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An international collaborative network for agricultural systems applications (ICASA)

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Abstract

In the 1970s and 1980s much progress has been made in studying agricultural production systems by using simulation modelling of agronomic processes. The International Benchwork Sites Network for Agrotechnology Transfer (IBSNAT) group in the USA and the group around Professor Kees De Wit in Wageningen were active in this new area of research which created an important 'niche' within the agricultural sciences because of its integrative, interdisciplinary character and its focus on quantitative, process-based approaches. A first joint scientific meeting of the two groups was held in Bangkok in 1991 (SAAD1 conference: Systems Analysis for Agricultural Development). At the SAAD2 conference at IRRI in 1995, in which also other groups took part, notably the Agricultural Production Systems Research Unit (APSRU) group from Australia, the International Consortium for Agricultural Systems Applications (ICASA) was established as a forum for researchers engaged in the study of agricultural systems at different spatial scales ranging from fields, farms to regions and beyond. The ICASA is an informal network with a focus on three major activities: (1) sharing experiences and joint development of compatible software allowing more widespread use of models having been developed by various member groups; (2) organization of joint courses on different aspects of dynamic modelling of agricultural production systems. There is an increasing interest in such courses, also in developing countries, and local researchers increasingly take an active part in them; and (3) joint research on projects dealing with dynamic characterization of agronomic production systems at different spatial scales. ICASA researchers take part in eco-regional methodology development, through projects that are funded by the Dutch and Swiss governments, with ISNAR acting as the administrative

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agency. ICASA intends to be an effective platform on which researchers, stakeholders and policy makers can interact.

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1. Introduction

The International Consortium for Agricultural Systems Applications (ICASA) envisions a future characterized by broad acceptance of systems-oriented methodologies in agriculture and natural resources. To achieve this vision, ICASA's goal is to advance national and international agricultural systems research through the development and application of compatible and complimentary systems analysis tools and methodologies. This goal includes, but is not limited to, the use of crop simulation models because of their increasing importance in decision support systems tailored for use by researchers and decision makers at field, farm, watershed, regional and national scales. ICASA first emerged from two major agricultural systems-oriented research programmes operating during the 1980s and early 1990s: International Benchwork Sites Network for Agrotechnology Transfer — IBSNAT (Uehara and Tsuji, 1993) and Simulation and Systems Analysis for Rice Production — SARP (Ten Berge, 1993). The IBSNAT project emphasized a systems approach for technology transfer, a research user-oriented package referred to as DSSAT (Decision Support System for Agrotechnology Transfer; Jones et al., 1998), minimum data set concepts (Hunt and Boote, 1998), and training for adoption and use of crop models and DSSAT for research purposes. The SARP approach emphasized the training of participants on understanding the mechanisms in rice production systems for model development and application for specific purposes. Leaders of these successful projects recognized potential for progress through closer co-operation. An international symposium entitled 'Systems Approaches For Agricultural Development' (SAAD) was held in 1991 to initiate this co-operation (Penning de Vries et al., 1993). Plans made at that meeting resulted in the formation of ICASA in 1993. Additional agricultural research groups joined the initiative later. Now ICASA consists of a Board of Directors, a secretariat, and an international network of researchers active in agricultural systems research and applications. One purpose of this paper is to describe the methods and approaches used by ICASA to meet its goals.

Approaches and tools are being developed and tested for systems at different levels of aggregation, including field, farm, watershed and region, to gain insight and to evaluate options for management or development. Central to many applications are crop and other biophysical models capable of simulating real world responses to climate, soil, and management variations at a field scale. After crop models were first introduced in the late 1960s and early 1970s, there was a long period of time, referred to as the 'dark ages' of crop modelling by Acock (1989), when only a few researchers were active in developing and applying crop models. In the 1980s, partly due to advances made by the two projects mentioned above and by a few other groups, several barriers were overcome, leading to more widespread uses and acceptance of crop models (Jones, 1998). However, barriers still exist. ICASA activities are aimed, in part, to help overcome these barriers so that models and other systems application tools are scientifically-sound, widely available, and effective in supporting agriculture and natural resource management decisions. Four important barriers were recognized to help guide ICASA activities:

1. the need for high quality data for developing and evaluating crop models;
2. the difficulty of obtaining crop model inputs across space and time for real world problems;
3. the time and other resources necessary to develop, validate, document, and maintain crop models; and
4. the focus on simulating potential and water-limited yield with continuing limitations of models to simulate actual yield in farmers' fields.

A second purpose of this paper is to present results of ICASA research efforts aimed at overcoming some of these barriers to achieve more widespread acceptance and use of these systems approaches and tools. This includes an outlook to the future.

2. Activities

At the core of methods used by ICASA is a network of agricultural systems scientists who are working together to accomplish ICASA goals. A Board of Directors with nine members is responsible for the ICASA network and its activities. Some network members participated in the SARP and IBSNAT projects that initially formed ICASA, but additional groups have also joined. For example, the Australian research group working on APSIM (Agricultural Production Systems Simulator; McCown et al., 1996) is now represented on the Board, and a new systems research centre in India has joined the network. The key to network success is a recognition that greater progress can be achieved through co-operation than can be achieved by working within resource limitations of individual groups or institutions, thereby bringing benefits to each member and to the scientific community.

ICASA carries out six types of activities to meet its goals and objectives. First, the ICASA Board holds meetings once or twice per year to review progress, determine new needs and opportunities, and plan activities. Second, ICASA participates in funded research projects. Instead of a single project providing financial support for their activities, network members receive funds from a number of national and international sources. This will further be discussed later. Third, working meetings are held to focus network expertise on specific objectives, such as writing recommended standards for data, integration of GIS (Geographic Information System) tools with DSSAT for precision agriculture applications, and developing frameworks for modular model development. ICASA does not have a central source of funds to support these activities. Instead, network members use their own resources as they see derived benefits for their own programmes. Fourth, ICASA organizes symposia entitled 'Systems Approaches for Agricultural Development', or SAAD. These symposia provide a forum for an international audience to present, discuss, and exchange formation on methodologies used across disciplines and at multiple scales to obtain a more integrated understanding of agricultural systems. The first in this series, held in Thailand in 1991 (Penning de Vries et al., 1993), led to the development of ICASA. The second SAAD symposium, held in the Philippines in December 1995, emphasized the links between biophysical and social sciences for dealing with complex issues at different scales ranging from a field to the globe (Kropff et al., 1997; Teng et al., 1997). At the third SAAD symposium, held in Peru in November 1999, the main focus was to review interdisciplinary and multiple-scale approaches being used in four large eco-regional projects. At this symposium, ICASA presented a series of papers summarizing results of their initiatives. Fifth, ICASA is active in developing models and various application tools for their own research activities as for the scientific community to use. ICASA members have contributed to new capabilities in DSSAT, such as the addition of new crop models such as sunflower (Villalobos et al., 1996) and application tools, such as incorporating software in DSSAT for analysis and optimization of management in spatially variable fields for precision farming (Booltink and Verhagen, 1997). Thus, ICASA members are enhancing and maintaining the DSSAT, with the latest release occurring in late 1998 (Hoogenboom et al., 1999). Finally, ICASA organizes training programmes for teaching interested researchers the concepts of crop modelling, approaches for adopting existing models in their research programmes, how to provide inputs, how to interpret outputs, how to use models to evaluate risks and uncertainties in crop production, and limitations that currently exist. These will be further analyzed later.

3. Software and tools

Wide ranges of tools are needed for studying agricultural systems at different time and space scales and for different purposes. Many biophysical and economic models have been developed in the past for specific applications. Although many researchers have developed their models with intentions for their use in other locations or for other purposes, many such efforts fail to achieve this goal for various reasons. One of ICASA's goals is to promote co-operation among different groups who are developing and applying agricultural systems models to address practical issues so that duplication of effort will be reduced through the use of existing models or components and compatible data. To a large extent, this level of compatibility has been realized within extended groups of researchers working together, but exchange of data and models among such groups has been time consuming. The approach that ICASA is using is to promote the evolution of software and tools among major groups of agricultural researchers using compatible data, models, and other components. Because the major emphasis of each of the groups in ICASA has been at the field scale previously, and each group has its own suite of crop models, the first attempt to achieve the needed compatibility is at the field level. Crop models, data management tools, and decision support systems developed by or adopted by ICASA are introduced below.

3.1. Field scale crop–soil models

Crop simulation models developed by different research groups over the last 10–20 years have been adopted by ICASA for different applications. Models for many of the major food crops of the world have been developed by building on early models of specific crops. For example, the CERES (Crop Estimation through Resource and Environment Synthesis) family of crop models evolved from wheat and maize models developed in the 1980s (Ritchie et al., 1998; Singh et al., 1998). Now, the CERES models simulate development, growth and yield for maize, wheat, rice, barley, grain sorghum, pearl millet, sugarcane, potato and taro using the same soil water and nitrogen components and similar subroutines for plant growth. Compatible models were developed for soybean, peanut, and dry bean under the leadership of researchers at the University of Florida (Boote et al., 1998) Similarly, different models evolved from research led by researchers in the Wageningen Agricultural University, including those for wheat, rice, and other crops (Bouman et al., 1996). Finally, models for more than 15 crops, including maize, wheat, barley, soybean, peanut, chickpea, and pasture, were developed by the APSRU group in Australia (McCown et al., 1996). One of the main thrusts by these different groups over the last 10 years was to develop user interfaces for the crop models to facilitate their testing and use by researchers not involved in model development. Now, these groups are actively co-operating in ICASA to achieve a practical level of compatibility among models as they continue to evolve.

3.2. Data management software

One of the major lessons learned as these models evolved was the need to standardize data formats and protocols for its use so that models from different groups could use the same input data, access observed data for model evaluation, and be used by the same application packages. Thus, a major effort of ICASA co-operation has been to build on earlier work of Hunt et al. (1994) to create a set of definitions and standards for data exchange and crop model input (Hunt et al., 2001). Because there are differences in data input requirements of crop models developed by different groups in ICASA, software is being developed to translate from these formats to facilitate their widespread use (J.W. White, personal communication; G. Wilkerson and G. Buol, personal communication).

Efforts are now needed to define compatible data types and formats for other levels of analysis, such as farm, watershed, and region. One of ICASA's aims is to help guide efforts to define these standards so that software can be developed or adopted to facilitate their widespread adoption and use. ICASA recognizes the importance of this and other decision support systems at field, farm, and other levels for supporting a wide range of applications as well as research and educational efforts.

3.3. Model development tools

Tools that helped many researchers learn how to develop and use crop models are the Fortran Simulation Environment (FSE; Van Kraalingen, 1991) and Fortran Simulation Translator (FST; Rappoldt and Van Kraalingen, 1996). These tools are used by the Wageningen group in training courses around the world, and were used to develop models for many crops by that group and its trainees (Penning de Vries et al., 1989; Kropff et al., 1997; Teng et al., 1997). Recently, these tools are available for MS-Windows.

3.4. Decision support systems

The DSSAT was developed by an international group of researchers in the IBSNAT project (Jones, 1993). This software package integrated crop–soil models, data bases, data base tools, and application programs to estimate production and economic risks at the field scale associated with different weather, soil, and management practices. ICASA continued to develop the DSSAT (Jones et al., 1998) after the 10-year IBSNAT project ended in 1993 (Tsuji, 1998), adding models for additional crops, adding spatial analysis components for use in precision agriculture and land use management applications (Stoorvogel, 1995, 1998; Booltink and Verhagen, 1997; Engel et al., 1997; Thornton et al., 1997; Bouma et al., 1999), maintaining it and releasing additional versions (Hoogenboom et al., 1999). Efforts are now underway to convert DSSAT into an MS-Windows application.

The APSIM (McCown et al., 1996) was developed by the APSRU in Australia, starting in 1991. This decision support system was engineered to solve many of the problems associated with documentation and maintenance of such comprehensive models. It also operates at the field scale and uses similar input data as other ICASA crop models.

4. Courses

ICASA has organized a number of workshops to provide researchers with an understanding of agricultural systems approaches, crop models, and practical uses of models using decision support systems such as DSSAT. Courses on application of simulation for crop and fertility management have been held annually in the USA since 1993. In addition, similar courses have been held in other countries in Latin America, Africa, Asia, and Europe. Instructors from different countries and groups have contributed to these training programmes. Two courses have also been held on techniques on 'Optimizing Management for Precision Farming: A Systems Approach'. Collectively, over 400 researchers have attended these courses during 1993–1999.

5. Research

5.1. Developments in systems analysis

Publications in the two SAAD proceedings, cited earlier, and in many other journals and bulletins clearly demonstrate the function of simulation modelling in characterizing important aspects of agricultural production systems. Models for crop growth as a function of climatic conditions and soil water and nitrogen supply are now operational after extensive field testing and can widely be applied. Literature provides many examples of such applications. An important problem can be lack of basic data to feed models but measurement techniques are continually improved not in the least because of developments in electronics and information technology. Proximal and remote sensing techniques allow measurement of leaf-area-indexes during the growing season which can be used to calibrate real-time models but also as independent input in modelling. Sensing techniques also allow measurements of water-stress in crops and estimates of N content of leaves. Aside from many new measurement techniques, procedures are available to relate available data to necessary but unavailable data by regression analysis as exemplified by pedotransfer functions for soil which are used to predict moisture retention and hydraulic conductivity data to simulate water fluxes (Wösten et al., 1999). Simulation of the occurrence of pests and diseases is as yet more problematic but progress is also being made here (Kropff et al., 2001).

The ideal situation of joint research in which ICASA researchers work together using models and software from different sources is still rather limited. As an example, DSSAT models were used by Booltink and Verhagen (1997) and by Stoorvogel et al. (2001) in the context of the TRADEOFF model. More examples are being generated, however. In the context of the eco-regional methodology programme, administrated by ISNAR (International Service for National Agricultural Research) and funded by the Dutch and Swiss governments, 10 programmes, each funded at the rate of $500,000, are in progress. These programmes now form the core of ICASA research, involving many new partners (Table 1). Results of some of this work are presented in this issue.

As methods for agricultural systems analysis are applied at both farm, regional and higher levels, it is important to realize that new developments take place in the role of systems analysis research. This certainly is not a static field of research and any review of ICASA activities should include a scan of future developments. A brief review will, therefore, be presented under the following two headings for the farm and regional level, respectively, which are the major focal points for systems research.

5.2. Farm level

Most studies on crop growth at farm level are backward-looking: calculations are made when the growing season is ended, when measurements of crop and soil characteristics have been made and when weather conditions are known. Calculated

Table 1
List of eco-regional methodology projects in progress

Integrating remote sensing, GIS and modelling for land-use monitoring in the arid/semi-arid Andes. (CIP: DME-SUR; October 1996–October 1999). Completed, including final review.
Regional scaling of field-level economic-biophysical models. (CIP: DME-NOR; October 1996–October 1999). Completed, including final review.
Methodologies for integrating data across geographic scales in a data-rich environment: examples from Honduras. (CIAT; October 1996–October 1999). Completed, including final review.
A systems research network for eco-regional land-use planning in tropical Asia. (IRRI: SysNet; October 1996–October 1999). Completed, after budget-neutral extension.
Resource use optimization at village district levels in the desert margins of West Africa. (ICRISAT: October 1996–October 1999)
Methodology and strategy development with crop growth modelling for sustainability in the South African highveld region. (ARC-Graincrops Institute; December 1998–December 2001)
A client-oriented systems toolbox for technology transfer related to soil fertility improvement and sustainable agriculture in West Africa. (IFDC: December 1998–December 2001)
Methodologies for assessing sustainable agricultural systems in the Hindu Kush-Himalaya region: An eco-regional framework. (ICIMOD)
System prototyping and impact assessment for sustainable alternatives in mixed farming systems in high-potential areas of Eastern Africa. (ILRI/ICRAF/KAR/WAU)
Development of an improved method for soil and water conservation planning at catchment scale in the East African Highlands (ICRAF/KAR/ARI/RELMA/SECAP/WAU)

yields are compared with measured yields to assess the success of the calculation procedures. This is certainly important to understand processes as they have occurred, but this type of research does not address the questions of the farmer who is, at the start of the growing season, faced with unknown conditions, requiring so-called adaptive management (Bouma, 1997a, 1997b). Surprisingly, systems analysis has paid little attention to this forward-looking approach. Recently, Bouma et al. (1999) have studied precision agriculture in The Netherlands in a forward-looking mode, using daily weather measurements in the farmer's field that were sent by e-mail to our laboratory, driving a simulation model for crop growth, incorporating water and nitrate fluxes. The model, intended to function as a decision support system, was quite effective in predicting N-shortages in soil which would lead to reduced growth when no N-fertilizer would be applied. In fact, the system is being used as an early warning system. The farmer could be advised to adjust his fertilization practices which deviated strongly from the ones dictated by conventional wisdom. This advice not only applies to variation of applications in time but also to variations within the field. The system also calculates fluxes of nitrate to the groundwater and is programmed to avoid fertilization rates that lead to nitrate leaching exceeding threshold values of nitrates in groundwater defined by environmental laws. The same approach was used, in principle, for grassland in The Netherlands by Hack-Ten

Broeke et al. (1999). Farm management involves, of course, much more than nitrogen fertilization. A truly forward-looking decision support system needs also to address crop protection, weed problems and tillage. Here, a mixture of procedures is followed including crop modelling and solute fluxes as well as inclusion of various types of expert systems in so-called prototyping approaches where farming systems are 'designed' in close interaction with the farmer (Vereijken, 1997; Aarts et al., 1999).

Another example of using systems analysis at farm level can be given for growing bananas in Costa Rica (Stoorvogel, 1998) where careful measurement of site-specific yields within defined soil units of a soil map, allowed precision application of fertilizers and biocides. The latter rates were based on detailed simulations of potential leaching rates of a variety of biocides in the various soil types occurring at the banana farm. Risks could be quantified by running the model for different weather conditions. In this case, the systems analysis did not imply real-time simulations of the growth of the banana plant (which is not yet possible) but implied a systematic application of expert knowledge. This work receives much attention because major economic interests are at stake.

The two examples relied strongly on continuous co-operation with farmers who played a crucial role in the research process, as data provided by simulation or external expert knowledge could only contribute a small part to the entire very complex decision making process by the farmer. Data generated by the systems approach are intended to be used and interpreted by the farmer; they certainly do not represent a set of clear-cut decisions. Ideally, research results are presented to the farmer and are generated upon his request in a continuous process of interaction. Thus, scientific independence is maintained, as the scientist does not pretend to make the decisions for the farmer. The true nature of the process is characterized by constant adaptation of management procedures as a function of weather conditions as the season progresses. This contrasts strongly with backward looking studies and with studies which characterize farming systems by generating lumped input–output coefficients for the entire growing season (Hengsdijk et al., 1998).

5.3. Regional level

At the regional level, interaction with stakeholders is also increasingly important. Here, some important stakeholders are planners and politicians. Generating alternative options for land use by using systems analysis is only meaningful when planners can identify with the products that result from such analyses and when these products are effective when plans are discussed with the users of the land. In fact, researchers occupy a special position between planners and politicians on one side and citizens on the other. The decision-making process is facilitated by independent research on possible land-use patterns producing options on demand by either of the two groups. The term land-use planning suggests a top-down approach, which is increasingly irrelevant as citizens become more literate and opinionated. Rather, we should speak of land-use negotiation where researchers face the challenge of providing independent and relevant research which can help the decision making process. Researchers may be seen as knowledge brokers (Bouma, 1997a). In a comprehensive study on land use in Costa Rica (Bouman et al., 2000), it was pointed out that diverse questions of different stakeholders can best be addressed by using a methodological toolkit, rather than single methods. Different methods are used as questions vary. In this study, projective, exploratory and predictive methods were presented, which together, could answer many of the questions that were raised by land users and planners. In addition, decision support methods were used to implement land-use systems that were designed by the planning exercise. In fact, application of a sequence of methods rather than single methods turned out to be advantageous here, supporting the idea of having a 'tool-kit' from which appropriate tools can be taken as needed.

The term: 'regional' which is being used here is very general and can indicate areas of different size. Processes of land-use negotiation can often be best studied within areas of land that operate under a given administrative structure, such as a county, province or country as a whole. From an agro-ecological point of view, consideration of watersheds is quite attractive because water and solute fluxes are then related according to observable landscape patterns: what happens upstream has specific effects downstream, which can be understood and interpreted. This facilitates the analysis of tradeoffs between contrasting land-use demands. Still, watersheds may cover different administrative areas and what may be gained in terms of clarity from an agro-ecological point of view, may be lost again in politically inspired discussions.

These developments in land-use negotiation, as briefly explored here, have major consequences for systems analysis on a regional level, which are being made by different ICASA partners. In fact, most attention has been paid so far to agricultural production at field and farm level. Increasing demands on the land by other (politically much more powerful users than farmers) will, however, increasingly require regional approaches and ICASA should pay proper attention to this.

5.4. Outlook for the future

Developments in agriculture itself and the place of agriculture in society at large are both subject to major changes and this should have clear effects on future agricultural systems research. Even though economic conditions for farming are currently quite poor in many areas of the world because of low commodity prices, we may assume that this condition will not last forever. A growing, more prosperous world population will require more food of higher quality while at the same time the suitable area of land for agricultural production is decreasing because of degradation processes and non-agricultural use of the land. These facts have been documented extensively elsewhere. The risk that funding for agricultural research will diminish because of these developments is clearly present, as policymakers conclude that our knowledge, after a 100 years of agronomic research, is adequate to face the challenges of the future. This is not correct, but any statement to this effect by scientists will be qualified as being self-serving and will tend to have little impact. Of course, basic research is essential to keep any science alive and it is therefore important to discuss the manner in which future agronomic research should develop. Clearly, systems analysis will have to play a central role in developing innovative farming systems that can produce crops. The required interdisciplinary research approach is increasingly shaped in close interaction with farmers, working on commercially operating farms. The prototyping approach (Vereijken, 1997; Aarts et al., 1999; Hack-Ten Broeke et al., 1999) has, along these lines, been applied successfully in the Netherlands. There is, however, still a barrier between practicioners and experts on the one hand and scientists on the other. Specifically, the role of simulation modelling in the overall prototyping context is not clear to all even though we can demonstrate that necessary trade-offs between production demands and environmental requirements can only be made using quantitative approaches.

But there is more. The rapid development of information and communication technologies will have a major effect on modern farming. It will indeed be possible to fine tune management to the diverse needs of individual plants in fields as the growing season unfolds, while environmental thresholds are not exceeded. Thus, precision agriculture has a clear future although its operational form is, as yet, not clear (National Research Council, 1997). Precision agriculture requires close interaction among disciplines. Fertilization, for example, not only affects plant growth, but also leaching of chemicals with possible adverse environmental effects and occurrence of pests and diseases. Much still needs to be done to break through the disciplinary molds. An additional challenge is the advance of organic farming systems which exclude synthetic agro-chemicals, thus removing some of the technical degrees of freedom that are available to prototype innovative farming systems that are both productive and environmentally acceptable. Still, a process-based approach is needed to realize such systems, and technology can play a key role here as well. Finally, the discussion about introducing genetically modified plants is bound to continue. Agricultural system analysis is eminently suitable to define which plant properties could most effectively be subject to genetic modification, considering agro-ecological conditions and limitations in a given area.

An active research approach, as broadly outlined here, is essential to position agriculture in a pro-active manner for the future. Many non-agricultural interests are very powerful and tend to ignore agro-ecological aspects of land use. The latter aspects should be presented clearly, using modern communication techniques, also in a broader regional context where important land use negotiations take place. The time that rigid suitabilities for given forms of land use were presented for certain tracks of land has passed. Now, the key word is alternative options, each with a set of tradeoffs. Focussing on stakeholder involvement, approaches can reflect different types of stakeholder questions using projectory, exploratory and predictive methods (Bouman et al., 2000).

In a time of apparent abundance of agriculture produce, mankind tends to forget that it depends on the earth for its existence. The continued study of agricultural systems is essential to develop operational tools allowing meaningful fine tuning of land use patterns and land management in future in a society where agricultural has its proper place.

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