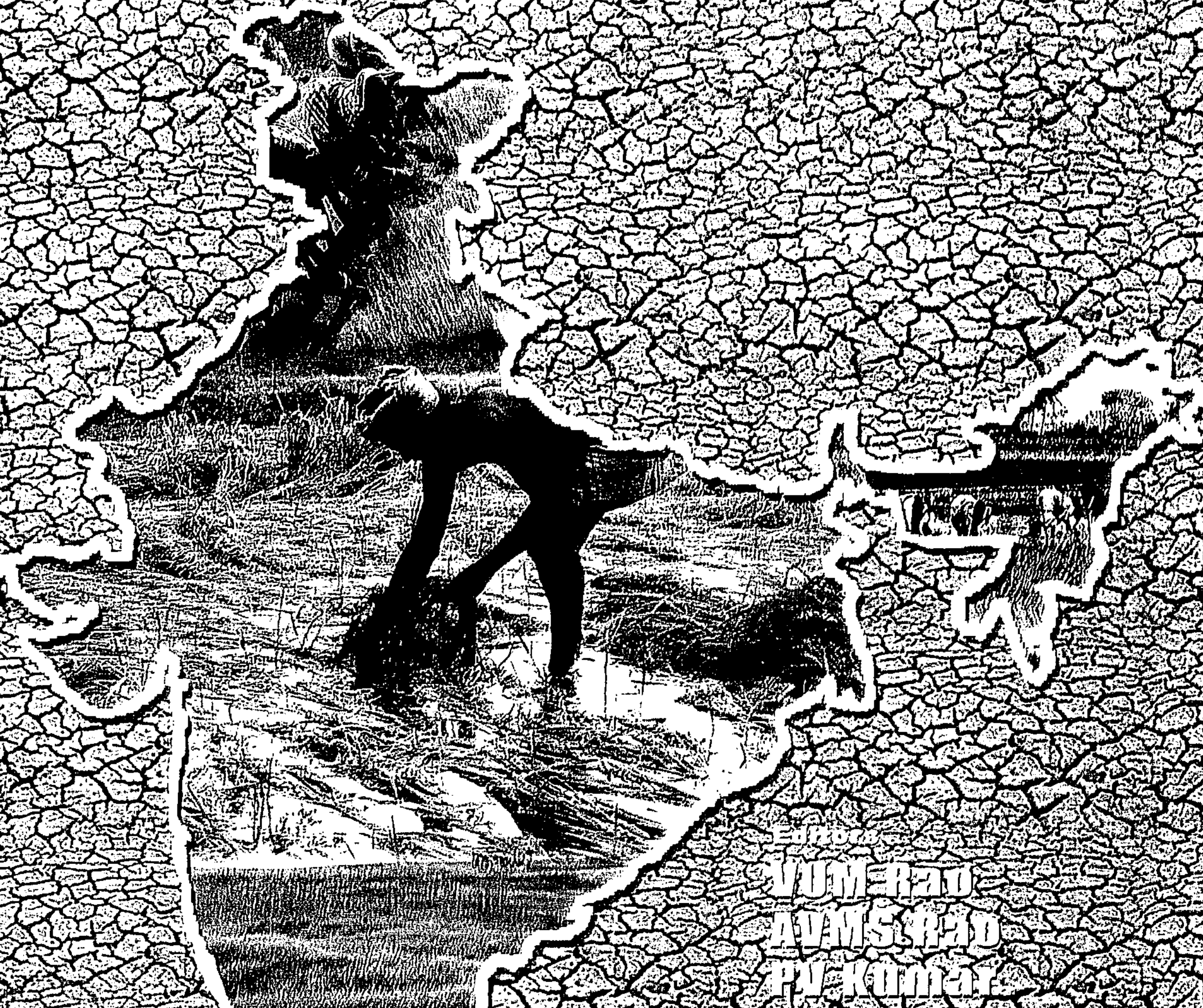
Agricultural Drought: Climate Change and Rainfed Agriculture



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CROP GROWTH SIMULATION MODELS VIS-A-VIS CLIMATE CHANGE IMPACT AND ADAPTATION STRATEGIES

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Introduction

Agricultural production is highly sensitive to climate because it depends on rainfall, temperature and solar radiation, all climate variables. Global Circulation Model (GCM)-based assessment of the Inter Governmental Panel on Climate Change (IPCC) contemplates higher global surface temperature rise of 1.5 to 4.5°C by the year 2050, as a result of enhanced contribution from greenhouse gases. Climate change predictions for India based on a family of GHG emission scenarios indicate that warming is likely to be above the global mean and fewer very cold days are very likely. Change in the monsoon rainfall quantity and distribution increases the risks in agriculture, the sector that contributes almost to a fourth of the national income. New areas might become vulnerable to the monsoon aberrations. In the semi-arid tropic (SAT) regions of India, agriculture sector is highly vulnerable to climate variability and change, and with potential to exacerbate the loss of biodiversity in the region. SAT ecosystems, where most rural poor live, are characterized by extreme rainfall variability, recurrent but unpredictable droughts, high temperatures and low soil fertility. Projected impacts on agriculture are expected to be adverse and widespread and farmers will need to adapt with layers of resiliency in their farming practices and investment decisions. Crop growth simulation models help in understanding the effects of genotype, climate, soil and management practices on crops and thus help in assessing the impacts of climate variability and change on crop production.

Crop growth simulation models

Crop growth simulation models are mathematical, computer-based representations of crop growth and interaction with weather, soil and other nutrients. These models play an important role in scientific research and resource management, and have been used to help students understand, observe and experiment with cropping systems. The greatest use of crop growth simulation models for researchers primarily is for organizing knowledge gained in experimentation and to evaluate the models. These models allow the researchers to find out relevant solutions for the problems in the real world. The models have a useful role to play as tools in education, both as aids to learning principles of crop and soil management, and also in helping students to develop a 'systems' way of thinking to enable them to appreciate their specialty as part of a larger system. Strengths of models include the abilities to:

- Provide a framework for understanding a system and for investigating how manipulating it affects its various components
- Evaluate long-term impact of particular interventions
- Provide an analysis of the risks involved in adopting a particular strategy
- Provide answers quicker and more cheaply than is possible with traditional experimentation

Crop simulation modeling tools

Development of crop simulation tools started in the 1970's. The most important and most used models are DSSAT models which were developed by a team of researchers from University of Georgia, Florida, Hawaii, Guelph and Iowa State under the hood of International Benchmark Sites Network for Agro-technology Transfer (IBSNAT). The DSSAT models simulate 26 different crops. The Agricultural Production Systems Simulator (APSIM) is a modular modeling framework that has been developed by the Agricultural Production Systems Research Unit (APSRU) in Australia (McCown *et.al.*, 1996). Many other tools are also available like Cropsyst developed by Washington State University, Gossym for cotton, Glycim for soybean and ORYZA 2002 for rice simulations.

InfoCrop, a generic crop model developed at the Indian Agricultural Research Institute, simulates the effects of weather, soils, agronomic management (planting, nitrogen, residues and irrigation) and major pests on crop growth, yield, soil carbon, nitrogen and water, and greenhouse gas emissions (Aggarwal *et.al.*, 2006a and 2006b).

Decision Support Systems for Agro Technology Transfer (DSSAT)

The Decision Support System for Agrotechnology Transfer (DSSAT) is a software package integrating the effects of soil, crop phenotype, weather and management options that allows users to ask "what if" questions and simulate results by conducting, in minutes on a desktop computer, experiments which would consume a significant part of an agronomist's career. It has been in use for more than 15 years by researchers in over 100 countries.

DSSAT is a microcomputer friendly software product that combines crop, soil and weather data bases into standard formats for access by crop models and application programs. The user can then simulate multi-year outcomes of crop management strategies for different crops at any location in the world.

DSSAT also provides for validation of crop model outputs; thus allowing users to compare simulated outcomes with observed results. Inputting the user's minimum data, running the model and comparing outputs, accomplish crop model validation. By simulating probable outcomes varied of crop management strategies, DSSAT offers users information with which to rapidly appraise new crops, products, and practices for adoption.

The release of DSSAT Version 4 incorporates changes to both the structure of the crop models and the interface to the models and associated analysis and utility programs. The DSSAT package incorporates models of 27 different crops with new tools that facilitate the creation and management of experimental, soil, and weather data files. DSSAT v4 includes improved application programs for seasonal and sequence analyses that assess the economic risks and environmental impacts associated with irrigation, fertilizer and nutrient management, climate change, soil carbon sequestration, climate variability and precision management. As on December 2010, the latest and official version is DSSAT v4.0.2.0 and version 4.5 is to be released soon.

The Minimum Data Set (MDS)

The minimum data set (MDS) refers to a minimum set of data required to run the crop models and validate the outputs. Validation requires:

- Site weather data for the duration of the growing season,
- Site soil data, and
- Management and observed data from an experiment.

MDS Weather Data

The required minimum weather data includes:

- Latitude and longitude of the weather station,
- Daily values of incoming solar radiation (MJ/m^2-day), maximum and minimum air temperature (^oC), and Rainfall (mm).
- Accessory data sets, such as daily dry and wet bulb temperatures and wind speed, are optional.

The period of weather records for validation must, at a minimum, cover the duration of the experiment and preferably should begin a few weeks before planting and continue a few weeks after harvest so that "what-if" type analyses may be performed as desired.

MDS Soil Data

Desired soil data includes soil classification (e.g. USDA/NRCS), surface slope, soil color, permeability, and drainage class. Soil profile data by soil horizons include:

- Upper and lower horizon depths (cm)
- Percentage sand, silt, and clay content
- 1/3 bar bulk density
- Organic carbon
- pH in water
- Aluminum saturation and
- Information on abundance of roots.

Management and Experiment / Observed Data

Management data includes information on planting date, dates when soil conditions were measured prior to planting, planting density, row spacing, planting depth, crop variety, irrigation, and fertilizer practices. These data are needed for both model validation and strategy evaluation.In addition to site soil and weather data, experimental data includes crop growth data, soil water and fertility measurements. These data are needed for model validation.

DSSAT version 4 allows consistent access to the crop models, data, input and output tools, and analysis programs. The hierarchy is commodity-based within a tree structure where model inputs can be created and results analyzed. The basic menu structure of DSSAT version 3.5 is maintained for backward compatibility. A suite of tools is supplied for data management and analysis. XBuild is used to create and modify experiment files (X-Files). The suite of tools includes (but is not limited to) ATCreate (observed data), Weatherman (Weather data), GBuild (Graphing of outputs), and SBuild (Soil database). XBuild can be used to create various climate change scenarios by increasing or decreasing temperature and rainfall.

Crop growth simulations for assessing climate change impact

Chaudhari *et.al.*, 2009 used regional models of yield response to temperature (minimum, maximum and its diurnal range) and precipitation developed for meteorological (met) sub-divisions of India to study the impact of future climate change on major food crops. A negative response of yields to increased minimum temperatures was observed for all the crops. Based on A2 scenario of temperature and precipitation change, as derived from PRECIS (Providing Regional Climates for Impact Studies) regional climate model, it was found that, during the period 2071-2100, the rice yields in irrigated regions would reduce up to 32% in Haryana followed by 18% in Punjab while it may increase in rainfed regions up to 28% in Orissa followed by 18% in Madhya Pradesh. Reduction in wheat yields will be 21% in East Rajasthan followed by 18% in West Rajasthan and 14% in East Madhya Pradesh. The climate change scenario may lead up to 39 % reduction in rapeseed-mustard and 19% reduction in potato yields.

A study (Srivani *et.al.*, 2006) was conducted in Tamil Nadu to evaluate the impact of future climate change on the productivity of major cereal crop, rice at different time periods of 21st century (2020, 2050 and 2080) using InfoCrop. Future changes in temperatures and precipitation for the years 2020, 2050 and 2080 were acquired from HADCM3 model run outputs and integrated with the base year (2000) data. Results indicated that the crop duration, days to anthesis, LAI and DMP of rice crop steadily decreased from 2000 to 2020, 2050 and 2080 due to increase in temperature under enriched CO2 levels. The magnitude of decrease from 2050 to 2080 is expected to be more than that of from 2000 to 2020 and 2020 to 2050. Similarly model recorded lesser number of grains per square meter over years. There might be inefficient translocation of photosynthates, reduction in yield attributing characters and in turn huge reduction in the productivity of the crops: It is necessary to tailor the management options such as shifting sowing window, growing heat tolerant varieties etc., to overcome the ill effects of changing climate.

Singh and Lal (2009) concluded that in India, without adaptations, potato production under the impact of climate change and global warming may decline by 3.16 and 13.72 % in the year 2020 and 2050, respectively based on results from InfoCrop. Possible adaptations like change in planting time, breeding heat tolerant varieties, efficient agronomic and water management and shifting cultivation to new and suitable agro-climatic zones can significantly arrest the decline in the production.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is one of the 15 Future Harvest Centers of the Consultative Group on International Agricultural Research (CGIAR). It recognizes that opportunities for sustainable productivity increases in the SAT will be firmly anchored on Integrated Genetic and Natural Resource Management (IGNRM) strategies, improved input-output market delivery systems for agricultural produce, and knowledge dissemination through capacity building. ICRISAT's Strategic Plan to 2020 is targeted towards Inclusive Market Oriented Development (IMOD) for smallholder farmers in the tropical drylands. In rainfed areas, rainwater management at watershed / catchment scale is used as an entry point for increasing agricultural productivity (Wani *et.al.*, 2003). Integrated watershed management with focus on productivity enhancement and livelihoods approach is one of the high priority areas identified and promoted for producing both tangible and non-tangible benefits to the individuals as well as for communities as a whole.

Singh *et.al.*, (2009) have studied the yield gaps of important crops in various countries by simulating potential yields of sorghum, pearl millet, maize, soybean, groundnut and chickpea using DSSAT. They used InfoCrop software for rice and cotton and APSIM for pigeonpea potential yield estimations. They showed that the actual yields of food and other crops obtained by the farmers are much below the potential yields that can be obtained with improved management. Crop yields can be at least doubled from their current levels by the promotion and adoption of existing 'on-the-shelves' technologies available with the national and international research institutes. The governments need to provide more suitable policy environments and institutional support to promote greater adoption of new and improved technologies to benefit the poor farmers of rainfed areas and to meet the challenge of greater food needs of the future.

Global warming is likely to reduce 'days to maturity' resulting in crop yield reduction. ICRISAT's Integrated Genetic and Natural Resource Management (IGNRM) philosophy is to help farmers mitigate the challenges and exploit the opportunities that are posed by climate change through (i) the application of existing knowledge on crop, soil and water management innovations, and (ii) through the re-deployment and re-targeting of the already available germplasm of ICRISAT's mandate crops *viz.,* sorghum, pearl millet, pigeonpea, chickpea and groundnut. Simulations on sorghum at Aurangabad (Maharashtra state) using the DSSAT software considering treatments of low input farming, improved practices, enhanced temperature and better variety have indicated encouraging results (Cooper *et.al.*, 2009).

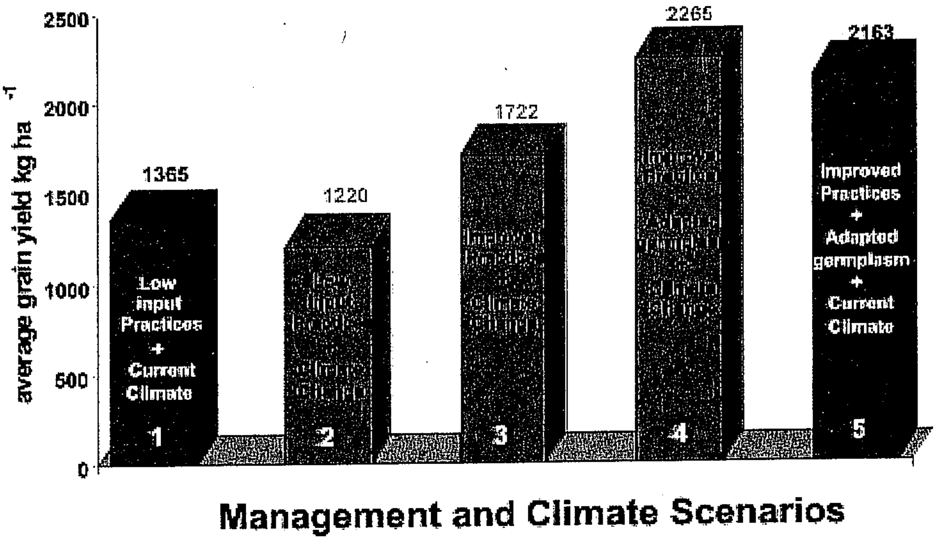

Fig.1. Sorghum yield (Kg / ha) simulations (DSSAT) at Aurangabad, India 1955 - 1983

The simulations show that the impact of projected climate change on the yields of low input agriculture is likely to be minimal, as other factors will continue to provide the overriding constraints to crop growth and yield. Adoption of existing recommendations for improved crop, soil and water management practices, even under projected climate change conditions, will result in substantially higher yields than farmers are currently obtaining in their low input systems. This Hypothesis of Hope being advanced by ICRISAT could result in addressing the current climate variability and almost complete mitigation of projected climate change effects.

Way forward

Simulation modeling has great scope in assessing the climate change impacts on crops. Crop-growth simulation modeling is complex and needs team work. Choice of climate change scenario, crop and cultivar, soil and water management options affect individually and in combination, the simulated and the actual impact of climate change. Impact of CO_2 fertilization is still complex and several uncertainties exist. There is need for experiments on major crops and cultivars in which high CO_2 concentration is combined with water and nitrogen stress for a clear understanding of impacts of elevated CO_2 levels on crops. Long-term daily weather data is a pre-requisite for crop-growth simulation studies, which is an issue at many locations. Though weather generators are useful, however, they cannot replace the observed data. Quality radiation data is not available at many locations. Calibration of models for various popular crop cultivars based on field experiments in varied agroclimatic zones is the need of the hour for simulating future climate change impacts. Capacity building in the country on crop-growth simulation modeling needs to be taken up on high-priority.

Future climate change is likely and we will have to develop strategies to adapt to these changes. Adaptation involves adjustments to decrease the vulnerability of agriculture to current climate variability and future changes. Production losses may be averted or at least mitigated through the concerted efforts of agricultural research and policies aiming to improve crop varieties and accompanying management strategies. Integrated Watershed Management has been identified as the engine for sustainable agricultural production even in the projected climate change scenarios.

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