Economic and Social Commission for Asia and the Pacific

CGPRT Centre Monograph No. 43

Coping against El Nino for Stabilizing Rainfed Agriculture: Lessons from Asia and the Pacific

Proceedings of a Joint Workshop
Held in Cebu, the Philippines
September 17-19, 2002

United Nations

Assessing the Impacts of Climate Variability on Crop Production, and Developing Coping Strategies in Rainfed Agriculture

Felino P. Lansigan[*]

Introduction

Anthropogenic activities and internal stresses induced by natural variability of global biophysical processes have led to significant environmental problems including inadequate water resources and deteriorating, clean and dependable freshwater supply for human consumption and for agriculture. Water availability, in terms of its temporal and spatial distribution, is further exacerbated by climate variability which affects the human systems, the hydrologic cycle, and also food production systems in a particular area.

Water resource management in rainfed agriculture has important implications on food security and environmental integrity. Increased productivity in rainfed agriculture reduces the pressure on the limited land and water resources. Developments in efficient and effective management of water resources lend promise to increased crop production, improved livelihoods and food security in many rainfed areas. Water availability for agriculture, in terms of its temporal and spatial distribution, is expected to be highly vulnerable to climate variability.

Increasing water scarcity and water quality deterioration have continuously threatened human livelihoods and environmental systems, including rainfed agriculture in many tropical regions. Addressing the complex water resource issues requires that these challenges be approached in the context of their biophysical and socio-economic environment. IWMI (2000) presented the global water scarcity scenario for 2025 for biophysical and economic reasons considering the increasing need for water resources for agriculture, food and other water uses. Regions facing physical water scarcity are those areas that do not have sufficient water resources to meet the different water demands by 2025. Areas with economic water scarcity are those with enough utilizable water resources but where much more water will have to be developed by various means to satisfy the projected water requirements. The challenge to achieve water and food security in developing countries requires efficient management of water resources in the light of emerging water scarcity. The question of whether rainfed areas can contribute substantially to increased crop production to meet the growing food demand is becoming increasingly important as the competition among water uses and users escalates. Suitable areas, where climatic conditions are favorable for rainfed agriculture, need to be identified.

The latest scenarios on climate research studies (IPCC, 2001) suggest that anticipated future climate will be characterized by a temperature increase from 1.4^{o} C - 5.8^{o} C and changes in precipitation patterns with increased frequency and intensity of extreme weather events such as an increase in the occurrence of successive years of dry and wet periods, tropical cyclones, and typhoons. These hydrologic changes will have major impacts on human and natural systems

---

[*] International Water Management Institute (IWMI), Southeast Asia Regional Office, Bangkok, Thailand, (on sabbatical from the University of the Philippines Los Baños, 4031 College, Laguna, the Philippines).

as well as on rainfed areas in the tropics. Successive and prolonged occurrences of drought and floods will greatly affect the ability of rainfed agricultural areas to produce food, and to protect the integrity of the environment.

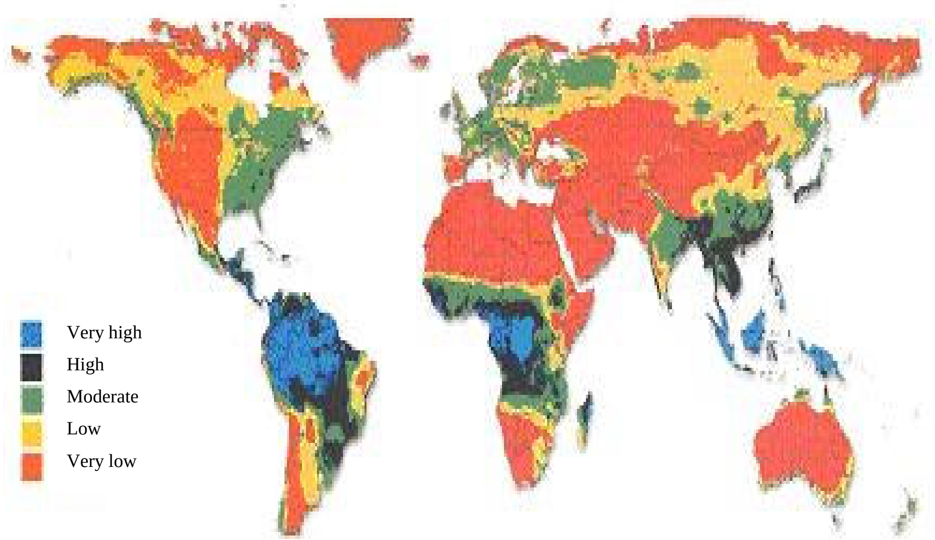
The reality of global climate change and climate variability has focused attention on the need to evaluate its effects and impacts on human and environmental systems including agricultural production systems, especially on food security in specific regions. Design and implementation of effective coping mechanisms requires an objective and scientific understanding of the effects and impacts so that appropriate adaptation strategies and mitigation measures can be formulated. Tackling the assessment of effects and impacts and identifying adaptation and mitigation measures needs a systematic approach that is built on better understanding of the processes in biophysical and socio-economic aspects of the environment, so that changes and consequences can be related to other processes. The systems approach allows the linking of changes at different levels such as changes in the basin level to the field level.

The objectives of the paper are (1) to present a systems analysis approach to evaluating effects and impacts of climate variability on rainfed agriculture at the basin and field scale levels; (2) to discuss recent research results on the analysis of climate variability and its impacts on crop production systems; (3) to present initiatives on coping with climate variability and changes in water and food systems; and (4) to rationalize the need for linking science and policy through knowledge-based policy formulation and decision-making in coping with and managing climate variability in rainfed agriculture and water food systems. Section 2 of the paper describes some results of previous assessment studies on climate change and climate variability based on field experiments and simulation modeling and analysis. Research and development activities including some global, regional and local initiatives to cope with and manage climate variability with particular focus on agriculture and food production systems are discussed in Section 3. Formulation of knowledge-based adaptation strategies and mitigation measures including policy design are presented in Section 4. The paper concludes with the emerging need for objective and scientific tools as components of a decision support system, the increasing necessity for capacity building, and the urgent call for cooperative and collaborative action as part of the overall strategy to manage climate variability.

Systems approach to analysis of climate variability and its effects and impacts on crop production systems in rainfed areas

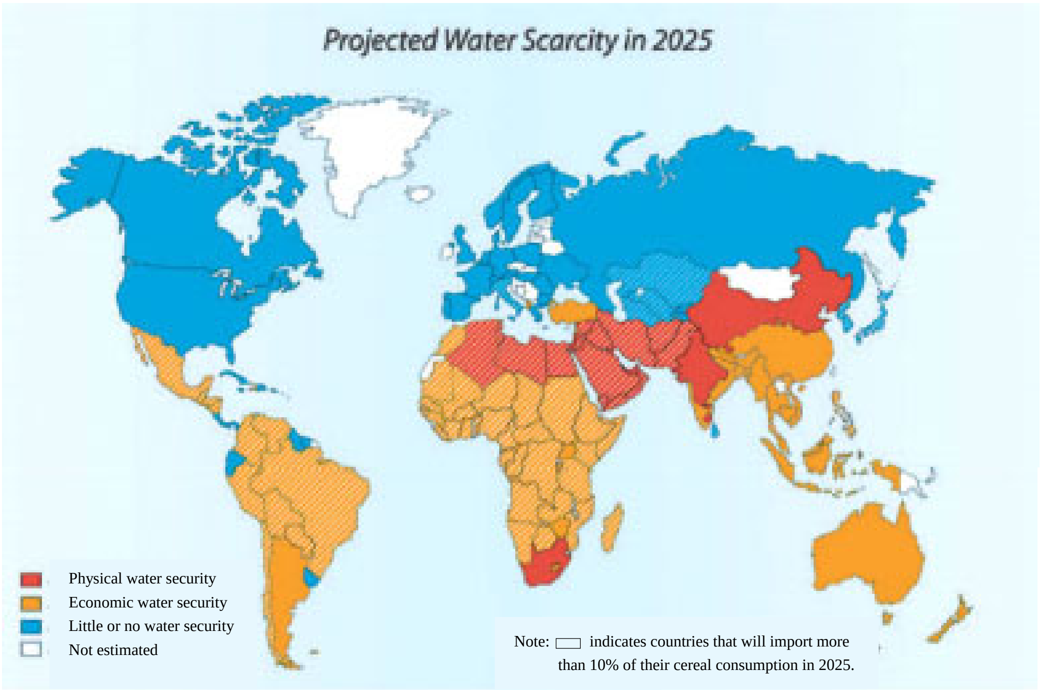
Assessments of climate-induced impacts and formulation of adaptation and mitigation measures should be analyzed at three different hydrologic scales, namely: global scale, basin scale, and field level. Potential areas for rainfed agriculture on the global scale are shown in Figure 1. It is estimated that at the global scale, 46 per cent of the earth’s surface is unsuitable for rainfed agriculture due to climatic constraints, and of the remaining 7 billion ha with the potential for rainfed crop production, only 4.7 billion is considered to be moderate to highly suitable (IWMI, 2000). It is also noted that those potential areas for rainfed agriculture are also the regions facing physical and economic water scarcity (Figure 2) where inadequate financial and human resources will limit the ability to explore supplemental water resources needed.

Figure 1. Potential areas for rainfed agriculture on a global scale



Source: IWMI, 2000.
Note: Preliminary estimates are currently being refined taking into account non-climate related factors (e.g. areas not available for conversion to agriculture).

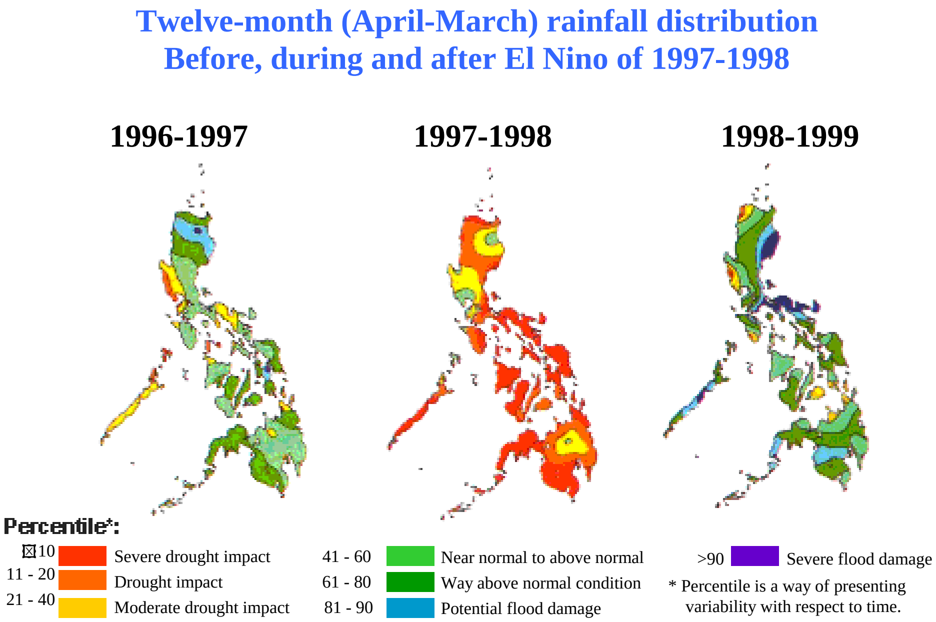
Figure 2. Global water scarcity map



Note: ▭ indicates countries that will import more than 10% of their cereal consumption in 2025.

Source: IWMI, 2000.

Figure 3. El Nino of 1997-1998 in the Philippines



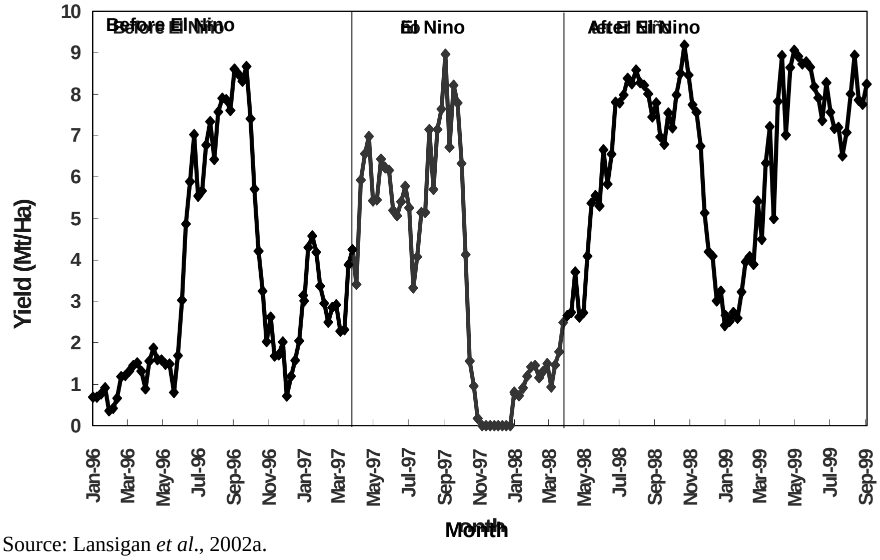
Source: PAGASA (2000).

At regional and national scales, wide variability in climate and the fluctuations in weather are important factors in crop production systems. Climate and weather determine the cropping and management systems, including the scheduling of crop production activities. Unfavorable weather remains to be a major cause of crop failure. During the 1997/98 El Nino for example, the Philippines lost more than PhP3.2B on corn production which primarily affected the two major corn growing provinces of Isabela and South Cotabato (Lansigan et al., 2002a). Monthly average rainfall data indicates moderate to severe drought conditions during the 1997/98 El Nino event (Figure 3). The figure shows that before and after El Nino, rainfall conditions in Isabela were above normal while South Cotabato conditions were near normal to above normal. During that year, Isabela experienced moderate drought to normal conditions, however, severe drought occurred in South Cotabato.

Advances in science and the development of systems research tools (e.g. simulation models, optimization techniques, geographic information systems and use of databases) have facilitated the integration of information and knowledge from different disciplines (see Aggarwal *et al*., 1996 and Teng *et al*., 1997). Dynamic process-based simulation models have been used in various practical applications at the global, regional and field levels. Ecophysiological simulation models have enabled the evaluation of effects of exogenous factors like weather in crop production for impact assessment studies (Matthews et al., 1995 and Horie, 1993). Climate risk and vulnerability of rainfed crop production systems to climate variability and change can be quantitatively evaluated. Combined use of simulation models with temperature gradient tunnel (TGT) experiments have greatly facilitated better understanding of the effects of change in the climatic environment on crop growth and development as well as crop yield (Lansigan, 1993 and Horie *et al*., 1995).

Better understanding of processes via systems simulation modeling helps improve resource management in crop production. Crop simulation models are used to determine crop responses and predict crop performance under different environmental and management conditions. As a case study, analysis of corn yield gaps in the major corn growing areas in the Philippines was conducted which involved estimating crop yields considering weather, soil, genetic and management factors using the DSSAT CERES-Maize model parameterized for local corn varieties, and validated for different locations. CERES-Maize model simulates corn growth and yield, taking into account processes such as phenological and morphological development, biomass accumulation and partitioning. Minimum data on variety-specific genetic coefficients was determined, and local corn variety-specific coefficients were obtained from field experiments conducted in 2000-2001 at different locations, namely: U.P. Los Baños, Laguna; Isabela State University, Echague, Isabela; Central Mindanao University, Musuan, Bukidnon; University of Southern Mindanao, Cotabato; and Leyte State University, Baybay, Leyte. On-farm trials on farmers' fields were also carried out in Alcala, Pangasinan; La Carlota, Negros Occidental; Argao, Cebu; and Koronadal, South Cotabato. Varieties used were IPB Var 911, USM Var 5, ViSCA Var 2, CMU Var 12 and Cargill 818/Pioneer 3014 as a check variety. Variety-specific coefficients and local daily weather data (solar radiation, rainfall, minimum and maximum temperatures) covering the period from planting to harvesting were used to simulate corn yields across locations. Aside from assessing climatic risk to corn production, the study also revealed the extent of crop physiological and agronomic data gaps in corn research and development which have to be incorporated in rationalizing research priorities (Lansigan *et al.*, 2002b).

Figure 4a. Simulated corn yields in Isabela, Philippines before, during and after 1997-1998 El Nino.



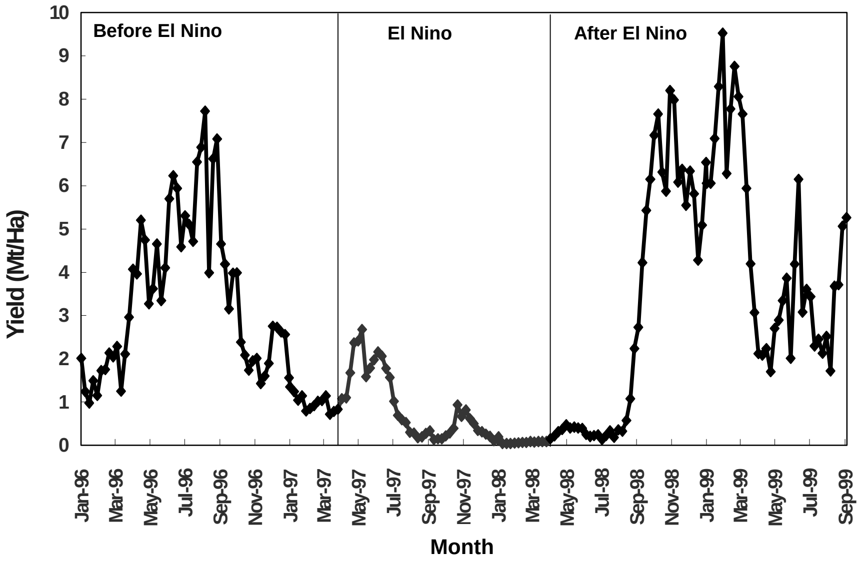
Source: Lansigan *et al*., 2002a.

Simulated corn yields for Isabela (Figure 4a) and South Cotabato (Figure 4b) were determined at sequential weekly planting intervals using the daily weather data from 1996-1999 at the two sites (Lansigan *et al*., 2002a). Traditionally, the planting calendar for Isabela is from June to July for the wet season (WS), and from November to December for the dry season (DS) cropping. Simulation analysis shows a wide planting window for Isabela even in the face of El Nino. This perhaps explains the moderate impact of the 1997/98 El Nino on corn production in the province. On the other hand, the planting schedule in South Cotabato is usually from March to April (WS), and August to September (DS). Simulated corn yields during the 1997/98 El

Nino were much lower than those before and after the said period. Trends also show that there was a very narrow window available for planting corn during El Nino that year. This may be attributed to the severe impact of the 1997/98 El Nino in that province.

Crop simulation models can provide estimates of corn yields as affected by various factors such as weather, and can be used to evaluate the effects of climate variability on crop growth and development. For instance, effects of temperature increase coupled with a double CO2 level on rice yield using simulation analysis had been reported in earlier studies (e.g. Lansigan, 1993; Horie, 1993; Matthews *et al*., 1995). Simulation results indicated a reduction in rice yields due primarily, to increased spikelet sterility which is highly sensitive to an increase in temperature (e.g. Horie *et al*., 1995). Similarly for corn, the adverse effects of El Nino are inevitable and prolonged drought spells, coinciding with the tasseling stage may lead to extensive yield losses. These results illustrate that the occurrence of extreme climate events coinciding with critical periods of crop growth and development can significantly reduce crop yields. Thus, timing of cropping periods with advanced seasonal climate forecasts are critical in coping with climate variability.

Figure 4b. Simulated corn yields in South Cotabato, Philippines, before, during and after 1997-1998 El Nino



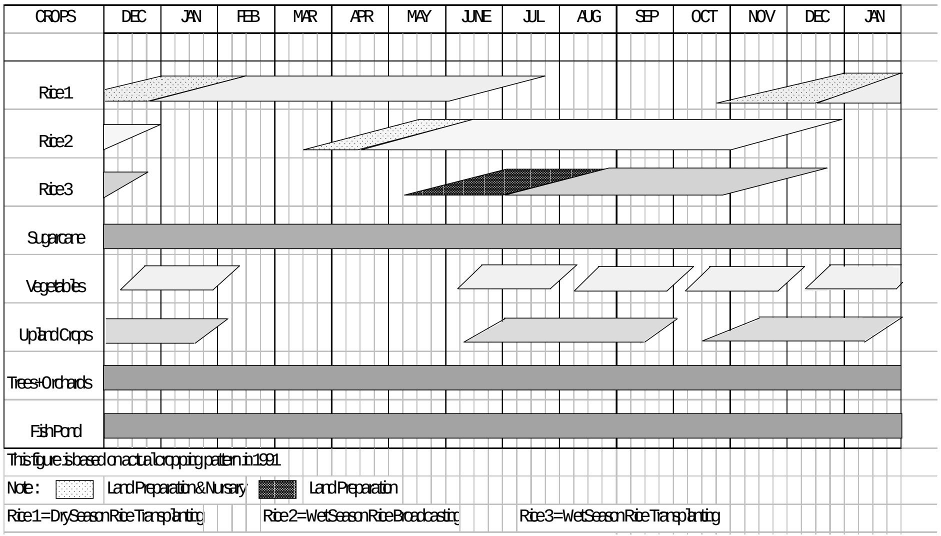
Source: Lansigan *et al*., 2002a.

Climate variability affects the availability of water in the basin in terms of spatial and temporal distribution of water for crop production. At the basin scale, variability in climate alters the basin hydrology which will bring changes in water availability for various water uses and users (e.g. agricultural, hydropower, domestic and industrial, and environmental). Changes in water distribution and allocation can be evaluated and their impacts assessed using simulation models e.g. STREAM Model (Aerts *et al*., 1999) and SWAT model (Neitsch *et al*., 2001). Use of a basin level model enables the evaluation of changes in the spatial and temporal distribution of water in the catchment. Field scale models (e.g. SWAP: Soil, Water, Atmosphere and Plant Model; Bastiaanssen *et al*., 1996) can be used to relate changes in the basin with changes and processes in the crop production system and environment. The analysis will be useful in designing an appropriate cropping calendar, cropping sequence, and crop management system in the face of anticipated climate conditions. It is also important to recognize and consider in impact assessment and analysis, the transient nature of climate variability and the uncertainties in the simulation modeling associated with input data used.

Coping with and managing climate variability in rainfed agriculture

Some rationale adaptation and mitigation measures to climate variability are being practiced in different areas at various levels. Adjusting the cropping calendar based on crop simulation studies and considering the risks involved is one adaptation strategy to manage climate variability in crop production. Figure 5a shows the typical cropping calendar for various crops in the Mae Klong river basin in west central Thailand. Altering the cropping period in the face of forecasted climate conditions for the growing season is one option to mitigate the effect of extreme climate variability such as the El Nino phenomenon. This requires timely and accurate advanced seasonal forecasts of climate and weather to guide in changing or adjusting the planting and growing period.

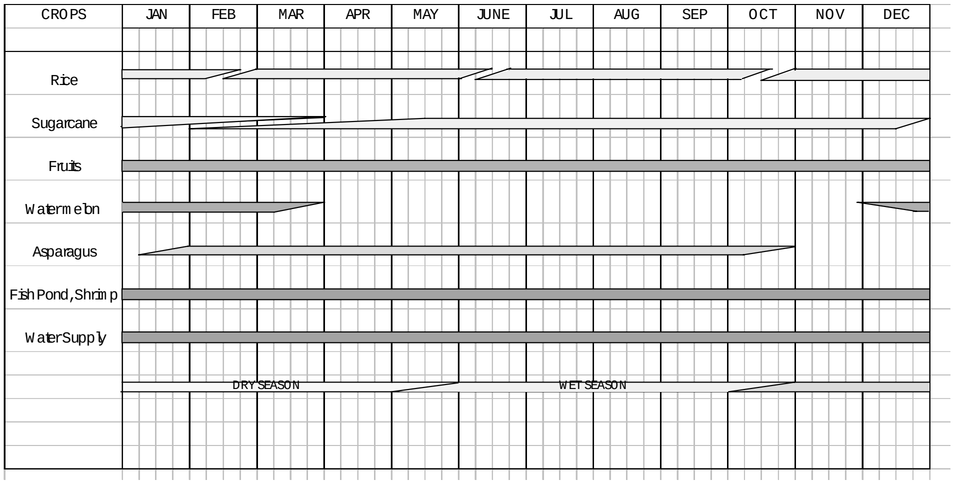
Figure 5a. Typical cropping calendar in Mae Klong, Thailand



Source: Final Report, Study of Potential Development of water resources in the Mae Klong River Basin, Volume II Main Report.

Modifying the cropping systems in terms of changing the variety of crops or considering entirely different crops to grow, is another adaptation to climate variability. Drought-tolerant crops or heat-resistant crop varieties may be planted which are more adapted to warmer or drier conditions. The genetic resources of crops and seeds in the germplasm collections may be screened to determine sources of resistance to heat and water stress as well as compatibility with new agricultural technologies such as use of less water in crop production. Figure 5b shows the current cropping calendar in Song Phi Nong area within Mae Klong basin when adequate irrigation water is available.

Figure 5b. Cropping calendar when irrigation water is available



Source: Song Phi Nong Irrigation Project.

Use of crop decision support systems in managing climate variability

Crop simulation models such as InfoCrop (Aggarwal *et al*., 2002), CROPWAT (FAO, 1992), and DSSAT (Tsuji *et al*., 1998) are now part of decision support systems (DSS) in resource management (Matthews and Stephens, 2002). DSS has facilitated the objective assessment of the effects of climate variability on crop production systems. User-friendly computer simulation models have facilitated the task of optimizing crop growth and deriving recommendations regarding crop management. They can also be used to evaluate and design adaptation and mitigation measures to cope with climate variability. These DSS tools provide an objective approach to simulate effects of soil, weather, management as well as pest factors on crop production. They can also be useful in assessing economic risks and environmental impacts associated with crop production including water and nutrient management, climate variability and change. However, while DSS's have been applied successfully in some practical problems, these tools should be used with caution because of the risks and uncertainties associated with the reliability of models used or some components of the models as well as on the reliability and uncertainties of the input data including weather and soil data.

Crop insurance to manage climate variability-induced risk

Potential damage to crop production and yield loss due to weather, are partly alleviated by providing crop insurance coverage to farmers. However, current crop insurance policy is based solely on the cost of production with little or no consideration to the differences and extent of environmental risks, which are location-specific and time-dependent. In a related case study (Lansigan, I.C.G. *et al*., 2002), risk in corn production due to weather and climate variability for estimating crop insurance premiums was evaluated using an ecophysiological CERES-Maize crop model parameterized and validated for a local corn variety (IPB Var 911) based on field experiments in two selected locations in the Philippines, namely, Isabela and South Cotabato representing different climatic types. Crop variety-specific genetic coefficients and available historical daily weather data such as rainfall, solar radiation, maximum and minimum temperature covering the period from planting to harvesting were used to simulate corn yields in different locations. Probability distributions of crop yields and probabilities of crop failure (i.e. yield below certain level) are estimated using the relative frequencies of simulated yields for various planting dates. Different yield distributions and yield probabilities obtained using simulation models indicate that risks to corn production due to weather and climate variability vary across locations, and at different planting periods. Quantified risk levels provide useful information in formulating policy for crop insurance coverage to assist agricultural banks and insurance companies in processing applications for loans and insurance. The study also shows that there is a need to review the policy on crop insurance premiums being levied across different locations. Figures 6a and 6b shows the probability distributions of corn yields in different locations (Isabela and South Cotabato) which provide a useful basis for determining insurance premiums for crop insurance coverage across sites.

Figure 6a. Probability distributions of simulated corn yields for different months of planting in Isabela, Philippines

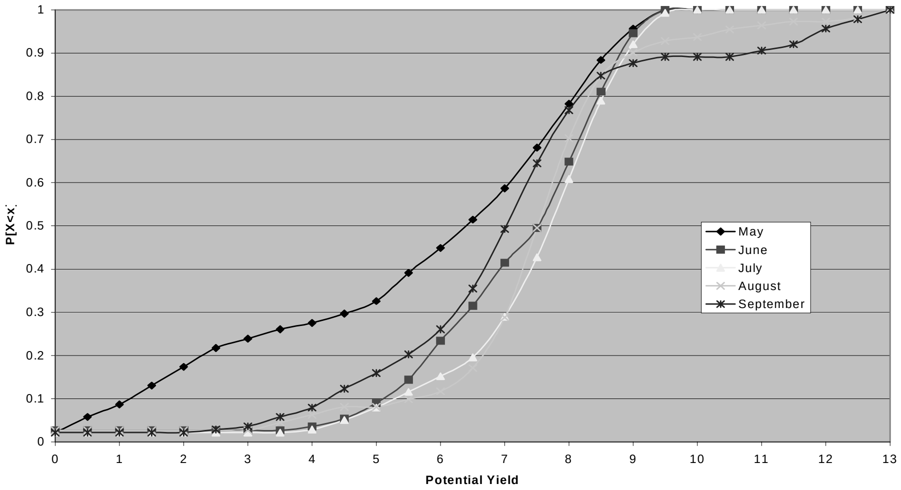
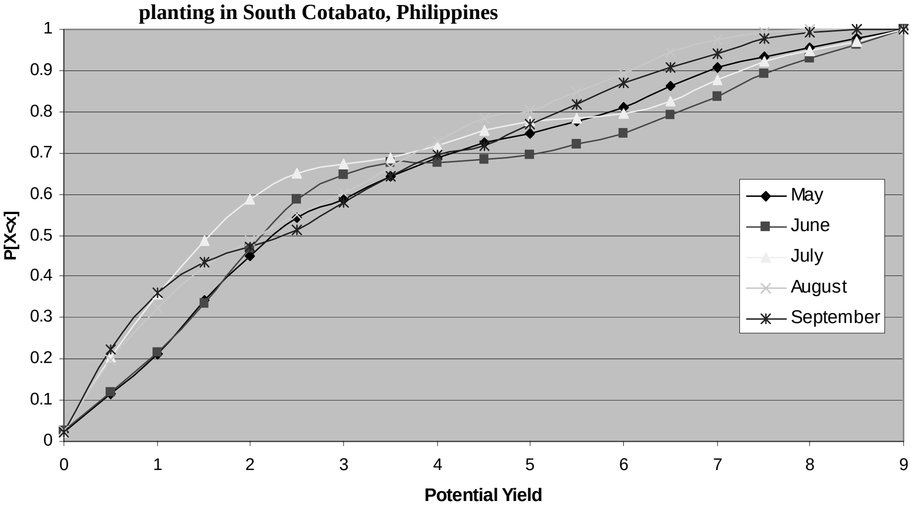


Figure 6b. Probability distributions of simulated corn yields for different months of planting in South Cotabato, Philippines



Source: Lansigan, I.C.G. *et al*., 2002.

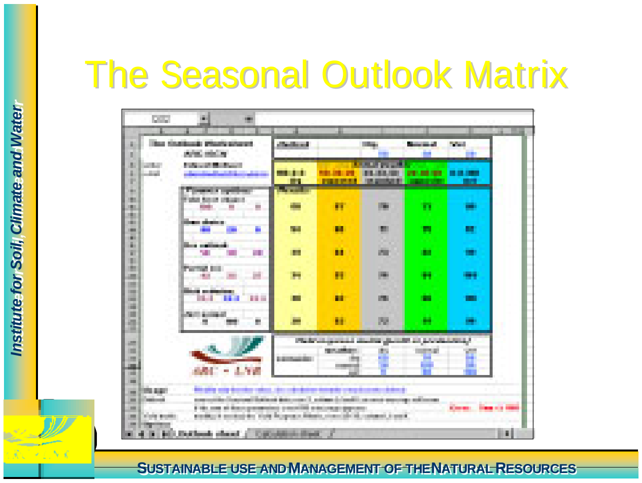
Advanced seasonal outlook and crop forecasting

Advances in systems research tools and recent developments in climate research and related studies provide opportunity to predict or forecast seasonal climate and weather up to a certain lead-time and with reasonable accuracy. Forecasted weather conditions under the predicted seasonal climate, serve as inputs to a DSS which provides information in terms of appropriate management actions to take, considering the climatic risk (and even economic risk) involved. The system developed and being implemented in South Africa by the Institute for Soil, Climate and Water (ISCW) is a good example of practical application of simulation models for decision making and extension (Kuschke, 2002). ISCW Seasonal Outlook system provides interpretational values to the available agro-meteorological data from the weather agency, and the probabilistic analysis available by estimating seasonal weather conditions and assessing potential crop responses under the predicted environment. Advisories on seasonal outlook and crop management responses under dry, normal and wet conditions as well as cropping or management plans are generated. Analysis and comparison of actual results versus projected outlooks are also included (Figures 7a and 7b). Operationally, the South African Weather Service produces and disseminates a monthly probabilistic forecast. These are compiled by consolidating various seasonal forecast models. Rainfall probabilities are presented as terciles of outcome (i.e. per cent above normal, per cent near normal, and per cent below normal). The objective of the seasonal outlook is to provide the user with an estimation of potential results under various weather conditions and cropping management plans.

Figure 7a. ARC-ISW Seasonal Outlook

Source: Kuschke, 2002.

Figure 7b. Output of the ARC-ISCW Seasonal Outlook

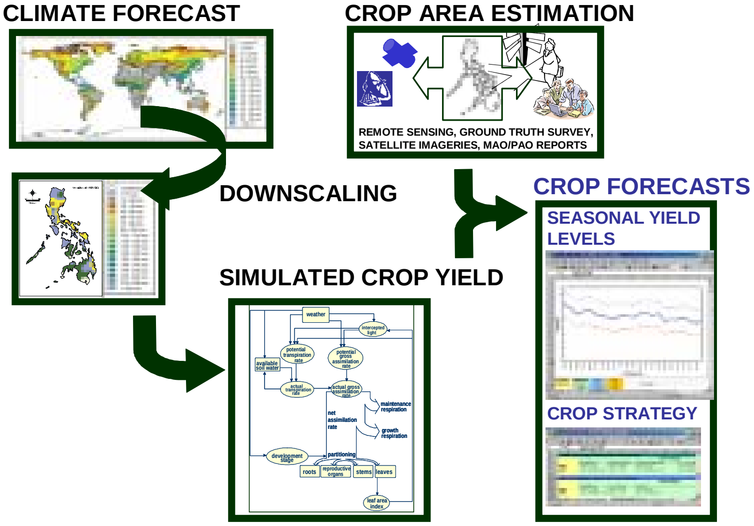


Source: Kuschke, 2002.

A similar crop forecasting system is now being developed and will be implemented at the Department of Agriculture in the Philippines. The system involves crop yield forecasting using advanced seasonal climate forecasts, a process-based crop simulation model, remote-sensed data on crop area, and geographic information systems (Figure 8). The procedure requires at least 3 months advanced climate information which is downscaled to a specific location. The downscaled daily weather data will be inputted into a crop model for provincial yield estimation. The methodology integrates the use of systems tools in delivering crop yield forecasts for the Philippines. The knowledge-based crop forecasting systems hope to have a big contribution and impact in decision making, especially in implementing programs on staple crops such as rice and corn. Potential users of outputs of the crop forecasting system include the livestock and feed milling industries, producers and traders, and policy makers.

Figure 8. Systems approach to crop forecasting at DA, the Philippines

Figure 8.



Some initiatives on managing climate variability

There are essentially a number of international research initiatives related to the assessment of the effects and impacts of climate variability and change on water and food systems as well as on the human environmental system. The International Geosphere-Biosphere Programme (IGBP; http://www.igbp.kva.se) is an international research program whose aim is to develop a better understanding of the global environment and how it is changing through time. The International Human Dimensions Programme of Global Environment Change (IHDP: http://www.ihdp.org) is concerned with the effects and impacts of global change, and on how human systems adapt and interact with a changing environment. Adaptation and mitigation aspects are major issues of interest to IHDP. The World Climate Research Programme (WCRP; http://www.wcrp.org) involves research studies on atmosphere, climate and weather that greatly affect the environment. IGBP, IHDP and WCRP work together with other global environmental change programmes to collaborate on core projects, which address major issues of global sustainability including water resources, food systems and the carbon cycle.

The joint Global Project on Carbon (http:/www.gaoms.sr.unh.edu/cjp/) was launched to have a better understanding of the entire carbon cycle including the issue of carbon sequestration. The project on "Global Environmental Change and Food Systems (GECaFS; http://www.gecafs.org) was initiated to analyze how global environmental change affects food provision and vulnerability of different social groups in different regions as they adapt to cope with global environmental change, and on how these adaptations feedback into these changes. The research project on water resources is concerned with the impacts of global environmental change on local and regional water systems as well as on feedback mechanisms and sustainability of water resource systems.

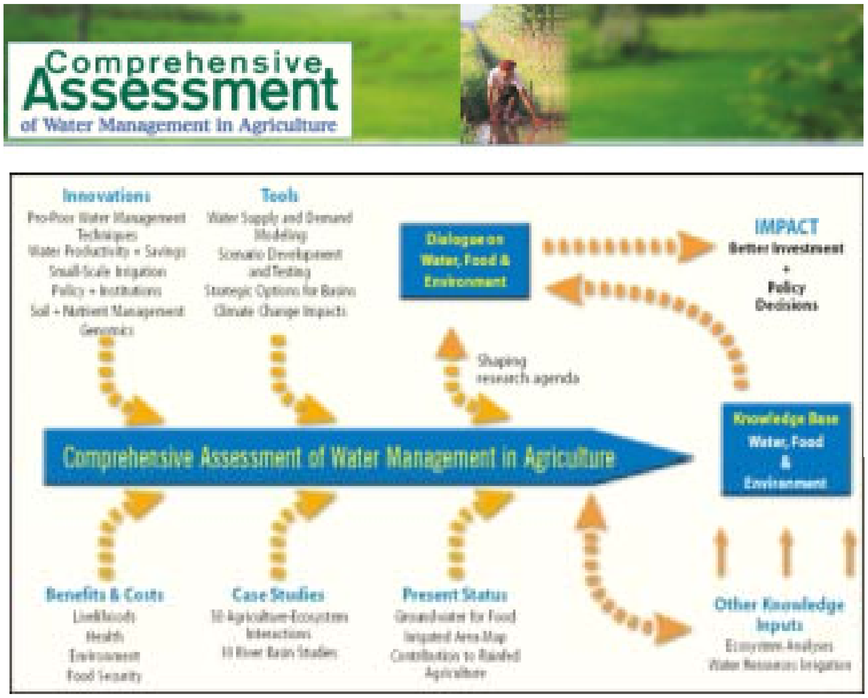
The CLIMAG (Climate Prediction and Agricultural Productivity) project was initiated to study the predictability of seasonal climate, and how this advanced information can be used by farmers to assist and make decisions regarding crop management. Case studies have been conducted to demonstrate the applicability and use of advanced information in improving the management of crop production systems in rainfed areas.

The Consultative Group for International Agricultural Research (CGIAR) has also launched related activities such as the Comprehensive Assessment of Water Management in Agriculture, and the Challenge Program on Water and Agriculture. The main objective of the Comprehensive Assessment of Water Management in Agriculture is to evaluate the potential to grow more food with less water, such that rural poverty is reduced, and improved human and environmental systems are sustained. The components and main activities of the assessment program are illustrated in Figure 9.

On the other hand, the CGIAR Challenge Program on Water and Agriculture aims to catalyze the effective and efficient improvements of water productivity in food production systems in a manner that is "pro-poor, gender-equitable, and environmentally sustainable." Details of these initiatives and related activities can be viewed at CGIAR's website (http://www.cgiar.org).

Collaboration and cooperation between the research programmes and the national research and development institutions and local researchers and experts will be useful and beneficial to furthering better understanding of climate variability. This understanding will contribute substantially to designing strategies to increase the flexibility of human, water and food systems to respond to extreme climate events such as the El Nino and La Nina phenomena, floods and droughts.

Figure 9. CGIAR Comprehensive Assessment of Water for Agriculture



Source: CGIAR, 2002.

Linking science and policy in adaptation strategies and mitigation measures to climate variability

It has become increasingly important to apply science in designing and developing knowledge-based policy analysis in addressing climate variability in rainfed agriculture.

As evident in previous sections, recent advances have increased our scientific understanding of processes of crop growth and development which allow more rational, efficient and effective adaptation and mitigating measures to be employed. For example, adjusting the cropping calendar and modifying the cropping systems to adapt to changes in the environment would require consideration of the suitability of the variety or the crop under the particular climate scenarios. This involves analysis of the characteristics and potentials of the crops and/or the varieties in a given location.

Similarly, developing new crop genotypes resistant to stresses and related to climate variability, such as crops or varieties which are drought resistant, heat tolerant, more water-use efficient, etc. involves rationalizing the national research and development agenda in agriculture, particularly on plant breeding, germplasm collection and genetic improvements. Research is needed to define the current limits to heat resistance and feasibility of manipulating such attributes through modern genetic techniques.

Crop insurance coverage may also be provided, including agricultural loans to support farmers affected by climate variability. Climate-induced risk in crop production should be evaluated more objectively. The current practice of charging a uniform crop insurance premium across locations with different risk levels should be reviewed. Simulation models parameterized and validated under different locations can be applied to evaluate risk.

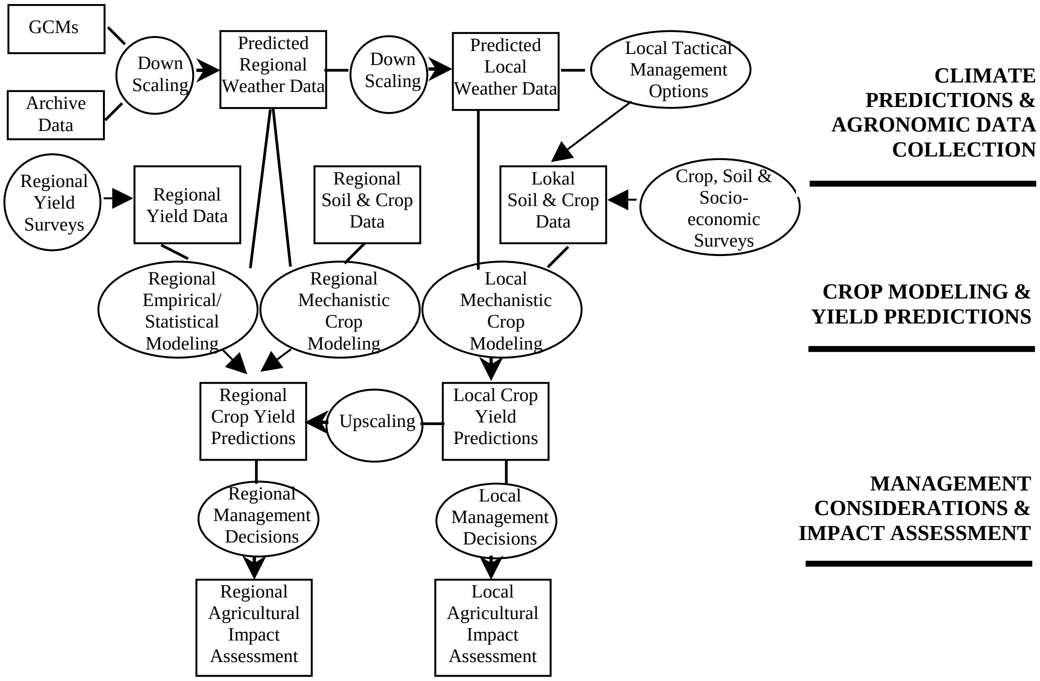
Climate variability and change, impinge on diverse, complex and dynamic forms of environmental disasters such as floods, droughts, typhoons, heat waves and storm surges. As mentioned earlier, extreme weather events are likely to become more frequent and intense in the future. Changes in storm tracks are also possible as evidenced in recent years. Thus, a wide range of precautionary measures at regional and national levels including awareness, perception and acceptance of risk and uncertainty factors in regional communities is imperative. This is to avert or reduce the impacts of such disasters on the economic and social environments, especially in rainfed areas of the tropics. The delegations from the 11 countries who participated in the Asian Ministerial Roundtable Dialogue on Water Issues and Challenges, 20-21 May 2002 in Bangkok, Thailand (see e.g. http://www.iwmi.org) have strongly indicated in a joint statement released during the conference, the emerging and urgent need for establishing an early warning system for disaster management, and for networking and collaboration among research and development institutions in the region.

Concluding remarks

The wide range of significant effects and impacts of climate variability on crop production systems in rainfed areas necessitates that a systems approach be applied. This approach will be useful in designing and developing appropriate, efficient and cost-effective adaptation and mitigation strategies and measures to cope with climate variability. Process-based simulation models (or ‘tools’) and databases are being developed and organized into a “toolbox” for smallholder land and water management to assist in promoting knowledge-based management decisions using systems approaches in collaboration with researchers and intended users of the tools (Penning de Vries and Lansigan, 2002b).

While empirical studies and impact assessments have been conducted, it appears that these are not readily accessible, and an integrative analysis to synthesize some generic guidelines across different locations for impact assessment as well as adaptation and mitigation analysis is not possible. It is becoming increasingly important to build the capacity of the use of scientific assessment procedures, and applications of objective methodologies in assisting policy design and formulation and decision-making. This may include promoting adjusted or revised crop production systems including water management, subsidies and support like crop insurance, etc. to cope with and manage climate variability (Figure 10). Cooperative and collaborative actions on coping with climate variability and change in agricultural production systems to increase the flexibility of the systems at different levels are imperative. These activities may involve data and information exchange among concerned agencies within the country and in the region, sharing of knowledge and expertise, and also testing new methodologies. Integrated planning to address the issue of climate variability and extreme events is indeed a challenge within institutions in the country and in the region. It is also equally important that all stakeholders including planners, policy makers and the public are informed of the impacts and consequences as well as of the appropriate adaptation and mitigation measures in order to promote preparedness, resilience and flexibility to climate variability.

Figure 10. Framework for climate variability, crop forecasting and impact assessment



References

Aerts, J.C., J.H. Kriek and M. Schepel, 1999. STREAM, Spatial Tools for River basins and Environment and Analysis of Management options. Physics and Chemistry of the Earth, Part B. Elsevier Science 23(3): 345-354.

Aggarwal, P.K. et al., 2002. InfoCrop: A User-friendly System for Applications of Crop Models (version 1.09), New Delhi, India: IARI.

Aggarwal, P.K., F.P. Lansigan, T.M. Thiyagarajan and E.G. Rubia, 1996 (Eds.) Integrating Simulation Modeling in Rice Research. SARP Research Proceedings, Wageningen: AB-DLO; Los Baños, Philippines: IRRI.

Bastiaanssen, W.G.M, R. Singh and S. Kumar, 1996. Analysis and recommendations for integrated farm water management in Haryana, India: a model approach. Report No. 118, Wageningen: Alterra Green World Research.

FAO, 1992. CROPWAT: A computer program for irrigation planning and management. Irrigation and Drainage Paper No. 46. Rome.

Horie, T., 1993. Predicting the effects of climate variation and elevated CO2 on rice yield in Japan, Journal of Agricultural Meteorology 48:567-574.

Horie, T., M.J. Kropff, H.G. Centeno, H. Nakagawa, J. Nakano, H.Y. Kim and M. Ohnishi, 1995. Effect of anticipated change in global environment in rice yields in Japan. *In* Peng, S., K.T. Ingram, H. Nueue, and L.H. Ziska (eds.). Climate Change and Rice, Berlin Heidelberg, Springer-Verlag.

IPCC, 2001. Intergovernmental Panel on Climate Change Third Assessment Report (TAR), Washington D.C., USA.

IWMI (International Water Management Institute), 2000. World water supply and demand in 2025. *In* Rijsberman, F. (ed). World Water Scenario Analyses, London, U.K: Earth Scan Publications.

Kuschke, R., 2002. A tool to evaluate long-range weather forecasts under various cropping plans. South African Agricultural Research Council Institute for Soil, Climate and Water.

Lansigan and J. L. Orno, 1993. Simulation analysis of risk and uncertainty in crop yield due climatic variations and change. *In* B.A.M., Bouman et al. (eds.) Agro-ecology of Rice-based Cropping Systems, SARP Research Proceedings, Oct. 1993, Wageningen, The Netherlands.

Lansigan, F.P., 1993. Evaluating the effect of anticipated climate change on rice production in the Philippines. Journal of Agricultural Meteorology 48:779-782.

Lansigan, F.P.**,** W.L. delos Santos and J.L Orno-Coladilla, 2000. Agronomic impacts of climatic variability in the Philippines, Journal of Agriculture, Ecosystems and Environment 82:129-137.

Lansigan, F.P., W.L. delos Santos, M.T. Fabellar and R.G. Perez, 2002a. Trends in simulated corn yields during El Nino in the Philippines. Proceedings, Crop Science Society of the Philippines Annual Conference, April 20-22, 2002, Tagbilaran City, Philippines.

Lansigan, F.P., W.L. delos Santos, M.T. Fabellar and R.G. Perez, 2002b. Estimating corn yields in selected locations in the Philippines using an ecophysiological process-based crop simulation model. Proceedings, National Corn R&D Conference, Nov. 27-29, 2002, Quezon City, Philippines.

Lansigan, I.C.G., F.P. Lansigan and M.T. Fabellar, 2002. Evaluating weather-induced risk in corn production for crop insurance using an eco-physiological crop simulation model. Proceedings, National Corn R&D Conference, Nov. 27-29, 2002, Quezon City, Philippines.

Matthews, R.B. and W. Stephens (eds.), 2002. Crop-Soils Simulation Models: Applications in Developing Countries, Wallingford: CAB International.

Matthews, R.B., M.J. Kropff, D. Bachelet, and H.H. van Laar, 1995. Modeling the Impacts of Climate Change on Rice Production in Asia, Philippines: IRRI and CABI.

Neitsch, S.L. et al., 2001. Soil and Water Assessment Tool (SWAT).

Penning de Vries, F. and F.P. Lansigan, 2002a. Site- and situation-specific management for smallholder agricultural enterprise. Keynote paper, Proceedings of International Agronomy Congress, November 2002, New Delhi, India.

Penning de Vries, F. and F.P. Lansigan, 2002b. Smallholder Toolbox for Land and Water Management. Proceedings of the Workshop, July 18-19, 2002, Bangkok, Thailand.

Teng, P.S., M.J. Kropff, H.F.M. ten Berge, J.B. Dent, F.P. Lansigan and H.H. van Laar (eds.), 1997. Applications of Systems Approaches at the Farm and Regional Levels: v. 1, Dordrecht, Netherlands: Kluwer Academic Publishers.

Tsuji, G.Y., G. Hoogenboom and P.K. Thornton, 1998. Understanding Options for Agricultural Production, Dordrecht: Kluwer Publisher.