PROCEEDINGS

OF THE

26th ANNUAL MEETING

July 29 to August 4, 1990

Mayaguez, Puerto Rico

Published by:

Caribbean Food Crops Society

with the cooperation of the USDA-ARS-TARS

Mayaguez, Puerto Rico

AGROTECHNOLOGY TRANSFER IN THE INFORMATION AGE

F.H. Beinroth

Department of Agronomy and Soils
University of Puerto Rico, Mayaguez, Puerto Rico 00708

ABSTRACT

The transfer of agrotechnology has evolved along an evolutionary path that led from trial and error to statistical analysis and analog reasoning to systems-based methods. Conventional transfer procedures are described briefly, but the paper is focused on a systems approach made possible by recent advances in the development of computerized simulation models for crops, soils, weather and pests; expert systems; data management techniques; and the integration of these components into coherent conceptual structures called decision support systems. Such systems can be used for the strategic planning of agricultural research and development at the policy level and tactical decision making at the farm level. Agrotechnology transfer occurs through the knowledge and experience built into these "thought tools," which are beginning to revolutionize agriculture. The transfer process, after having been "pedocentric" and "genocentric," will thus become "infocentric." Telecommunication networks linking computers will be the conduit for exchange and transfer of agricultural information in the future.

INTRODUCTION

Transfer of agrotechnology may be defined as the application of material and/or knowledge of the mechanical and biological components of agricultural technology at new locations. Such transfers are not new: diffusion of husbandry practices, and information about crops and livestock were a major source of productivity growth already in prehistoric times. Yet, even successful transfers, such as the introduction of new cultivars from the New World in Europe in the 16th century and the more recent promulgation of high-yielding varieties of wheat and rice, cannot obviate the enormous complexity of the transfer process (Beinroth et al., 1980). Although this complexity has now become reasonably well understood, the pace of translating the emerging concepts and notions into operational methodologies has not been encouraging.

Traditional agricultural research has led to very important breakthroughs--hybrid maize, short-strawed wheat and rice varieties--and indeed has created an immense pool of agricultural information. The breakthroughs and knowledge are useful only, however, if they can be packaged into products and practices that are transferable to and implementable by the target user. For, as John Naisbitt (1982) has pointed out in his book "Megatrends," we may be "drowning in information but starved for knowledge" --information that can be applied to practical problems and facilitate their solution.

Advances in computer technology and system science now allow to address these issues with innovative tools, techniques and perspectives. This paper attempts to outline one of these information age methodologies.

APPROACHES TO AGROTECHNOLOGY TRANSFER

The diffusion of agricultural technology evolved through time in a sequence of approaches that led from trial and error and statistical methods to transfer by analogy and, more recently, systems analysis and simulation.

In transfer by trial and error, failure is inevitably more common than success and, if at all, success occurs more by accident than by design and intent. Progress is thus attained slowly and at high social cost. Statistical techniques, mainly analysis of variance and multiple regressions, are widely used but are better suited to interpolations than extrapolation and are, therefore, of limited value for intercountry transfers.

Transfer by analogy has been traditionally advocated by pedologists on the rationale that soil classification stratifies the agroenvironment in sufficient detail to facilitate transference. In an extensive study involving taxa of Soil Taxonomy, the Benchmark Soils Project of the Universities of Hawaii and Puerto Rico has shown that this assumption is essentially valid (Beinroth, 1982; Silva, 1985). Yet, while this approach works well for broad assessments at a low level of specificity, it is less suited for specific predictions and prescriptions. Another limitation is that technology cannot be transferred to nonanalogous locations, thus creating the need for ever more research sites. More importantly, as agroproduction is a function of many interacting factors, basing a transfer method almost exclusively on soil conditions constitutes a reductionist approach that is inherently flawed.

The key to the solution of this dilemma is a systems-based approach which is discussed in more detail in the remainder of the paper.

SOME CONCEPTS OF SYSTEMS AND SYSTEMS SCIENCE

Webster's dictionary defines a system as "A set or arrangement of things so related or connected as to form a unity or organic whole." As everybody is aware, system is a word that is much en vogue in today's vernacular; even as simple a thing as a razor may be referred to as an "unwanted body hair removal system." In a scientific and technical context, however, systems are usually thought of as large and complex and comprising a hierarchy of levels of organization, each of which has an appropriate scale of resolution in both time and space (Nix, 1984).

System science studies the structure and function of systems, tries to identify their various levels of organization, and seeks to understand how their components or subsystems are related and connected. The study of systems may therefore be defined as "research on the interaction among the factors affecting the performance of the system" (Holt, 1988). It is essential in this research that a holistic system is treated as a single entity from a functional perspective, a geographic perspective, and a time perspective (Rawlins, 1988).

The systems approach to scientific research is characterized more by "synthesis" and linked, interdisciplinary teamwork than by "analysis" and scientists working in isolation. But, as Rawlins (1988) noted, "research focused on synthesis is swimming against the analysis tide of science." The latter may be a historical phenomenon. Stafford Beer, cited by Rawlins (1988), speculated that "Perhaps the most damaging outcome...of two thousand years of analytical thinking.. has been a cultural inability to think about the integrity of integral systems--the organization of organisms, the whole that is held to be greater than the sum of its parts, the viability of lively ensembles."

Whatever the reasons, although the conceptual benefits of cross-disciplinary team work have been recognized for some time, it appears that it is difficult to implement this approach in practice. Farming systems research, for example, which obviously calls for a holistic perspective, is more often than not multidisciplinary rather than interdisciplinary. The prevailing attitudes in agricultural research organizations led Holt (1988) to believe that nothing would improve agricultural production and marketing research more than a liberal infusion of systems science and systems scientists. But given the present state of affairs and the rather conservative nature of the agricultural scientific community, this may be easier said than done.

DECISION SUPPORT SYSTEMS FOR AGROPRODUCTION

Growing concerns about the sustainability of agriculture have precipitated a shift in the emphasis of agricultural research from production to productivity, from output-focused to input-oriented production systems. As the concerted management of the biological, environmental and socioeconomic resource base of agriculture becomes more and more important, the complexity of the agricultural decision environment increases substantially. Yet, as Holt (1988) has pointed out, "there is so much factual information and there are so many complex interrelationships associated with even a relatively simple system that it taxes the memory, reasoning power, and mental computing capacity of even a brilliant individual." Fortunately, advances in computer technology and information science now allow agriculturalists to address this problem effectively with computerized decision support systems that "link together scientific information with processes for using this information to make management decisions" (Rawlins, 1988).

Decision support systems typically consist of data bases, decision software, and a user interface or dialogue generator, all linked together through a series of utility and application programs. In the case of a decision support system for crop production, the data base should contain soil, crop, weather, and socioeconomic information; the decision software should comprise simulation models, expert systems, and analysis programs; and the dialogue generator should facilitate user interaction with the system for practical applications.

Data Bases

As the number of soil, genotype, weather, and socioeconomic factors that conceivably bear on the performance of agroproduction systems is very large indeed, a data base containing all of them would be exceedingly difficult to generate, use and maintain. Realistically, therefore, the complexity must be reduced to manageable proportions without sacrificing those parameters which critically determine system performance. Nix (1984) has coined the term "minimum data set" for that aggregate of crop, site and management data which allows to make useful predictions about systems performance. As differing objectives of decision systems applications call for different levels of resolution and accuracy, e.g., simple analysis of genotype/environment interaction vs. testing process-based crop models, the minimum data requirements vary with the purpose of the application. The innovative aspect of the concept of minimum data sets is that it has been developed in the context of a systems-based research strategy (Nix, 1984).

The storage and retrieval of data sets in standardized and usable forms requires an efficient data base management system. Systems with relational structures, such as dBASE III, are traditionally preferred because they are relatively easy to use, flexible, precise, relatable, and data independent. However, new approaches to information retrieval that combine data management with frame-based knowledge representation and expert systems techniques are now being considered (Beck et al., 1987).

Since much of the information in the data base has a geographic dimension and since many agricultural decisions require analysis of various sets of spatially referenced data, it is advantageous to employ a new computer technology known as Geographic Information Systems or GIS. Such systems comprise software packages for coding, storing, retrieving, transforming, and displaying maps of the data for a particular purpose. GIS also has relational data base capabilities which permit the storage of many attributes of a given point or area on a map. This information can be manipulated to create and display new maps and data elements based on combinations of attributes. With such maps, decision makers can quickly visualize, for example, the magnitude of pollution hazards, land potential, consequences of production strategies, etc. and see how they vary over space.

Simulation Models

Since modelling in the environmental and agricultural disciplines has become a fashionable scientific endeavor, numerous models, ranging from very simple to highly complex, are now available. These may be broadly grouped into empiral models, deterministic process models and stochastic models. Empirical models are those in which relations have been observed, but the mechanisms are not understood; deterministic or mechanistic process models are attempts at mathematical simulations of the physiological, physical and chemical processes which control the system; and stochastic models describe the occurrence of events or processes in terms of probability theory. In practice, these distinctions are somewhat diffuse and many models incorporate elements of all three groups.

Modelling in the agricultural disciplines began some 20 years ago but most advances have been made in this decade as evidenced by a proliferation of models dealing with various components of production systems. Operational growth and yield models are now available for many crops (Jones, 1989). Considerable progress has also been made in modelling soil conditions and processes, particularly soil water and, more recently, nutrients and chemical reactions. Several models exist to simulate weather conditions from historical data, e.g., WMAKER and WGEN (Richardson, 1981). Much effort has further gone into pest and pest loss models (Teng, 1988), and modelling of farming systems is now in progress (Dent, 1987).

Expert Systems

Various aspects of agroproduction systems defy the mathematical treatment that characterize simulation models, either because knowledge is insufficient to develop algorithms or because qualitative information or subjective judgements are involved. However, the techniques of knowledge engineering known as "expert systems" now allow these aspects to be addressed, either in combination with or independent of simulation models. Expert systems employ concepts of artificial intelligence to mimic human reasoning. They consists essentially of three parts: (1) a knowledge base of facts, heuristic knowledge, and If-Then production rules which represent the reasoning logic; (2) processing procedures for deriving conclusions from the knowledge base and user-supplied data called the "inference engine;" and (3) a user interface for communication with the system. There are many applications for expert systems within the framework of a decision support system. For instance, an expert system could be devised to estimate soil parameters required as model inputs from soil resource inventories and a general soil data base. Other systems could be used to diagnose problems such as disease or nutrient deficiencies, interpret model output relative to a specific user query and recommend a course of action (Jones, 1989). In the context of this symposium it should be of interest to note that Yost et al. (1986) have developed an expert system for correcting acidity in soils of the humid tropics. In this system, the parameters for a model are based on user response to questions about crop and soil and information from a data base of soil properties. Equations then compute lime requirements and relative yield loss without lime application.

It should be obvious from the above examples that agricultural expert systems are most effective when used in combination with simulation models and data bases. It may further be mentioned that although expert systems have been used successfully for some time in fields like medicine and oil exploration, they are relatively new to the agricultural scene. There can be little doubt, however, that they will soon emerge as a major tool in the systems approach to agricultural decision making.

Analysis Programs

These programs add to decision support systems the capability to evaluate systems output and explore alternative strategies so that the most appropriate can be selected for a specific situation. Strategy analysis software could include optimization programs that would automatically search through decision alternatives and select the best course of action. It could also include statistical analysis software to help users differentiate between decisions when outcomes are not certain, e.g. stochastic dominance/risk analysis software. Other programs could provide the capability for graphical display.

User Interface

Various programs are needed to link the components of the decision support system together and allow easy user access to data bases, simulation models, expert systems, and analysis programs. In view of the advances in the field of artificial intelligence, it is not unrealistic to assume that natural language processing will provide the user interface to decision support systems in the not too distant future (Beck et al., 1987).

Scenarios for Application

An agricultural decision support system computes how a specific agricultural production system will perform under stated conditions of environmental and management inputs. This output can be used to make (a) strategy decisions such as land use planning, and (b) tactical decisions such as when to irrigate and how much to fertilize. Decision support systems can thus enhance decision making at all levels of the agricultural sector, from political arena to farmer fields.

Nix (1984) has listed some possible applications of agricultural decision support systems:

- determination of which crops/cultivars are best grown where;
- development, testing, and application of new and modified management of strategies and tactics;
- development of optimum networks for research and extension;
- development of improved understanding of the structure, process, and function of crop systems;
- production forecasting; and
- assessment of environmental consequences of agricultural practices.

Obviously, a decision support system that can address all of the above issues and the host of others that are conceivable would have to be unrealistically large and complex. However, a common shell may be developed that can be tailored to specific applications by adding appropriate data bases, decision software and analysis programs.

DSSAT, an Example of a Decision Support System

In what must be considered a pioneer effort, a decision support system for agrotechnology transfer, DSSAT, was developed by an international team of scientists collaborating in the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) project of the University of Hawaii. The DSSAT integrates crop models, data bases and data base management programs, and production strategy evaluation functions into a holistic system operating on a microcomputer. These components are linked together by a shell that permanently resides in computer memory to provide convenient access to the different functions. DSSAT, which will be released and distributed by IBSNAT in July 1989, was designed to (1) enable researchers to organize experimental data and test crop models for their conditions, (2) help researchers and extension specialists study alternative crops, cultivars and management strategies for increasing yield and yield stability, and (3) assist decision makers in formulating national and regional agricultural production policies (Jones, 1989). A detailed discussion of DSSAT is presented in subsequent paper by U. Singh.

OPPORTUNITIES AND CONSTRAINTS OF COMPUTER-AIDED DECISION MAKING AND AGROTECHNOLOGY TRANSFER

The potential of computerized systems in support of agricultural decision making can hardly be overstated. Rawlins (1988) considers such systems as "knowledge products" that represent a new kind of input to the food system that is as transferable as a new seed or fertilizer.

The intrinsic advantages of a computer-facilitated systems approach to agricultural decisions over conventional methods is evident. Decision support systems allow to perform "ex ante" experiments, that would require many years to duplicate in the field, in a matter of hours at a desktop computer. Moreover, in real-time experiments there is no going back to ask and seek answers to "what if" questions--what if, in a given experiment, the plant density or a fertilizer treatment had been different. Also, there are many instances where field experimentation would be logistically or financially prohibitive. And in simulated experiments the researcher can control the time horizon of the simulations thus permitting the long-term assessment of the consequences of alternative agricultural practices.

Yet, notwithstanding the potential of decision support systems, there are circumstances that impede their successful application. As the degree of sophistication of data management, simulation models, and expert systems increases, so does the amount and specificity of the data required to drive the software. But for most areas around the world, particularly in the developing countries, detailed and complete site-specific soil, diurnal weather, crop genetic, and management data are rarely available. Burrough (1988) has termed this state of affairs "the parameter crisis" -- too many models chasing too few data. There are basically three solutions to this predicament, none of them easy: (1) collect more data in traditional ways, (2) make better use of existing data, and (3) generate data with innovative techniques. The first method is obviously very costly and time-consuming, but it is becoming possible to generate temperature and rainfall data with stochastic models from historical records (Richardson, 1981) and to estimate solar radiation from satellite data (Tarpley, 1979). The estimation of soil properties and their spatial variability, however, needs much further research.

At this stage of development and input data availability, the strength of decision support systems appears to be more in the area of strategic decisions, particularly in the planning and managing of agricultural research and development, than in area of tactical decisions at the farm level. A partial reason for this is that farm-scale microvariability of soil and weather conditions can be significant and a decisive yield determinant. With adequate input parameters, a decision support system can conceivably deal with this situation, but not in a practical way. It would seem preferable, as Sinclair (1989) has suggested, to develop farming systems that are robust enough to be less sensitive to farm-scale variations in environmental conditions.

CONCLUSION

Exciting progress has been made in the development of agricultural and environmental models, expert systems, data management techniques and their integration into the coherent conceptual structures that are decision support systems. Much more progress is yet to come. Yet, there appears to be a widening discrepancy between the degree of sophistication that the decision support systems have already attained and the ready availability of reliable, site-specific input data that are the prerequisite for their successful application. Although bridging this gap is a major challenge that will require concerted efforts, this should not detract from the intrinsic value and potential of decision support systems. It should, rather, provide an impetus to resource inventory and stimulate the development of innovative methods of data acquisition which capitalize on the availability of space age technology.

In agriculture, as elsewhere, it is axiomatic that in order to effectively confront the problems of the times, one must employ the tools and techniques of the age. The innovations of the information age have made it possible to incorporate agricultural knowledge and experience and environmental data bases in powerful computer systems that are capable of interactively processing this information. These "thought tools," supported by efficient telecommunication networks, will become the vehicle for modern agrotechnology transfer.

ACKNOWLEDGEMENT

Dr. James W. Jones, Professor of Agricultural Engineering at the University of Florida, kindly reviewed a first draft of this paper. His perceptive comments and suggestions provided substance and acuity and are gratefully acknowledged.

REFERENCES

Beck, H.P., Jones, P., Jones, J.W., and Peart, R.M. 1987. Expert databases for agricultural information retrieval systems. Paper 87-5010, Amer. Soc. Agric. Eng., St. Joseph, MI.

Beinroth, F.H., Uehara, G., Silva, J.A., Arnold, R.W., and Cady, F.B. 1980. Agrotechnology transfer in the tropics based on Soil Taxonomy. Advances in Agronomy 33:303-339.

Beinroth, F.H. 1982. Research on the transfer of agrotechnology-Final report of the Puerto Rico Benchmark Soils Project. Dept. of Agronomy and Soils, College of Agric. Sciences, Univ. of Puerto Rico, Mayaguez, P.R., 155 pp.

Burrough, P.A. 1988. Modelling land qualities in space and time: The role of geographical information systems. In: Invited Papers presented at the Symposium on Land Qualities in Space and Time, Wageningen, The Netherlands, 22-26 August 1988, pp. 91-105. Agricultural University Wageningen, The Netherlands (mimeo).

Dent, B. 1987. IBSNAT crop models in a socio-economic whole farm framework. Agrotechnology Transfer, no 6. IBSNAT Project, University of Hawaii, Honolulu, HI.

Holt, D.A. 1988. Agricultural production systems research. Phi Kappa Phi Journal/Summer 1988/National Forum:14-18.

Jones, J.W. 1989. Integrating models with expert systems and data bases for decision making. In: A. Weise (ed.). Proceedings of Workshop on Climate and Agriculture: Systems approach to decision making in agriculture. Univ. of Nebraska, Lincoln, NE (in press).

Naisbitt, J. 1982. Megatrends. Warner Books, New York, p. 24.

Nix, H.A. 1984. Minimum data sets for agrotechnology transfer. In: V. Kumble (ed.). Proc. of the Symposium on Minimum Data Sets for Agrotechnology Transfer, 21-26 March 1983, ICRISAT Center, India. Patancheru, A.P. 502324, India: ICRISAT, pp. 181-188.

Rawlins, S.L. 1988. Systems science and agricultural sustainability. Phi Kappa Phi Journal/Summer 1988/ National Forum: 19-22.

Richardson, C.W. 1981. Stochastic simulation of daily precipitation, temperature and solar radiation. Water Resour. Res. 17:182-190.

Silva, J.A. (ed.) 1985. Soil-based Agrotechnology Transfer. Benchmark Soils Project. Dept. Agronomy and Soil Sci., Hawaii Inst. Trop. Agric. and Human Resources, Univ. Hawaii, Honolulu, HI, 292 pp.

Sinclair, D.F. 1989. On understanding variability. IBSRAM Newsletter No. 11, IBSRAM, Bangkok 10900, Thailand.

Tarpley, J.D. 1979. Estimating incident solar radiation from geostationary satellite data. J. Appl. Meteor. 18: 1172-1181.

Teng, P.S. 1988. Pest and pest-loss models. Agrotechnology Transfer No. 8. IBSNAT Project, University of Hawaii, Honolulu, HI.

Yost, R., Uehara, G., Wade, M., Widjaja-Adhi, I.P., and Zhi-Cheng Li. 1986. Expert Systems in Agriculture: Determining the lime recommendations for soils of the humid tropics. Series 000. Hawaii Institute of Tropical Agriculture and Human Resources, University of Hawaii, Honolulu, HI.