ASSESSMENT OF THE WATER QUALITY IMPACTS OF FARMING SYSTEMS BY INTEGRATING DATABASES AND SIMULATION MODELS

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Abstract

Understanding the impact of farming practices on environmental quality requires an integrated approach across different scales. The Management Systems Evaluation Areas (MSEA) program was developed to provide a comprehensive evaluation of the impact of different farming practices across the Midwest on ground and surface water quality. The MSEA monitoring program was developed to capture the movement of nutrients and pesticides in the soil and vadose zone in different soils and hydrology settings using standard protocols for sampling and analysis. The scale of research ranged from laboratory to watershed scale studies. For each site a comprehensive database of meteorological, soils, pesticide, nutrient, soil water, plant growth, and leaching and runoff data was assembled. This database was used to provide an intensive evaluation of the Root Zone Water Quality Model and other water transport models. The MSEA effort has produced a unique database of information across the Cornbelt for assessment of farming practices on water quality and a model for multi-discipline and multi-scale research.

Introduction

In the mid-80's there began to be increasing concern about the potential impact of farming practices on ground and surface water quality. These concerns led to the development of the Presidential Initiative on Water Quality in 1989. The principles of this Initiative were described by Swader (1993) as:

> "The nation's ground water resources should be protected from contamination by fertilizer and pesticides without jeopardizing the economic viability of U.S. agriculture; Both the immediate needs to halt contamination and the future needs to alter farm production practices should be addressed; Farmers ultimately must be responsible for changing production practices to avoid contaminating ground and surface waters."

In developing this program there were several challenges for the overall program within the United States Department of Agriculture (USDA). These challenges were to: 1) conduct biological, physical, and chemical research; 2) address the management of chemicals for crop production; 3) develop alternative cropping systems, in order to 4) educate, demonstrate, and assist farmers in making appropriate changes in production practices; and 5) monitor implementation of improved management practices and systems.

These goals and challenges were the foundation to the formation of the Management Systems Evaluation Areas (MSEA) Program that began in 1990 and described by Onstad et al. (1991). Development of the MSEA research and education program revolved around the goal to "Identify and evaluate agricultural management systems that can protect water quality for the Midwest." To achieve this goal there were six general objectives:

1. Measure the impact of prevailing and modified farming systems on the content of nutrients and pesticides in ground and surface waters;
2. Identify and increase understanding of the factors and processes that control the fate and transport of agricultural chemicals;
3. Assess the impact of agricultural chemicals and practices on ecosystems associated with agriculture;
4. Assess the projected benefits of implementing modified farming systems in the Midwest;
5. Evaluate the social and economic impacts of modified management systems; and,
6. Transfer appropriate technology to farmers for use on the land.

The overall structure of the MSEA program has been described by Hatfield et al. (1993a, 2000). To accomplish the MSEA goals the MSEA program involved over 150 researchers from the USDA-Agricultural Research Service, USDA-Cooperative State Research, Education and Extension Service, U.S. Department of Interior-United States Geological Survey, U.S. Environmental Protection Agency, and participating State Agricultural Experiment Stations and Cooperative Extension Services in Iowa, Minnesota, Missouri, Nebraska, Ohio, North Dakota, South Dakota, and Wisconsin. Within each project there were numerous state and local agencies that were involved in the project development and implementation.

The objective of this paper is to describe the MSEA program and the structure that was used to obtain the success for the original objectives of the project and the development of database for potential evaluation and development of new best management practices.

Research and Education Sites

The research and education programs of MSEA were designed to cover a number of different soils, climates, and geological areas. A detailed description of the individual projects and their setting is described for Iowa (Hatfield, et al, 1993b), Minnesota-Northern Sand Plains (Anderson et al., 1993), Missouri (Alberts et al., 1993), Nebraska (Watts et al., 1993), and Ohio (Ward et al., 1993). A general overview of the sites is given in Hatfield et al. (1993a) and the range of tillage practices and cropping systems is given in Table 1. To help understand linkages among the projects and the overall MSEA program it is necessary to examine the individual project objectives. This overall list of objectives provides an understanding of the scope of the project, which covers all aspects of agricultural chemical movement, fate, and dissipation within a wide range of soils, climates, and geologic settings. Across all of the projects there was an underlying expectation for the development of products to enhance water quality. The expected products from these studies included: 1) identification of environmentally sound

Table 1. Tillage and cropping systems evaluated within the MSEA program.

Crop Rotation	Tillage Practice	Number of sites	Sites
Grass and legumes	No-till	1	MO
Continuous corn	Moldboard Plow	2	IA
	Chisel	8	IA, MN, NE, OH
	Disk Only	2	IA
	Ridge-Till	2	IA
	No-Till	2	IA
	Moldboard Plow	1	IA
Corn/Soybean	Chisel	4	IA, MO, OH
	Ridge-Till	7	IA, MN, OH
	No-Till	3	IA, MO, OH
	Disk & Till-Plant	1	NE
Soybean/Sorghum	Chisel (sorghum)	1	MO
Corn/Soybean/Wheat	Chisel (corn)	1	MO
Corn/Soybean/Wheat/Cover	Ridge-Till	1	OH
Sweet Corn/Potato	Chisel	1	MN

farming systems that are acceptable to farmers; 2) assessments of landscapes and farming systems for their vulnerability to water contamination from farm chemicals; 3) information about the effects of farm chemicals on a region's ecology; 4) information about the suitability of management systems for specific farms in the Midwest; and 5) basic understanding of the behavior of farm chemicals in the environment. These products have been developed through research studies at each site, and there are reports beginning to emerge that represent the integration of information among sites. Specific objectives for each project are listed below:

Iowa: Evaluation of the Impact of Current and Emerging Farming Systems on Water Quality

1. Quantify the physical, chemical, and biological factors that affect the transport and fate of agricultural chemicals.
2. Determine the effects of crop, tillage, and chemical management practices on the quality of surface runoff, subsurface drainage, and ground water recharge.
3. Integrate information in meeting objectives 1 and 2 with data about soil, atmospheric, geologic, and hydrologic processes to assess the impact of these factors on water quality.
4. Evaluate the socioeconomic effects of current and newly developed management practices.
5. Understand the ecological effects of agrichemicals, distinguishing them from the impacts of other agricultural practices. Evaluate alternative management practices for their long-term effectiveness in preventing ecological degradation, in contributing to restoration of the ecosystem, and in maintaining agricultural productivity.

Minnesota-Northern Sand Plains: Midwest Initiative on Water Quality: Northern Corn Belt Sand Plain

1. Investigate the impact of ridge-till practices in a corn and soybean cropping system on ground water quality and on the transport of nitrate-nitrogen, atrazine, alachlor, and metribuzin in the saturated and unsaturated zones.
2. Determine the effects of nitrogen management by soil tests and plant analysis.
3. Characterize ground water flow through the sand and gravel aquifers and correlate the characteristics of the aquifers to the transport and storage of agrichemicals.
4. Determine the relationship between the rates of ground water recharge and the rates of agricultural chemical loading to ground water.

Missouri: Alternative Management Systems for Enhancing Water of an Aquifer Underlying Claypan Soils

1. Measure the effects of conventional and alternative farming systems on surface and ground water quality.
2. Study the mechanisms responsible for the fate and transport of agrichemicals in soil and water.
3. Determine how information from the plots and fields can be scaled up to watershed and regional levels.
4. Develop and refine models of the physiochemical, economic, and social processes of farming activities that affect soil and water contamination.
5. Develop and evaluate alternative cropping systems and technologies designed to protect water quality through the use of site-specific management techniques.
6. Establish the relative profitability of alternative farming systems and determine farmer's attitudes toward adoption of these systems.
7. Develop education programs to increase farmer's awareness and understanding of the relative profitability and environmental benefits of alternative farming systems.

Nebraska: Management of Irrigated Corn and Soybeans to Minimize Ground Water Contamination

1. Compare the net effects on ground water quality of conventional and alternative management systems for irrigated crop production.
2. Increase knowledge about the fate and transport of agricultural chemicals under conventional and improved irrigated production systems.
3. Develop and evaluate new technologies for managing pesticides, nitrogen, and irrigation to reduce ground water contamination.
4. Develop models and decision-making systems to aid farmers in choosing management strategies that are environmentally sound and profitable.
5. Identify and analyze the social and economic factors that influence the acceptance and use of management options for improving water quality.
6. Evaluate the economic impacts on the farm and estimate the economic impacts on the region of alternative management practices to improve water quality, including household income and aggregate economic output.
7. Develop a nitrogen budget for the various management systems to evaluate fertilizer efficiency and the potential for nitrate leaching.

Ohio: The Ohio Buried Valley Aquifer Management Systems Evaluation Area

1. Characterize the baseline hydrogeologic, geochemical, and geomicrobial environments of the buried river valley aquifer at the Ohio MSEA, in the Piketon region, and in each of the research plots.
2. Assess the effects of the different farming systems on the ecological, hydrogeologic, geochemical, and geomicrobial environment of each system.
3. Determine the dynamic and spatial leaching fluxes of applied pesticides and nitrate under different agricultural management systems.
4. Determine crop production responses to the different agricultural management systems.
5. Determine the expected profitability of each commodity produced under alternative agricultural systems and the variability of profits.
6. Identify areas in a region in which to establish the most promising alternative agricultural systems and then to assess the likely benefits of the systems in the locations.
7. Determine socioeconomic factors affecting the adoption of alternative agricultural management systems.

8. Develop practical predictive models and systems for identifying the effects of an agricultural management system on water quality at specific sites, as well as the production levels and profitability of the system.
9. Augment existing agricultural databases related to water quality.
10. Disseminate MSEA research results and provide technical assistance to farmers who are implementing new farm management systems.

Structure of the MSEA Program

Communication and coordination of the MSEA program was foremost in the initial meetings of the project investigators. Facilitation of the communication and coordination management of this program was delegated to a Steering Committee comprised of a Principal Investigator (PI) from each project who was typically an Agricultural Research Service (ARS) and a State Agricultural Experiment Station (SAES) investigator and a representative from the United States Geological Survey (USGS), the U.S. Environmental Protection Agency (EPA), and the USDA Cooperative Extension Service Water Quality Coordinators. Each of the PI's represented a different agency within USDA so that a broad representation of the USDA agencies was possible with a small number of individuals. The primary responsibility of the Steering Committee was to coordinate the technical details, research, and scientific progress of the MSEA program. Scientific management of the individual projects remained with the Principal Investigators within each project. It was felt that the Steering Committee was needed to ensure that the overall goals of the Water Quality Initiative were being addressed through the scientific accomplishments of the projects selected to address these objectives within the Midwest Water Quality Initiative. During the period from 1996-98, the composition of the Steering Committee expanded to include three representatives from each project. These were the ARS Principal Investigator, the SAES Principal Investigator, and the Cooperative Extension Specialist. This evolution in the committee structure has allowed for a broader diversity of representation from each project and more focus on the integration of the research, education, and technology transfer goals of the MSEA program. The overall administrative structure of the MSEA program has been fluid to accommodate the program needs rather than a dictate from any of the agencies. This has allowed the project investigators to adopt a structure that has facilitated the original goals to be focused and evaluated as rapidly as possible.

Within the Steering Committee there were a number of Technical Subcommittees and Working Groups. The Technical Subcommittees were considered as key overarching components of the MSEA program critical to the success of the program while the Working Groups were considered to be groups that would have a changing function throughout the life cycle of the program. The Technical Subcommittees were: Data Base Development and Management; Quality Assurance and Quality Control; and Technology Transfer. The Technical Working Groups were: Cropping Systems Evaluation, Process Modeling, and Socio-Economic Evaluations. Each of these committees was chaired by representatives from the Steering Committee but comprised of investigators from individual projects in order to incorporate the greatest amount of scientific and educational expertise into the project as possible.

Water quality monitoring efforts

The overall MSEA goal was to evaluate the impact of farming systems on water quality. The MSEA sites provided a wide range of conditions of water movement and potential transport mechanisms. The hydrologic parameters for the MSEA sites are shown in Table 2. We divided the hydrologic system into the saturated and unsaturated zone in order to understand the dynamics of fate and transport in different parts of the hydrologic system. The experimental procedures described in the various reports were implemented to be able to quantify the movement of herbicides and nitrate-N throughout the year. The measurements of different components are shown in Table 3. Instrumentation used during the MSEA program was positioned throughout the experimental plot or fields within watersheds to collect water samples that could be analyzed for the various constituents. There were a variety of different instruments used but the primary type was an automatic sampler for surface water or subsurface drainage samples and hand-collected samples from ground water wells. Soil samples for nitrate-N and herbicides were

Table 2. Hydrologic components of MSEA program for all sites.

Site	Unsaturated Zone	Saturated zone	Surface water
Iowa			
Walnut Creek	Subsurface drainage Evapotranspiration	Alluvial aquifer	Stream Skunk River Wetland
Deep Loess	Vadose zone	Saturated loess Glacial till aquifer	Stream
Nashua	Subsurface drainage Vadose zone	Glacial till aquifer	
Minnesota-Northern Sand Plains			
Princeton, MN	Direct recharge	Sand Plain aquifer	Stream Wetland
Aurora, SD	Vadose zone	Sand Plain aquifer	
Oakes, ND	Evapotranspiration	Sand Plain aquifer	
Sand Plains, WI	Vadose zone	Sand Plain aquifer	Stream
Missouri			
Goodwater Creek	Vadose zone	Fractured clay pan	Stream
Nebraska			
Platte alluvium	Vadose zone	Alluvial aquifer	Losing stream
Ohio			
Scioto alluvium	Vadose zone	Alluvial aquifer	Stream Wetland

collected with zero-contamination liners to a depth of 1.5 to 2 m depending upon the research site. These samples were divided into soil layers.

The complexity of the monitoring effort is described in detail in Hatfield et al. (1999). They describe the efforts to quantify the water quality program within Walnut Creek watershed and the various parameters that were measured within this watershed as part of the MSEA program. The foundation described in this paper was used to generate a series of research reports on leaching, ground water quality, surface water quality, ground water dynamics in glacial till and alluvium soils, volatilization, and deposition of herbicides and nitrogen in precipitation. Water quality efforts at the watershed scale must be documented because there are potential uses beyond the original experimental design. However, to accomplish this goal will require the development and population of databases that arise from the study.

One of the unique components of the MSEA program was the quality assurance/quality control protocols. Protocols were developed for each parameter as part of the overall data collection process. This was most critical in the herbicide and nitrate-N analyses for the different components. To ensure proper analytical process in the laboratory an external laboratory was used to audit each MSEA site and their analytical process. This same process was used for the soil analytical process although all of the soils samples were processed at the National Soil Tilth Laboratory. All data were subjected to quality assurance/quality control procedures to add confidence in the sharing of data among sites and increase the confidence in the use of the data in various models to estimate herbicide fate and transport.

Database development

One of the products of the MSEA program was the development of databases for each site and a metadata file for the database. Elements of the database are similar to those shown in Table 3 for specific experimental treatments. These data are available on both CD and will be posted on an ARS website

Table 3. Parameters measured in the MSEA program across all sites

Parameter	Matrix	Frequency
Herbicides		
Atrazine	Soil	Pre-application in spring through post-harvest
Simazine	Surface water	Runoff events and weekly sampling
Metoalchlor	Ground water	Monthly
Alachlor	Rainfall	Each event
Metribuzin	Volatilization	Selected studies during spring application
Nutrients		
Nitrate	Soil	Pre-application through post-harvest
	Subsurface drainage	Weekly
	Surface water	Runoff events and weekly sampling
	Ground water	Monthly
	Rainfall	Event
Meteorological data		
Air temperature	Atmosphere	Continuous measurements with data acquisition
relative humidity		
windspeed		
wind direction		
solar radiation		
soil temperature		
precipitation		
Soil data		
Water holding capacity	Depth increments within profile	Initial experiment setup
Bulk density		
Texture		
Color		
Organic carbon content		
Cation Exchange Capacity		
Nutrient availability (P, K)		
pH		
Microbial activity	Surface layer	Throughout specific studies
Plant data		
Plant height	Plots or fields	Periodically throughout growing season
Leaf area		
Biomass		
Yield		

during 2002. The metadata file has been assembled to provide a description of each parameter within the database, the units, and references to the measurement technique. The purpose of assembling the database and the metadata file is to provide a legacy of the MSEA program and to aid those that would like to use these data for evaluation of various models. One of the examples of the use of the MSEA database has been the evaluation of the Root Zone Water Quality Model (RZWQM) as described by Watts et al. (1999). The RZWQM model was evaluated at each MSEA site for various parameters within the model, e.g., crop growth, microbiological activity, nitrate-N movement, and pesticide movement. The goals of the effort was to improve, calibrate, and validate the RZWQM and to simulate across multilocations several specific management systems in corn/soybean production across the Midwest. The

MSEA database provides data for the continued refinement and enhancement of the RZWQM and is being extended to evaluation of potential management practices for water quality improvement in the Midwest.

Best Management Practices

One of the original goals of MSEA was to evaluate best management practices that could lead to improved water quality. There are some examples of the integration of information across the MSEA sites to develop best management practices. All of the management practices across the MSEA sites were summarized to determine the differences among practices and to determine the potential for management strategies. An analysis of the MSEA data showed that nitrate-N transport from Midwestern soils was one of the primary environmental impacts and Power et al. (2000 and 2001) summarized the MSEA data into some general conclusions. These general conclusions are:

1. For tile drained soils in Iowa, continuous corn was not environmentally acceptable because of the large quantities of nitrates intercepted and discharged into surface waters.
2. Reduced and no-till practices, compared with clean tillage, did a better job of synchronizing soil N mineralization activity with N uptake requirements of corn, thereby reducing nitrate accumulations in the soil and subsequent potential for nitrate leaching.
3. In irrigated crop production, sprinkler systems were superior to gravity systems because of more uniform water distribution and their ability to apply limited amounts of water per irrigation.
4. A corn-soybean rotation may not reduce nitrate N accumulation and leaching compared to continuous corn if inadequate N credits for soybean are used.
5. Present farming systems provide near-maximum economic return with acceptable levels of nitrate leaching, but may fail due to abnormal weather and inherent soil variability.
6. Soil testing is necessary to provide information on the best rate of fertilizer N for corn.
7. New technologies that will address weather and soil variability are needed to help improve management decisions.
8. Continual research efforts must be integrated with public policy to increase the effectiveness of farming management practices.

Dinnes et al. (2002) refined the current information on N management for tile-drained soils to show where potential improvement could be made in reducing nitrate-N losses from production fields. Their efforts are a result of the MSEA program that identified the role of artificial drainage systems on surface water quality because these drains act as shallow direct conduits. Nitrate-N is soluble in water and rapidly moves with water through the soil profile. They showed that nitrate-N losses from fields were not due to any single factor but a combination of tillage, drainage, crop selection, soil organic matter levels, hydrology, precipitation, and temperature. Hatfield et al. (2001) examined various best management practices and showed that variability in response is due to soil variation and position within the watershed. To understand the response of different best management practices and demonstrate the effectiveness of different practices will require information collected from different scales typical of the MSEA program.

Another example of the evaluation of management practices is the effort within MSEA to compare tillage practices. Ward et al. (1994) summarized efforts to compare tillage practices under the corn-soybean cropping systems as one of the primary goals of the MSEA program. This was extended for a specific tillage system, ridge-tillage, to evaluate the environmental quality response across a number of sites (Hatfield et al., 1998). Ridge-tillage provides a tillage practice that reduces both surface runoff and leaching through changes in the surface and the application of the herbicides and nutrients into portions of the ridge that are less susceptible to water movement. The attributes of this tillage system are being used as guides for comparing other tillage practices across the Midwest through continuing research efforts.

Herbicide movement from different farming practices was evaluated in the MSEA sites, although the movement was very limited in all sites. Surface runoff was the transport mechanism that caused the largest loss of herbicides from agricultural fields. This information was used as the foundation for large scale watershed studies in Illinois (Lake Springfield) and Missouri (Lake Smithville) to determine the impact of farming practices distributed across the watershed on herbicide movement into the lake which is used as the drinking water resource for these communities. These projects were developed as a result of the MSEA program that helped identify the critical parameters controlling herbicide loss and potential farming practices that would reduce loss from fields. The second phase of these studies is to implement changes throughout the watersheds and observe the impact on water quality and production efficiency.

Information produced from the MSEA program provided a baseline of understanding for various management practices that have led to potential new best management practices that can enhance both production efficiency and environmental quality. Further developments of best management practices can utilize the MSEA information as a guide to help understand the variation across soils, cropping systems, and weather patterns.

Conclusions

The MSEA program was designed to evaluate the impact of farming practices on environmental quality. This program was conducted across 10 Midwestern sites from 1990 through 1997 with some of the original efforts continuing in Iowa and extension to watershed sites in Illinois, Indiana, Missouri, and Ohio. The findings from MSEA have provided guidelines for improving farming practices to achieve an environmental improvement. The database assembled from the MSEA program serves as a resource for the evaluation of models and comparisons of best management practices for herbicides and nutrients. The original MSEA goals were fulfilled and changes were made in the efforts to accommodate a larger scale of effort through the Agricultural Systems for Environmental Quality (ASEQ) program with additional sites in Mississippi and North Carolina. These projects were able to reach a level of maturity very quickly because of the MSEA experiences.

The key to the success of the MSEA program can be traced to effort on assembling a quality assurance/quality control program for all components that were observed. Quality assurance/quality control protocols provided confidence among the MSEA research and education investigators about the observations and the potential extrapolation of the data to other sites within the Midwest. Adherence to these protocols also increased the acceptance of the results by public policy groups that the results being observed were valid and increased their confidence in variation among soils, cropping systems, and hydrologic settings.

Findings from MSEA have been summarized to help guide development of management practices. The conduct of research at a range of scales from small plots to watershed projects provides a unique opportunity to demonstrate the complexities of soils, cropping systems, tillage practices, agronomic management, weather, and hydrology. The database assembled from the MSEA effort will become available in 2002 to help other members of the research community to evaluate refinements in fate and transport research across a range of soils and weather conditions. Research findings generated from MSEA can be used to guide future research on best management practices.

References

Alberts, E.E., T. Prato, N.R. Kitchen, D.W. Blevins. 1993. Research and education to improve surface and ground water quality of a claypan soil. Proc. Agricultural Research to Protect Water Quality; Soil and Water Conservation Society, Ankeny, IA. p. 21-38.

Anderson, J.L, R.H. Dowdy, J.A. Lamb, G.N. Delin, R. Knighton, D. Clay, and B. Lowery. 1993. Northern Cornbelt Plainis Management System Evaluation Area. Proc. Agricultural Research to Protect Water Quality; Soil and Water Conservation Society, Ankeny, IA. p. 39-47.

Dinnes, D.L., D.L. Karlen, D.B. Jaynes, T.C. Kaspar, J.L. Hatfield, T.S. Colvin, and C.A. Cambardella. 2002. Nitrogen management strategies to reduce nitrate leaching in tile-drained Midwestern soils. Agron. J. 94:153-171.

Hatfield, J.L, Anderson, J.L., Alberts, E.E., Prato, T., Watts, D.G., Ward, A., Delin, G., Swank, R. 1993a. Management Systems Evaluation Areas--An Overview. Proc. Agricultural Research to Protect Water Quality; Soil and Water Conservation Society, Ankeny, IA. p. 1-15.

Hatfield, J.L., J.L. Baker, P.J. Soenksen, and R.R., Swank. 1993b. Combined agriculture (MSEA) and ecology (MASTER) project on water quality in Iowa. Agricultural Research to Protect Water Quality; Soil and Water Conservation Society, Ankeny, IA. p. 48-59.

Hatfield, J.L., D.A. Bucks, and M.L. Horton. 2000. The Midwest Water Quality Initiative: Research Experiences at Multiple Scales. *In*. Steinheimer, T.R., L.J. Ross, and T.D. Spittler (eds.) Agrochemical Fate and Movement: Perspective and Scale of Study. American Chemical Society, Washington, DC. pp. 232-247.

Hatfield, J.L., Allmaras, R.R., Rehm, G.W. and Lowery, B. 1998. Ridge tillage for corn and soybean production: environmental quality impacts. Soil & Till. Res. 48:145-154.

Hatfield, J.L., Jaynes, D.B., Burkart, M.R., Cambardella, C.A., Moorman, T.B., Prueger, J.H. and Smith, M.A. Water Quality in Walnut Creek Watershed: Setting and Farming Practices. J. Environ. Qual. 28:11-24. 1999.

Hatfield, J.L., S.A. McCaslin, and J.H. Prueger. 2001. Crop production BMP effectiveness and prediction of water quality improvements. TMDL Science Issues Conference. Water Environ. Federation, Washington, DC. pp 205-224.

Onstad, C.A., M.R. Burkart, G.D. Bubenzer. 1991. Agriculture research to improve water quality. J. Soil and Water Conserv. 46:184-188.

Power, J.F., R. Wiese, and D. Flowerday. 2000. Managing nitrogen for water quality: Lessons learned from Management Systems Evaluation Area. J. Environ. Qual. 29:355-366.

Power, J.F., R. Wiese, and D. Flowerday. 2001. Managing farming systems for nitrate control: A research review from Management Systems Evaluation Areas. J. Environ. Qual. 30:1866-1880.

Swader, F.N. 1993. Agricultural Research: The Challenge in Water Quality. Proc. Agricultural Research to Protect Water Quality; Soil and Water Conservation Society, Ankeny, IA. p. 16-20.

Ward, A.D., S.D. Nokes, S.R. Workman, N.R. Fausey, E.S. Bair, M.L. Jagucki, T. Logan, and S. Hindall. 1993. Description of the Ohio buried valley aquifer agricultural management system evaluation area. Proc. Agricultural Research to Protect Water Quality; Soil and Water Conservation Society, Ankeny, IA. p. 69-79.

Ward, A.D., J.L. Hatfield, J.A. Lamb, E.E. Alberts, T.J. Logan, and J.L. Anderson. 1994. The Management Systems Evaluation Areas Program: Tillage and water quality research. Soil & Tillage Res. 30:49-74.

Watts, D.G., J.S. Schepers, R.F. Spalding, and T.A. Peterson. 1993. The Nebraksa MSEA: Management of irrigated corn and soybeans to minimize ground water contamination. Proc. Agricultural Research to Protect Water Quality; Soil and Water Conservation Society, Ankeny, IA. p. 60-68.

Watts, D.G., N.R. Fausey, and D.A. Bucks. 1999. Background of the MSEA-RZWQM modeling project. Agron. J. 91:169-170.