Advanced computational procedures for the understanding of agricultural processes

Growth of crops obeys certain physiological principles, which have been described, most of the times, in qualitative terms but can be quantified in response to the environment by mathematical formulae by linking the equations to each other. In process, a mathematical model is obtained that can be written as a computer program. Rapid accumulation of knowledge in the agricultural fields and increased accessibility to information technology have contributed to the development of a wide number of agricultural models. Crop simulation models can be used as a tool to assist farmer in their decisions on agronomic and management operations.

Crop growth is a complex interaction of various soil, water, plant and atmospheric components, and thus it becomes difficult to completely represent the system in mathematical terms. Several dynamic models have been developed in the recent past, generally robust either in soils and crops, or in greenhouse gases (GHG) emissions. Pest-induced yield loss is generally not addressed in most models, thus limiting their usefulness. The most popular and widely used models for crop growth and yield assessment and for appropriate resources and inputs management are DSSAT, APSIM, WOFOST, ORYZA, INFOCROP, WTGROWS[1–5].

INFOCROP, a generic dynamic crop model, has been developed for tropical and sub-tropical environments; it deals with several important crops particularly for the South Asian region[6,7]. The model provides integrated assessment of the effect of weather, variety, pests, soil, and management practices on crop and soil processes. Its general structure is based on WTGROWS[8]. Another version of the model, developed for increasing model applications, has a user-friendly interface written in Microsoft.Net while the back-end has Fortan Simulation Environment (FSE) models and databases in MS-Access. The model has been validated for several crops in different production environments.

Crop simulation models have been used for recommending suitable resource and input management options[8], and for the evaluation of climate change impacts[9–13]. These models operate well under point application for various biotic and abiotic stresses. However, model development becomes difficult to handle all biotic/abiotic stresses simultaneously. There is a need to effectively integrate relational layers of biophysical and socio-economic aspects with crop models for realistic estimates. Effective linkage of remote sensing inputs for the capture of spatio-temporal variability has been demonstrated on a limited/regional scale. There is a strong need to introduce advanced computational tools, viz. neural network, artificial intelligence, big-data handling, multi-goal linear programming and agri-informatics, linked with crop simulation models for effective agriculture management.

Agriculture, specifically in the South Asian region, is intensive with large spatio-temporal variations in biophysical and socio-economic inputs. There could be a chance of error propagation while extrapolating the results over a large region through crop models, when run on point scales. Recent versions of DSSAT have also included phosphorus and potassium fertilization effects simulation, but there is need to include secondary and micronutrients. Sub-routines for handling problem soils, viz. saline, sodic, acidic and waterlogged need to be added in the simulation models.

Data base management system plays a crucial role in the capture of spatio-temporal variations in biophysical and socio-economic aspects, which are important in running crop models for regional assessment of agricultural production over a larger region. Information on these aspects exists in a scattered manner; there is a need to collate them, for which remote sensing and geographic information system can be effectively utilized.

We provide a few examples using decision tools for applications in managing agricultural production systems.

Soil health assessment: Soil health is dependent on several attributes: physical (texture, structure, moisture retention/release/transmission characteristics, aeration, compaction), chemical (soil reaction, nutrients availability, organic carbon) and biological (microbes, nematodes). Various soil quality indices have been developed for addressing crop choices and management of inputs, but on limited/regional scale. There is need to re-look big-data for generating response functions, taking care of various biotic/abiotic stresses through artificial intelligence and neural networks.

Pedo-transfer functions for computing soil water and nutrient characteristics on the basis of easily determinable soil parameters[14], are used in crop simulation models.

Climate informatics: This includes characterizing inter- and intra-climatic variations; probability of occurrence of extreme climatic events, transfer functions to compute solar radiation and vapour pressure, and precise future climate change scenarios.

Crops/cropping systems informatics: This deals with the predominant crops and cropping systems in various regions, including crop capability classification for choice of alternate land-use types under adverse conditions.

Package of practices: Agronomic and inputs management practices for crops/cropping systems in different production environments, recommendations for problem/degraded soils to be on operational window.

Hydrological aspects: Surface/ground water (quality/quantity) on regional scales to be quantified; water production functions (seasonal/dated) to be developed for water management. Conjunctive water use to deal with poor quality water and linked with rapid land-use and land-cover change.

Insect pests informatics: Delineating major insects/pests (spatio-temporal); crop yield reduction associated with insect pests, associated control options, and pest forewarning system are priorities to be addressed through crop models.

Some examples of simulation tools and decision support systems (DSS) are given below.

Soil health assessment/management service: Huge soil test values have been reported in the literature, but effective/operational soil health service does not exist; limited regional studies have been successfully demonstrated. There is need for effective operational on-line soil health service (region-based), which requires development of suitable soil

quality indices derived from easily determinable soil parameters[15]. Soil health service should address water management (irrigation scheduling, conjunctive use, fertigation), nutrients management (balance fertilization, customized fertilization[16], foliar nutrition, slow release fertilizers, plant growth promoters, biofertilizers), tillage options (zero tillage, conventional tillage, bed planting, resource conservation technologies), problem soils management (saline/sodic/acidic/waterlogged/compact soils), and soil conservation techniques.

Weather-based agro-advisory service: This facility is already available for synoptic/medium/long-range weather forecast, but needs further improvements in linking with simulation/remote sensing tools for effective agro-advisory services.

Crop condition assessment and yield forecasting: Remote sensing inputs provide acreage and crop growth conditions (although they are not able to delineate stress types), net primary productivity, land-use/land-cover change dynamics[17,18] and through statistical methods can effectively forecast the productivity. There is a need to link this input with crop models.

Climate change and its variability effects on agriculture: In the last couple of decades, there has been a drastic increase in events such as drought, flood, heat, cold, strong wind and cyclone. Crop yields in some areas have already started to decline. The agricultural sector is a high emitter of methane and nitrous oxide, through livestock and fertilization.

The purpose of mitigation and adaptation measures is to attempt a gradual reversal of the effects caused by climate change and sustain agricultural development. Although crop models have effectively demonstrated the impact of climate change/variability on agriculture, we need to improve methodology through careful extrapolation of results of Free-Air Carbon Dioxide Enrichment/Open-Top Chambers, effective inclusion of other biotic/abiotic stresses, linking future socio-economic scenarios and including intra- and inter-sectoral interaction.

For this purpose, advanced computation in understanding of agriculture processes needs to be developed where the crop models along with optimization tools, artificial intelligence and neural network play an important role.

Further scope in advanced simulation techniques includes:

(1) Crop models to be run with appropriate set boundary conditions and assumptions.

(2) Models require strong regional calibration and validation before reaching the application platform.

(3) For better model performance, capture of strong spatio-temporal database of various biophysical and socio-economic aspects is necessary.

(4) Sensitivity analysis for inputs (for soil, weather, crops/cropping systems, agronomic and management practices) needs to be performed for identifying minimum inputs dataset, which is strongly built in the DSSAT model.

(5) Micro- and secondary nutrients, insect pest routine and socio-economic aspects to be strengthened in the simulation models for effective outcomes. The solution might be through empirical approach following advanced computational techniques.

(6) Minimizing error propagation of modelling outputs by careful handling of agri-production environments.

(7) Use of advanced computational procedure, with historic datasets of field trials, for evaluating interaction of various biotic/abiotic stresses unaddressed through simulation models. Artifical intelligent network, neural network, multigoal linear programming and optimization tools have to be included within crop models to undertake this process.

(8) Integration of remote sensing inputs with crop models and relational layers for preparing DSS is essential.

1. Aggarwal, P. K., Kalra, N., Singh, A. K. and Sinha, S. K., *Field Crops Res.*, 1994, **38**, 73–91.
2. Hoogenboom, G. *et al.*, Decision Support System for Agrotechnology Transfer (DSSAT) Version 4.6, DSSAT Foundation, Prosser, Washington, USA, 2015; http://dssat.net
3. Jones, J. W. *et al.*, *Eur. J. Agron.*, 2003, **18**, 235–265.
4. McCown, R. L., Hammer, G. L., Hargreaves, J. N. G., Holzworth, D. P. and Freebairn, D. M., *Agric. Syst.*, 1996, **50**, 255–271.
5. van Diepen, C. A., Rappoldt, C., Wolf, J. and van Keulen, H., Crop growth simulation model WOFOST version 4.1, Documentation. SOW-88-01. Centre for World Food Studies, Wageningen, The Netherlands, 1988.
6. Aggarwal, P. K., Kalra, N., Chander, S. and Pathak, H., *Agric. Syst.*, 2006, **89**, 1–25.
7. Aggarwal, P. K. *et al.*, *Agric. Syst.*, 2006, **89**, 47–67.
8. Aggarwal, P. K. and Kalra, N., *Field Crops Res.*, 1994, **38**, 93–103.
9. Kalra, N. *et al.*, *Curr. Sci.*, 2008, **94**(1), 82–88.
10. Kalra, N., Chakraborty, D., Ramesh Kumar, P., Jolly, M. and Sharma, P. K. *Agric. Water Manage.*, 2007, **93**, 54–64.
11. Kalra, N., Chander, S., Pathak, H., Aggarwal, P. K., Gupta, N. C., Sehgal, M. and Chakraborty, D., *Outlook Agric.*, 2007, **36**(2), 109–118.
12. Chander, S., Kalra, N. and Aggarwal, P. K., *Outlook Agric.*, 2007, **36**(1), 63–70.
13. Aggarwal, P. K. *et al.* (eds), *Land Use Analysis and Planning for Sustainable Food Security*, Indian Agricultural Research Institute, New Delhi, India, IRRI, Los Banos, Philippines and Wageningen University and Research Centre, Wageningen, The Netherlands, 2001.
14. Adhikary, P. P. *et al.*, *Aust. J. Soil Res.*, 2008, 46, 476–484.
15. Rattan, R. K., *Indian J. Fert.*, 2015, **11**(4), 40–61.
16. Singh, R., Kalra, N. and Mehan, K., *Indian J. Fert.*, 2007, **3**(6), 13–16; 19–26 and 54.
17. Sehgal, V. K., Sastri, C. V. S., Kalra, N. and Dadhwal, V. K., *Photonirvachak, J. Indian Soc. Remote Sensing*, 2005, **33**(1), 1–6.
18. Das, D. K., Mishra, K. K. and Kalra, N., *Int. J. Remote Sensing*, 1993, **14**, 3081–3092.

NAVEEN KALRA[1],*
J. C. BISWAS[2]
M. MANIRUZZAMAN[2]
A. K. CHOUDHURY[3]
S. AKHTER[3]
F. AHMED[3]
M. A. AZIZ[3]
M. M. RAHMAN[4]
M. M. MIAH[4]

[1]Division of Agricultural Physics,
Indian Agricultural Research Institute,
New Delhi 110 012, India
[2]Bangladesh Rice Research Institute,
Gazipur 1701, Bangladesh
[3]Bangladesh Agricultural Research
   Institute,
Gazipur 1701, Bangladesh
[4]Bangabandhu Sheik Mujibur Rahman
   Agricultural University,
Gazipur 1706, Bangladesh
*For correspondence.
e-mail: drnkalra@gmail.com