Food Security in the face of Global Change: the GCTE Rice Network as a framework for international collaborative research.¹

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Abstract

The ability to feed the world's rapidly growing population would be substantially achieved by reducing the "yield gap", ie. by improving the management of agroecosystems to yield crops nearer to their maximum physiological potential. An enhanced integrated research effort is therefore needed to determine the relationships between potential yield and yield reducing factors; the incorporation of new understanding within a "systems analysis" framework will help develop improved management.

The Global Change and Terrestrial Ecosystems Core Project of IGBP has launched a series of international research networks (the GCTE Crop Networks for wheat, rice, potato, cassava, sorghum, maize and groundnut) which aim to develop an improved predictive capacity of the effects of global change on crop production. They adopt a systems analysis approach and involve an iterative programme of experimentation and modelling. Network results are designed to develop a strong predictive capability of the effects of future scenarios on crop production, but they can also be used to help improve yields under today's environmental conditions. The rationale, objectives and *modus operandum* of the GCTE Crop Networks are described.

Results of model comparisons in the GCTE Rice Network are summarised. The current rice models are able to provide a good estimate of yield potential in a wide range of rice growing environments where yield potential ranges from 6 to 15 t ha⁻¹; and that in the temperature range -3 to +3 °C there is general agreement on the yield change of about -4.5% (or -0.3 t ha⁻¹) for each degree of temperature difference from the base climate.

Key Words

Crop Growth Simulation Models; Global Change; International Research Networks; GCTE

¹ Parts of this paper build on a presentation given by Professor Peter Gregory, GCTE Focus 3 Leader, at the IRRI Systems Analysis Symposium, December 1995 (Gregory and Ingram, 1996).

1. Introduction

The ability to feed the world's rapidly growing population is one of the most serious issues facing society. Even without the added burden of increasing population, food production in many parts of the world is threatened by damage to soil and water resources through poor technology. This situation has usually arisen because increased demands have led to excessive land-use intensification, the consequences of which are now critical in some instances. It is clear that the fundamental solution for increasing food supplies must come about by developments in two areas: in our social, economic and political systems; and in better use of the resource base and technology. In many cases, however, there is little room for improved management of the resource base. This is where technological development can make a substantial contribution by reducing the "yield gap", that is by improving agroecosystem management to yield crops nearer to their maximum physiological potential. In many parts of the world, and particularly in those areas expected to see the most rapid rise in population, the yield gap is often large; losses to pests, diseases and weeds, and insufficient supplies of water and nutrients are common reasons.

The general concerns about food security may however be exacerbated still further by two additional and interactive forces of global change - changes in atmospheric composition and associated changes in climate. These factors will affect these already stressed and rapidly changing systems in ways we cannot yet predict with any accuracy. However, while global change is further confusing an already complicated situation, it may also bring the possibilities of hitherto unavailable opportunities. Ensuring food security in the coming decades will mean capitalising on potential benefits while minimizing the adverse aspects - but to do this, we need to develop appropriate adaptive strategies to understand the potential impacts of global change on agroecosystems. An enhanced, integrated research effort to determine the relationships between potential yield and yield reducing factors (and how global change will affect them) is an important stage in this process.

2. The GCTE Crop Networks

While the lack of knowledge about the precise environment in the future makes exact predictions impossible, it is important to be able to predict the consequences of defined scenarios and to identify the most sensitive components of cropping systems. To this end, and as part of its research programme on key production systems, GCTE Focus 3 ("Global Change Impact on Agriculture, Forestry and Soils") has initiated strategic, interdisciplinary research to improve our general predictive ability for selected agronomic species. This work is being implemented through a series of Crop Networks which adopt a "systems analysis" approach and involve an iterative programme of experimentation and modelling. The crop production models currently under development are primarily designed for predicting the effects of future scenarios on food production systems. The systems analysis approach does however have an important bonus: it can also be used to help improve yields under today's environmental conditions.

Seven crops have been selected for initial studies (wheat, rice, potato, cassava, sorghum, groundnut and maize) chosen both in recognition of their importance in global food production, and as representatives of a diverse range of crop "functional types".

The GCTE Crop Networks have linked objectives:

- To refine and adapt current crop production models for use in global change studies in a wide variety of conditions.
- To design and undertake experiments to provide improved mechanistic understanding of global change impact on crop production, to aid in model development.

GCTE launches crop networks with a call for international participation and the soliciting of "metadata" (information describing a piece of research, as distinct from the data or model code itself). Standard metadata forms are widely distributed, together with an invitation to apply to join the Network. All applications are then reviewed by an international expert panel (Network Working Group), the conditions of acceptance being twofold: the quality of science and the pertinence to Network objectives. The collation of metadata serves more than just the establishment of network membership; it helped determine what GCTE-type studies are ongoing, where coordinative effort should be placed, and where new projects should be initiated.

An initial goal is the identification of the most suitable models, or modules, for application to global change field experimental programmes. This is the first step towards providing a guide to the application of crop models within national programmes to assist them in planning site-related management strategies and adaptive research for both today's rapidly changing environment, and for future conditions. GCTE Crop Networks for wheat, rice and potato are already well developed, and many researchers from around the world are actively participating in collaborative experimental, modelling and synthesis activities.

3. Model Validation and Development

Robust, reliable crop models are the key to predicting the responses of these important agronomic species to changing environmental conditions. Many different crop models have been developed with a wide range of characteristics and initialisation requirements. Existing models, however, are frequently constructed and validated using experimental data from one locality, so the identification of modelling approaches that yield generic capability is needed. Models need to be compared with contrasting datasets to determine their ability to simulate crop growth across a wide range of environments, that is their "robustness". To compare and develop models satisfactorily, data is needed on phenology, yield (and other plant components), total biomass and LAI development. The GCTE Crop Networks are collating datasets which will provide a balanced coverage representing a range of crop growing environments. To achieve this, datasets are needed for both normal growing conditions and, where possible, extreme conditions, and they should cover a representative range of cultivars and management practices (including pest and disease control). To obtain quality data, variability must be recognised (ie. an adequate number of samples must be taken), and also the problems inherent in datasets, ie. consistency. Standardised protocols (based on the IBSNAT protocol) for the collection and dissemination of data from crop growth experiments have been established to facilitate data management and exchange.

A crucial aspect for model validation and development is clearly the increased understanding and experimental data gained from experiments on crops grown under "global change" conditions. These usually come from "tailor made" experiments on crops grown under eg. elevated CO₂, often as part of the GCTE "Elevated CO₂ Consortium" research, and are of great interest to the Networks. The GCTE worldwide network approach has however also helped to identify datasets from experiments where other key crop-growth variables have been manipulated, or those where detailed physiological measurements have been made. The latter are particularly useful when a given crop has been studied "outside" its normal cultural environment, ie. in one that could be thought of as acting as a surrogate for future conditions.

It is hoped that ultimately the models, which may often have been developed from experimental data from growth chamber and OTC experiments, will be tested against datasets generated by field-scale experiments, eg. FACE and tunnels. (The proposed GCTE Rice Network multi-site temperature gradient tunnel experiment discussed below will be particularly important for this, especially if calibration against the Japanese FACE experiment proves possible.)

While it is clearly important to have confidence in our understanding of the basic physiological processes, potential yield models assume no water or nitrogen limitation, and optimal pest control. The next step therefore is to include the "yield-reducing" factors to simulate crop production under conditions more typical of farmers' fields. The GCTE Crop Networks are working towards this by developing collaborative research programmes involving crop physiologists and specialists in soils, pests, diseases and weeds; and by identifying crop growth experiments where these factors have been included in the design.

4. The GCTE Rice Network

Given the importance of rice in South and Southeast Asia, coupled with the expected population increase in the region, preparing for global change impact on rice production is crucial. Although the precise climate in the future is unknown, it is important to be able to predict the consequences of defined scenarios and to identify the most sensitive components of rice production systems. As for the other crops, this needs the initiation of strategic, interdisciplinary research to improve our general predictive ability.

The GCTE Rice Network was launched at an international workshop in IRRI in March 1994 (Ingram, 1994), where the overall and specific objectives of the Network were established:

Overall GCTE Rice Network Objective

To improve understanding of the effects of global change on rice, and thereby develop a predictive capability for determining the impact of these effects on rice production systems worldwide.

Specific Objectives

1. To develop, improve and validate models of the rice crop/ecosystem. Such models will serve as tools to make reliable assessment of global change projections, including the better evaluation of management options.
2. To conduct experiments that will test scientific hypotheses while providing data that will contribute to development and evaluation of rice production models.
3. To foster improved experimental protocols that will support the needs of both scientific hypothesis testing and crop modelling.
4. To promote aggregation and sharing of scientific data and information, and research tools such as models for more effective evaluation of global change and its effects and impacts.
5. To plan and conduct impact assessments that will contribute to crop management strategies under present conditions and anticipated global change.

As for other GCTE Crop Networks, the first stage has been to identify datasets that will help model validation (even if they are not ideal), and current models. Several suitable rice datasets and models are now included in the Network² (see Table 1), and the exercise has helped plan the next generation of experiments.

Comparison of rice models

In addition to formalising the GCTE Rice Network and establishing Network protocols, the inaugural workshop at IRRI included a presentation of a rice production model evaluation and comparison (Kropff *et al.*, 1994). This aimed to quantify and explain the yield potential of current varieties in contrasting environments using simulation models which quantitatively describe the processes of yield formation. Experimentally determined yield potential in four environments (wet and dry seasons for a tropical environment at IRRI, Los Baños, Philippines, and in temperate/subtropical environments at the Yanco Agricultural Research Institute in Australia and at Kyoto University in Japan) ranged from 5.7-14.7 t ha⁻¹.

Four models of varying complexity (ORYZA1, CERES-Rice, SIMRIW and TRYM) were tested using these data. Predictions from each model were evaluated and compared with data on rice growth in the environment for which they were developed, and also with data from a range of contrasting environments. The models simulated yield potential differences among environments very well: the maximum difference between simulated and observed yield ranged from 0.4-2.2 t ha⁻¹ in the different locations. The results indicate that the current crop models are able to provide an estimate of yield potential in a wide range of rice growing environments where yield potential ranges from 6-15 t ha⁻¹.

² Further applications to join the GCTE Rice Network are welcome at any time; please contact the author at the above address, or email j.ingram@unixa.nerc-wallingford.ac.uk.

Table 1. The GCTE Rice Network: Inaugural Membership, models and datasets

Principle Investigator	Institution	Model	Data-sets
Aggarwal, P.K.	Indian Agricultural Research Institute, Division of Environmental Sciences, New Delhi, (India)		
Badawi, A.T.	Agricultural Research Center, Rice Research and Development Program, Giza, (Egypt)		1
Casanova, D.	Wageningen Agricultural University, Department of Soil Science, Wageningen, (The Netherlands)	(Based on ORYZA modules, SUCROS based)	1
Changhan, Q.	Crop Science Research Institute, Jiangxi Agricultural University, (China)	RICAM V1.0	3
Defeng, Z.H.U.	China National Rice Research Institute, Zhejiang, (China)		1
Horie, T.	Kyoto University, Laboratory of Crop Science, Faculty of Agriculture, (Japan)	SIMRIW	
Kobayashi, K.	National Institute of Agro-Environmental Sciences, Tsukuba, (Japan)	VSM	
Nakagawa, H.	Kyoto University, Laboratory of Crop Science, Faculty of Agriculture, (Japan)		1
Ranganathan, T.B.	Tamil Nadu Agricultural University, Tamil Nadu, (India)		1
Sheehy, J.E.	International Rice Research Institute, Manila, (Philippines)	ORYZA1 V1.3	
Singh, U.	IFDC-IRRI Collaborative Project, IRRI, (Philippines)	CERES-Rice	
Williams, R.L.	Yanco Agricultural Institute, NSW Agriculture, (Australia)	maNage Rice	1
12		7	9

A follow-up workshop in Bangkok in 1995 (Ingram, 1996) reported results of a refined model sensitivity analysis for five models parameterised with common data. The comparisons involved assessment of the effects of increases in atmospheric CO₂ concentration (to twice current levels) and changes in air temperature from -6 to +6 °C. Figure 1 summarises the temperature response of the models, from which it can be seen that in the temperature range -3 to +3 °C there is general agreement on the yield change of about -4.5% (or -0.3 t ha⁻¹) for each degree of temperature difference from the base climate. Three models (ORYZA, SIMRIW and VSM) consistently predicted a larger decrease in yield for the second step in temperature rise between +3 and +6 °C. Full results of the model sensitivity analysis are presented in GCTE Working Document 19 (Annex 2; prepared by Dr Peter Mitchell, University of Sheffield, UK) (Ingram, 1996).

Design of a multi-site Rice Network Experiment

Although several useful experiments are already included in the GCTE Rice Network (Table 1), there is a lack of detailed experimentation on the critical issue of the interactions of environmental modification and nutrient management on rice. Increased understanding of this interaction brings not only the benefit of helping to improve food security - it will also help improve the control of methane emissions from rice production systems, another key issue facing rice-growing nations. A standardised experimental research programme within the region would provide the detailed datasets needed for a thorough analysis to be conducted.

To address this lack of appropriate data, the Bangkok workshop also designed a multi-site experiment. Temperature gradient tunnel technology was considered the best approach for this type of research - cost, experimental scope and limitations, logistics and research sampling area are all considered. Tunnels are commercially available, and the global change technology is rapidly gaining momentum and standardisation. An initial two year (4 - 6 season) study is envisaged, but subsequently, elevated CO₂ treatments could be included once the basic environmental control had been refined. Ideally four facilities would be established in the region, with a further three in temperate regions. The sites would be selected to offer a range of environmental conditions, while bearing in mind local interest, capabilities and infrastructure for such experimentation. In addition to providing greatly improved understanding of the impact of global change on crop/soil physiology, these sites would provide "tailor-made" datasets for model validation and development, the lack of which is currently limiting progress. A detailed description of the proposed experimental design is given in GCTE Working Document 19 (Annex 1; prepared by Dr James Morison, University of Essex, UK) (Ingram, 1996). When implemented, this multi-site experiment will yield datasets and understanding which are ideally suited for model validation and development.

Figure 1. The temperature response of five models, shown as the yield relative to that of the base climate, for the wet season (above) and dry season (below). The model VSM was not run with the base climate alone, so the average of yields at -3 and +3 °C was used for the reference value.

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