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P. Heilman

R. W. Malone

L. Mac

Jerry L. Hatfield

L.R. Ahuja

See next page for additional authors

Presenter/Author Information
P. Heilman, R. W. Malone, L. Mac, Jerry L. Hatfield, L.R. Ahuja, J. Ayen, K. Boyle, and R. Kanwar

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P. Heilman[a], R. W. Malone[b], L. Ma[c], J. L. Hatfield[b], L. R. Ahuja[c], J. Ayen[d], K. Boyle[e], and R. Kanwar[f]

[a] *Southwest Watershed Research Center, USDA-ARS, 2000 E. Allen Rd., Tucson, AZ 85719*

[b]*National Soil Tilth Laboratory, USDA-ARS, Ames, IA*

[c]*Great Plains Systems Research Unit, USDA-ARS, Fort Collins, CO*

[d]*Iowa State Office, USDA-NRCS, Des Moines, IA*

[e]*West National Technology Support Center, USDA-NRCS, Portland, OR*

[f]*Iowa State University, Ames, IA*

Abstract: Farmers will adopt alternative management systems to improve water quality more readily if they understand how those management alternatives affect the release of contaminants, crop yields, and ultimately, their net income. We propose a method to address these issues by integrating observed data from field experiments, a comprehensive simulation model, review by local experts, and application through a decision support system by technically trained conservationists. An example for reducing nitrogen loading from tile-drained corn and soybean production in Iowa demonstrates the approach. Fourteen years of observed data from 30 research plots on the Northeast Research and Demonstration Farm near Nashua, Iowa were used to calibrate the Root Zone Water Quality Model (RZWQM) to simulate the effects of 35 management systems on crop yields and nitrogen (N) loadings into tile drains. The EconDocs tool was used for an economic analysis of the management effects. An Expert Panel reviews the simulations and the long term average annual management effects. Those management effects, as well as the daily values of variables that describe the crop growth and nitrogen loading in tile flow processes, are put into a database. As part of the conservation planning process, Conservationists and farmers would use the database inside a decision support system to select management systems that meet the farmers' goals and reduce water quality problems.

Keywords: Nitrogen management; water quality; decision support; modelling

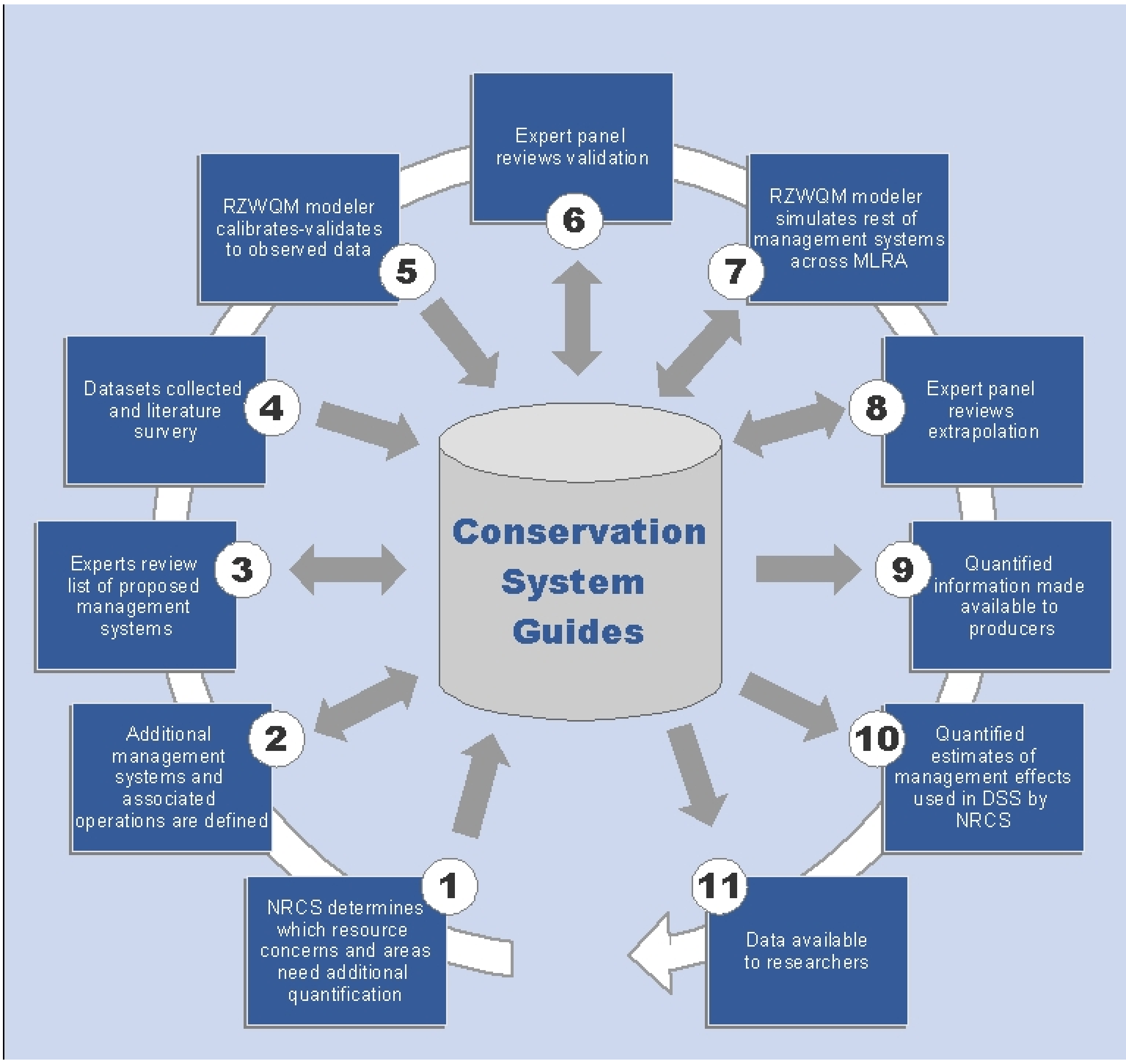
1. INTRODUCTION

Improved management of nitrogen in agriculture is needed to meet national water quality goals. According to the USEPA (2006), over 4,000 water bodies in the U.S. are considered impaired because of nitrogen, which is over 12% of the nation's impaired waters. Negative effects from excessive nitrogen include potential health risks, increased water treatment costs, eutrophic conditions in ponds and lakes, and hypoxic conditions in the Gulf of Mexico. In addition, there is growing concern that significant ecological change could result from increasing the availability of nitrogen in many systems that had previously been nitrogen limited (Ecological Society of America, 1997).

Nitrogen, as a nonpoint source pollution problem, is difficult to address because of its spatially diffuse nature, the fact that nitrogen is invisible, and the overall difficulty in quantifying loadings. This paper presents an approach to quantifying management effects on both farm income and N loadings from agriculture. The approach quantifies management effects across a large area by using a team to systematically apply the best available observed data and expert opinion, as well as knowledge embedded in simulation models. The end result is a database populated for conservation planning and technical support by the Natural Resources Conservation Service (NRCS).

2. OVERALL APPROACH

Parts of this approach and its justification have been addressed previously, in Hatfield et al. (1999) and Heilman et al. (2002b). Figure 1 shows the overall process for quantifying management



system effects on water quality. The potential benefit of this approach is that better science could be

Figure 1. The proposed process to populate a database of field scale management system effects on water quality has 11 steps.

provided by taking full advantage of experimental station observed data, simulation models, and expert knowledge. A necessary simplification is the assumption that representative fields can adequately characterize the physical factors affecting N loading, so that a database of results can be populated and used rather than customized simulations for each individual field.

An existing NRCS database called Conservation System Guides could be expanded to store more water quality information. Each guide attempts to quantify the impact of the management systems on the resource concerns (i.e. conservation tillage reduces erosion by 2 tons per acre). A typical system in the Midwest might include conservation tillage, grassed waterways, and conservation crop rotations. The guides are stored in a national database and available on-line. If the current effort is successful, then an effort to systematically populate a similar database across a larger area in the Midwest will be explored. Each of the 11 steps in the proposed process is discussed in more detail below, with the discussion divided into three stages: problem definition, quantification of management effects, and application of the resulting information. For the Nashua case study, steps 1-5 have been completed, as well as portions of remaining steps.

3. PROBLEM DEFINITION

3.1 NRCS determines which resource concerns and areas need additional quantification

In conservation planning the NRCS addresses a long list of resource concerns divided into soil, water, air, plants, animals and human categories, although quantified estimates of management effects are not available for most resources. An efficient method to expand the quantified estimates of management effects is to build on previous work applying the RUSLE2 soil erosion model within Major Land Resource Areas (MLRAs), which are areas with similar climate, soils, management practices, and resource problems. Within a given MLRA, identifying the greatest resource problems will determine the focus of the overall effort.

3.2 Additional management systems and associated operations are defined

Although the approach taken by the NRCS varies by state, in Iowa the RUSLE2 model has already been used to quantify sheet and rill erosion under different management systems for each soil and slope combination. As the focus of those simulations was erosion, management options were primarily alternative crop rotations and tillage methods. Fertilizer applications have been specified, but in general, additional work will be needed to define management systems that address nitrogen management, as well as defining quantities of other agricultural chemicals applied and the machinery needed to apply them. The NRCS would perform the task of defining the soil and slope combinations and management system effects that will need to be quantified.

3.3 Experts review list of proposed management systems

Before investing a lot of time simulating the proposed management systems, an Expert Panel is convened to review the proposed management systems. Current models may not be able to adequately simulate management systems where data or process understanding is lacking. As there is a recognized need to simulate those management systems, model developers may want to add that capability, if possible. On the other hand, there may also be some newer, non-traditional management systems that have the potential to expand rapidly across the landscape, which the Panel may want considered. Steps 1-3 will specify the soil and slope groups, common resource problems and management systems that will define the structure of the database.

4. QUANTIFICATION OF MANAGEMENT EFFECTS

4.1 Datasets collected and literature surveyed

Dinnes et al. (2002) provide a good literature review of management effects on nitrogen from tile-drained fields. In addition to survey papers, the modeler will need to collect data and literature related to management at the experimental site and across the MLRA. Table 1 shows the management systems studied at the Nashua, Iowa Research Farm. Previous research on management effects on nitrogen at Nashua includes Kanwar et al. (1988, 1997) and Bakhsh et al. (2002).

Table 1. Management systems studied at the Northeast Research and Demonstration Farm in Nashua, Iowa: NT is no till; CP is chisel plow; MP is moldboard plow; RT is ridge till; CC is continuous corn; CS is a corn soybean rotation (corn in even years); SC is a soybean corn rotation (corn in odd years); UAN is Urea-Ammonium Nitrate; LSNT is Late Spring Nitrate Test; LCD is Localized Compaction and Doming; and SM is swine manure. Unless otherwise noted, N is only applied to the corn crop.

Treat-ment	Till-age	Rotation	N Form	N Appli-cation Method	Years
1	NT	CC	Anhydrous		90-92
2	NT	CS	Anhydrous		90-93
3	NT	SC	Anhydrous		90-92
4	CP	SC	Anhydrous		90-92
5	CP	CS	Anhydrous		90-93
6	CP	SC	Anhydrous		90-92
7	MP	CC	Anhydrous		90-92
8	MP	CS	Anhydrous		90-92
9	MP	SC	Anhydrous		90-92
10	RT	CC	Anhydrous		90-92
11	RT	CS	Anhydrous		90-92
12	RT	SC	Anhydrous		90-92
13	NT	CS	UAN	LSNT	94-98
14	NT	SC	UAN	LSNT	93-00
15	CP	CS	UAN	LSNT	94-99
16	CP	SC	UAN	LSNT	93-00
17	NT	CS	UAN	Spring Pre-plant	94-99
18	NT	SC	UAN	Spring Pre-plant	94-99
19	CP	CC	UAN	Spring Pre-plant	93-98
20	CP	CS	UAN	Spring Pre- plant	94-03
21	CP	SC	UAN	Spring Pre-plant	93-03
22	CP	CS	UAN	Split LCD	00-03
23	CP	SC	UAN	Split LCD	01-03
24	CP	SC	SM	Fall	93-98
25	CP	CS	SM	Fall	94-03
26	CP	SC	SM	Fall	93-03
27	CP	SC	SM UAN	Fall Spring	99
28	CP	CS	SM UAN	Fall Spring	00-03
29	CP	SC	SM	Fall	00-03

			UAN	Spring	
30	CP	CC	SM Corn and Beans	Fall	00
31	CP	CS	SM Corn and Beans	Fall	01-03
32	CP	SC	SM Corn and Beans	Fall	01-03
33	NT	CS	SM	Spring Preplant	00-03
34	NT	SC	SM	Spring Preplant	01-03
35	CP	CS	SM	Spring Preplant	99-00

4.2 RZWQM modeler calibrates and validates to observed data

The Root Zone Water Quality Model, RZWQM (Ahuja et al., 2000), or another comprehensive simulation model, will then have to be parameterised and calibrated to the observed data, and validated for key output variables. The procedure for validation will have to be developed jointly with the Expert Panel in step 6. Goodness-of-fit tests will be used to assess the ability of the model to simulate important processes.

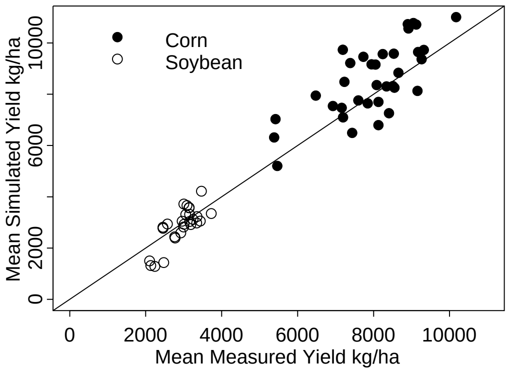


Figure 2. Mean crop yields for each of the management systems studied at Nashua.

We simulated all 35 management systems studied at Nashua for 30 of the 36 plots. The observed and simulated results for all management systems are shown in Figure 2. Some factors that reduce observed yields, such as hail and pest damage, are not represented in RZWQM, so over-prediction of yields, particularly for corn, was expected. The model under-predicted yields when swine manure was used.

Mean annual N loading quantifies the N leaving fields by integrating the effects of calibrated tile flow and simulated N concentration. Figure 3 shows the mean annual N loadings for all 35 management systems, split into corn and soybean years. Except for a few of the high N loading observed systems, the crop does not appear to have a very strong effect on annual concentrations.

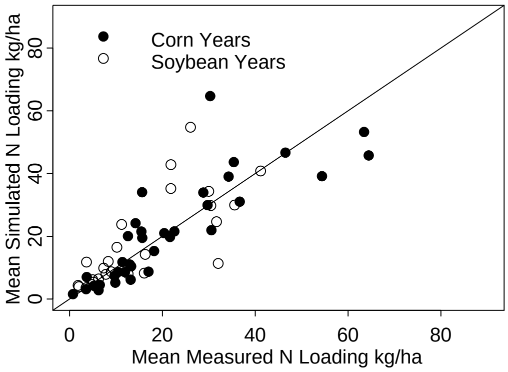


Figure 3. Mean annual N concentrations for both crops and all management systems.

Observed data on N loading and crop yields (Figure 4) indicate that there are a number of management systems with high yields and low N loadings. A number of the most promising systems are from management systems with only a few years of data, so it will be necessary to run RZWQM with a common, long-term climate input dataset to properly compare management systems before determining which systems are preferable.

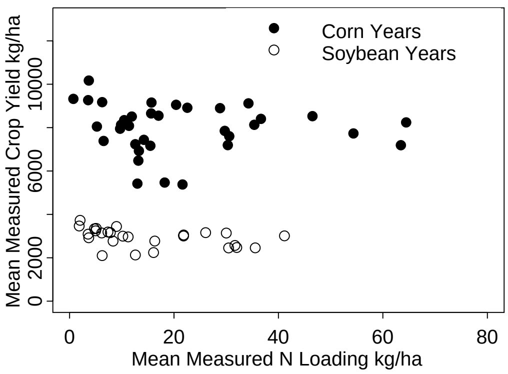


Figure 4. Mean crop yields plotted against mean N loadings for all 35 management systems.

As management systems differ in costs as well as revenues, another necessary step is to develop budgets to properly compare management systems, rather than simply comparing crop yields. EconDocs, an on-line budgeting tool developed by NRCS will be used for this purpose. Results are stored on-line, in XML format, making the data accessible for further manipulation (i.e. using web services). EconDocs also supports cost effectiveness analysis so that potential tradeoffs between emission control costs (i.e. N loading reductions) and farm profitability can be explored. EconDocs can be accessed using the google keyword "EconDocs", or by going to http://ssiapps.sc.egov.usda.gov/EconDocs/.

4.3 Expert panel reviews data

A significant benefit of the proposed approach is the ability of an Expert Panel to systematically assess the quality of the simulation runs. A sequential effort will be used to review the water budgets, crop yields, nitrogen budgets, and economic budgets. The review process (and the remaining steps outlined in Figure 1) have not yet been performed. The Panel could require additional work to parameterize the model, or that certain model components need to be improved. Ultimately, if simulations do not meet agreed upon standards, the simulations would have to be excluded from the Conservation System Guide database.

4.4 RZWQM modeler simulates rest of management systems across MLRA

Assuming that the modeler is able to reproduce much of the observed record, the next step would be to simulate management effects from any remaining systems identified in step 3. Some management systems could be simulated for the same conditions as the experimental site. For most of the MLRA, however, there will be little measured data for comparison, so the same parameterization for the experimental area will be used, although soil parameters and climatic inputs can be varied.

4.5 Expert panel reviews extrapolation

The Expert Panel will check the extrapolated data to ensure that variations across management systems and/or soil textures conform to expected responses. The data should also be in line with other datasets, such as county crop yield averages. Again, after reviewing the simulation results, the Panel will decide to either include the estimates in the Conservation System Guide database, or not.

5. INFORMATION DELIVERY

5.1 Quantified information made available to producers

Summary information from the database will be made available to the public. For example, a producer could zoom in on a map of his farm, select a field, and then be presented with a list of available management systems for yield, economic, and water quality effects for fields with the same soils and slope.

5.2 Quantified estimates of management effects used in DSS by NRCS

More sophisticated tools would be available to the NRCS than the producers, as part of an integrated decision support system for conservation planning. The main contributions would be quantitative estimates to compare management systems, and graphics summarizing simulation results to help explain how management affects water quality.

Given a quality controlled database for representative fields, it would be possible to customize existing runs of the simulation model with site-specific parameters for a particular field if needed. Another option is to use RZWQM to estimate values of reference points and then statistically estimate intermediate values. Tools to support multiobjective decision-making will be needed to select management systems with different economic returns, erosion, and N Loading rates. A previous trial of a multiobjective decision support system by the NRCS in Iowa will provide a basis (Heilman et al., 2004) for a revised DSS for conservation planning. The multiobjective component will be a web-based implementation of the Facilitator, described in Heilman et al. (2002a). More information on the decision support system to support conservation planning can be found at http://www.tucson.ars.ag.gov/dss/.

5.3 Data available to researchers

The data used to calibrate/validate the model, as well as the quality assurance documentation will be available. Researchers may compare the results with those from other models, or against other datasets collected within the MLRA, or against additional data collected at the research sites. The results in the database would be regarded as “state of the science” at the time populated, but could be improved over time, especially as more observed data is collected and the models improved.

6. CONCLUSIONS

A necessary, if not sufficient, condition for addressing water quality problems across predominantly agricultural landscapes is to quantify management effects on both contaminants delivered from fields to the stream system and the cost to producers of realizing the reduction in pollution. Other information relating to fate and transport in the stream system, the potential for mitigating practices in the stream system, etc., will also have to be considered. As management decisions are made at the field scale, information about field scale water quality improvement, and a mechanism for delivering that information in a decision-making context, are needed to adequately address water quality issues.

The idea of using a database of management effects for conservation is not new. However, the development of longer-term datasets, more mature and comprehensive simulation models, and especially the ability to collaborate at a distance make the development of broad scale, quality controlled databases much more feasible than had been the case in the past. Perhaps more importantly, it is also much easier to provide information directly to producers, conservation planners, and other researchers over the internet.

The strength of the proposed approach is the systematic application of available observed data, knowledge embedded in simulation models, and expert opinion during the quality control process. Weaknesses include the need for a substantial initial time investment for both calibration and database population. Alternatives include allowing Conservationists to parameterize simulation models themselves or use simpler screening tools.

Although to date the proposed approach has only been completed through step 5, the effort to extend information from the Nashua Research and Demonstration Farm to northeastern Iowa will provide a test of the feasibility and utility of the approach. Areas with significant nonpoint source water quality problems will then have a stronger basis to decide if the need for quantified management effects justifies the effort required to create a quality assured database of management system effects.

7. ACKNOWLEDGEMENTS

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