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Participatory modeling in dairy farm systems: a method for building consensual environmental sustainability using seasonal climate forecasts

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Abstract Dairy farmers face increasing pressure to decrease environmental impact while remaining economically viable. Adaptation of farm management practices in response to seasonal climate forecasts may be one means of achieving these objectives. This paper describes the interactive and iterative process by which farmers, researchers, extension agents, regulatory agencies, and other stakeholders collaborated to create, calibrate, and validate the Dynamic North Florida Dairy Farm model (DyNoFlo), a whole-farm decision support system to decrease nitrogen leaching while maintaining profitability under variable climate conditions. Participatory modeling may enhance the creation of adoptable and adaptable user-friendly models that include environmental, economic and biophysical components. By providing farmers, policy makers, and other stakeholders with a more holistic view of current practices, common ground among them was more easily identified and collaboration was fostered. Farmer values included willingness to be good environmental stewards when they are profitable. The participatory research and development process enhanced understanding of and potential adaptation to seasonal climate variability conditioned to the El Niño Southern Oscillation (ENSO) phases in light of increasing environmental regulations and economic challenges. Adoption of the collaboratively-developed DyNoFlo is expected to be higher than usual because stakeholders feel greater ownership of the final product.

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1 The need for participatory modeling that includes climate variability

Seasonal climate forecasting has the potential to increase preparedness and lead to better social, economic and environmental outcomes. Adoption of this technology, however, is one addition to an already complex package of risk management tools available (Meinke and Stone 2005). To incorporate climate information more effectively into the decision-making process Meinke and Stone (2005) suggest a participatory, cross-disciplinary research approach that brings together different institutions, disciplines, and people as partners in a learning process to develop mental models and methods that will allow stakeholders to better capture benefits of climate forecasts. We describe such a process.

Little effort has been invested to describe the process of stakeholder interaction and participatory modeling that should increase adoption of models among end users (Meinke and Stone 2005). Many models never become tools used by stakeholders because they do not adequately meet their felt needs and because they are not user friendly. An important change required in model development is intensive and effective participation of all stakeholders (Stoorvogel et al. 2004). This study highlights interactions with stakeholders in a learning process involving multiple feedback loops that will likely increase adoption.

Traditional analytical methods including quantitative modeling, rational planning, economic analysis, and operational research used for complex societal and policy problems have not always been helpful because of the absence of stakeholder participation, the inclusion of social and economic impacts, and empirical data (Stoorvogel et al. 2004; Jones et al. 1997; Rosenhead 1989). One efficient way to elicit up-to-date and high quality empirical data is through stakeholder interaction. During the 1980s, systems analysts realized that much of the understanding of a problem is generated in the process of model building. The participation of potential users enables researchers to enrich the models by including subjective sources of knowledge in addition to the objective knowledge derived from theories and empirical studies (Geurtz and Joldersma 2001; Geurtz and Vennix 1989; Verburgh 1994). Systems approaches at the farm scale must include not only the biophysical component, but also the social, economic, and political environment of the farm, together with a 'bottom-up' approach (Jones et al. 1997). A 'bottom-up' approach is understood here as the participation of all the grass root stakeholders in the whole process of addressing and meeting the needs of local communities. Benefits of involving farmers in research to encourage engagement and learning for scientists and farmers are documented (Lightfoot 2003; Paine et al. 2002; Onema et al. 2001; Shaner et al. 1982). This framework holds true for climate research in farming systems.

Developments in simulation modeling methods show a shift from a uni-central, analytic, scientific approach to a more multi-central and interactive stakeholder approach. Participatory Rural Appraisal (PRA) methods describe a growing family of approaches and methods to enable local people to share, enhance and analyze their knowledge of life and conditions, to plan and to act (Chambers 1994). PRA has sources in participatory action research, agro-ecosystem analysis, applied anthropology, and field research on farming systems. Farming system research advocates for interdisciplinary and participatory approaches to deal with farm scale simulations (Norman and Collison 1985).

Connectivity and dialogue among key players is essential for achieving relevant and significant intervention in farm management. In this sense, the dialogue around the simulation process could be as important as the underpinning models. The literature provides examples of these approaches and emphasizes that they are not about science simply providing the answers for management to practitioners, but rather employing cooperative learning to develop solutions (Nelson et al. 2002, Meinke and Stone 2005).

Direct participatory action research with farmers helps to establish credibility of models and simulation analyses (Meinke et al. 2001; Hammer et al. 2000; Keating and McCown 2001; Nelson et al. 2002; Robertson et al. 2000). If model simulation software is created for farmers, extension agents, and farm advisers, it should be designed to be user friendly and to require minimum data inputs. It is not only important that the model be able to predict what is required, but also to make the predictions quickly and easily, in a readily accessible form, for site-specific conditions, in real time (Archer et al. 2002; Cabrera et al. 2005). The link between participatory agricultural system modeling and stakeholder participation in climate research for farm management is of great interest in this research. Understanding and following stakeholder networks leads to the use of existing opportunities and ex ante insights into constraints to the adoption of climate forecast information for agricultural systems management adjustments (Ziervogel and Downing 2004).

Everett Rogers argues that any adoption process requires: knowledge of the existence of an innovation, persuasion of the value of the innovation, decision to adopt the innovation, implementation of the innovation, and confirmation of the adoption. This process develops over time following a typical s-shaped curve in which innovators and early adopters start the process, followed by early and late majorities, after which a group of people called the laggards finalize the adoption process (Rogers 2003). Participatory methods empower people to switch roles to become innovation diffusers early on in the diffusion process, so the risk of adoption failure is substantially reduced and the speed of the adoption proceeds faster (Chambers 1994).

North Florida's climate is highly affected by El Niño Southern Oscillation (ENSO) (Hansen et al. 1999; Jones et al. 1999). Because agriculture is one of the most vulnerable activities to climate variability, farmers should be able to benefit from new methods of seasonal climate forecasts connected to system simulation models to tailor management options regarding agricultural, economic, and environmental outputs (Jagtap et al. 2002; Hansen 2002a). Dairy production in North Florida is a very intensive system. Intensive technologies offer a broad range of options for adaptive responses to climate information (Hammer et al. 2000). The Southeastern Climate Consortium (secc.coaps.fsu.edu) was created as an interdisciplinary, multi-institutional partnership involving researchers from six universities in Florida, Georgia and Alabama with the aim of decreasing farm risks by using climate information. The research group found that it is critical to involve stakeholders actively from the beginning of a process to understand the effects of climate variability on agriculture and resource management. Agencies with strong established relationships and trust with end users must be engaged to improve the delivery of operational applications of climate information to final users (Jagtap et al. 2002). One such application to emerge is DyNoFlo, a dairy decision support system (DSS) whose development process is the subject of this paper.

The mathematics of the DyNoFlo decision support system can be found in Cabrera et al. (2006b) and Cabrera et al. (2005). The main aim of this paper is to describe the process of collaborative creation of DyNoFlo, a regional dairy farm decision support system with a strong seasonal climate component. The study was undertaken in North Florida's Suwannee River Basin, covering Alachua, Gilchrist, Levy, Lafayette, and Suwannee counties. The purpose of DyNoFlo is to tailor dairy farm adaptive management strategies for different climate conditions to decrease environmental impacts while maintaining profitability.

2 Participatory modeling methodology

An interactive and dynamic stakeholder (including researchers) process was used to create DyNoFlo. Figure 1 shows the conceptual framework of participatory modeling shaped

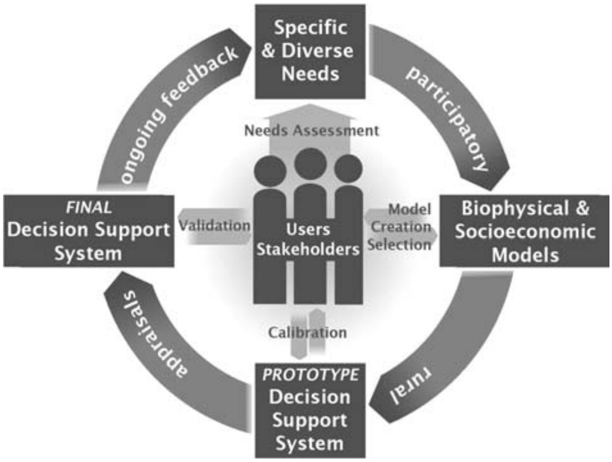

Fig. 1 Methodology of participatory modeling

during this study. All those involved in the issue of nitrogen pollution in groundwater by dairy farms are referred to as "users" or "stakeholders." Figure 1 shows a continuous participatory learning process among stakeholders to create useful simulation models and from them a decision support system. The "Final" decision support system is a relative term in Fig. 1 because it is a current, interim decision support system that can always be improved as new socioeconomic and climatic situations arise. The framework implies a continuum of participatory work and feedback loops starting with needs identification and ending with the validation of the DyNoFlo decision support system. When participatory methods are used in model building, validation occurs when researchers and stakeholders agree the model fits real or measured conditions adequately. The framework emphasizes the importance of the process, rather than the final product.

First, diverse users with their specific and wide ranging needs were identified and their differences recognized. In Fig. 1, the various arrows indicate diverse users with wide ranging needs engaged in an interactive and dynamic process with the researchers to identify those felt needs that must be incorporated into the modeling effort. The next step included the identification of extant models and the new models required. A two-way loop between researchers and stakeholders to select and create biophysical and socioeconomic models initiated a highly interactive process in which users' preferences and requirements were incorporated with researchers' expertise and experience.

Inclusion of prototype decision support systems in the next step was useful because it translated abstract ideas into a concrete – though unfinished – product. A continuously modified prototype decision support system was used as the principal tool for discussion between researchers and other stakeholders during multiple interactions in order to better capture the real situation. This can be described as on-going participatory calibration. The goal of the interactive process was to create a product flexible enough to fit the diversity of most final users.

2.1 Model building procedures

Following is a description of the participatory modeling methodology. A summary of interactions with stakeholders and their contributions incorporated in this modeling exercise are shown in Table 1.

Table 1 Interactions with stakeholder and their incorporated contributions

Month and year	Interaction format	Participants/ stakeholders	Contributions incorporated
Jul 2002	Interaction	3 Univ. Florida, 1 Univ. Georgia scientists	Use soil series data. Use DSSAT
Aug 2002	Interview	1 farm manager	Climate important for crop yields and N leaching
Sep2002	Interview	3 soil scientists	Participate in sample collections
Sep–Oct 2002	Interviews	3 farmers	Involve other farmers
Nov 2002	1st focus group	6 stakeholders	Use 20-farm sample. One-hour limit to interviews
Nov 2002	Dairy farm visit	1 farmer	Main components of a dairy farm
Nov 2002	Interaction	1 Univ. Florida scientist	Use GIS maps to select dairy soil types
Jan 2003	Interaction	1 Univ. Florida scientist	Request hydrological Suwannee information
Jan–Feb 2003	Rapid rural survey or *Sondeo*	13 stakeholders including 2 farmers	Take heterogeneity of farm sizes and types into account. Use model to test economic feasibility of BMPs
Feb 2003	Dairy farm visit	3 farmers	Diversity stressed
Feb 2003	2nd focus group	8 stakeholders	ENSO deterministic outputs requested
Feb 2003	Interaction	1 SRWMD scientist	Request Suwannee N pollution data
Mar2003	Meeting with private consulting company	2 consultants	Importance of crop models, economic module and climate component
Mar 2003	3rd focus group	3 scientists from NRCS, USDA	WATNUTFL offered as model and data
Mar 2003	Private consulting company	2 consultants	Waste management and experimental data provided
Mar 2003	Crop consultant	1 consultant	Request crop/N data on dairy
May 2003	4th focus group	6 stakeholders	Improve visuals. Slow down runs. Use color. Follow herd flow
Jul 2003	5th focus group	7 stakeholders, including 2 farmers	Adjust replacement and freshening coefficients. Raise heifers off farm. Reduce prices. Use deterministic prices as well. Include more crop sequences
Aug 2003	6th focus group	5 stakeholders, including 1 farmer	Include more crop rotations
Sep 2003	7th focus group	8 stakeholders, including 5 farmers	Include all spray fields. Create a variable to input nitrogen data
Sep 2003	Meeting	1 climate specialist	Refined use of DSSAT with daily weather data
Sep 2003	Meeting	2 dairy specialists	Importance of user friendliness
Oct 2003	Interaction	2 Univ. Florida specialists	Calibration of crop models on lab
Oct 2003–Jan 2004	Meetings	Farmers	Outputs in tables and graphs. All coefficients calibrated
Feb 2004	Interaction	2 Univ. Florida specialists	Statistical analyses and calibration of DyNoFlo outcomes

Table 1 (continued)

Month and year	Interaction format	Participants/ stakeholders	Contributions incorporated
Feb 2004	8th focus group	8 stakeholders, including 3 farmers	Keep model in Excel. Keep model user friendly. Use Markov chains herd-flow model. Include optimization module

BMPs Best Management Practices, *DSSAT* Decision Support System for Agrotechnology Transfer, *DyNoFlo* Dynamic North Florida Dairy Farm Decision Support System, *ENSO* El Niño Southern Oscillation, *GIS* Geographic Information System, *NRCS* Natural Resource Conservation Service, *SRWMD* Suwannee River Water Management District, *USDA* US Department of Agriculture, *WATNUTFL* Water Nutrient for Florida Software

2.1.1 Needs assessment: specific and diverse needs

Specialists in forages for dairy farms, dairy waste management, soils, and crop modeling were individually approached for specific information and ideas about using simulation techniques to reduce environmental impacts of North Florida dairy farms under varying climate conditions. Through interaction with these stakeholders, we learned that most soil series in Florida required for a modeling effort were available and were contained in a database that could be accessible to use in later phases of the research. Also, the current system of crop models contained in the Decision Support System for Agricultural Transfer (DSSAT) (Jones et al. 2003) was ideal to use in the research for the estimation of nitrogen leaching according to climate variability. Furthermore, the research was timely in that a growing body of research related to environmental issues and dairy farms in North Florida was emerging. The study could take advantage of, for example, annual reports on water quality from the Suwannee River Water Management District (SRWMD), basin status report from the Department of Environmental Protection, water resources investigation series from the US Geological Service, water quality assessments from the Environmental Protection Agency, and studies on natural resource management from the Natural Resource and Conservation Service, NRCS. Also, important contact information with end users and other stakeholder networks was obtained that would be needed in the following research steps.

Two key issues were revealed in exploratory interviews. Sensitivity of dairy farmers to the issue of nitrogen pollution and the need for alternative ways to estimate environmental accountability of dairy farms was important. Also, climate variability was perceived to have little effect on livestock performance but a very high impact on forage yields and on potential nitrogen release to the environment from those fields.

To engage existing research networks, we contacted soil scientists working in the study area on a project regarding nitrogen pollution from farm activities, including dairy farms (Florida Department of Environmental Protection 2001). These scientists provided further contacts (the beginnings of a snowball sample) and references to add to the research. Suggestions from these contacts also led to one-day field visits and participation in the collection of soil and water samples.

Next, stakeholders including members of the Suwannee River Partnership (SRP), agents from the Florida Cooperative Extension Service (FLCES), and dairy farmers were contacted to involve them in the research project. Farmers whose farms were located in the heart of the study area, the middle Suwannee River Basin, were more receptive to the research idea because they face increasing regulation pressure due to higher environmental degradation in this area. During this first contact a brief oral presentation was given and a short flyer of research intentions was handed to each stakeholder present. The general reaction on the part of stakeholders was "let us begin and involve more stakeholders so we can all better understand the project and define further steps."

A first focus group (Stewart and Shamdasani 1990) was convened in the SRWMD with six attendees. These included members of the SRWMD, the SRP, and the FLCES. This meeting was critical to understand the interests of all sides in the project and to guide the direction of the study. It was agreed that there were commonalities between our proposed research and work currently underway within the SRP. Interest existed in supporting our research and in benefiting from its outputs. Specifically, the group committed to contacting farmers and encouraging them to participate in the research. It was agreed that a purposive sample of 20 farms (out of 64 in the area) would be sufficient to cover diversity present in these systems. All stakeholders agreed that the main researcher should prepare a short document explaining the potential outcomes of the research together with a list of topics to be included in future surveys. Topics could be sent to farmers ahead of time in order to gain insights even before the interviews were conducted. A time limit of 1 h for interviews was established because dairy farmers "are really busy people and they don't have much time." The protection of the anonymity of participants was set forth as a must because the nitrate issue is very sensitive. Neither farmers nor their management practices regarding estimations of waste should be identified in the work. Dairy farms were visited to understand activities that are dynamically occurring in the system and that can be represented by simulation models. Owners highlighted the fact that most farms were following environmentally friendly practices (or Best Management Practices, BMPs) suggested by regulatory agencies under incentive-based programs.

A *sondeo* (Hildebrand 1981) or rapid rural survey showed that adopting BMPs may help farmers remain in business (Alvira et al. 2003). However, initial investment in BMPs, even though costs could be shared with official agencies, can be cumbersome (DEP 2001; Ribaudo et al. 2003). Therefore, it is important that proposed practices to protect the environment be cost effective taking into account that dairy farmers will first look for survival strategies and then for good stewardship just as any other business. It was recognized that BMPs can better reach cost effectiveness when a climatic component is associated with them. This last statement had great implications in the modeling process since the economic outputs of the whole farm would be vital in determining which of the BMP practices a North Florida dairy could implement. It was agreed that the decision support system to be developed must have an important economic component and this component must be taken into consideration for potential proposed practices along with seasonal climatic variations.

The SRP was formed in 1999 to determine the sources of nitrogen loads in the basin, and to work with local producers to minimize future nutrient loading through voluntary, incentive-based programs. The SRP works under a non-regulatory, preventive approach, through monitoring pollution, education, promotion, and adoption of BMPs (FLDEP 2001). Those BMPs developed by the SRP group include nutrient and manure management, irrigation, technical design and engineering aspects in dairy farming (Suwannee River Partnership, 2004). Stakeholders see BMPs as research generated solutions to reduce potential environmental hazards from farm enterprises. Farmers expressed that they care for the environment and are generally willing to do their part to reduce the portion of nitrogen emanating from their farms. Simulation could reproduce farm conditions and test the environmental and economic impacts of intervention without risking the normal functioning of a farm and adding the climatic component. Outputs from simulations could be used to verify technical viability of BMPs before their implementation. Also, the simulation has to be performed in a way that incorporates diversity of farms and allows for individual farm economic and environmental analyses as complete and separate units.

2.1.2 Model creation and selection: farm, climate, and economics

To initiate the actual model-building process three dairy farms in the study area were visited. All dairies had a livestock component, forage fields, feed facilities, and some means of disposing of waste produced by confined cows. Some differences existed on specifics, e.g., some farms did not raise heifers (young females) or some farms grew more forage crops than others. Nevertheless, it was believed that common components could be found in order to represent all North Florida diaries in one general model that could be adjusted for any specific farm. Farmers noted “although dairy farms can be very different, they all have common components.”

To enrich model building, another focus group was convened. In it, a deeper discussion on the climate component was conducted. Key stakeholders attending the meeting felt that uncertainty and low accuracy in seasonal climate forecasts could create problems in the models. Researchers proposed that a way to handle uncertainty and low skill forecasts would be to present results in a probabilistic way. It was argued that not all El Niño years for example are of the same intensity. A distribution of results instead of just one discrete outcome would better capture the uncertainty. Farmers argued that it was important to be careful not to further complicate existing uncertainty. They warned that excessive model complexity would cause farmers to lose interest. Farmers requested that results be provided in the simplest possible way. It was agreed that deterministic results would be the default model output, but an option to also see the distributions should be available. Also, it was agreed that if for example an El Niño phase is anticipated, the model should present the results for an average El Niño year. Additionally, an option to present results for average La Niña or for Neutral years should also be available. Following up on this discussion a producer proposed that a probability distribution should be applied to milk prices in the economic portion of the model. Farmers clearly understood that there is no true factor that explains milk price variations and the variations are in fact stochastic. The DSS should take this fact into account.

Another important point that emerged was that the participants better understood the research idea and found similarities between it and the “nutrient balance” approach that the NRCS has been using for planning environmental accountability (NRCS 2001). The NRCS was invited to become involved with the research project and to actively participate in order to avoid duplication of efforts. Additionally user friendliness of the model was emphasized as being extremely important. Again, stakeholders reminded the researchers that the DSS must be easily adaptable to different farms because no two dairy farms are exactly alike. One stakeholder, supported by all others including the main researcher, suggested that a “prototype” DSS be created to clearly show what was intended to be accomplished. The idea was to have a prototype to use as a tool for increasing farmer and other stakeholder involvement and feedback. The DSS would be shaped and molded through further stakeholder interaction.

Finally, farmers encouraged continuation of the research because they were beginning to see how they could benefit from a final product. They mentioned that testing BMPs with the model for their farm would be useful. Large dairy farms that do not usually participate in cost share programs might see the advantage of decreasing potential risk of fines from regulations. Additionally, dairy people were eager to see the economic impacts of any potential management changes.

A meeting with private dairy consultants highlighted three points. These were: details on the incorporation of the climate component, parameters of the economic module, and contact with other networks of stakeholders. The consultants agreed that climate variability would affect dairy farm outputs mostly through its effects on crops. According to their experience, even when crops are irrigated, they respond to rainfall patterns and temperature variability. The incorporation of crop models had potential to take these suggestions into account. Private consultants also mentioned that the inclusion of an economic module might help to gain farmers' attention and eventual adoption of the models. Finally, we learned that the consultants regularly promote and participate in a network of stakeholders on the nutrient issue. An invitation to participate in these meetings was accepted. On a monthly basis meetings were held and novel aspects of the nutrient problem and dairy farms were discussed. Again, this iterative process was based on the premise that “any scientific breakthroughs in climate forecasting capabilities are much more likely to have an immediate and positive impact if they are conducted and delivered within a participatory framework” (Meinke and Stone 2005). Private consultants provided large datasets with detailed information of several years of experiments on a dairy farm in the study area. The experiments dealt with waste handling and crop systems. This information had not been published and was delivered under the consent of the dairy owner.

Another focus group was convened at the US Department of Agriculture NRCS facility in Gainesville, FL. Three professionals agreed that the research was relevant even though a similar product, The WATNUTFL software (NRCS 2001) or Worksheets for Water Budget and Nutrient Management, already existed. They clearly understood that the research was going beyond the WATNUTFL application because it would have dynamic, economic, and mostly climatic components that are not included in WATNUTFL. The NRCS researchers expressed their willingness to work and provided literature as well as the WATNUTFL v 2.0 software for use as a baseline in the modeling process.

2.1.3 Calibration: prototype decision support system

The prototype DyNoFlo (Cabrera and Hildebrand 2004) containing prototype modules of livestock, nutrient, crops, climate, and economics was presented for the first time during another focus group discussion. Specialists, extension agents, and technicians proposed selected improvements to the application. In addition, the prototype DyNoFlo was also presented at one local, one regional, and one international scientific meetings to elicit feedback from peers. Feedback received during these meetings helped to narrow down the selection of models to be integrated into the final DSS.

An improved prototype model was presented and explained to four farmers, two extension agents, and one technician in another focus group meeting. A number of unanticipated uses were suggested for the DSS, such as an administrative and accounting tool. One farmer remarked at the end that the prototype DyNoFlo output numbers were “reasonably” good and that he would like to see more and would be glad to work directly in calibrating and validating the final DSS. Many suggestions were collected at this meeting. Among them, adjustments on numbers of replacement cows, seasonality of births, simplification of inputting cow categories, use of real milk invoice prices deterministically, more crop sequences (especially important for climate-based decisions), time on concrete, raising heifers, using multiple breeds, and to include some means to optimize the results.

During the sixth and seventh focus group meetings emphasis was placed on learning more about crop and forage rotations, as these were especially climate sensitive. Participants' main suggestions were to increase crop rotations that they found to be missing, include pasture fields in addition to spray fields, allow easy input of farm-specific data, and incorporate BMPs to reduce N pollution under climate variability.

In a next step DSSAT crop models (Jones et al. 2003) were incorporated in the DSS. These models function with daily weather data. In order to incorporate this component in the DSS, climate would have to be analyzed for a long time series (e.g., 40 years) and results would be classified by ENSO phase (Hansen et al., 1999; O'Brien et al. 1999). Years would be divided into El Niño, La Niña, and Neutral categories.

During a first round of personal interviews (Bernard 1995) with 21 individual farmers, the need to maintain and improve user friendliness of the applications (a user-friendly interface) was highlighted by all. Two farmers interviewed mentioned that they would use the model as a complement to tools they already used for their nutrient balance (they were using tools described in Van Horn et al. 1998 and NRCS 2001). Opinions regarding the use of climate information to adjust management strategies were split. About 67% of interviewees believed that they could proactively use climate variability information to decrease nitrogen leaching or to increase profitability. Farmers who favored the use of climate forecasts were inclined to include it as a user choice option (Cabrera et al., 2006a). The interviews were very useful for sensitivity analysis and calibration of the Prototype DyNoFlo as the DSS was run for specific conditions on various farms.

3 End product: the DyNoFlo decision support system

A new DSS was built taking into account all previous suggestions of stakeholders and the experience with the prototype. Five main components were new and all the others were completely revisited. The new components were: a Markov-chain probabilistic simulation of the cows, a climate forecast interface, crop models from DSSAT, an option to select deterministic or stochastic prices, and an optimization linear programming module.

The Markov-chain stochastic simulation of herd-flow was the researchers' response to the request to simulate herd dynamics using only minimal livestock input data and account for real conditions of livestock seasonality. DSSAT crop simulation models were selected because they were the only ones capable of simulating the real conditions of the extensive list of forage systems used on North Florida dairy farms under selected seasonal climate conditions. And the optimization linear programming module met the need of climate forecast-based decision making.

The process of completion of the final DyNoFlo did not end the participation process; rather, interaction continued as actively as during previous phases. Farmers suggested that a forage crop specialist should be incorporated in the discussions because they felt this component was still missing the characteristics of several forage sequences. Because of their sensitivity to climate variability, these were precisely defined after meetings with the specialist, including tillage sequences, intercropping options, and harvest choices.

Intense work on climate and crop models started in order to incorporate them into the main shield of the DyNoFlo DSS. Because of the detailed nature intrinsic to this work, more specialists were contacted for feedback at this time. Input was received not only for the specific crop models or climate components, but also for the whole simulation approach. During these exchanges, feedback loops were incorporated into the model. A specialist on DSSAT crop simulation models validated the main results before they were incorporated into the main DyNoFlo shield.

Eight stakeholders participated in the eighth focus group. The meeting was a discussion of the final DyNoFlo model (Cabrera et al. 2005, 2006b). Attendants tested and were satisfied with the DyNoFlo performance. All appreciated the reduced need for initial data to start runs. Farmers also approved the improved user-friendly interface, and the integration of models into a simple decision support system. Stakeholders appreciated the possibilities of selecting management options, especially ENSO phase-sensitive crop rotations.

The ultimate validation of the DyNoFlo was through a second round of individual interactions with four farmers who had not previously participated in model development. Selected parameters of milk production, principal crop yields, herd cow-flow, and farm profitability were used to compare simulation outputs with farm records. These parameters were selected because they are readily available in dairy operations. Producers confidentially compared outputs from the model with their own farms and they all agreed that the similarity of the outputs to their own records gave them confidence that the model worked correctly. They all expressed willingness to use the model in their management strategies.

4 Discussion and lessons learned

In a comprehensive analysis of limitations to generalization and adoption of climate forecasts and applications, Sivakumar (2006) listed several adoption barriers based on works of Stern and Easterling (1999); Nicholls (2000); Phillips et al (2001); Hansen (2002b); and Palmer (2005): (a) user inappropriate content, (b) complexity of systems where forecasts are intended to be used, (c) communication problems, (d) need of information for specific events, and (e) need of downscaling climate models and upscaling application models. Based on these limiting factors, Sivakumar (2006) proposed a series of considerations to improve the quality and use of climate applications: (a) include direct feedback from the agricultural community and other stakeholders; (b) promote a four-way communication among climate forecasters, agro-meteorologists, agricultural researchers, and the agricultural extension community; (c) deliver the right information to the right audience; and (d) involve social scientists in the whole process.

The participatory methods used in this study overcame most of the barriers cited above and included each of the proposed considerations to improve the use of climate applications. End users were involved from the start of the project and open dialogue among all the actors, including social scientists, was always pursued. Consequently, we believe we understood the complexity of the problem and addressed the right information content in the decision support system created. Although opportunities exist to upscale our decision support system to larger regional areas and transfer our methodology to other regions, some issues on adoption of climate applications are beyond the scope of our framework such as increasing the use of forecasts for specific events or the implementation of downscaled forecasts.

We propose to add one more item to the Sivakumar (2006) list of considerations to improve climate applications: "create a sense of ownership." We have found that the greatest supporters, pioneers and leaders in accepting our application, have been those ones who have seen their inputs represented in the DyNoFlo application.

Roncoli (2006) believes stakeholder participation and partnerships are essential to developing relevant climate applications, but they may introduce biases. Roncoli (2006) proposes, and we agree, that PRA and the emphasized dialogue between farmers and researchers should be combined with other comparative and complementary methodologies to ensure consistency and integrity in the whole process. All actors in the process, including researchers, are equally stakeholders and should be equally listened.

The Southeast Climate Consortium (SECC), a Regional Integrated Science and Assessment (RISA) project overseen and funded by the National Oceanographic and Atmospheric Administration (NOAA), is a research and outreach group whose mission is to create and disseminate climate forecast knowledge for societal benefit. The SECC, made up of researchers from six universities, aside from meteorologists and climatologists, includes a social science team in charge of bridging the gap between climate scientists and natural resource managers. These scientists – anthropologists, economists, interdisciplinary ecologists – continually elicit feedback from end users to co-develop, design, and improve forecast applications. Participatory modeling for climate applications holds a great promise for future work but requires interdisciplinary teams to embrace the greater complexity among human, natural resource management, and climate systems.

As an additional note, the "field work" presented in this paper is not always attractive to all scientists because it may be considered a time-consuming activity that in addition requires a special personality to engage stakeholders. However, we have found in our experience that the effective use of interdisciplinary teams may overcome these issues.

5 Summary, conclusions, and recommendations

Participatory modeling has the potential to enhance the creation of adoptable and adaptable user friendly decision support systems that include environmental, economic and biophysical components. Multiple feedback loops with a broad range of stakeholders, both institutional and individuals were used during a two year process of interaction with stakeholders to create the Dynamic North Florida (DyNoFlo) decision support system, which is intended to be a tool to help farmers to pursue ecologic safety and economic sustainability under seasonal climate variability. A highly interactive process involving selection and creation of models, construction of a prototype, and improvements of the prototype into the DyNoFlo DSS, yielded a collaboratively created tool. Many adjustments were made to coefficients and parameters originally obtained from secondary data. Expert advice was incorporated from specialists in the government, private, extension, university and production sectors, following suggestions made by farmers.

The reality of using secondary information as a starting point and then calibrating and validating "in the field" has especially strong implications for adoption and long term use of models that include climate forecasts (Meinke and Stone 2005). A feeling of ownership was created in stakeholders by listening attentively to all their suggestions. An especially strong interaction among farmers, extension agents, and modelers occurred during the calibration and validation processes. Modelers and farmers were able to backtrack into the model to adjust coefficients that were deemed possibly to be skewing results. Producers expressed reasonable ranges within which model parameters should be confined. Through this process of model transparency, each farmer felt included in contributing to the success of the final DyNoFlo DSS.

Climate variability was especially relevant as a problem considered by all members during many meetings. In the past, it had been rather difficult to get extension agents and producers "to buy into" the idea that management can be tailored to seasonal climate forecasts based on ENSO phenomena. By working together on the models and incorporating long series of rainfall and temperature data for different ENSO phases, producers were able to understand the effects of seasonal variability on production and nitrogen leaching. Understanding the climate-nitrate interaction through model development was expected to greatly increase the probability of proactive use of climate information to mitigate negative environmental impacts, while watching profits.

After undergoing an arduous but fruitful stakeholder interaction process to develop the DyNoFlo DSS, the following is recommended as a procedure for participatory modeling. Initial contacts should be made with local producers and other stakeholders to identify felt needs. If models are useful for addressing the felt needs, models that best address the problem should be identified or created. Later, a prototype DSS should be developed using secondary data. The prototype model should be thoroughly discussed using participatory rural appraisal methods with stakeholders. Farmers, private consultants, extension agents, officials from government agencies, and university faculty, among others, should be included in the modeling process. Researchers should elicit comments on structure and function of systems, coefficients, parameters, and individual modules from stakeholders. After adjustments to the prototype, a final DSS should be developed and taken back to the stakeholders for validation.

In order to ensure long term adoption, good science must be used to respond to specific concerns of stakeholders. Farmers want to be good environmental stewards, but they need to remain profitable. When farmers say “profit is the bottom line,” an economic component must be an essential DSS component. When farmers or consultants suggest that crops will be highly affected by climate variability, researchers should respond by using state of the art crop models such as DSSAT. When producers call for a user friendly and simple interface, modelers should respond by creating an interface that is usable from the farmers' points of view. By following these relatively simple steps, which are not always in the mindset of scientists, use of climate-based agriculture and natural resource decision support systems can be greatly improved.

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