisfactorily for both rice and wheat. Simulated grain yields of rice were compared with data collected from experiments under optimum conditions conducted in different locations of the country in 1992 (Table 2).

Table 1. Simulated and observed days to flowering and days to maturity for rice (1993) and wheat (1992) in field experiments at Joydebpur.

Crops & Cultivar	Date Sown/planted	Days to flowering Sim.	Days to flowering Observed	Days to maturity Sim.	Days to maturity Observed
Rice (BR14)	August 15	104	100	132	128
Wheat	November 15	56	50	100	102
(Kanchan)	December 1	59	63	102	100
	December 19	54	59	95	92
	January 4	54	57	94	83

Table 2. Simulated and observed grain yield (kg ha^{-1}) of BR14 rice transplanted on August 15, 1993, at six locations in Bangladesh.

Location	Observed		Simulated	
	Irr.	Rainfed	SWT	DWT
Rajshahi	4770	3500	4991	3665
Rangpur	4260	3550	4609	3933
Joydebpur	3680	3031	5042	3696
Jessore	-	-	4411	3242
Barisal	3110	3612	4612	3059
Khulna	2600	-	3071	4136

Irr. = irrigated; SWT = shallowwater table; DWT = deepwater table

Rice yield

Simulated rice yields for areas with shallow and deep water in 1992 for the six locations tables are presented in Table 2. Observed rice yields under irrigated and rainfed conditions are also presented for comparison. Simulated rainfed rice yield varied, depending on location, between about 3 to 5 t ha^{-1} with a shallow groundwater table, and between 3 to 4 t ha^{-1} with a deep groundwater table. With a shallow groundwater table, simulated rainfed yields were always higher than observed yields (both irrigated and rainfed). With a deep groundwater table, simulated rainfed yields were only 0.2 to 0.6 t ha^{-1} higher than observed rainfed yields in Rajshahi, Rangpur and Jessore, but 0.6 t ha^{-1} lower than observed rainfed yields at Barisal.

The simulated irrigated rice yields in Bangladesh as reported by Sattar (1993) varied between 4 to 5 t ha^{-1}, and were thus some 1 - 2 t ha^{-1} higher than the simulated rainfed rice yields (shallow water table). This indicates that the model has satisfactorily taken into account the sensitivity of rice to water stress.

Wheat yield

Simulated rainfed wheat yields varied from 0.5 to 2.1 t ha^{-1} in areas with a deep water table, and from 1.5 to 3.2 t ha^{-1} in areas with a shallow water table (Figure 2). For comparison, simulated grain yield of wheat (cv. Kanchan) under irrigated conditions varied from 5 to 7 t ha^{-1}, depending on location, when sown on mid-November (Sattar, 1993).

With a deep groundwater table, wheat did not produce any grain at all at Rajshahi and Rangpur. At the other four sites, simulated yields were highest at Joydebpur and Barisal and lowest at Khulna and Jessore. Grain yields steadily decreased with increasing sowing

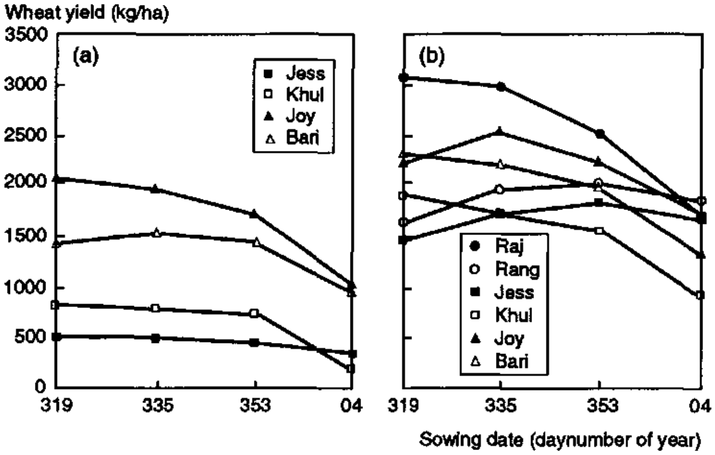

Figure 2. Simulated rainfed wheat yields with a deep groundwater table (a) and a shallow groundwater table (b), as function of sowing date in 1992, for six locations in Bangladesh. Raj = Rajshahi, Rang = Rangpur, Jess = Jessore, Khul = Khulna, Joy = Joydebpur, Bari = Barisal.

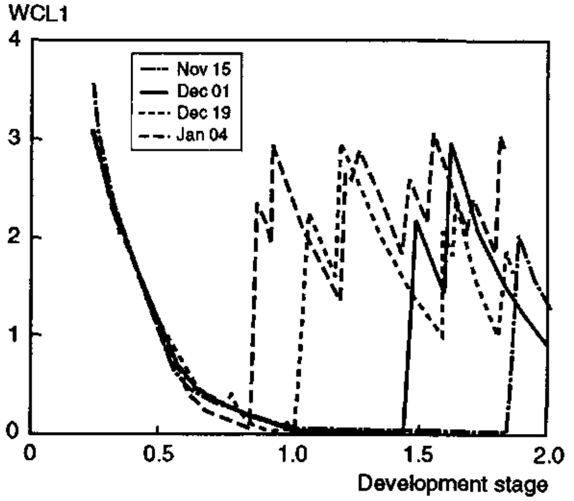

Figure 3. Simulated soil moisture content in the top 10 cm layer (WCL1) under a wheat crop versus simulated development stage of the crop, Rangpur, 1992. The wheat crop was sown on four different dates: November 15, December 1, December 19 and January 4 (1993).

date at Joydebpur, but decreased only when sowing was later than December 19 at the other locations. At all locations, wheat experienced severe water stress during the early growth period. At Jessore, crop growth stopped during grainfilling period. The simulated soil moisture regime in the top 10 cm soil layer at Rangpur is shown in Figure 3.

With a shallow groundwater table, simulated yields varied between 1.5 and 3.1 t ha^{-1}. Rajshahi had the highest yield level followed by Joydebpur. Grain yield decreased with increasing sowing date at Rajshahi, Barisal and Khulna, while an opposite trend was observed at Rangpur and Jessore. This difference was due to variations in thermal conditions which play a major role in crop growth (Sattar, 1993). At Joydebpur, the highest yield was obtained with sowing on December 1. Decreasing yields with later sowing cannot be attributed to any soil moisture deficit (Figure 4), but rather to the prevalence of unfavourable temperatures during the reproductive phase.

Under rainfed conditions, wheat should be sown around early November in the North and Mid-Western zones of the country (i.e. Rangpur, Dinajpur, Rajshahi and Jessore districts) to obtain highest yields (Figure 2). Though these areas have a favourable temperature regime for wheat (Sattar, 1993), moisture becomes limiting particularly with a deep groundwater table (mostly at Rajshahi and Jessore) when the crop is sown in early November. However, in the case of early sowing, the main reason for low yields in these areas is the low level of solar radiation during the grainfilling period due to heavy fog (unpublished data from Saifuzzaman - personal communication, 1994). Therefore, higher yields were obtained from the late sowing cropping.

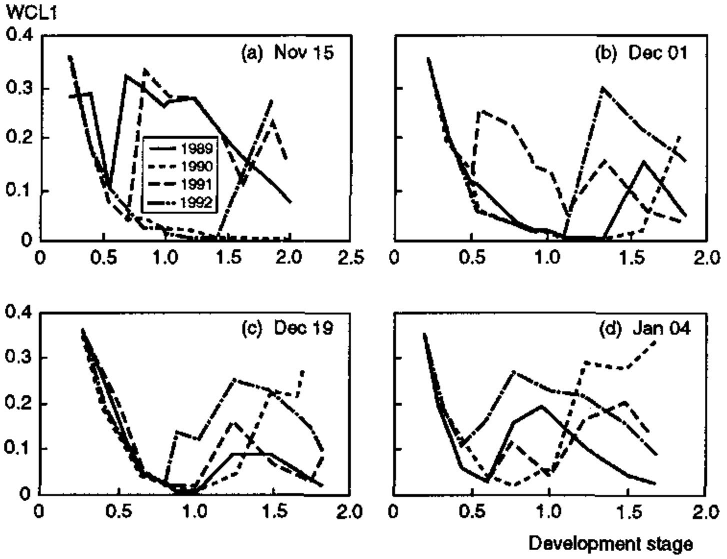

Figure 4. Simulated soil moisture content in the top 10 cm layer (WCL1) under a wheat crop versus simulated development stage of the crop, with four different sowing dates: November 15 (a), December 1 (b), December 19 (c) and January 4 (d). Simulations were carried out for 1989, 1990, 1991 and 1992.

Soil water balance in wheat

The soil moisture content of the top 10 cm layer during the growth of wheat at Joydebpur (with a deep groundwater table) was simulated for four years (1989 to 1992). A large annual variation in soil moisture regime was observed for all sowing dates due to the irregular distribution of rainfall (Figure 4). Based on the thermal requirement for an optimum yield, wheat should be sown between November 15 and December 15. The data in Figure 4, however, show that there was sufficient soil moisture for growing wheat in two out of four years with early sowing, and only in one year with late sowing during.

Conclusions

Simulated rainfed rice yield in Bangladesh varied from 3 to 5 t ha^{-1} in areas with shallow water tables, and from 3 to 4 t ha^{-1} in areas with deep water tables. Although a favourable temperature regime would be expected to result in higher rice yields in the North and Northwestern zones, no such effect was observed under rainfed conditions. There was no variation in regional rice yield level across the country.

Thermal zones 3 and 4 had the highest yield potential for wheat under rainfed conditions, provided that the crop was sown not later than first week of December. In the Northern regions (thermal zone 5), wheat should be sown in late December for optimum yield levels.

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Simulation of peanut yield for a rice-peanut cropping system at four sites in the Philippines

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Los Baños, Laguna, Philippines

Abstract

Crop growth modelling was used to quantify yield level, yield variation, risk and uncertainty of peanut in rainfed rice-peanut rotations at Los Baños, CLSU, Davao City and Dumaguete in the Philippines. The results were used to explore the possibility of using crop growth models as a tool for designing rice-peanut cropping calendars. Simulated yield levels of peanut at Los Baños, CLSU and Davao City were 3.2 - 3.9 t ha^{-1}, and the yield variation was 3 - 10%. At Dumaguete, yield levels were 2.4 - 2.8 t ha^{-1}, with a yield variation of 5 - 10% when planted in May-August, and of 10 - 20% when planted during the rest of the year. Lowest yield risk at any planting date was observed in areas with no distinct wet and dry season but with evenly distributed rainfall throughout the year. Highest risk was observed in areas with no pronounced rainy season but with a relatively long, somewhat wetter period. Crop modelling was useful in designing rice-peanut cropping calendars in areas with distinct wet and dry seasons. Some limitations of the present study that must be addressed in future work were (a) absence of field experiments for validation of results, (b) unavailability of a specific crop growth model for peanut, and (c) lack of a module that simulates the water balance in the fallow period between rice and peanut.

Introduction

Peanut (*Arachis hypogaea* L.) is an important component of cropping systems in about 80 countries where it is planted either as mono-crop, inter crop or relay crop on about 20 million hectares (Rao, 1980). Production, however, is limited by pests, diseases, soil and weather conditions. Unfavourable weather conditions, particularly erratic rainfall, cause considerable yield loss (Singh, 1980).

In the Philippines, peanut is commonly planted in rotation after a main crop such as rice. In these rotations, the peanut crop depends on the residual soil moisture left over from the preceding crop. Thus, a well synchronized cropping calendar can mean significant yield differences. This is especially important in areas with varying climatic conditions from one site to the other like in the Philippines. Cropping trials are needed to determine cropping

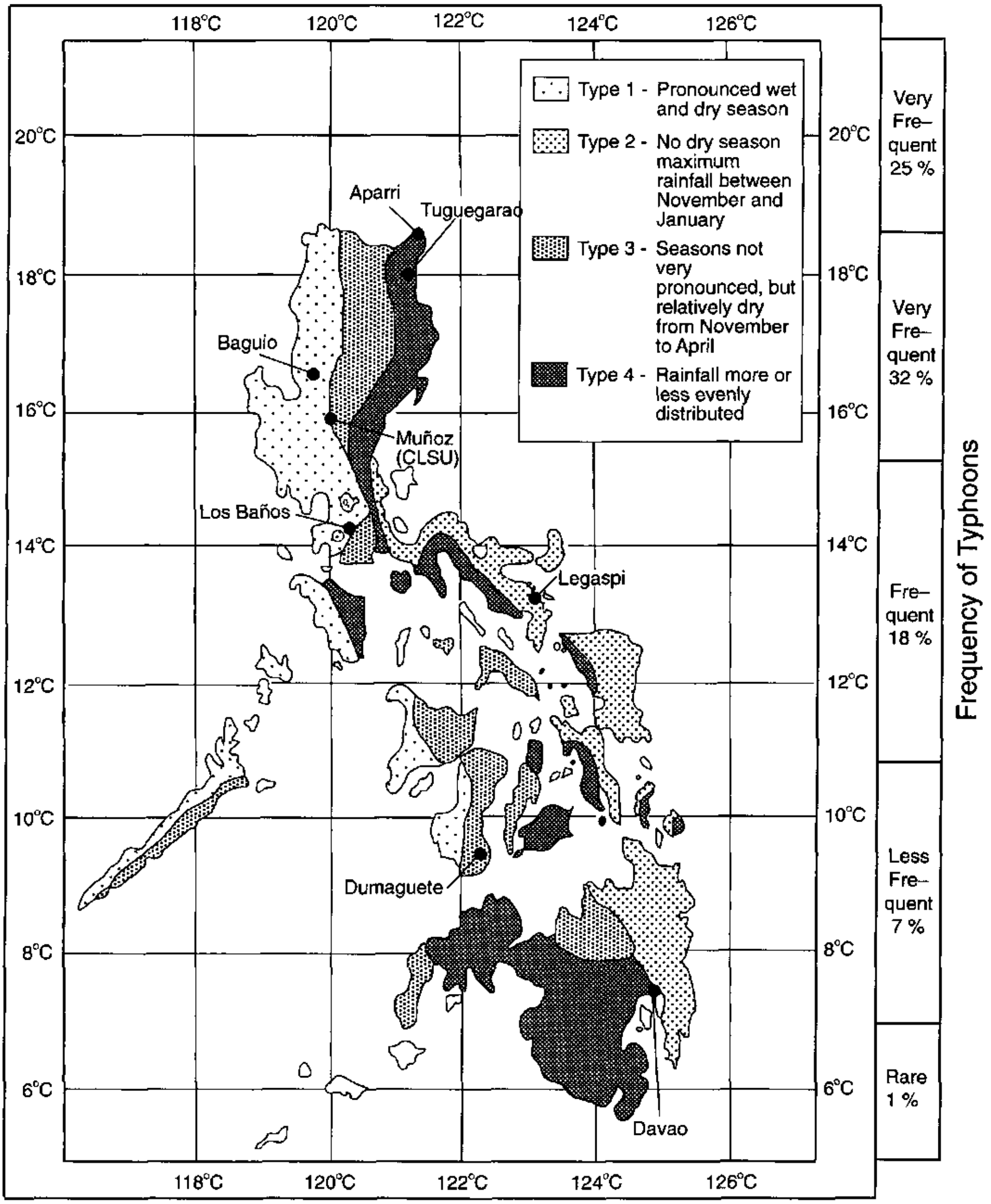

Figure 1. Climate map of the Philippines showing the location of the four sites used in the simulation study (Los Baños, CLSU (Muñoz), Davao City and Dumaguete) and the relative frequency of occurrence of typhoons.

calendars that minimize risk and uncertainty. However, actual on-farm trials cover only relatively small areas. Expanding their scope of coverage is too expensive and time consuming. In situation like this, the potential of using crop growth simulation as a simple, fast and cheap method of extrapolating cropping calendar recommendations should be exploited (Garrity et al., 1988). This paper explores the possibility of using crop modelling in determining an optimal cropping calendar for rainfed rice-peanut cropping at four sites in the Philippines.

Material and methods

Four representative sites in the Philippines with different climates were selected for this study: Los Baños, Central Luzon State University (CLSU), Davao City and Dumaguete (Figure 1). Los Baños and CLSU represent a climate characterized by two pronounced seasons: a dry season from November to April, and a wet season during the rest of the year. Dumaguete has no very pronounced rain period but a somewhat dry season from December to April, and a wetter period during the rest of the year. The climate in Davao City has no distinct wet and dry seasons and rainfall is more or less evenly distributed throughout the year. Figure 1 also indicates the relative frequency of occurrence of typhoons which may affect peanut production. However, the effect of such extreme meteorological phenomena on peanut production is not taken into account in the simulation study.

The crop growth model used was MACROS-L1D coupled to the water balance module L2SU for free-draining soils (Penning de Vries et al., 1989). Simulations were carried out for upland, rainfed conditions (both rice and peanut). It was assumed that weather conditions are the only limiting factor to crop growth, i.e. there are no pest, disease or weed infestations. Model input concerned weather data and soil and crop characteristics:

Weater data Twenty years of generated and actual weather data for all four sites from the database of IRRI's Climatic Unit were used. At least three years of actual weather data were used in generating synthetic data using the weather data generator SIMMETEO (Geng et al., 1988). The weather data were daily values of rainfall, solar radiation, wind speed, temperature (minimum and maximum) and relative humidity.

Soil data were taken for a standard loamy soil as given by Penning de Vries et al., 1989.

Crop data for *Kinandang Pula*, an upland rice variety grown in the Philippines, were used with the following parameters adapted from the IR36 variety data presented by Penning de Vries et al. (1989):

Plant height (PLHT) = 0.0787
Growth rate of crop (GCR) = 0.0133
Initial Weight of Stem (WSTI) = 4.33
Development Stage (DS) = 0.1316
Initial Weight of Leaves (WLVI) = 4.33

For peanut, crop data for the determinate variety *Arachis fastigiata* were used.

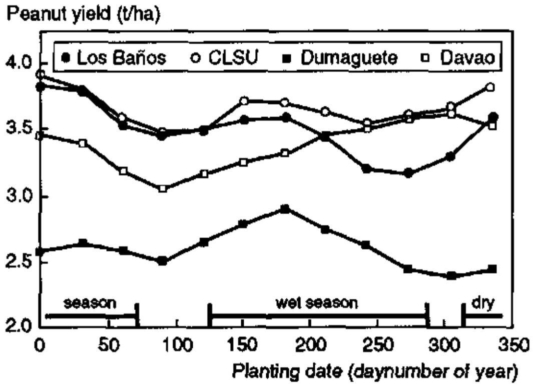

Figure 2. Mean simulated peanut yield, using 20 years of weather data, versus planting date at Los Baños, CLSU, Davao City and Dumaguete.

Yields of rice and peanut were simulated using the 20 years of weather data with different planting dates throughout the year. For each planting date, simulated (climatic) yield variation was calculated using the formula:

$$\%\text{ Yield Variation} = \frac{(\text{3rd quartile yield} - \text{1st quartile yield})}{\text{Median Yield}} \times 100\%$$

Simulated average and quartile yields of rice and peanut and the Yield Variations were plotted against planting date to evaluate the associated risks and opportunities for growing these crops in rotation at the selected sites.

Results and discussion

Peanut

The mean simulated yield of peanut is plotted against planting date for all four sites in Figure 2. The yield level in Dumaguete was lower (2.4 - 2.8 t ha^{-1}) than at the other three sites (3.2 - 3.9 t ha^{-1}). Except at Davao, the same relative yield pattern was observed at all sites. In the wet season, peanut yield was highest when planted in June and July (day number = 150 and 180), and in the wet season, when planted from December to February (day number = 1 and 335).

At CLSU and Los Baños, rainfed yields reached up to 3.6 t ha^{-1} in the dry season, and up to 3.9 t ha^{-1} in the wet season. Actual yields obtained by farmers, using UPL-Pn variety (BPI, 1990) were about 1 to 3 t ha^{-1} lower (Figure 3). In farmer's fields, crop growth is affected by biotic and abiotic stress factors that are not taken into consideration in the simulation model.

Figure 4 shows the calculated Yield Variation. Except for Dumaguete, Yield Variation was quite evenly distributed over the year and varied between 3 to 10%. In Dumaguete,

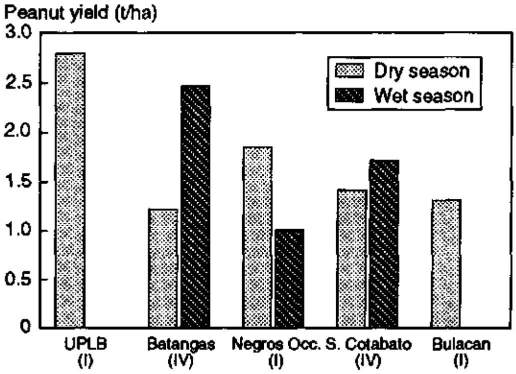

Figure 3. Yields of peanut in farmer's fields. Data from the Philippine Council for Agriculture, Forestry, and Natural Resources Research and Development (PCARRD) and the Philippine Rice Research Institute (PhilRice) trials, 1990.

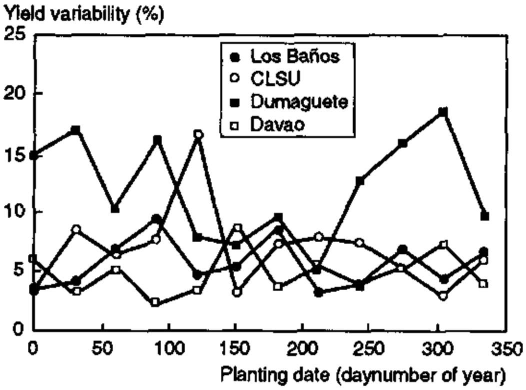

Figure 4. Calculated Yield Variation of peanut versus planting date at Los Baños, CLSU (Muñoz), Davao City and Dumaguete.

Yield Variation is highest (10 - 20%) with planting from August to May. Thus, growing peanut in Dumaguete is more risky than at the other sites, as reflected by its low yield (Figure 2) and relatively high Yield Variation.

Rice and peanut

Plotting together the simulated yield pattern of peanut and upland rice at different planting dates shows the possibility of growing peanut in the selected sites. Simulation shows that in Los Baños peanut can be best planted in December and harvested in the period of April - May, and rice be planted in April - May and harvested in October - November (Figure 5). The same cropping pattern is also possible at CLSU (Figure 6). The same cropping pattern could be practised in other locations with the same climate. In Davao, rice can be grown throughout the year with equal yield level. Peanut would give slightly higher yields when planted in the months of October to December (Figure 7).

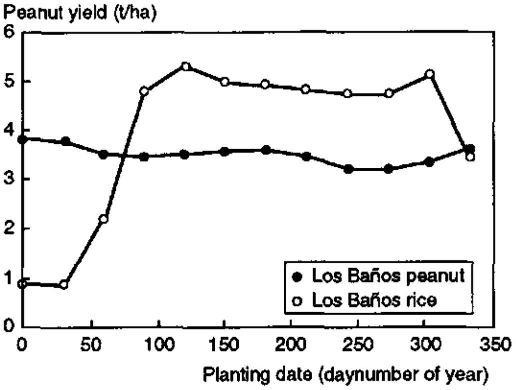

Figure 5. Mean simulated yield of upland rice and peanut versus planting date at Los Baños.

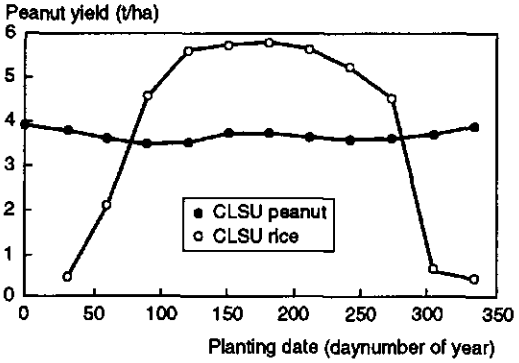

Figure 6. Mean simulated yield of upland rice and peanut versus planting date at CLSU (Central Luzon State University, Muñoz).

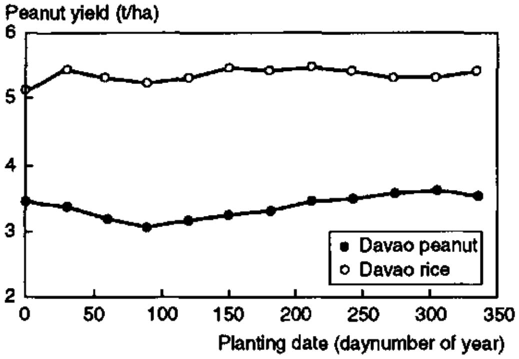

Figure 7. Mean simulated yield of upland rice and peanut versus planting date at Davao City.

Conclusions

Cropping calendars for rice-peanut cropping at four sites with different climates in the Philippines were determined on the basis of simulated long-term yield levels and yield variation. The derived cropping calendars, however, should be regarded as a first approximation and be interpreted with great care because of a number of simplifications in the simulation study:

- The derived cropping calendars were based on separate simulations of the two crops, thus ignoring carry-over effects of residual soil moisture during the fallow period between the two crops. An 'interface' module for this period needs to be developed.
- The simulated risks in this study only reflect the effects of weather fluctuations. The simulations were carried-out for rainfed growing conditions with optimum supply of nutrients and with no pest, disease or weed infestations. There is a yield gap between simulated yields and yields currently realized by farmers.
- The crop model used for peanut was a general growth model, and not specifically designed for this crop. MACROS needs to be adapted for peanut based on well-planned field experiments.

However, these first simulation results show the potential of using crop growth models as a research and planning tool. Its usefulness together with other tools for planning and decision making in crop rotation design and optimization should be further explored.

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Simulation analysis of interplanted corn in Deqing county, P.R. of China

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Abstract

The crop growth model L1D, coupled with the modules L2C and L2SS of the MACROS crop growth series was used to simulate potential and water-limited yield of corn transplanted in (ripening) barley in Deqing county, P.R. of China. The simulation results for 1993 indicated that corn (Yedan No. 12 variety) transplanted in March or April, with an optimum plant density of 75000 - 90000 plants ha^{-1}, had a yield potential of about 6.5 t ha^{-1}. Water-logging for more than five consecutive days resulted in yield decreases of 12 - 18%. Late sowing of corn (May) decreased corn yields because of shorter growth durations and because of prolonged water-logging caused by excessive rainfall. The effects of water-logging during the reproductive stage on growth of the crop should be further investigated.

Introduction

Deqing county, located in the North of Zhejiang Province, Peoples Republic of China, is rich in climatic resources (see also Figure 1 by Pan Jun, this volume). The average annual temperature, total annual rainfall and total annual sunshine hours are 15.9 °C, 1430 mm and 1774 hours, respectively. Until the late eighties, local cropping patters were triple cropping of wheat-rice-rice, rape seed-rice-rice and green manure-rice-rice. These triple crop rotations, however, are labour intensive, time-consuming (particularly in land preparation), and give low economic benefits. Therefore, more productive and economically more efficient cropping systems are being explored by farmers and agricultural extension workers. One of the new cropping patterns being explored is barley-corn-(second-)rice, where corn is transplanted in ripening barley crops. Until now, however, the yield stability of this system, and optimum management practices (such as plant density and planting time) are not yet sufficiently known. In this paper, crop growth simulation modelling is applied to find yield potentials and optimum management practices of the interplanted barley-corn system in Deqing county.

Material and methods

Field experiment

A field experiment was conducted in Deqing county in 1993. Corn, variety Yedan 12 with erected leaves, was sown on March 18 and April 5 in seed beds and transplanted into a (ripening) barley field on April 12 and April 20, respectively. Barley was grown in rows with a density of 75000 plants ha^{-1}. Ample manure was added to the soil. Total biomass and leaf area index (LAI) of the corn crop, and the soil water content in the upper 20 cm layer were measured regularly.

Crop simulation model

From the MACROS series (Penning de Vries et al., 1989), the modules L1D, L2C and L2SS were used for the simulation of corn growth. Crop data on assimilate partitioning and on rate of development (vegetative, reproductive stages) were derived from the experimental measurements. Data on the effect of temperature and daylength on the rate of crop photosynthesis were taken from Jingping & Pingping (1992), Xin Diquan (1992) and Penning de Vries et al. (1989).

Fifteen years of historical weather data were obtained from the Deqing meteorological station. Average monthly data on amount of rainfall, number of rainfall days and evapotranspiration are given in Table 1. Data on soil properties (bulk density, texture) were taken from a local agricultural research station. The texture of the soil is light clay: 3.7% fraction 0.25 - 0.05 mm; 41.08% fraction 0.05 - 0.01 mm; 12.1% fraction 0.01 - 0.005 mm; 20% fraction 0.005 - 0.001 mm; and 23.12% fraction smaller than 0.001 mm. The water content at field capacity (WCFC) of the soil was estimated using the formula presented by Qian Shenguo, 1981):

$$WCFC = K_0 - K_1 \times SBD$$

where K_0 and K_1 are constants determined by the soil texture, and SBD is soil bulk density (g cm^{-3}). The average water table depth was obtained from the local agricultural research

Table 1. Average monthly rainfall (in mm), number of rainy days, evaporation (mm) humidity and soil water table depth (m) at the experimental site in Deqing county.

Month	1	2	3	4	5	6	7	8	9	10	11	12
Rainfall (mm)	34	65	143	147	139	144	171	107	158	98	50	22
Raindays	9	9	16	14	11	13	13	11	12	13	10	5
Evap. (mm)	43	52	72	104	131	116	161	151	100	80	55	56
Water table depth (m)	1.0	1.0	0.5	0.5	0.6	0.6	0.7	0.9	0.6	0.7	0.8	1.1

station (Table 1). The other soil input parameters for the L2SS module were taken from Penning de Vries et al. (1989) for a light clay soil.

The model was used to quantify the effects of plant density and sowing date on potential production, as affected by light and temperature only, and on water-limited production, as affected by light, temperature, rainfall and soil conditions. In both cases, the crop was supposed to be growing free from pests and diseases, and under ample supply of nutrients. In the so-called water-limited situation, corn growth in Deqing is not affected by stress caused by water shortage, but by stress caused by water-logging. Since the soils have traditionally been used mainly for lowland rice growing (two out of three crops; see above), drainage of excessive rain water for non-rice crops is generally a problem. Previous studies (e.g. Xin Diquan, 1992) indicated that the period from seedling emergence to the 7-leaf stage is the most sensitive stage of corn to water-logging. Soil water content near 95% of WCFC (water content at field capacity) could lead to five days water-logging and flooding which could reduce the leaf area by 12 - 23%. Water-logging during the 4 - 11 leaf stage could result in a yield decrease of 15 - 25% (Wang Zongli & Liu Xiaozhong, 1987).

Results and discussion

Model validation

The simulated and measured dates of heading and of crop maturity, and the simulated and measured yields of corn are shown in Table 2; the simulated and measured biomass (stems, leaves) and soil water content in time are given in Figure 1. For the two sowing dates (March 18 and April 1), the simulated dates of heading and of maturity differed from the observed dates by only 1 - 2 days. The simulated yield, however, seriously overestimated observed yield by about 1200 kg ha^{-1}. The simulated trends of stem and leaf biomass were similar to observed ones. The simulated soil water content (in upper 20 cm layer) was in good agreement with observed values (only 2% absolute difference!).

Overall, it was concluded that the model simulated trends of corn growth fairly well, but that yield was seriously overestimated.

Table 2. Simulated and obtained dates of heading, maturity, and simulated and obtained yields of corn in Deqing county, 1993.

Sowing date (day/month)	Heading date (day/month)		Maturity date (day/month)		Corn yield (kg ha^{-1})	
	Sim.	Obtained	Sim.	Obtained	Sim.	Obtained
18/3	19/6	17/6	14/7	15/7	5745	4545
1/4	24/6	25/6	16/7	18/7	5352	4185

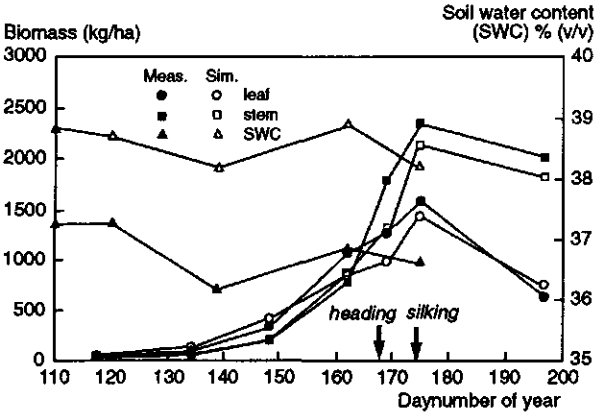

Figure 1. Simulated and measured biomass of leaves and stems, and of soil water content in the upper 20 cm of the soil, Deqing county, 1993.

Table 3. Simulated corn growth and potential yield at different planting dates in Deqing county, 1993.

Transplanting date (month/day)	Vegetative period (days)	Reproductive periods (days)	Maturity date (m/d)	LAI at heading (ha ha^{-1})	Yield (kg ha^{-1})	Total biomass above-ground (kg ha^{-1})
4/7	80	32	7/12	5.12	6550	10948
4/17	71	32	7/15	4.57	6245	10376
4/27	65	32	7/19	3.92	5709	9315
5/6	61	30	7/25	3.45	5156	8507
5/16	58	29	8/1	3.17	4904	8094

Table 4. Simulated corn growth and potential yield at different planting densities in Deqing, 1993.

Corn density (plants ha^{-1})	Vegetative period (days)	Reproductive period (days)	Maturity date (m/d)	LAI at heading (ha ha^{-1})	Yield (kg ha^{-1})	Total biomass above-ground (kg ha^{-1})
45000	66	32	7/21	2.98	5087	7964
75000	65	32	7/21	3.52	5500	8893
90000	65	32	7/21	4.12	5686	9394

Potential production

Table 3 shows the growth performance and potential yield of corn at different planting dates in 1993. The simulation results indicated that the earlier the corn is sown or transplanted, the higher the yield. This is mainly due to the longer vegetative growth period in the field. The difference in growth duration between the earliest and the latest transplanted corn was 25 days, the yield difference was 1645 kg ha^{-1}.

Table 4 shows the growth performance and potential yield of corn at different planting densities in 1993. The optimum plant density was 75000 - 90000 plants ha^{-1}. A plant density higher than 90000 plants ha^{-1} gave only slightly higher yields because of relatively high maintenance respiration.

Water-limited production

Rainfall exceeded evaporation in Deqing county during the whole growing period except during the months of January, August, November and December (Table 1). The soil water table was relatively shallow during the whole year, i.e. 0.5 - 1.2 m (Table 1). In this study, water-logging was considered to occur when soil moisture content exceeded field capacity for five consecutive days. Simulation results of corn growth under water-logged conditions (water-limited production) are presented in Table 5 for different planting dates, and in Table 6 for different planting densities.

Similar to the potential production situation, 'water-logged' corn yields were highest with early transplanting and decreased with later transplanting (Table 5). However, water-logging resulted in decreased LAI development and biomass accumulation. Water-logging showed little influence on the growth duration of the crop. Crop yields at the five different transplanting dates were 87, 86, 83, 82 and 82% of potential yields. Also, the (extra) decrease in 'water-logged' corn yield with late sowing can be attributed to worsening soil drainage conditions as a result of excessive rainfall from late May until July, which may also shorten the flowering, grain-filling and reproductive periods. Finally, prolonged water-logging may also damage the roots of the crop.

Table 5. Simulated corn growth and yield under water-logged conditions, at different planting dates in Deqing, 1993.

Transp. date (m/d)	Vegetative period in (days)	Reprod. period (days)	Maturity date (m/d)	LAI at heading (ha ha^{-1})	Yield (kg ha^{-1})	Total biomass above-ground (kg ha^{-1})	Rainfall (mm)
4/7	78	37	7/14	3.10	5697	8897	548
4/17	70	36	7/18	3.09	5432	8447	508
4/27	65	35	7/23	2.47	4805	7447	549
5/6	61	32	7/28	2.46	4253	6728	520
5/16	58	30	8/4	2.12	4028	6115	531

Table 6. Simulated corn growth and yield under water-logged conditions, at different planting densities in Deqing county, 1993.

Corn density (plants ha^{-1})	Vegetative periods in the field (days)	Reproductive periods (days)	Maturity date (M/D)	LAI at heading (ha ha^{-1})	Yield (kg ha^{-1})	Total biomass above-ground (kg ha^{-1})
45000	67	32	7/23	1.89	4116	6211
75000	67	32	7/23	2.46	4805	7447
90000	67	32	7/23	2.92	5016	8091

Table 7. Simulated corn yields under water-logged conditions, at different water table depths in Deqing county, 1993.

Water table (m)	LAI at heading	Yield (kg ha^{-1})	Total biomass above-ground (kg ha^{-1})
0.55	2.3	4456	7083
1.2	2.83	5061	8213

For the different corn stand densities of 45000, 75000 and 90000 plants ha^{-1}, the simulated yields were 82%, 87% and 88% of the potential yields respectively (Table 6). Thus, with higher plant densities, the relative adverse effect of water-logging on corn yield decreased.

In a comparative simulation run, it was found that a yield increase of about 13% could be realized when the water table was lowered from 0.55 m to 1.2 m depth (Table 7).

Conclusions

The simulation study in 1993 has indicated the opportunities for growing corn interplanted in a (ripening) barley crop in Deqing county. With early sowing between early March and early April, and with an optimum plant density of 75000 - 90000 plants ha^{-1}, potential yields of up to 6500 kg ha^{-1} were simulated. Later sowing of corn reduced corn potential yields because of shorter growth durations. Plant densities larger than 90000 plants ha^{-1} hardly increased yields. Water-logging in the area reduced the corn yields by 12 - 18%. Thus, good soil drainage and deep water tables should be realized for better crop performance and higher crop yield.

The difference between simulated and actually observed corn yields in the field experiment of 1993 was about 1200 kg ha^{-1}. Therefore, future studies should aim at increasing the accuracy of the simulation model. Also, the effects of adverse soil moisture conditions (i.e. water-logging) during the reproductive stage on growth of the crop should be further investigated. A rotation model should be developed to simulate the whole crop rotation of barley (interplanted)-corn-rice in a year.

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Systems analysis and simulation applied to the 'Central China Double and Single Rice-Cropping Region'

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Abstract

Socio-economic farm household data and agronomic data of rice production in Fengshui village (Tonglu county in Zhejiang Province) and in Dongchan village (Jurong county in Jiangsu Province) were analysed in a systems approach. Data were collected through a survey of 30 farm households in each village in 1993. The crop growth model ORYZA1 was used to calculate potential rice yield levels and to analyse the yield gap with current yield levels.

The current rice-based cropping systems are intensive and relatively stable. The average net farm income and total farm household income in Fengshui was 1282 and 5640 yuan, respectively; in Dongchan, it was 1114 and 5078 yuan, respectively. These incomes were sufficient to meet farm family requirements. About 50% of the total farm household income was derived from employment outside agriculture; this percentage was higher for high-income households (58 - 66%) than for low-income households (29 - 40%). Average rice yields of 6.5 t ha^{-1} were close to simulated potential production levels of 7.5 - 8 t ha^{-1}. Because rice-cropping is already intensive in this area, further increases in rice yield will be difficult to obtain. Increases in net returns for farmers should aim at decreasing labour input and further diversified cropping patterns.

Introduction

The 'Central China Double and Single Rice-Cropping Region' contains the most important single and double rice-cropping regions in China. The rice area of this region accounts for 66% of the total area of rice in the country, and for 66% of the total rice grain output (Zhao, 1990). Increased rice production in this region would be very important to support the increasing population in China. Recent research has indicated that the potential yield of current rice varieties is about 10 t ha^{-1} in the tropics, more than 13 t ha^{-1} in sub-tropical regions, and about 7 - 11 t ha^{-1} for south China (Pan Deyun et al., 1991a; Penning de Vries, 1993; Kropff et al., 1994a).

Much work has already been done to increase the production of rice in the Central China rice cropping region: the use of high yielding varieties, improved irrigation facilities, chemical fertilizer and pesticide application. However, most of this work and research was

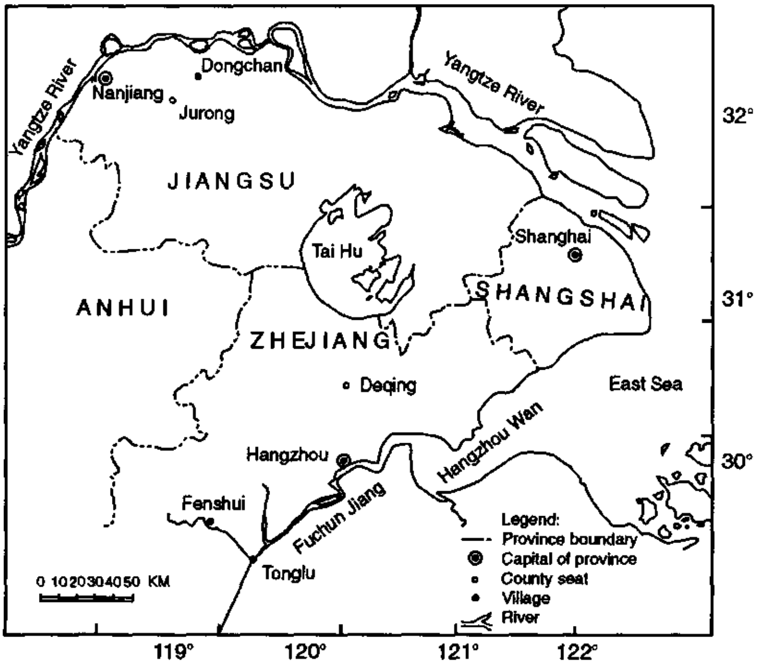

Figure 1. Location of the study area in 'Central China Double and Single Rice-Cropping Region': Fengshui in Tonglu county, Zhejiang Province, and Dongchan in Jurong county, Jiangsu Province.

done in a 'commodity-oriented approach' and only paid attention to increases in rice yield. A systems approach that looks both at the agronomic and socio-economic factors involved on farm-level is still rarely applied in the region. Therefore, the objectives of this study are: (1) to present and analyse socio-economic household data together with agronomic information; (2) to emphasize the importance of agriculture, in general, and of rice cropping, in particular, to total household income, and (3) to suggest ways to improve income from agriculture and rice production. Tools of systems analysis and simulation (Penning de Vries et al., 1989) are applied in this study.

Material and methods

Site description

Two representative counties in Central China were selected for this study: Tonglu county in Zhejiang province, and Jurong county in Jiangsu province (Figure 1). In these counties, local industries are less developed compared to other counties in the area, and most of the labour force is engaged in farming. Actual cropping systems are mainly determined by climate, soil type, availability of irrigation water and accessibility to markets. Major crops grown are cereals such as rice, wheat and rapeseed, but also vegetables, tea and mulberry. Farmers are self-sufficient, and silkworm, tea and livestock provide a cash income. Different cropping systems are observed in different ecosystems, but rice-based cropping in which rice is followed by wheat is by far the most dominant pattern in the two counties. In the triple wheat-rice-rice cropping sequence, the first rice is transplanted in early May and harvested in late July to early August. The second rice crop is transplanted from nurseries established in mid-July to early August and is harvested in October or early November. Wheat matures early, and is harvested in March.

Tonglu county is located between 29° 35' and 35° 05' N and 119° 11' and 119° 58' E. It is 90 km away from Hangzhou city, the capital of Zhejiang Province. The area is located in the south subtropical climate zone with an annual accumulated temperature >10 °C of 5235 °Cd. There are, on the average, 254 frost-free days in a year, and mean annual precipitation is 1452 mm. The county lies in hilly and plain areas, and has a land area of 1844 km^2. The arable area is 19040 ha, and 86.6% of households are owned by farmers. The population density based on the recent census is approximately 207 persons km^{-2}. Tonglu county is divided into administrative areas of 30 townships and 7 market towns. The total value of production in 1993 in Tonglu county was 952 million yuan (1 US$ = 8.71 yuan) of which 814 million yuan came from industry and 138 million yuan from agriculture.

In Tonglu county, the village of Fengshui was randomly selected as study site. This village is located northwest in Tonglu county, and is about 25 km away to Tonglu township. The total village population is 19508 with 16144 engaged in farming. Average family size is 3.5, and average farm size is about 0.33 ha. The village topography is hilly and plain, and the arable area is 1497 ha. Most of the soil types are red soil (65.6%) and paddy soil (18.5%).

Jurong county is located southwest of Jiangsu Province, and is 45 km away from Nanjing city, the capital of Jiangsu Province. The county lies between 31° 37' N and 32° 12' N, and 118° 57' E and 119° 22' E. Most of the soils are alluvial sand and loam deposits from the Yangtze river. The area is in the central subtropical climate zone with an annual mean air temperature of 15.3 °C. The annual accumulated temperature >10 °C is 5010 °Cd. There are, on the average, 220 frost-free days, and the mean annual precipitation is 1000 mm. Total land area of the county is 1385 km^2, of which 48667 ha is arable area. The population density is approximately 430 persons km^{-2}. Jurong county is divided into administrative areas of 22 townships and 4 market towns.

The total value of production in 1993 in Jurong county was 6400 million yuan, of which 5550 million yuan came from industry and 850 million yuan from agriculture. The total yield of grain, cotton, oil, silkworm, and tea in 1993 was 336, 2.150, 30.18, 1.17, and 1.15 million kg, respectively.

In Jurong county, the village of Dongchan was selected as study site. This village is located midway between Nanjing and Zhejiang cities, some 15 km south of Jurong township. The village has a total land area of 54 km^2 with 1800 ha arable. The village population is 18000 with 4878 families. Average family size is 3.7.

Farmer surveys

Socio-economic data and current agricultural practices were collected in 1993 in surveys at two villages in Tonglu and Jurong counties, and from secondary sources of information. The two sample villages were selected by random sampling in each county. Farmers for interviews in the villages were selected by stratified random sampling (Shaner, 1982) with sampling frame established from township records. Thirty farmers were interviewed per village. The farm households were divided into three groups according to the level of net income per capita. Groups I, II and III were considered low, medium and high income farm families with net income per capita of <1000, 1000 - 1500, and > 1500 yuan, respectively.

Crop growth simulation modelling

Potential yield levels and possibilities for yield increases of rice were investigated using the crop growth simulation model ORYZA1 (Kropff et al., 1994b). ORYZA1 simulates growth and development of rice that is grown with ample supply of water (irrigated) and nutrients, and without any pest, disease or weed infestation (potential production). The crop and management data for ORYZA1 were taken for the rice variety IR72 at IRRI (Kropff et al., 1994b). Because not all of these data were suitable for the conditions and varieties used in the study area (Tonglu and Jurong counties), some parameters and functions were changed according to relevant field data (Pan Jun et al., 1989; Pan Jun et al., 1991; Zhu et al., 1989). As example, the data used for a medium maturing rice cultivar Erjiufeng and a late maturing variety indica Guangluai4 (varieties used for the first rice crop) are given below.

Management parameters

NPLH	= 3	Number of plants per hill
NH	= 30	Number of hills per m^2

Crop characteristics

DVRJ	= 0.00085	Development rate during juvenile phase ($^\circ$Cd)$^{-1}$
DVRI	= 0.00082	Development rate during photoperiod-sensitive phase ($^\circ$Cd)$^{-1}$
DVRR	= 0.00190	Development rate during panicle development phase ($^\circ$Cd)$^{-1}$
WGRMX	= 0.0000270	Maximum individual grain weight (kg grain^{-1})
SHCKD	= 0.30	Delay in phenological development parameter ($^\circ$Cd ($^\circ$Cd)$^{-1}$)
SHCKL	= 0.20	Delay in leaf area development parameter ($^\circ$Cd ($^\circ$Cd)$^{-1}$)
RGRL	= 0.00900	Relative growth rate of leaf area ($^\circ$Cd)$^{-1}$

Light use efficiency as a function of temperature ($^\circ$C, kg CO_2 ha^{-1} h^{-1} (J m^{-2} s^{-1})$^{-1}$):

EFFTB = 0.,0.54, 10.,0.54, 40.,0.36

Nitrogen fraction in the leaves as a function of development stage (-, g N m^{-2} leaf)

NFLVTB = 0.00,0.57, 0.16,0.57, 0.33,1.61, 0.65,1.28, 0.79,1.64, ...
1.00,1.35, 1.46,1.44, 2.04,0.87

Other varieties used were Hybrid rice cv Xianyou64, Japonica rice cv. and Xiushui27 (see also Tables 9 and 10).

Weather data were collected from Tonglu and Jurong Agricultural Research Institutes in Zhejiang and Jiangsu provinces, respectively. Five years of data (1988 - 1992) were obtained with daily values of solar radiation, maximum and minimum temperature, relative humidity, wind speed, rainfall.

Results

Major characteristics and constraints of rice production

Rice was the major food crop in both Fengshui and Dongchan. At Fengshui, the annual area planted with rice was about 86% of the total area of food crops, and the rice production accounted for 88% of total grain production. Triple cropping with double rice accounted for 81% of all cropping systems in this village. The average grain yield was 6599 kg ha^{-1}, which was some 18% higher than the average of the province. Most of the harvested rice was used for home-consumption (Table 1). At Dongchan, the area planted to rice was 1251 ha and the average yield was 6552 kg ha^{-1}, which was some 4% higher than the average of the whole province (Table 2).

Recent reforms in rice cropping in both sites were the practice of double cropping rice and new triple cropping systems. To alleviate the constraints that resulted from the (new) multiple cropping systems - such as limitation of seasonal labour and fertilizer - and to increase production, high-yielding technologies for multiple cropping have been studied and popularized.

The identified constraints to increased yields of rice were: (i) short growing period in a year; (ii) decreased soil fertility; (iii) low recovery of nitrogen fertilizer applied; (iv) natural calamities; and (v) the puddling of cultivated soil horizon. Beside these constraints, pests and diseases, low prices for agricultural products, and non-availability of technology transfer and extension services are still problems in the study areas.

Table 1. Average rice production for the 30 farm households at Fengshui in 1993.

Group	Total yield (kg)	Planted area (ha)	Grain yield (kg ha^{-1})	Sold (kg)	Income (yuan)
Group I	1679	0.22	7632	308	217
Group II	1369	0.21	6417	272	177
Group III	1226	0.21	5749	131	70
Average	1427	0.21	6599	253	170

Table 2. Average rice production for the 30 farm households at Dongchan in 1993.

Group	Total yield (kg)	Planted area (ha)	Grain yield (kg ha^{-1})	Sold (kg)	Income (yuan)
Group I	1295	0.19	6938	434	242
Group II	1354	0.21	6552	173	117
Group III	1274	0.21	6165	318	181
Average	1319	0.20	6552	272	163

Socio-economic data analysis

Net farm income Farm income is defined here as the income of a farm household that is only derived from on-farm agricultural activities. Net farm income includes cash and non-cash items. Farm net cash flow is a measure of the capacity of the farm to generate cash. Non-cash items are particularly important in small-scale farming systems. The non-cash farm receipts are the rice consumed by farm family, and the inventory such as storage of some rice and livestock for next year. The annual depreciation costs of farm capital items are considered to be non-cash expenses and average 740 and 735 yuan per year at Fengshui and Dongchan, respectively. The net farm income in 1993 averages about 1282 and 1114 yuan in Fengshui and Dongchan, respectively (Tables 3 and 4). These net farm incomes are sufficient to meet the farm family requirements.

Gross margin of rice production The measure 'gross margin' (GM) is used by economists in the context of measuring farm performance when studying farming activities. In farm planning, GM is defined as gross returns minus variable costs, calculated per unit of production area per unit of time. For a rice crop, this may be 1 ha per season. This is called unitary gross margin which is the criterion to evaluate enterprise budgets. One hectare of land is presently allocated for cultivation of rice to meet the family consumption requirements. It is also among the objectives of a farmer to grow one hectare of rice where currently only about 0.2 ha is the average rice land per farm (Tables 1 and 2).

To calculate gross margins, it is necessary to have an indication of on-farm wage rates. The wage rates in Tonglu and Jurong counties were estimated according to Hang (1992) by:

Wage per man-day = Average yearly living expenditure per capita times burden population per labour force/360

The gross margins of rice production in Fengshui and Dongchan in 1993 were calculated as 2484 and 2626 yuan ha^{-1} rice land season^{-1}, respectively (Tables 5 and 6). With economic development in the region, the opportunity cost of labour increases and work outside agriculture will become more attractive. The labour cost already makes up a large part of the total costs of production.

Table 3. Farm income and profitability analysis at Fengshui (1992/1993). Unit: Yuan.

Item	Cash	Non-cash	Inventory	Total
Farm income				
Grain *	316	616	526	1458
Oilseed	13	--	--	13
Vegetable	60	236	--	296
Tea	26	--	--	26
Silkworm	271	--	--	271
Livestock & Fishery	520	176	121	817
Total gross farm income	1206	1028	647	2881
Variable farm expenses				
Crop	407	--	--	407
Silkworm	87	--	--	87
Livestock & fishery	365	--	--	365
Total variable expenses	429	0	0	859
Total gross margin	777	1028	647	2022
Fixed expenses				
Depreciation				
Farm house & building (20%)	--	420	--	420
Implements & tools (20%)	--	320	--	320
Total fixed expenses	--	740	--	740
Net farm income	777	288	647	1282

* grain includes rice, wheat and corn.

The data used were taken from the Tonglu and Jurong Statistics Bureau in 1992:
For Fengshui: the wage per man-day = (4594/3.7) × 4.2 /360 = 14.5 yuan
For Dongchan: the wage per man-day = (4685/3.7) × 4.2 /360 = 14.8 yuan

Table 4. Farm income and profitability analysis at Dongchan (1992/1993). Unit: Yuan.

Item	Cash	Non-cash	Inventory	Total
Farm income				
Grain*	333	694	490	1517
Vegetable	94	305	--	399
Tea	42	--	--	42
Silkworm	58	--	--	58
Livestock & fishery	499	387	--	886
Total gross farm income	1026	1386	490	2902
Variable farm expenses				
Crop	613	--	--	613
Silkworm	36	--	--	36
Livestock & fishery	400	-	--	400
Total variable expenses	1049	0	0	1053
Total gross margin	–23	1386	490	1849
Fixed expenses				
Depreciation				
Farm house & building (20%)	--	392	--	392
Implements & tools (20%)	--	343	--	343
Total fixed expenses	--	735	--	735
Net farm Income	–23	651	490	1114

* grain includes rice, wheat and corn.

Table 5. Gross margin of rice production at Fengshui in 1993. Unit: Yuan ha^{-1} rice area per season.

Item	Quantity	Unit	Price $unit^{-1}$	Value	%
Gross Return Grain	6599	kg	0.62	4091	
Variable cost					
Seeds	53	kg	1.47	78	5
Fertilizer	458	kg	0.72	330	20
Pesticides	14	kg	5.85	82	5
Family labour	77	day	14.50	1117	70
Total variable costs				1607	100
Gross Margin				2484	

Table 6. Gross margin of rice production at Dongchan in 1993. Unit: Yuan ha^{-1} rice area per season.

Item	Quantity	Unit	Price unit^{-1}	Value	%
Gross Return Grain	6552	kg	0.65	4259	
Variable cost					
Seeds	51	kg	1.52	78	5
Fertilizer	827	kg	0.52	430	27
Pesticides	24	kg	4.33	105	6
Family labour	69	day	14.80	1020	62
Total variable costs				1633	100
Gross Margin				2626	

Sensitivity analysis Grain yields, inputs and produce prices can vary from location to location and from year to year. Sensitivity of these parameters to returns above variable costs (RAVC), gross return (GR) and total variable costs (TVC) are therefore of concern. At Fengshui, when the output (grain yield×price) decreases within 54%, and input (production cost) increases within 120%, the rice cropping system with the popular variety is still profitable (Figure 2). The system is insensitivity to external change in output and input prices. This indicates that the cropping system is stable in this area. Similarly, the cropping system in Dongchan is also insensitivity to external change in the environment, and is stable.

Table 7. Sources of farm household income for the different income groups at Fengshui in 1993. Unit: Yuan. Source: Farm household survey in 1994, Tonglu rural social and economy survey team in 1993.

Item	Average		Group I		Group II		Group III	
	yuan	%	yuan	%	yuan	%	yuan	%
Total income	6127		8924		5629		3827	
Total net income	5640		7785		4241		3147	
Net income per capita	1609		2292		1202		764	
Agriculture	3042	50	3792	42	2604	46	2731	71
Crop	1178	18	1449	16	1067	19	779	20
Livestock & fishery	804	12	1092	12	523	9	588	15
Other*	1060	20	1251	14	1014	28	1364	36
Non-agriculture	3084	50	5132	58	3025	54	1096	29
Industry	1791	27	2932	33	1518	27	135	4
Service & business	1150	20	1474	12	1310	23	665	17
Other	460	7	726	8	197	4	296	8

* simple household processing, household forestry, collection.

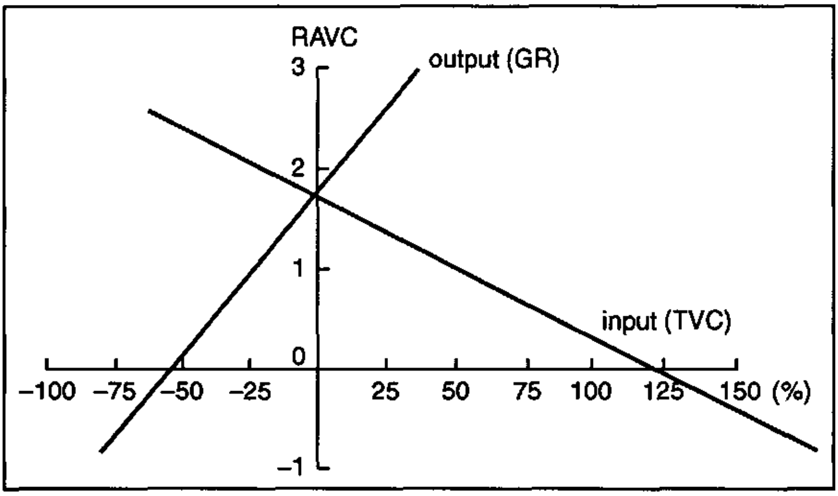

Figure 2. Sensitivity analysis of farmers' rice crops in Fengshui, Tonglu county, Zhejiang Province. RAVC = returns above variable costs × 1000 yuan; GR = gross return, and TVC = total variable costs.

Table 8. Sources of farm household income for the different income groups at Dongchan in 1993. Unit: Yuan. Source: Farm household survey in 1994, Jurong rural social and economy survey team in 1993.

Item	Average		Group I		Group II		Group III	
	yuan	%	yuan	%	yuan	%	yuan	%
Total income	7916		11116		7497		5135	
Total net income	5078		7150		5156		3120	
Net income per capita	1319		2072		1274		742	
Agriculture	3755	47	3788	34	4391	59	3087	60
Crop	1721	22	1797	16	1700	23	1695	33
Livestock & fishery	886	12	972	9	837	11	917	18
Other*	1148	13	1049	9	1854	25	475	9
Non-agriculture	4161	53	7328	66	3106	41	2048	40

* simple household processing, household forestry, collection.

Farm household income Total farm household income comprises farm income (income derived solely from on-farm agricultural activities) and off-farm income (e.g. income from labour employment outside agriculture). Income and expenditure of farm households is greatly affected by labour employment off-farm. High-income families generally have a high proportion of family labour employment in non-agriculture sectors. With increasing labour employment outside agriculture, total farm household income also increases.

Table 7 lists the sources of farm household income for the different income groups at Fengshui in 1993. The average total net income of farm households in Fengshui was 5640 yuan. The net income of the high-income families was 7785 yuan, and that of the low income families 3147 yuan. The group of high-income families had a high proportion of the income from the non-agriculture sector (58%), and the group of low-income families had a relative low proportion of income from outside agriculture (28%).

Table 8 lists the sources of farm household income for the different income groups at Dongchan in 1993. The average total net income of all farm households was 5078 yuan, that of the highest income group 7150 yuan and that of the lowest income group 3120 yuan. The percentage income from non-agriculture was high for high-income families (66%) and low for low-income families (40%). For the high income families, only 16% of family income came from the crop, and for low-income families 33%.

Potential production of rice and yield gap

Potential rice yields were simulated for the first and second rice crop for each of the five years of weather data at Fengshui and Dongchan (Tables 9 and 10). The following conclusions were drawn:

- Simulated yield levels were higher in Tonglu county than in Jurong county for both the first and second rice crops; the differences were about 0.6 - 0.7 t ha^{-1} for the first crop and 0.3 - 0.4 t ha^{-1} for the second crop.
- For the first rice crop, yields of the late maturing variety Guangluai4 were some 0.3 - 0.4 t ha^{-1} higher than those of the medium maturing variety Erjiufeng in both counties. For the second rice crop, yields of the hybrid rice Xianyou64 were about 1 t ha^{-1} higher than those of the Japonica rice Xiushui27 in both counties.
- Yield differences between the years were caused by differences in weather. The highest yielding year (1990) had relatively high (cumulative) radiation. Yield variation was caused by both variation in weather and differences in varietal characteristics.

The average simulated rice yield (averaged over five years, over the two varieties and over the first and second crop) was 8.0 t ha^{-1} in Tonglu county and 7.5 t ha^{-1} in Jurong county. These yield levels were respectively 1.4 and 0.9 t ha^{-1} higher than the average yields from the farmer surveys in 1993 (Tables 1 and 2) for Tonglu and Jurong, respectively.

At the Tonglu Agriculture Institute in Tonglu county, the average observed yield of Guangluai4 (first crop) between 1988-1992 was 6.7 t ha^{-1} which is 1.3 t ha^{-1} lower than simulated yields (8.0 t ha^{-1}). There was no yield gap between rice grown by farmers and rice grown at the Tonglu Agriculture Institute.

Table 9. Simulated potential grain yield of the first rice crop (1988-1992).

	cv Guangluai4		cv Erjiufeng	
Transplanting date month/day/year	Harvest date (m/d)	Potential yield (kg ha^{-1})	Harvest date (m/d)	Potential yield (kg ha^{-1})
Tonglu county (Fengshui)				
5/5/1988	7/25	7983	7/20	7624
5/5/1989	7/25	8052	7/20	7811
5/5/1990	7/30	8228	7/25	7958
5/5/1991	7/30	7993	7/20	7439
5/5/1992	7/25	7881	7/25	7563
Average		8027		7679
Jurong county (Dongchan)				
5/10/1988	7/30	7412	7/30	7133
5/10/1989	7/30	7624	8/04	7351
5/10/1990	8/04	7802	8/04	7528
5/10/1991	8/04	7369	7/30	6982
5/10/1992	7/30	6589	7/30	6437
Average		7359		7086

Table 10. Simulated potential grain yield of the second rice crop (1988-1992).

	Hybrid rice cv Xianyou64		Japonica rice cv Xiushui27	
Transplanting date month/day/year	Harvest date (m/d)	Potential yield (kg ha^{-1})	Harvest date (m/d)	Potential yield (kg ha^{-1})
Tonglu county (Fengshui)				
8/04/1988	11/04	8765	11/09	7632
8/04/1989	11/04	8843	11/09	7614
8/04/1990	11/09	8924	11/13	7858
8/04/1991	11/09	8519	11/13	7719
8/04/1992	11/09	8246	11/09	7425
Average		8659		7650
Jurong county (Dongchan)				
8/09/1988	11/09	8312	11/13	7289
8/09/1989	11/09	8285	11/18	7305
8/09/1990	11/13	8621	11/18	7612
8/09/1991	11/13	7992	11/18	7433
8/09/1992	11/09	7908	11/13	7079
Average		8224		7344

Conclusions and recommendations

Farm household The current rice-based cropping systems in the study area (Tonglu and Jurong counties) are intensive and relatively stable. The average net farm income of 1282 yuan in Fengshui village (Tonglu county) and of 1114 yuan at Dongchan village (Jurong county) in 1993 was sufficient to meet farm family requirements. Average net farm household income was 5640 yuan in Fengshui village, and 5078 yuan in Dongchan village. About 50% of total farm household income was derived from employment outside agriculture; this percentage was higher for high-income households (58 - 66%) than for low-income households (29 - 40%). The opportunity cost of labour outside agriculture is increasing and is becoming more and more attractive in the study sites. This will put a strain on agricultural activity in the area.

Rice cropping Average rice yields (6.5 t ha^{-1}) were close to simulated potential production levels (7.5 - 8 t ha^{-1}). Because rice-cropping is already intensive in this area, further increases in rice yield will be difficult to obtain. Farmers mainly used the produced rice for home-consumption and only sold about 20% to the market. The average gross margin of rice production in 1993 was about 2500 yuan. Relatively low market prices for rice are no incentive to further increase rice production. Estimated labour costs accounted for about 62-70% of the variable costs of rice production.

From the above analysis, it is concluded that increased rice production to feed a growing population in China will be difficult to realize from this area. Main strategies to increase rice production can be: (i) increasing the rice crop growing period in a year (e.g. use of long-duration seed-bed for second rice during first rice crop); (ii) improving soil fertility and soil physical structure; (iii) increasing recovery of nitrogen fertilizer; and (iv) alleviating the influence of natural calamities. Moreover, increases in net returns for farmers should aim at decreasing labour input.

The following recommendations are made to increase the net returns from farm activities in this area in general:

- Further crop diversification. Using intercropping, relay intercropping and rotation cropping techniques to develop cash crops, and to combine food, feed, cash and manure crops for improving efficiency.
- Use of improved varieties and improvement of seedling techniques. Selection and use of early and medium-maturing varieties for the second and third (rice) crops should be encouraged. Development of combined multiple seedling techniques such as dapog and sparse sowing seedling can help to decrease labour input.

Crop growth modelling can help to design and optimize new cropping patterns, and to explore their stabilities (in terms of e.g. yield) under a wide range of environments (e.g. Pan Deyun et al., 1991b; Yang Jingping, 1993).

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Rice-upland crop rotations in rainfed lowland rice areas in Bulacan, Philippines

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Abstract

Four crop rotation systems, rice-green corn, rice-mungbean, rice-peanut and rice-sweet potato were compared to the farmers' cropping pattern (CP) of rice-fallow in terms of crop production and economic performance in six on-farm trial sites in rainfed lowland rice areas in San Ildefonso, Bulacan, the Philippines. Incorporated in the CP trial is a rice variety trial with six Philippine Seed Board (PSB) rice varieties planted in subplots and compared with PSB RC-4 variety in the main plot. Also superimposed in the variety and crop rotation trials was a fertilizer trial comparing four fertilizer levels involving various combinations of inorganic and bio-organic fertilizers (BOF).

Among the green corn varieties tested, Improved Macapuno and Supersweet applied with 500 - 1000 kg ha^{-1} BOF + 92 kg N ha^{-1} produced the best yields and high net benefits. Sweet potato varieties UPL SP2 and UPL SP5 when applied with 28-28-28 kg NPK ha^{-1} using inorganic fertilizer produced better tuber yield. Peanut variety EG red produced better grain yield and higher net benefit. Mungbean did not thrive well due to the low soil pH (4.0 - 4.5) in the area. Rice varieties PSB RC-10, PSB RC-14, and PSB RC-6 were observed to be most adaptable in the area in terms of production and economic performance.

Introduction

Rice-based crop rotation system is a strategy adopted by farmers to increase farm productivity and farm income particularly in areas with no dependable irrigation water during the dry season. The province of Bulacan, the Philippines, for example, has 72000 hectares of rice land of which approximately 58% is irrigated. Most of the rainfed lowland areas have limited rainfall during the year. Thus, rice and other crops cannot be grown successfully throughout the year, and only a limited area is devoted to crop production particularly during the dry season, much so in the rainfed upland areas. The production of upland crops after rice crop during the wet season offers opportunities for increasing the productivity and income of farmers. However, crop establishment during dry season is constrained by limited water for irrigation.

One intervention introduced to supplement irrigation is the construction of small farm reservoirs (SFR). The SFR is a small water impoundment structure with water volume capacity ranging from 1000 - 1500 m^3 used primarily to provide supplementary irrigation to the rice crop during the wet season and to upland crops during the dry season. Moreover, high yielding, early maturing, and resistant rice varieties are used to maximize the available water from rainfall and the supplemental water from the SFR thereby improving the productivity of the farm.

Besides the choice of good combinations of the rice crop and the second crop in a rotation system, determining the appropriate fertilizer recommendations that will maximize crop production and economic net benefits is also important. Thus, in order to determine the best crop rotation strategy and management practices (e.g. fertilizer application levels, variety), on-farm trials are conducted along side the farmers' fields in selected rainfed areas.

This study, therefore, was conducted (1) to evaluate the production and economic performance of different Philippine Seed Board (PSB) rice varieties (as main crop) and upland crops (second crop) under lowland rainfed conditions in the province of Bulacan; and (2) to identify the most productive and highly feasible cropping systems (considering cultivars, fertilizer levels and management practices) that can perform better under rainfed lowland conditions in the province of Bulacan.

Material and methods

Study site

The research was conducted on farmers fields in two adjacent barangays (rural communities), Pinaod and Mataas na Parang, of San Ildefonso, Bulacan Province, Philippines from October 1992 to March 1994 (Figure 1). The area is undulating with side slopes crafted into terraced paddy fields. Soil types are silty clay to clay loam; the pH ranges from 4.0 - 4.5, with Mataas na Parang having lower pH than Pinaod. The climate is Type 3, characterized by distinct wet and dry seasons, and with the dry season commencing as early as November (Figure 2; see also Orno & Lansigan, this volume). Rainfed rice is only grown in the wet season (i.e. cropping pattern is rice-fallow).

Pinaod and Mataas na Parang are also the sites where the Small Farm Reservoir (SFR) technology is being piloted.

Experimental design

Three farms that participate in the SFR Pilot Project were used as test sites in each barangay (leading to a total of six sites). Three experiments were conducted:

1. Cropping pattern (main trial),
2. Philippine Seed Board (PSB) rice variety trial,
3. Upland crop variety and fertilizer trial.

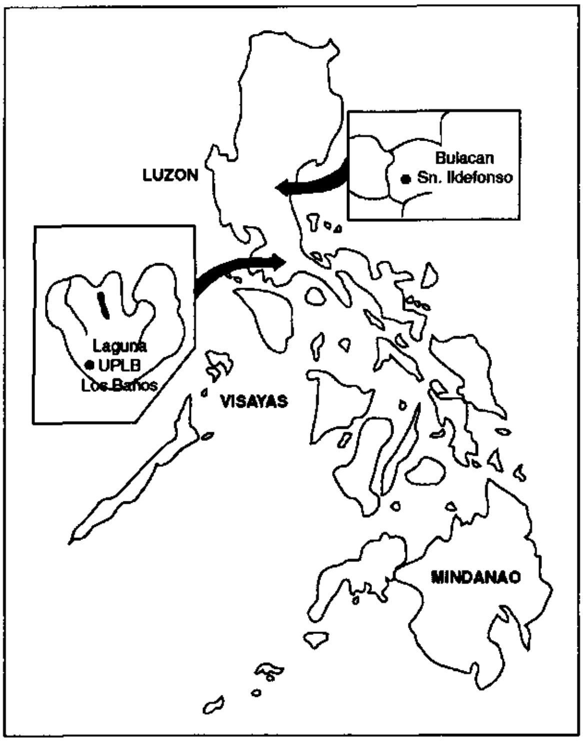

Figure 1. Location of the key sites for the UPLB-DA-FFTC collaborative project for the integration of upland crops in lowland rice areas (University of the Philippines at Los Baños, Department of Agriculture, Food and Fertilizer Technology Center).

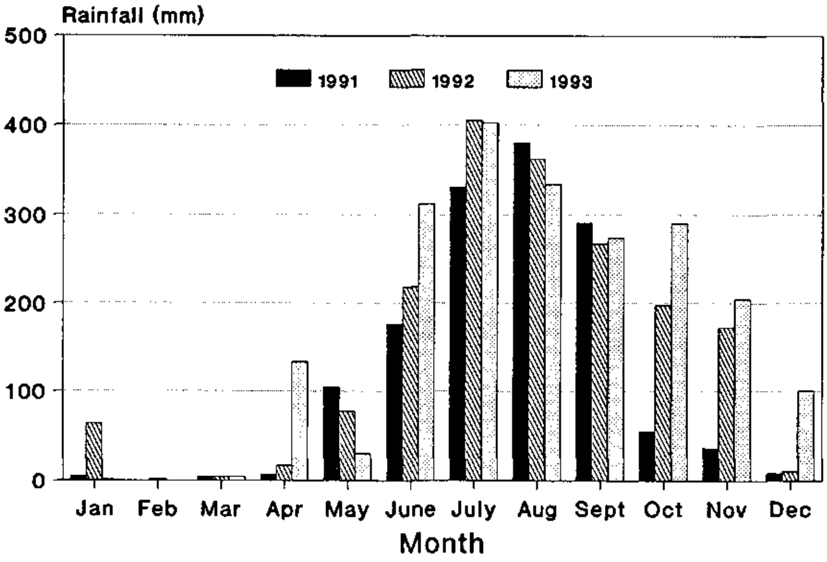

Figure 2. Monthly rainfall at San Ildefonso, Bulacan, in 1991, 1992 and 1993.

Cropping Pattern trial The farm plot for the Cropping Pattern (CP) trial was 3000 m^2 per test site. Four cropping patterns were tested: CP1 - Green corn after rice; CP2 - Peanut after rice; CP3 - Mungbean after rice; and CP4 - Sweet potato after rice. The rice crop was grown in the wet season as lowland crop; the upland crops were grown in the dry season. In the wet season, different rice varieties were used (PSB rice variety trial), and in the dry season different upland crop varieties and fertilizer levels were used (upland crop variety trial).

PSB rice variety trial In the 3000 m^2 plot for the CP trial, subplots of 100 m^2 were created and planted with six different PSB varieties in: PSB RC- 6, PSB RC-8, PSB RC-10, PSB RC-12, PSB RC-14, and BPI RI-10 (BPI, Bureau of Plant Industry). The main field of 3000 m^2 was planted with PSB RC-4.

Upland crop variety and fertilizer trial In the dry season, the following upland crop varieties were used on subplots of 100 m^2:

1. Green corn:	V1 - Improved Macapuno
	V2 - Lagkitan
	V3 - IES White
	V4 - Supersweet
2. Mungbean:	V1 - BPI Mg 9
	V2 - Pag-asa 5
	V3 - Pag-asa 7
3. Peanut:	V1 - EG Red
	V2 - Pn 4
	V3 - Pn 8
4. Sweet Potato:	V1 - UPL SP1
	V2 - UPL SP2
	V3 - UPL SP3
	V4 - UPL SP5

The following fertilizer levels were used:

1. Green corn:	F1 - Check (no fertilizer)
	F2 - 110-42-42 kg NPK ha^{-1}
	F3 - 500 kg ha^{-1} BOF + 92 kg N ha^{-1}
	F4 - 1000 kg ha^{-1} BOF + 92 kg N ha^{-1}
2. Mungbean:	F1 - Check (no fertilizer)
	F2 - Nitro plus (inoculant) + 250 kg ha^{-1} BOF
	F3 - 15-15-15 kg NPK ha^{-1}
	F4 - Nitro-plus alone
3. Peanut	(Same as mungbean)
4. Sweet Potato:	F1 - Check (no fertilizer)
	F2 - 28-28-28 kg NPK ha^{-1}
	F3 - 150 kg ha^{-1} BOF + 23 kg N ha^{-1}
	F4 - 350 kg ha^{-1} BOF + 23 kg N ha^{-1}

Crop establishment and maintenance

Lowland rice (wet season) The soil was thoroughly puddled; ploughing and harrowing were done twice. Rice was transplanted in Pinaod, while the technique of wet seeded rice (WSR) was adopted in Mataas na Parang, as commonly practised by farmers in the area. In Pinaod, the rate of seeding was 80 kg ha^{-1}, and seedling age at transplanting was 18 to 21 days. In Mataas na Parang, the rate of seeding was 150 kg ha^{-1} for wet-seeded rice.

The recommended rate of fertilizer used was 50-28-28 NPK kg ha^{-1} (low-cost technology). All P and K, and half of N were applied as basal fertilizer during the last harrowing. The remaining half of N was applied before panicle initiation. Sources of fertilizer were bio-organic (BOF), with a fertilizer grade of 2-4-4% NPK, and urea. All the test sites were mainly dependent on rainwater, with supplemental irrigation provided by the SFR whenever necessary.

Upland crops (dry season) The usual method of land preparation for upland crops was followed. Furrows were made at a distance of 80 cm for corn and sweet potato, and of 50 cm for mungbean and peanut. The full amount of organic fertilizer, P and K and half of N were applied basally (see above for amounts per treatment). The plots were irrigated with water from the SFRs two to three times on the average, depending on the volume capacity of the SFR. All crops were 'hilled-up' after side-dressing of the remaining amount of N fertilizer. Integrated pest management was applied to prevent and control pests and diseases.

Data collection

Crop parameters were collected to study the 'agronomic' performance of the various treatments (varieties, fertilizer levels), e.g. yield, fresh biomass, growth duration, pest and disease infestation. The prizes of inputs and outputs of the production systems were collected to perform economic profitability analyses.

Results and discussion

PSB rice variety trial

Mean crop parameter values of the rice variety trial are given in Table 1. The highest mean yield was obtained for PSB RC-10 (4.86 t ha^{-1}), although this was not significantly different from those of the other varieties. The lowest yield was obtained for PSB RC-4 with mean yield of only 3.82 t ha^{-1}. In terms of fresh biomass, PSB RC-8 was significantly different from the other varieties with the highest mean biomass yield of 17.2 t ha^{-1}. The lowest fresh biomass yield was obtained for PSB RC-14, with a mean value of 12.9 t ha^{-1}. PSB RC-4, which was the earliest maturing variety and used as 'standard' variety in the Cropping Pattern experiment, lodged most. Minimal or no lodging at all was

Table 1. Mean value of grain yield and other agronomic parameters of different rice varieties in Pinaod (PTR, Pinaod transplanted) and Mataas na Parang (MWS Mataas na Parang wet-seeded), San Ildefonso, Bulacan, wet season 1993.

Variety	Grain yield (DM t ha^{-1})			Fodder yield (fresh t ha^{-1})		Plant height (cm)		Tiller count (no.)	Pests & diseases (rating no.)		Lodging rate (rating no.)		Seedling vigor (rating no.)		Maturity (days)	
	MWS	PTR	Mean	MWS	PTR	MWS	PTR	MWS	MWS	PTR	MWS	PTR	MWS	PTR	MWS	PTR
PSB RC-4	3.83	3.80	3.82	16.2	14.5	79.6	96.5	17.66	1	1	5	7	3	3	93	102
PSB RC-6	4.20	5.20	4.70	15.8	17.9	84.2	99.6	18.93	1	1	1	3	3	3	103	111
PSB RC-8	4.33	4.20	4.27	18.1	19.3	76.4	103.7	18.30	1	1	1	3	3	3	100	106
PSB RC-10	5.00	4.73	4.86	16.0	19.1	74.1	98.9	13.80	3	3	1	3	3	3	96	105
PSB RC-12	4.40	4.60	4.50	16.3	16.3	81.7	101.0	12.23	1	1	1	3	3	3	102	107
PSB RC-14	4.77	-	4.77	15.0	-	80.3	-	-	-	1	-	1	-	3	106	-
BPI RI-10	4.27	4.20	4.23	15.0	15.2	74.0	93.4	17.13	1	1	1	3	3	3	97	106
Mean	4.40	4.46	4.45	16.1	17.1	78.61	98.8	16.34	1.285	1.33	1.66	3.666	3	3	99	106

Pests and disease rating:	Lodging rating	Seedling vigor:
1-light	1-no lodging	1-extra vigorous
3-moderately light	3-moderately (>50% slightly lodged)	3-vigorous
5-moderately heavy	5-most plants moderately lodged	5-plants intermediate or normal
7-heavy	7-most plants nearly flat	7-plants less vigorous than normal
9-severe infestation	9-all plants flat	9-plants are weak and small

observed in the other varieties.

A summary of costs and benefits of the different varieties is given in Table 2. At Mataas na Parang, PSB RC-10 resulted in the highest net income of P 18 835 ha^{-1}, and in Pinaod, PSB RC-6 with P 18 954 ha^{-1}. The 'main' variety of the Cropping Pattern trial, PSB-RC-4, resulted in the lowest net benefits at both sides.

Upland crop variety and fertilizer trial

Green corn after rice (CP1) Among the corn varieties tested, Lagkitan had the highest yield with 76 300 ears ha^{-1} (Table 3). In terms of net benefit, however, Supersweet, that had the lowest ear yield, had the highest net benefit with P 85 900 ha^{-1} (Table 11). This variety commanded a higher price in the market due to its palatability.

The enhancing effect of fertilization is reflected by higher ear yield with inorganic and organic fertilizer application (Table 4). The combination of 1000 kg ha^{-1} BOF + 92 kg N ha^{-1} resulted in the highest net benefit, with P 72 550 ha^{-1} (Table 12). The lowest net benefit was produced by the control treatment (no fertilizer) with only P 24 450 ha^{-1}.

Mungbean after rice (CP2) None of the varieties tested for mungbean gave acceptable grain yields (Table 5). The crop may have been adversely affected by the existing soil conditions in the area, the soil pH being strongly to extremely acid (i.e. pH 4.0 - 4.5). At these pH levels, leguminous crops such as mungbean will not perform well.

Table 2. Yield production and economic analysis of different rice varieties at Pinaod and Mataas na Paring, San Ildefonso, Bulacan, wet season 1993.

Variety	Grain yield (t ha^{-1})		Gross benefit (P ha^{-1})		Production cost (P ha^{-1})		Net benefit (P ha^{-1})	
	MWS	PTR	MWS	PTR	MWS	PTR	MWS	PTR
PSB RC-4	3.83	3.80	22980	22800	11683	12246	11297	10554
PSB RC-6	4.20	5.20	25500	31200	11683	12246	13817	18954
PSB RC-8	4.33	4.20	25980	25000	11683	12246	14297	12954
PSB RC-10	5.00	4.73	30000	28380	11683	12246	18317	16134
PSB RC-12	4.40	4.60	26400	27600	11683	12246	14717	15354
PSB RC-14	4.27	-	25620	-	11683	-	13937	-
BPI RI-10	4.40	4.20	26400	25200	11683	12246	14717	12954
Mean	4.40	4.46	26125	26730	11683	12246	14442	14484

Assumptions: P 6.00 kg^{-1}
Exchange Rate: $1.00 = P 25.00
MWS - Mataas na Parang, Wet Seeded Rice
PTR - Pinaod Transplanted Rice

Table 3. Mean values of the parameters measured in green corn grown after wetland rice (variety trial, Bulacan, dry season 1993).

Variety	Ear yield (pcs ha^{-1})	Fodder yield (kg ha^{-1})	Plant height (cm)	Ear length (cm)
V1 - Improved Macapuno	69000 ab	7450 c	183.70 ab	11.93 b
V2 - Lagkitan	76300 a	11317 b	193.93 ab	13.87 b
V3 - IES White	66500 ab	7650 c	173.40 b	12.33 b
V4 - Supersweet	64000 b	14733 a	202.90 a	18.73 a
LSD 0.05	1611	3197	26.12	2.37

There were no significant differences observed in grain yield due to the levels of fertilizer applied (Table 6). All treatments recorded net financial losses! (Table 12). In terms of economic benefits, fertilizer inputs will not prosper unless the soil acidity is checked.

Peanut after rice (CP3) The highest mean peanut yield was obtained with EG Red (1631 kg ha^{-1}; Table 7), that also gave the highest net financial benefit with P 40 804 ha^{-1} (Table 12). Additional inputs of fertilizer (compared with control) did not increase grain yield

Table 4. Mean values of the parameters measured in green corn grown after wetland rice (fertilizer trial, Bulacan, dry season 1993).

Fertilizer	Ear yield (pcs ha^{-1})	Fodder yield (kg ha^{-1})	Ear length (cm)	Plant height (cm)
F1 - Control	37000 c	3967 b	11.76 b	123.83 b
F2 - 110-42-42 kg NPK ha^{-1}	53666 ab	8000 ab	13.76 a	172.26 a
F3 - 500 kg ha^{-1} BOF + 92 kg N ha^{-1}	63666 a	6900 ab	13.56 a	152.20 ab
F4 - 1000 kg ha^{-1} BOF + 92 kg N ha^{-1}	67000 a	8837 a	12.56 ab	139.90 ab
LSD	23154	4621	1.58	34.40

Table 5. Mean values of the parameters measured in mungbean grown after wetland rice (variety trial, Bulacan, dry season 1993).

Variety	Grain yield (kg ha^{-1})	Fodder yield (kg ha^{-1})	Plant height (cm)
V1 - BPI Mg 9	353.0 a	407.5 a	31.73 a
V2 - Pag-asa 5	446.6 a	442.6 a	33.55 a
V3 - Pag-asa 7	120.1 a	99.7 a	30.13 a
LSD 0.05	505.70	509.50	9.07

Means followed by the same letter are not significantly different at LSD 0.05

Table 6. Mean values of the parameters measured in mungbean grown after wetland rice (fertilizer trial, Bulacan, dry season 1993).

Fertilizer	Grain yield (kg ha^{-1})	Fodder yield (kg ha^{-1})	Plant height (cm)
F1 - control	57.67 a	68.00 a	18.93 ab
F2 - Nitro Plus (inoculant) + 250 kg ha^{-1} BOF	61.15 a	74.50 a	17.96 b
F3 - 15-15-15 kg NPK ha^{-1}	67.50 a	80.50 a	16.80 b
F4 - Nitro Plus	60.00 a	88.00 a	23.40 a
LSD 0.05	50.15	85.68	4.74

Means followed by the same letter are not significantly different at LSD 0.05

Table 7. Mean values of the parameters measured in peanut grown after wetland rice (variety trial, Bulacan, dry season 1993).

Variety	Grain yield (kg ha^{-1})	Fodder yield (kg ha^{-1})	Plant height (cm)
V1 - Pn 8	1075.76 b	2550 b	33.03 a
V2 - Pn 4	1379.48 ab	3420 ab	31.70 a
V3 - EG Red	1631.13 a	4710 a	32.87 a
LSD 0.05	446.40	1791.00	2.99

Means followed by the same letter are not significantly different at LSD 0.05.

Table 8. Mean values of the parameters measured in peanut grown after wetland rice (fertilizer trial, Bulacan, dry season 1993).

Fertilizer	Grain yield (kg ha^{-1})	Fodder yield (kg ha^{-1})	Plant height (cm)
F1 - Control	873.3 a	1074 ab	23.76 a
F2 - Nitro Plus (inoculant) + 250 kg ha^{-1} BOF	826.6 a	936 c	24.00 a
F3 - 15-15-15 kg NPK ha^{-1}	825.0 a	3436 a	24.26 a
F4 - Nitro Plus	792.0 a	955 bc	23.97 a
LSD 0.05	231.70	156.80	2.31

Means followed by the same letter are not significantly different at LSD 0.05.

significantly (Table 8), and slightly decreased net financial returns. Like with mungbean, additional fertilizer under the reigning acid soil conditions does not bring about agronomic and financial beneficial results.

Sweet potato after rice (CP4) There was a large difference in tuber yields of sweet potato: UPL SP-2 had the highest yield with 15.75 t ha^{-1}, and UPL SP1 produced the lowest tuber yield with only 4773 kg ha^{-1} (Table 9). No significant differences in tuber yield were observed with different fertilizer treatments. It could be noted, however, that application of 28-28-28 kg NPK ha^{-1} (F2, Table 10) gave the highest mean yield of 6833 kg ha^{-1} (Table 10). Economic analysis (Table 12) also showed that F2 gave the highest net profit of P 25 865 ha^{-1}, while F4 gave the least.

Corn and peanut were already perceived to be good upland crops to be planted after rice as they have a high production potential and are easily marketed. This observation supports the

Table 9. Mean values of the parameters measured in sweet potato grown after wetland rice (variety trial, Bulacan, dry season 1993).

Variety	Tuber yield (kg ha^{-1})	Fodder yield (kg ha^{-1})
V1 - UPL SP1	4733 c	11733 a
V2 - UPL SP2	15750 a	12733 a
V3 - UPL SP3	7050 ab	6917 b
V4 - UPL SP5	12950 ab	11800 a
LSD 0.05	7782	3788

Means followed by the same letter are not significantly different at LSD 0.05.

Table 10. Mean values of the parameters measured in sweet potato grown after wetland rice (fertilizer trial, Bulacan, dry season 1993).

Fertilizer	Tuber yield (kg ha^{-1})	Fodder yield (kg ha^{-1})
F1 - Control	5333 a	4600 b
F2 - 28-28-28 kg NPK ha^{-1}	6833 a	6760 a
F3 - 250 kg ha^{-1} BOF + 23 kg N ha^{-1}	5767 a	7230 a
F4 - 350 kg ha^{-1} BOF + 23 kg N ha^{-1}	5433 a	6030 ab
LSD 0.05	7529	1592

Means followed by the same letter are not significantly different at LSD 0.05.

results of the on-farm trials. Sweet potato is considered as another good crop but there are associated problems such as its susceptibility to pests (e.g. potato weevil) and its difficult to marketability.

Small farm reservoir potentials

Small farm reservoirs (SFR) served as a good source of water to support the rice crop during wet season. It assured irrigation water especially for seedbed preparation and for crop establishment. In the dry season, an SFR with a storage capacity of 1000 - 1500 m^3

could provide the water requirement of an area of 2500 - 3000 m^2 planted with upland crops. Additional income could also be generated through stocking of fish, like tilapia, while utilizing the SFR for irrigation purposes.

Table 11. Yield production and economic analysis of different varieties of crops tested at Pinaod and Mataas na Parang, San Ildefonso, Bulacan, dry season 1993.

Crop/Variety	Yield	Gross benefit (P ha^{-1})	Production cost (P ha^{-1})	Net benefit (P ha^{-1})
1. Green corn (pc. ha^{-1})				
Macapuno	69000 b	86250	10100	76150
Lagkitan	76300 a	76300	10100	66200
IES-White	66500 b	66500	10000	56400
Supersweet	64000 b	96000	10000	85900
2. Mungbean (kg ha^{-1})				
Mg 9	353.0 a	14120	5630	8490
Pag-asa 5	446.6 a	1784	5630	(3846)
Pag-asa 7	120.1 a	4084	5630	(1546)
3. Peanut (kg ha^{-1}) (shelled)				
Pn 8	1075.76 a	32250	8130	24120
Pn 4	1379.48 a	41384	8130	33254
EG Red	1631.13 a	48934	8130	40804
4. Sweet Potato (kg ha^{-1})				
UPL SP1	10130 ab	50650	8450	42200
UPL SP2	15750 a	78750	8450	33254
UPL SP3	7050 ab	35250	8450	26800
UPL SP5	12950 ab	64750	8450	56300

Assumptions:

Price per kilo of: Green corn: P 0.85
Mungbean: P 40.00
Peanut (shelled): P 30.00
Sweet potato: P 5.00

Exchange rate of $1.00= P 25.00

Table 12. Yield production and economic analysis of various crops as affected by various fertilizer levels, 1992-1993 Pinaod and Mataas na Parang, San Ildefonso, Bulacan, dry season 1993.

Treatment	Yield (kg ha^{-1})	Gross benefit (P ha^{-1})	Production/ treatment cost (P ha^{-1})	Net benefit (P ha^{-1})
1. Green corn	(pc.)			
F1 - Control	37000 c	31450.00	7000.00	24450.00
F2 - 110-42-42 kg NPK ha^{-1}	53666 ab	67082.00	8300.00	58732.00
F3 - 500 kg ha^{-1} BOF + 92 kg N ha^{-1}	63666 a	79582.00	9700.00	69882.00
F4 - 1000 kg ha^{-1} BOF + 92 kg N ha^{-1}	3700 a	83750.00	11200.00	72550.00
2. Mungbean				
F1 - Control	57.65 a	2306.50	5030.00	(2724.00)
F2 - Nitro plus + 250 kg ha^{-1} BOF	61.15 a	2446.00	5880.00	(3434.00)
F3 - 15-15-15 kg NPK ha^{-1}	67.50 a	2700.00	5630.00	(2930.00)
F4 - Nitro plus alone	60.00 a	2400.00	5130.00	(2730.00)
3. Peanut (shelled)				
F1 - Control	873.3 a	25199.00	7530.00	17589.00
F2 - Nitro plus + 250 kg ha^{-1} BOF	826.6 a	24798.00	8380.00	16418.00
F3 - 15-15-15 kg NPK ha^{-1}	825.0 a	24750.00	8130.00	16620.00
F4 - Nitro plus alone	792.0 a	23760.00	7630.00	16130.00
4. Sweet Potato				
F1 - Control	5333 a	26665.00	7100.00	19565.00
F2 - 28-28-28 kg NPK ha^{-1}	6833 a	34165.00	8300.00	25865.00
F3 - 250 kg ha^{-1} BOF + 23 kg N ha^{-1}	5767 a	28835.00	7850.00	20985.00
F4 - 350 kg ha^{-1} BOF + 23 kg N ha^{-1}	5433 a	27165.00	8150.00	19015.00

Assumptions: Price per kilo of:		
	Green corn (pc.)	P 0.85
	Mungbean:	P 40.00
	Peanut (shelled):	P 30.00
	Sweet potato:	P 5.00

Exchange rate $ 1.00 = P 25.00

Conclusions and recommendations

Results of the on-farm trials revealed the following:

1. Cropping patterns tested under SFR which could be adopted in the area (arranged in their order of significance) include: (1) rice-green corn, (2) rice-sweet potato, and (3) rice-peanut.
2. Recommended varieties for various crops of the rotations, and the corresponding fertilizer levels are as follows:

Crop	Variety	Fertilizer rate
Lowland rice	PSB RC-10, PSB RC-8 PSB RC-14, PSB RC-6	50-28-28 kg NPK ha^{-1}
Green corn	Improved Macapuno and Supersweet	500 - 1000 kg ha^{-1} BOF + 92 kg NPK ha^{-1}
Sweet Potato	UPL SP2 and UPL SP5	28-28-28 kg NPK ha^{-1}
Peanut	EG Red	Nitro plus + 15-15-15 kg NPK ha^{-1}

3. Lowland rice variety PSB RC-4 is only recommended for the dry season. In the wet season, this variety will easily lodge if strong winds and heavy rains occur.
4. Wet-seeded rice entails lower production costs per hectare than transplanted rice, and net benefits are higher. The use of early maturing varieties of rice, which represent the majority in the area, favours the planting of upland crops after rice for dry season cropping that fully utilizes residual soil moisture.
5. The willingness of farmers to utilize paddy fields after the rice crop is clearly evident in areas where SFR is available. Farmers are much open to new production technologies which could improve their economic gains.

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