International Environmental Modelling and Software Society (iEMSs)
2010 International Congress on Environmental Modelling and Software
Modelling for Environment's Sake, Fifth Biennial Meeting, Ottawa, Canada
David A. Swayne, Wanhong Yang, A. A. Voinov, A. Rizzoli, T. Filatova (Eds.)
http://www.iemss.org/iemss2010/index.php?n=Main.Proceedings

The GPFARM DSS for Agroecosystem Sustainability: Past, Future, and Lessons Learned

J.C. Ascough II[a], G.S. McMaster[a], G.H. Dunn[a], and A.A. Andales[b]

[a]USDA-ARS, Agricultural Systems Research Unit, Fort Collins, CO 80526 USA (e-mail: jim.ascough@ars.usda.gov)
[b]Dept. of Soil and Crop Sciences, Colorado State University, Fort Collins, CO 80523 USA

Abstract: The USDA-ARS Agricultural Systems Research Unit (ASRU), in a collaborative effort with Colorado State University (CSU), developed the Great Plains Framework for Agricultural Resource Management (GPFARM) DSS. The general purpose of GPFARM is to serve as a whole-farm/ranch DSS for strategic agroecosystem sustainability evaluation across the U.S. Great Plains. Despite a reasonable level of producer involvement in the requirements analysis, development, and evaluation phases of GPFARM, it can be argued that the rate of adoption has been slow compared with the rate predicted at the initial development stage. In this paper, we provide a brief overview of the GPFARM DSS. We then discuss lessons learned (e.g., successes and failures) in over a decade of agricultural DSS development. A summary of conclusions resulting from discussion and critical analysis of the GPFARM project include:

- It is important that the DSS development process includes careful evaluation of the scope of the DSS in relation to the human and fiscal resources available.
- Careful attention should be paid to the needs of the intended target user group(s) through: 1) matching the proposed technology appropriately with the user, and 2) gathering input from a broad spectrum of potential users when performing a DSS requirements analysis.
- Simpler tools or database information generated from simulation analyses of alternative management options may have been more appropriate for delivery to producers and consultants (who do not have time to learn and use DSS tools).
- The capability to rapidly update major components (e.g., simulation model, databases) in order to address different farm/ranch management questions or problems is an absolute necessity.

Keywords: GPFARM; Decision support systems; Agroecosystem sustainability; Agroecosystem management; Software adoption; Producers.

1. INTRODUCTION

Sustainable agriculture demands consideration of many interrelated factors, processes, resources, and institutions. In the U.S. Great Plains, there has been a recognized need for a systems approach for sustainable agricultural research and development (Ascough II et al., 2007). Peterson et al. (1993) proposed that a systems approach to the study of soil and crop management problems is useful for testing present research knowledge to answer practical agricultural problems and simultaneously identify gaps in basic research knowledge. Support for system level decision support tools among agricultural advisors and producers has been mixed. In a 1995 Great Plains survey of 121 county extension directors, 173 USDA-Natural Resources Conservation Service (NRCS) District Conservationists, and 95 agricultural consultants, more than 90% were interested in using farm management decision support system (DSS) software (Frasier et al., 1997). However, Ascough II et al. (1999) reported that at this stage in time very few producers actually used decision aid software to manage their farm enterprises. Central to meeting the challenge of delivering viable decision support software, the USDA-ARS Agricultural Systems Research Unit(ASRU), in a collaborative effort with Colorado State University (CSU), developed the Great Plains Framework for Agricultural Resource Management (GPFARM) DSS (Ascough II et al., 2007; McMaster et al., 2002). The general purpose of GPFARM is to serve as a whole-farm/ranch DSS in strategic planning across the U.S. Great Plains. GPFARM runs on a field-by-field basis (with aggregation up to the whole-farm/ranch level), and provides production, economic and environmental impact analysis and site-specific database generation, from which alternative agricultural management systems can be tested and compared. Strategic planning is defined here as long-term planning (e.g., choice of sustainable crop rotation, choice of tillage/residue management system, etc.) as opposed to tactical planning (e.g., real-time management decisions such as seasonal crop or herd size selection, scheduling of irrigation, chemical application, harvesting, etc.). Agricultural consultants and producers (both farmers and ranchers) were targeted as the primary users of GPFARM. Initial user requirements were identified by a ASRU customer focus group comprised of eastern Colorado farmers, ranchers, agricultural consultants, and NRCS and extension professionals. The overall design goals of GPFARM were very minimal: (1) GPFARM should be simple to understand and easy to use; and (2) GPFARM should have minimum input data and parameter requirements.

The idea for developing GPFARM was conceptualized in the mid to late 1980's. Actual GPFARM development occurred from the early 1990's to 2005, ending with the current version 2.6. Despite a reasonable level of producer involvement in the requirements analysis, development, and evaluation phases of GPFARM, the adoption rate of GPFARM has been slow compared with the rate predicted for it over a decade ago at development initiation. Why has GPFARM fallen short of the high expectations in the early 1990's? Did we ignore early warning signs from user surveys that the system was likely not to be used because of producer time constraints or other factors? Did we underestimate the design features and delivery mechanisms required to bring a large-scale DSS from conceptual design to a fully operative, maintainable, and easy-to-use software package? In summary, did we fail to show the clear benefits of GPFARM to the target users in order to convince them that the DSS was worth their time and effort? The successor to GPFARM (iFARM – integrated Framework for Agroecosystem Resource Management) is currently under development. Can we use lessons learned from the GPFARM project to improve the usefulness of iFARM? In this paper, we first provide a brief overview of the GPFARM DSS. We then endeavor to provide some answers to the above questions by discussing the lessons learned (e.g., successes and failures) in over a decade of agricultural DSS development.

2. GPFARM DSS OVERVIEW

The GPFARM DSS is unique in bringing together a suite of decision support tools integrated with a comprehensive whole-farm/ranch simulation model and databases accessible through a Microsoft® Windows-based interface. The main contribution of GPFARM is not the introduction of new science, but rather the delivery of current research knowledge embodied in the simulation model and built-in databases (Andales et al., 2003). To lessen development time and reduce input parameters, simpler scientific approaches were used that hopefully would be adequate in distinguishing alternative management systems for long-term strategic planning. Databases of model input parameters, based on reported literature values, were integrated into GPFARM. Plant, soil, climate, and other component parameters are provided for the user, and all other inputs are minimized as much as possible (McMaster et al., 2003). Therefore, the GPFARM simulation model is a compromise between scientific rigor and simplicity (Andales et al., 2003). Additional details on the GPFARM DSS can be found in Ascough et al. (2007) and McMaster et al. (2002).

The GPFARM DSS is primarily composed of six major components designed to serve as an inclusive decision support tool for farmers and ranchers:

1. A Microsoft® Windows-based graphical user interface (GUI) that facilitates the entry of input data, provides simulation control, and displays output results.
2. Microsoft® Access databases containing the soil, crop, weed, climate, equipment, chemical, and economic parameters required by the simulation model and economic analysis components.
3. An object-oriented (O-O) modeling framework integrating modules for simulating soil water dynamics, N dynamics, crop and forage growth, weed population dynamics, chemical transport, water/wind erosion, and beef cattle production.
4. A set of analysis tools including a multi-criteria decision making module (MCDM), an output visualization module, and summary report tables and graphs for temporal and spatial comparison of different agricultural management scenarios.
5. A stand-alone economic analysis tool utilizing production data either from the simulation model or from user input for detailed economic analyses on a management unit or farm/ranch enterprise basis.

The remainder of the manuscript: 1) describes the GPFARM project though conceptualization, development, and implementation stages from the late 1980's to present day; 2) discusses issues affecting user adoption of GPFARM; and 3) conveys lessons learned during the course of GPFARM development.

3. CONCEPTUALIZATION ERA (LATE 1980'S - EARLY 1990'S)

The idea for GPFARM was conceived in the late 1980's. At this time, very little agricultural software existed. Certainly, no comprehensive DSS with the major components listed above had been developed, much less any other type of software that could perform integrated farm and ranch analysis of alternative agricultural management systems. There was much uncertainty related to computer adoption (who had computers), early agricultural computer software use (what type of software was being used and how was it being used), and where the agricultural industry was headed in the future with regards to computer hardware and software development (Ascough II et al., 1999).

Shortly after GPFARM conceptualization, a series of customer focus group meetings were held to determine initial GPFARM user requirements. Technology requirements for specific DSS output were not formalized, instead, producers at the meetings typically requested "more information" and "better access to research results." It was proposed that a whole-farm agricultural system DSS (e.g., a large-scale comprehensive software package) was an appropriate delivery technology to meet these requests. Formalizing user requirements at the beginning of a software development project is obviously critical, but often difficult if not fraught with misunderstanding when scientists are interacting with producers and agricultural consultants (the GPFARM primary intended users). McCown (2002) later offered insight on many of DSS and customer interaction issues, but they merit mentioning here.

Scientists and producers do not approach issues in the same manner, nor do they think in similar ways. Scientists must be keenly aware of this when asking questions and receiving feedback. For instance, the concept of creating the GPFARM DSS might have been driven in part by the ASRU scientists comfort level of their knowledge and expertise in simulation modeling and systems analysis, particularly as a result of responding to fairly general user requests. Indeed, while our customer focus group did not object when the whole-system DSS concept was presented as the primary means of knowledge transfer from the scientist to the user, we learned that not hearing any objections does not imply intent to adopt the system enthusiastically. In retrospect, it was unclear if we asked the "right" questions and whether the target users were clear about what software tools they needed and would use. Possibly exacerbating the problem of clearly determining user requirements was the small sample size representing our primary users. Our experience was that the questions frequently changed depending on who we talked with, and the same people might have different questions depending on what period in time we were conversing with them. However, U.S. agriculture is very broad and complex and this variety in feedback was not surprising.

After the initial customer focus group meetings, the focus shifted to overall component design and hardware/run-time requirements for GPFARM. We essentially assumed that if producers had a newer PC (Pentium III at that time), then they would be able to run the software. To further increase the likelihood of GPFARM being used, additional components were proposed. A simplified record keeper was added along with a large-scale Internet-based information system containing hyperlinks to a vast number of agricultural web sites. Based on informal conversations with producers, these products were additional technology that we thought the users wanted or would further attract them to GPFARM. The record keeper was later dropped from the GPFARM set of components; however, the information system was well-received and retained.

Prior to actual development, several software engineering issues presented themselves immediately. First, the GPFARM team had little or no experience with this scale of software development. Second, interface development software for Microsoft Windows® (e.g., Visual C++) was just starting to appear on the market. We had no prior development experience with Windows®-based software development tools, i.e., this was the era of the first appearance of Visual Studio, and little else was available other than DOS-based development tools. Most of us could not foresee the difficulty of: 1) developing a customizable Windows®-based GUI that producers would find easy to use; and 2) delivering the interface in a manner that producers (who differed greatly in what they like/want) would accept. Finally, the scientist and support staff at that time had no formal training in Windows®-based software development or advanced computer programming skills. After the project had been underway for a short period of time, a programmer with formal programming training and professional programming skills was hired.

To summarize, much is involved in clearly determining user requirements in order to enhance the likelihood of adoption. Importantly, we should have perhaps given greater consideration to whether "simple and specific" decision aids could have been developed as opposed to a comprehensive DSS of the complexity and scope of GPFARM. On the other hand, simple decision aids often sacrifice science for the sake of usability. Furthermore, real-world interactions in whole-farm agricultural systems are important, and decision support systems such as GPFARM that can capture these interactions are needed, even if complex, because agricultural systems are complex. In hindsight, it is always easy to question difficult decisions of this nature.

4. DEVELOPMENT ERA (EARLY 1990'S - 2005)

The initial GPFARM development focus was on the process-based simulation model component. The decision was made to build a new model using FORTRAN code from existing ARS agricultural system models for most major components (with the exception of the weed module written in Visual Basic). We did not wholly adopt and modify an existing agricultural system model (e.g., RZWQM, NLEAP, GLEAMS, WEPP, etc.) in part because some team members were not familiar with these models; we also wanted to make the GPFARM simulation model less complex and parameter intensive. The unit had extensive experience in developing complex simulation models (e.g., RZWQM - Root Zone Water Quality Model) so building a new model (from existing components) was not viewed as an overwhelming task. Concurrently, a decision also was made to develop a new object-oriented (O-O) framework in order to better structure whole-farm management at various spatial hierarchies (i.e., single management unit, field, or farm). It was hoped an O-O framework would offer the potential for better maintaining the simulation model. While this was a new and exciting advance in process-based simulation model programming (and we wanted to test and evaluate it), self-contained O-O framework development was a learning process for our scientists and the system implemented only partially attained the stated goals. For example, the framework was useful for dynamic control of the simulation model (and associated input/output); however, there were difficulties in evaluating the simulation model or individual model components because modularity was not strictly implemented in the framework and a significant amount of simulation code was embedded within the framework code. A consequence of this was that individual components were not tested outside of the model framework since the simulation code could not easily be extracted.

Determining how to model and display simulation output at a field and/or whole-farm scale presented challenges both in terms of the underlying science and in presentation to a diverse target user group. An iterative approach was used where we first tried an interface design consisting of four hierarchies (management unit, field, sub-farm, and farm) of spatial information. Later in the development phase, the number of hierarchies was reduced to only two (land unit and farm) because the volume of output at four spatial scales was simply too cumbersome to organize and display to the user. Difficulties also surfaced in developing the interface in conjunction with the O-O framework and simulation model development because the simulation model and database inputs were constantly changing. Interface changes were also externally driven. We were successful in developing and maturing the interface through consultant and producer feedback; however much effort was necessary (from both a user interaction and framework interaction standpoint).

It can be argued that the GPFARM project probably did not have enough critical mass (with respect to the number of personnel) to develop and debug a DSS of this magnitude. Furthermore, full-time testing of the entire GPFARM software package (not only simulation model testing but overall interface-model-database interaction testing) for a variety of management systems required additional personnel resources that were not available. In part, this was due to the fact that most GPFARM development team members were simultaneously trying to balance software development, scientific modeling, and experimental research across multiple projects. In terms of customer interaction during the development phase, there were continued customer focus group meetings with useful feedback from producers and consultants (particularly related to interface development).

5. IMPLEMENTATION ERA (LATE 1990'S - 2007)

After a series of Beta releases, Version 1.0 of GPFARM was released in 2000. Prior to this release, on-farm data collection was initiated in addition to producer evaluation of the GPFARM software package. The on-farm data collection effort was primarily soil moisture, soil nutrient, crop yield, yield/nutrient GIS mapping, and economic data. Ultimately, the data collected proved to be beneficial and useful for evaluating both tactical and strategic modeling approaches, but only as a comprehensive "enterprise" database across the whole-farm. In many ways, the on-farm data collection effort loosely mirrored the APSRU (APSIM/Farmscape) approach/opinion towards acquiring producer acceptance and trust: 1) work with producers to provide them with site-specific data/information (e.g., soil nutrient testing and management recommendations); 2) branch into working with them on developing modeling scenarios customized for their particular farming operation; and 3) learn more about producer behavior/sociology etc. in terms of their willingness to trust output from simulation models and DSS. It is unclear whether the above approach significantly increased user acceptance and trust of GPFARM. However, it did lead to greater interaction with the producers and much beneficial discussion and interaction.

After working closely with 4-5 producers, the project members assigned to on-farm technology transfer activities learned a tremendous amount about what was involved in promoting the adoption of GPFARM, i.e. what GPFARM should deliver to support on-farm decision-making. In general, the producers indicated they wanted help with management decisions and were willing to try a decision aid tool such as GPFARM. They wanted GPFARM customized for their farms and wanted to see what it would predict, but they were hesitant about changing their management approach (e.g., cropping/tillage systems) based entirely on GPFARM output. They were, however, interested in discovering if GPFARM confirmed their management decisions as illustrated by a producer in eastern Colorado working with the system. He ran GPFARM to determine if a wheat-millet rotation would work for his farm on a long-term basis. The crop yield simulation and economic analysis were favorable, and he eventually switched to a rotation with millet. The switch was not solely based on GPFARM analysis, but the analysis did substantiate his overall thinking towards making a change.

It was quickly apparent that despite extensive efforts to simplify and minimize input requirements, GPFARM setup time was still much too long for producers. One solution was to create some general scenarios so producers could quickly select a scenario, run the simulation model, and examine the output. We hoped this might encourage potential users to explore GPFARM further and customize to their own farm/ranch enterprise. We also tried working extensively with specific producers by setting up their farm for them (e.g., enterprise information such as field boundaries and soil types, crops grown, and management practices). Extensive training was provided after which the producers were then expected to work with the GPFARM software themselves. This did not happen for several reasons. First and foremost, the producers simply did not have enough time to work with a large DSS like GPFARM, even when a customized setup of their farming operation was provided. Producers also were frustrated by run-time issues, e.g., small changes on only one management unit meant re-running the entire simulation model for all management units (due to the spatial hierarchy/interconnectivity of the GPFARM simulation model). Currently around 15-20 producers have GPFARM on their computers and use it (with ASRU assistance) in some manner. The technology transfer team hoped that by training selected producers (leaders) in the Colorado farming community, their experiences with GPFARM would be spread to other producers, and farming groups (e.g. Colorado Association of Wheat Growers). Did this work? Results to date seem favorable, but more time is required to see the adoption effects of this effort.

6. GPFARM ADOPTION ISSUES

Rogers (2003) states that diffusion of an innovation (essentially adoption) occurs through a five-step process: knowledge, persuasion, decision, implementation, and confirmation. Of vital importance to the GPFARM project are the decision and implementation stages. In the decision stage, the individual takes the concept of the innovation and weighs the advantages/disadvantages of using the innovation and decides whether to adopt or reject the innovation. Due to the individualistic nature of this stage, Rogers (2003) notes that this is the most difficult stage to acquire empirical evidence. In the implementation stage, the individual employs the innovation to a varying degree depending on the situation. During this stage the individual determines the usefulness of the innovation and may search for further information about it. The GPFARM project could accurately be characterized as reaching the decision but not necessarily the implementation stage. That is, producers recognized the value of GPFARM, but were not willing to implement or fully adopt the system on their own.

To help determine possible reasons for the slow rate of GPFARM adoption, informal interviews were held with approximately 6-8 producers. The current generation of producers, while adopting computers at a rate comparable to the general public, were still not prepared to use computer software for decision making. They depend primarily on their past management experiences and their time is extremely limited. Another possible reason is that the wrong user groups may have been targeted. Producers and consultants did not think they would get enough value back for whatever amount of time they spent in working with the system. Why was that? Even with a user interface we perceived as simple and intuitively designed as possible (given the complexity of the model behind it), producers and consultants did not have the time to input necessary information. A logical conclusion from this is that the simulation model still may have had too many inputs available through the interface for the user groups targeted. There were also indications that GPFARM produced too much information and possibly the wrong type of information (i.e., information not directly relevant to the producer decision-making process). Many GPFARM outputs were related to water quality issues - issues not critical for Great Plains dryland producers who are struggling to survive through drought, hail, insects, etc. GPFARM output also appears to have been presented in a manner that was not precisely what the producers wanted. For example, producers were interested in output capabilities like GIS-based color ramping across management units, but uncertain on how to configure the output visualization component, interpret simulation results, or how to derive meaningful information from the output graphs and tables being presented. The GPFARM economic component was very well received, but may have been hampered by a crop growth simulation component that needed improvement (particularly for water stress calculations), and thus was less effective for predicting year-to-year crop yield variability (but reasonable for long-term strategic planning).

Rapidly updating many of the default GPFARM databases (e.g., climate and herbicides) was difficult, thereby reducing the usefulness of GPFARM to the producers. Also, the simulation model run-time for many management units over many years was too long for the producers, and a lack of modeling flexibility (e.g., the need to rerun all management units for changes in only one management unit or in commodity prices) further discouraged producer/consultant adoption. The expectation for producers to run GPFARM themselves will probably never be met fully on a consistent basis. Producers appear to have motivation to work with GPFARM during certain times of the year, but then return to on-farm activities and forget how to use the software.

Ultimately, we concluded that one-to-one contact with producers was essential and that it would be difficult to expand the number of users with only two full-time technology transfer personnel available. Many copies of GPFARM have been sent on request (~500) with offers of free phone technology support or on-farm visits (if within reasonable driving distance), but only two requests have been received! We do not know how many GPFARM installations reside on computers and how often GPFARM is actually being used. Many requests for GPFARM were outside the area of applicability, thus it was not possible to use the default climate, crop, and equipment databases. Furthermore, many if not most Great Plains producers do not follow a standard fixed crop rotation. Opportunity cropping is becoming much more common than long-term strategic planning with fixed crop rotations; thus these capabilities of GPFARM seem to be of limited use to producers. We also received much feedback that a tactical approach to management is needed. Finally, it is worth mentioning that the number of agricultural management issues facing U.S. Great Plains producers is truly staggering. Developing GPFARM and working with producers on-farm has provided tremendous benefits for ASRU in general (and especially the technology transfer team) in: 1) understanding the needs and thought processes of producers as they manage their farms and ranches; and 2) allowing the technology transfer team to be much more adept at posing questions for analysis and using GPFARM to construct valid "what-if" scenarios.

7. FUTURE PLANS

Recently, farm/ranch cooperators of GPFARM have been asking for an enhanced DSS to allow seasonal tactical planning and management of their operations based on climatic and price fluctuations, and other risk factors. The iFARM project will extend and expand GPFARM into a national-level DSS for both strategic and tactical planning/management that will include climate, market, and natural-hazard risks, as well as carbon sequestration and greenhouse gas emissions. New science modules and technologies will be introduced into the DSS for this purpose, such as a crop module that responds better to water/N/heat stresses; accounting of carbon and greenhouse gases; management effects on soil, precipitation capture, and water storage; soil temperature; economic and environmental risk assessment; estimation of field-scale model parameters; rule-based management; and Internet connection to national soil and climate databases. New crops and managements will be added for expansion into the northern and southern U.S. Great Plains, and the U.S. Midwest. To avoid limitations of current GPFARM technology transfer, cooperative agreements have been created with wheat- and corn-grower commodity groups to implement iFARM training and DSS evaluation across regional farms and ranches. The outcome of this research will be a validated iFARM DSS for use by farmers, ranchers, agri-businesses, and NRCS in strategic/tactical management and by scientists in research.

8. SUMMARY AND CONCLUSIONS

Because of the relatively slow adoption rate, it can be argued that GPFARM has not had the impact predicted for it over a decade ago. However, GPFARM is a noteworthy and significant scientific achievement. It remains one of the few integrated cropland/rangeland DSS in the world, the interface-simulation model-database linkage is still state-of-the-art, and the system is one of the few (if not only) spatial multi-criteria DSS for agriculture. We offer the following conclusions (lessons learned) from the GPFARM project. While many of these lessons learned are specifically related to GPFARM and should be useful in improving our new iFARM DSS, we hope that this list will prove to be useful to other researchers around the U.S. and world engaged in similar DSS development activities.

1. It is important that the DSS development process includes careful evaluation of the scope of the DSS in relation to the human and fiscal resources available (e.g., assessment of personnel available for developing, evaluating, implementing, and maintaining a DSS that matches the scope, scale, and complexity of the project). Formal project management and software engineering protocols and tools can aid in this regard.
2. Careful attention should be paid to the needs of the intended target user group(s) through: 1) matching the proposed technology appropriately with the user, and 2) gathering input from a broad spectrum of potential users when performing a DSS requirements analysis.
3. Simpler tools or database information generated from simulation analyses of alternative management options may have been more appropriate for delivery to producers and consultants (who do not have time to learn and use DSS tools).
4. The capability to rapidly update major components (e.g., simulation model, databases) in order to address different farm/ranch management questions or problems is an absolute necessity - the ASRU has recently developed an Object Modeling System (OMS) for this purpose. In addition, an appropriate compromise between scientific rigor and simplicity is essential for critical DSS components to ensure overall quality of the product (e.g., crop and forage simulation model response to environmental stresses; N and water balance response to management).
5. Initial component design is critical since new features and modifications are often requested well into the development phase. For example, rigorous integration of the range component was not considered in the initial design blueprint and the simulation framework could not easily accommodate this addition.
6. A complex DSS such as GPFARM may be more useful as a heuristic tool, primarily used by scientists and technology transfer personnel for demonstrating to farmers and ranchers the probable response of agricultural systems to various alternative management options.

REFERENCES

Andales, A.A., L.R. Ahuja, and G.A. Peterson, Evaluation of GPFARM for Dryland cropping systems in eastern Colorado, *Agronomy Journal* 95:1510-1524, 2003.

Ascough II, J.C., D.L. Hoag, W.M. Frasier, and G.S. McMaster, Computer use in agriculture: an analysis of Great Plains producers, *Computers and Electronics in Agriculture* 23:189-204, 1999.

Ascough II, J.C., G.S. McMaster, A.A. Andales, N.C. Hansen, and L.A. Sherrod, Evaluating GPFARM crop growth, soil water, and soil nitrogen components for Colorado dryland locations, *Transactions ASABE* 50(5):1565-1578, 2007.

Frasier, W.M., D.L. Hoag, and J.C. Ascough II, Computer use in agriculture: opportunities for farm advisors, *J. Am. Soc. Farm Man. Rural App.* 61:50-54, 1997.

McMaster, G.S., J.C. Ascough II, G.H. Dunn, M.A. Weltz, M.J. Shaffer, D. Palic, B.C. Vandenberg, P.N.S. Bartling, D. Edmunds, D.L. Hoag, and L.R. Ahuja, Application and testing of GPFARM: A farm and ranch decision support system for evaluating economic and environmental sustainability of agricultural enterprises, *Acta Horticulturae* 593:171-177, 2002.

McMaster, G.S., J.C. Ascough II, M.J. Shaffer, L.A. Deer-Ascough, P.F. Byrne, D.C. Nielsen, D.C., S.D. Haley, A.A. Andales, and G.H. Dunn, GPFARM plant model parameters: Complications of varieties and the genotype x environment interaction in wheat, *Trans. ASAE* 46(5):1337-1346, 2003.

McCown, R.L, Changing systems for supporting farmers' decisions: problems, paradigms, and prospects, *Agricultural Systems* 74(2002):179-220, 2002.

Peterson, G.A., D.G. Westfall, and C.V. Cole, Agroecosystem approach to soil and crop management research, *Soil Sci. Soc. Am. J.* 57:1354-1360, 1993.

Rogers, E.M., *Diffusion of Innovations* (5th Edition), Free Press (Division of Simon&Schuster), New York, NY, 512 pp., 2003.