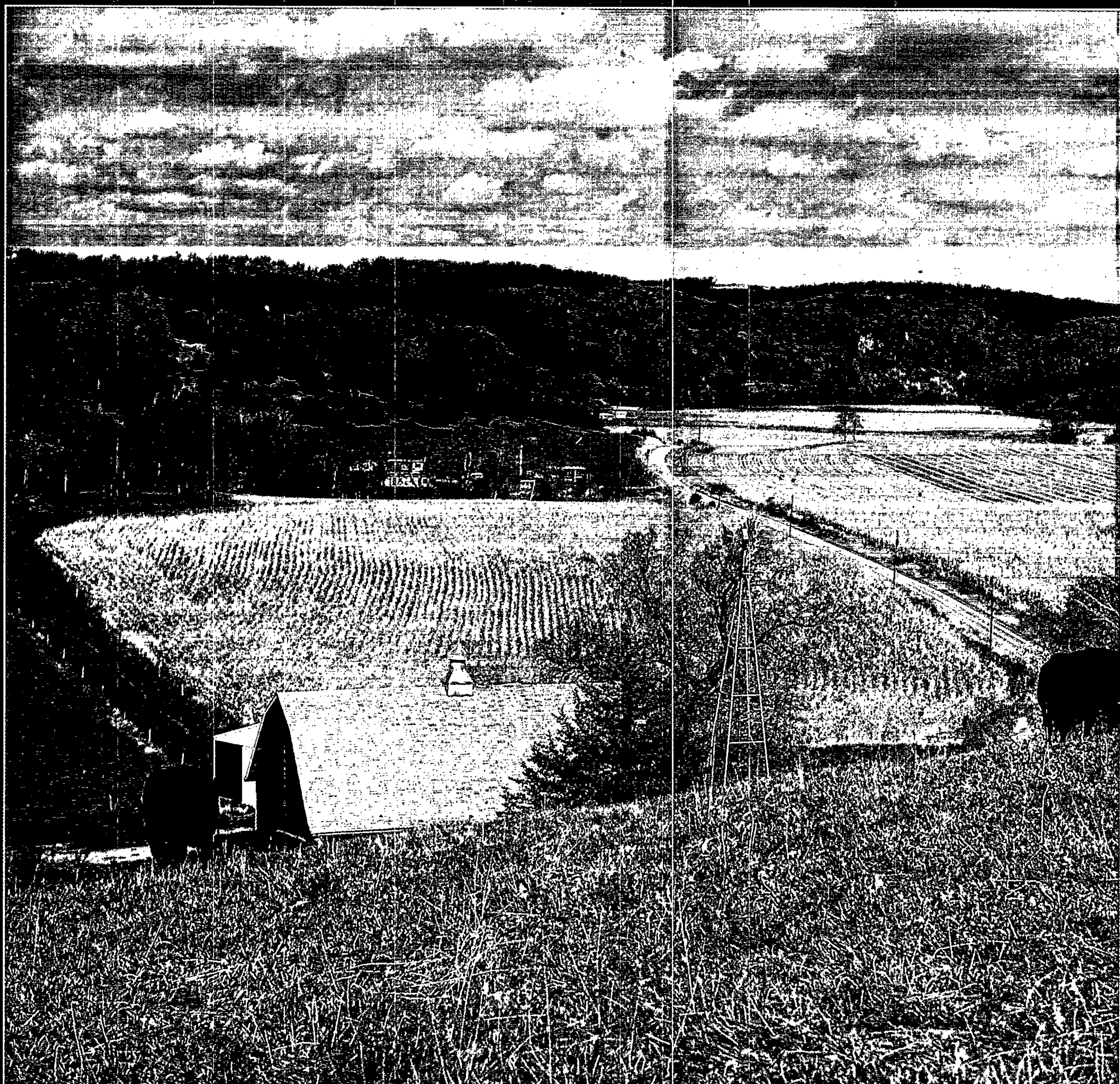
JOURNAL OF SOIL AND WATER
Conservation

Nutrient Management



Supplement to the Journal of Soil and Water Conservation Volume 49 No. 2

This special issue of the *Journal of Soil and Water Conservation* on nutrient management was prepared with support from the U.S. Environmental Protection Agency (EPA) under Cooperative Agreement 820524-01-0; Project Officer, Anne Weinberg. Articles presented herein do not necessarily reflect the views of EPA. Mention of commercial products or publications does not constitute endorsement, or recommendation for use by EPA.

This is a special supplement to the March-April 1994 issue of the *Journal of Soil and Water Conservation.*
The *Journal of Soil and Water Conservation* and this supplement are published by the Soil and Water Conservation Society, 7515 Northeast Ankeny Road, Ankeny, Iowa 50021.

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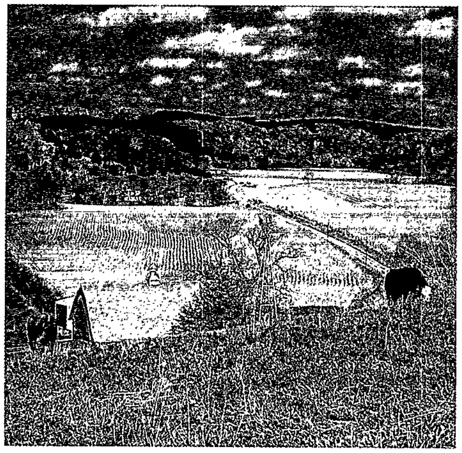


Preface

On April 20-22, 1993, about 300 people involved in nutrient management programs, representatives from federal, state, and local governments, producers, agribusiness representatives, academics, and representatives of other interest groups met in St. Louis, Missouri, to learn about effective approaches to nutrient management. This was the first such National Agricultural Nutrient Management Conference sponsored by the Conservation Technology Information Center (CTIC) and others. The papers presented at this conference are contained in this special issue of the *Journal of Soil and Water Conservation*, published by the Soil and Water Conservation Society.

The conference was organized to address concerns that significant portions of our nation's coastal waters, ground water, and inland surface waters are either impaired or threatened by excessive nutrient levels. Improved nutrient management is recognized by experts and practitioners nationwide as a solution for water quality problems and as a means by which producers can enhance both yields and profits. Also, federal, state, and local programs and regulations have increasingly focused on efficient nutrient management as an essential tool for preventing nonpoint source water pollution.

The conference was designed to assist local and state program managers in planning effective nutrient management programs and to provide the best current information for efficient field-level nutrient management. Lessons learned, technical information, and ways to overcome obstacles to good nutrient management were presented at the conference. In addition, there was a hands-on workshop where conference participants went through the steps necessary to develop a nutrient management plan on a farm.

A very encouraging sign at the conference was that conference participants were almost unanimously in agreement on the need for nutrient management programs. Thus, much of the discussion at the conference focused on how to develop such programs, how to deliver nutrient management plans to individual farmers, and on different technical approaches.

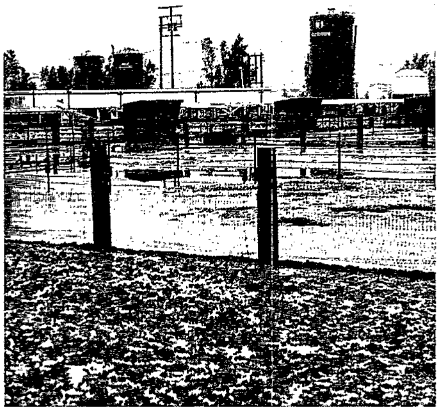
The Conservation Technology Information Center (CTIC) would like to thank all those who came to St. Louis. They made the conference a great success because they were eager to share their knowledge, energy, and insights. CTIC also extends special thanks to our cosponsors for their hard work in organizing and promoting the conference. The cosponsors were a diverse group: the Conservation Technology Information Center; U.S. Environmental Protection Agency; USDA Extension Service; Foundation for Agronomic Research; National Association of Conservation Districts; National Pork Board; National Pork Producers Council; Potash and Phosphate Institute; USDA Soil Conservation Service; Soil and Water Conservation Society; and the Tennessee Valley Authority.

In addition, we would like to thank the members of the Conference Steering Committee, and the Soil and Water Conservation Society for publishing the proceedings.

These conference proceedings are intended as a detailed reference tool. We hope they will prove valuable, both to conference attendees and to anyone interested in developing a nutrient management program or improving an established program. We encourage you, the reader, to contact the authors of the papers and other conference attendees and to continue to build the partnerships we need to develop strong nutrient management programs to protect water quality while maintaining profitability. We at CTIC enthusiastically support the need for developing effective nutrient management programs and will continue to provide our support.

Jerome C. Hytry
Executive Director, Conservation Technology Information Center

INTRODUCTION



Why nutrient management?

Lynn R. Shuyler

In order to begin to answer the question "Why nutrient management?" we need to address another question, "What have we done in the past?"

In the past, we viewed management of the land and land based resources as soil and water conservation management. This was the correct view to take when soil erosion and water volumes were our only concerns. In the past these were just about our only concerns and therefore the things we viewed as really important. It has only been in the very recent past that we have broadened our view and begun to include interests of other people and to treat them with the same concern as we had for soil and water conservation many years ago.

It has been less than 30 years since many managers and resource planners became concerned about the environment to any real degree. During this time, society began to voice concerns about the state of the environment and depletion of natural resources such as coal, oil, and natural gas. These events demanded change from those who work with natural resource planning and management. The message was to expand our tunnel vision, to look at all aspects of our resource use program, and to bring it all together into a true resource management plan for a field, a farm, but more importantly for the land user, the farmer. While it is very important that we expand our thinking, our planning, and our management, it is also important that we not lose sight of what we started with, soil and water conservation. The old concerns and old issues are just as important today as any of the new concepts that some rush to embrace. These must be given equal status with the new and must not be forgotten.

As we expand our concerns and begin to plan and manage new concepts, we face new problems, some of which need solutions before we can effectively move forward. The list of real and perceived problems is quite long and could force us back into tunnel vision or into a shotgun approach, as we look for solutions. Neither of these approaches is acceptable today. We must move forward with the implementation of total resource management, while at the same time refining the practices that we have to use and continue to look for new and better practices or better uses for existing practices. The real fear that we all should have and where real mistakes can be made is when we evaluate the problems in a watershed and begin to develop solutions for that watershed. In the past we have only seen our part of the problem and developed solutions for that portion. This is not enough today.

Today we must evaluate and pinpoint what the real problems are—ground water, surface water, air, soil erosion, wildlife losses, or any of a number of other items. Once the overall problems are defined, solutions can be crafted for all sources of problems, including nonpoint sources, point sources, air sources, and natural sources. Solutions can have cost estimates attached to them, which then become part of the political, economic, and technical tradeoffs to select the proper mix of solutions for the area and its problems. The trend today in many projects has been to develop stacks of plans to implement solutions, many different plans developed by many different planners not communicating with each other. Our society cannot and will not stand for this type of

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planning and implementation today. Society demands, and should be given, one overall integrated plan for the area, one plan that recognizes the conflicts of solutions and laws, one plan that allows all implementing agencies to work together, and one plan that has a single point of contact for each land owner, business owner, and the general public. As the planning process moves down the chain to smaller basins, to sub-basins, to farms and fields, the one-plan concept must hold. All of these plans and implementation must be based on the least costly, best available technology that passes the political test to be accepted by the affected party and still solve the original problems. Many planners are working toward this end today and we all should be moving in that direction in the near future.

Agricultural management plans should contain one common element, nutrient management. Why is it so important? It is the only element of a plan that can really manage nitrogen. It is the least costly of all components of the plan. It does not require much, if any, change in equipment. It has the potential to be an economic plus for the farmer. Although it is good and good for you, it can be hard to sell—it is too simple and it calls for a change in thinking on the part of management. The concept of nutrient management should be applied to land that has erosion control practices applied to it and to land that receives additional nutrients from any outside source, such as animal manure, sludge, and/or commercial fertilizer.

What should nutrient management accomplish? Nutrient management should reduce soluble nutrient transport and provide enough nutrients to produce a realistic crop yield. If these conditions are met, nutrient management will help protect groundwater resources, reduce nitrogen loadings into streams and estuaries, and balance the nutrient needs of the crop. Nutrient management should accomplish the following goals:

- maintain production at realistic yield goals,
- allow environmental conditions to improve, and
- provide for the wise use of all available sources of nutrients.

Nutrient management must allow commercial suppliers of nutrients to stay in business, not only as commercial sources of nutrients, but also as providers of assistance in the form of nutrient management plan development, and in some cases, as brokers for other sources of nutrients such as animal manures and/or sludge.

Some people strongly believe that nutrient management means a reduction in the amount of commercial fertilizer purchased and that it will put fertilizer dealers out of business if nutrient management plans are widely used. This belief is inaccurate; it is not true and this is not the intent of nutrient management. It is true that in the majority of cases nutrient management plans will call for less total nutrients than are now being used on the field. The plan must ensure that the proper nutrient balance is obtained and that the needs of the crop are met. We cannot afford to over-fertilize just to keep a dealer in business. We cannot afford to waste the natural resources required to produce, transport, and apply something we did not need in the first place, something that has the potential to harm the environment.

Nutrient management provides an opportunity for private sector business to sell a service, deliver the necessary nutrients to fulfill the needs of the client, and keep the client from polluting the environment. If such a service is provided, it should take little, if any, advertising to keep that farmer as a paying client. Therefore, if any part of the industry is impacted it might be only the advertising portion.

This is not to make light of the impact that wide-spread nutrient management could have on agricultural business interests in some areas. This is why we need to explore ways to involve fertilizer businesses in all aspects of the nutrient management concept, finding ways for them to recover the cost of plan development if they choose to offer the service.

There are many good reasons for nutrient management. It saves resources and reduces pollution. It is the most important component of a resource management plan and it is one of the most effective ways of managing nitrogen. It could increase the producer's profit margin. However, there are many problems that must be overcome before we can sit back and proclaim that nutrient management is a success. We do not have enough people in the field to deliver nutrient management to all the land area that should be using it. Government is not going to be able to provide the service at any cost. Government staffing is being reduced, so we can no longer look to the "agent" to solve our planning problems. The bulk of nutrient management planning must be delivered by the private sector as a profit-making venture.

How can this be done if publicly funded planners are in competition with the private sector? We must find ways to ensure that the private sector is paid a fair price for such work. At the same time, we must assure the farmer and the environmental agency that the planners are certified, and qualified to develop plans that will work for everyone.

Do we really need to do nutrient management? Yes! It is the cheapest way to reach our pollution reduction goal. While this paper is focused on nitrogen, the nutrient management concept can be used for any limiting element or nutrient. What is being controlled or limited with these plans will differ as different problems present themselves. Some sources of nutrients will have different components that could limit their use. For example, animal wastes could have very high total salts and need to be restricted on certain soils, or the phosphorus rate may be too high for some soils when the manure is applied at a nitrogen rate. The metal content of some sludge could cause concern, limiting the amount that could be applied to a field.

Much will depend upon the problem being solved, the source of the nutrients, the soil, the climate, and the crops being grown in the overall rotation. Each area of the country will encounter different problems that can be addressed with nutrient management planning. There are enough problems and opportunities to keep all of us busy for years with research to improve the concept, with plan development to help the land manager, and with program management to ensure that all players (consultant, dealers, and government) are treated fairly and that the land manager is given the best possible plan. This will not be an easy task, but we must do this or some other group will tell agriculture how much to use and where to use it, through laws or rule making. Agriculture does not need that—agriculture is well organized enough to do what is right and to do it now. ❑

Nutrient management, an integrated component for water quality protection

Lynn R. Shuyler

Is nutrient management ready to be integrated into water quality protection? The answer to that question is yes, but the real question is "are we as planners and users ready to integrate nutrient management into our management systems?" I think most of us here today [at the National Agricultural Nutrient Management Conference] would have a positive answer to that question. But if we were the average farmer, I do not think we would be very positive in our response to nutrient management and using it in our management system unless we had a good database on which to make the decision.

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As water quality and nutrient management professionals, we can analyze different water quality problems and develop strategies to address such questions as these:

- Are we dealing with surface water? If so, is it fresh or saline, or as with most estuaries, both?
- Is ground water our concern? Is it a source for surface water? Is it a drinking water source or not?
- What are the pollutants of concern, N, P, and/or total salts?
- What are the sources of pollutants causing this water quality problem? Are the sources of the pollutant background soil loads, commercial fertilizer, added organic wastes (animal manure or treatment plant sludge), atmospheric deposition?

In most cases it will be a combination of some, if not all, of these.

As professionals in this field we can evaluate large or small scale water quality problems and propose the necessary actions and goals required to solve the problems, thereby allowing regional or area specific strategies to be developed to attain the goals.

When we develop strategies or action plans for water quality restoration and protection, the concept of nutrient management must be the focus of our plan or strategy. Nutrient management is a prime example of pollution prevention—it requires a close examination of the farm operation, the "farm manufacturing process" being used, and attempts to optimize the inputs to accomplish a reduction of the undesirable outputs. When we think of nutrient management in a process engineering context, we see that it is not something new and that it has been used very successfully in other areas of pollution control. For example, the phosphate bans for certain types of soap in the Chesapeake Bay basin have greatly reduced the phosphate loads into the Bay without upgrading the treatment plants or increasing the cost of operation of the plants. The bans have increased the cost to the home owner a little, but given the difference in the cost of removal and the cost of prevention, there is no contest.

If nutrient management is to become an integrated component of water quality protection, it must also become an integrated component of the existing programs that are active on the land. These include U.S. Department of Agriculture Soil Conservation Service (USDA-SCS) total resource management planning, state and local land use planning and operation requirements, and the soon-to-be-implemented Coastal Zone Management NPS (nonpoint source) program. I believe nutrient management as a concept can be integrated into these existing activities today. I also believe most programs managers know the benefits of nutrient management and are interested in implementing it on agricultural lands.

The concept of nutrient management is very simple. If a nutrient is not applied, then it is still in storage or in the bag and not on the land where it would be available to move with soil particles or water. Some have incorrectly focused discussions regarding nutrient management on reducing the amount of commercial fertilizer applied to the land. This is not correct. Nutrient management is a balancing of the nutrient needs of a crop with the nutrient resources available to the producer. In some cases it will require changes in the mix of nutrient sources used on the field.

If a limiting nutrient concept is used to determine the application rate of organic sources, and the limiting nutrient is phosphorus, there may be a great increase in the amount of commercial fertilizer applied to provide the correct nitrogen balance for the crop. The point is, there are no hard and fast rules about what nutrient management is or is not. The only common thread is that it is a process that considers the following:

- source of nutrient
  - –manure, sludge, commercial, residual from crop and previous applications
- type of crop and realistic yield goal
- soil productivity
- weather
- previous history of land and producer

- environmental hazards of the land

As nutrient management is used throughout the nation we will learn more about how it works, the economics of using it, the water quality benefits, and the acceptance of the farmer to the practice. Some specific questions or areas that need answers or at least more data are the following:

- What is the cost or savings to producer?
- Can yield be sustained over time?
- Is the practice mining nutrients from the soil and will the practice destroy the soil in later years?
- Is nutrient management likely to reduce soil nutrient content during periods when nutrients are most subject to movement or loss from the field?
- Will the practice reduce the nutrient load to ground water?
- Will the practice reduce the nutrient load to surface water? and
- What is the time frame for these reductions to happen?

Some of these questions have been answered here [at the nutrient management conference] this week; others must await further research and study. The important point is that we have learned a great deal about this practice over the years. We have learned enough to recommend it strongly to farmers and land users across the country. We know that nutrient management is the most effective water quality practice that we have for controlling N, and it allows us to consider the limiting nutrient concept for all situations.

I do not believe that we need to wait for more information before we move forward with the implementation of nutrient management. I believe that we know enough to deliver this most useful tool as part of a program to the land managers in this country.

Many people want to make nutrient management mandatory across the U.S. Several states have considered mandatory nutrient management in legislative sessions in the past few years. So far none have enacted a fully operational requirement yet, but it is only a matter of time before it happens. I hope that you, the nutrient management professionals, will be active in ensuring that the technical concepts of nutrient management are correctly included in any new laws or regulations. Mandatory nutrient management seems to be a great idea; using the available nutrient sources correctly should reduce the cost of nutrient for the user, should allow the production of a realistic yield, and should be good for the environment. If it is all of these things then why do some people want to make it mandatory? I think the short answer to this question is that people just don't trust us. Or they know that not all farmers will do the right thing, even if it is better than what they are now doing. This is because farmers are just like the rest of the population: we do not all do what is correct all of the time!

I believe that nutrient management on agricultural land should be required to receive any form of government assistance. This would include federal assistance for conservation/water quality practices, assistance from the commodity programs, federal crop insurance, and operational and land loans from federal agencies. At the state and local level nutrient management should be required to receive state funded assistance for conservation/water quality practices, and to be considered an agricultural activity for state and local tax purposes. I also believe that nutrient management, as we know it, can be delivered to the urban sector for turf managers and home owners.

How can we deliver a nutrient management program that is effective in doing all of the things that we have been told it can do? Is it the responsibility of government to do it? The answer is yes and no. If nutrient management is part of a strategy to reach a goal, then the jurisdiction responsible for reaching the goal must see that all required actions are taken to reach the goal. In this example the state water quality agency might want assurances that nutrient management as a practice is being delivered according to some specifications. It is common knowledge that neither federal or state government is likely to have the funding to support the large number of nutrient management specialists required for full coverage of a program. I believe that nutrient management is a concept that can and should become part of the private sector's service to land users. This can take the form of private consultants and/or staff of fertilizer sales outlets. It makes no difference who writes a plan, how much or how little it costs, as long as it follows the concepts and specifications required for the area.

Planners should be responsible for their work. In the case of nutrient management, license by the state seems reasonable, since someone or some agency needs to be able to remove bad actors if a problem is found. Maryland has such a licensing law and has just finished the first testing cycle. A large number of people (about 130) were interested in taking the test, and about 80 of those who took the test passed it.

As a result of this new state law, Maryland will have many more nutrient management planners operating in the state this year, a mix of private consultants, fertilizer dealers, and government agency personnel, all working from the same knowledge base and developing similar plans. This should help Maryland meet a large acreage goal over the next few years.

We as professionals in this field can make a difference. We must make this happen if agriculture and the environment are to coexist and people are to enjoy the standard of living that we now have. Nutrient management is a critical part of the solution to most, if not all, of our agricultural NPS problems and we must use it effectively for the benefit of all. ❑

You need to start with the soil: The Soil Conservation Service experience

Robert R. Shaw

Let me share, from two perspectives, how the U.S. Department of Agriculture's Soil Conservation Service (SCS) is addressing nutrient management: first, how SCS currently is aligning its technology to fit soils and nutrient management into an ecosystems approach to resource conservation; and second, where we are going from here in terms of our capability to deal with a conservation systems approach to nutrient management.

Before looking at the ecosystems approach, let me mention that we are struggling with exactly what to call it. We have tried "total resource planning" as well as "ecosystem planning." But the bottom line is this: what environmental concerns compel us to do and what computers allow us to do is to help agriculture move in the direction of a holistic approach, an ecosystem approach to conservation planning.

This direction we are taking in SCS is based on three factors. The first is the need for balance between economics and ecology. Second is the proliferation of national, state, and local policy moving toward resource protection and sustainability. The third factor is the need to ensure that environmental aims are incremental to give agriculture time to adjust.

But in establishing the basis for change in the direction of nutrient management and other environmentally sound practices, we know that there is one key factor: the soil. You have to know your soil. You have to know its natural fertility, its capacity to hold the nutrients that are applied, its pH, and its structure, which affects how water and air move through it.

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For that reason, one of the ways that SCS is aligning itself for an ecosystems approach is by reassessing our soils database. Although that database is extensive, it needs further development. Some of the information needed for water quality and nutrient planning was not considered important at the time many of our soil surveys were conducted.

For example, in planning for groundwater protection, we need information about the area below the root zone—the "vadose" zone. A wealth of information about the vadose zone is available, but for the most part, it exists in well-drilling logs that are scattered around in various state agency files and in formats that are largely incompatible with our computer system.

We are funding a small project in Michigan that will rate aquifer vulnerability by using SCS's STATSGO (state soils map) database and digitized well logs. If this proves successful, we should have a tremendous opportunity to cooperate with other groups in augmenting soils data and increasing our knowledge of how nutrients move to groundwater. We also are trying to expand our soils database by using small samples to establish relationships between known information and needed information and then derive what is needed.

But that is not all we are doing to align nutrient management with ecosystems management.

- We have revised the SCS field office technical guides to include the five natural resources—soil, water, air, plants, and animals, plus human considerations. The technical guide is a compilation of technical materials tailored to local conditions. It guides SCS field people in the advice they give to their customers.
- We are helping with new practice standards involving nutrient and pesticide management, composting, chemical loading, and mixing facilities to deal with commercial agri-chemicals.
- We have cooperated on producing evaluation procedures that address potential pollution from the farmstead.
- We have embarked on the huge task of automating the best available technology so that our employees can help our customers plan and carry out their conservation systems at the field, farm, and watershed level.

As to SCS's capability to deal with fixture needs, let me put this in the context of how SCS has had to respond to environmental objectives in farm policy. I am talking primarily about the conservation requirements of the Food Security Act of 1985 and the Food, Agriculture, Conservation, and Trade Act of 1990.

SCS has long had the technology to address the erosion control aspects of the law. But we have had to make adjustments to meet the tremendous workload and to deal with the quasi-regulatory nature of the conservation compliance requirements. One of the adjustments we have had to make is to focus our attention almost entirely on single-purpose planning for erosion control. We have had very little time to devote to a more holistic, comprehensive approach in conservation planning.

Where are we headed? I believe that the future of the Soil Conservation Service hinges on public decisions as to a number of issues, especially issues dealing with the reconciliation of environmental and economic values, with water management being the biggest issue. There is a question of how profitability and economics will factor in to the environmental equation. What will the role be for incentives? What will the role be for regulation? Does it matter whether we have regulation or incentives?

Whatever direction society takes, SCS has a responsibility to deliver automated technology and to train the workforce in this technology. Essential to this task are our computer technology, our databases, and our geographic information system (GIS) technology. More and more, we see the importance of our role as "value add-ers" and as customizers of resource information. You can see that in what we are building toward—common data standards, shared databases, compatible hardware platforms for computer linkage with allied agencies, and remote access.

The next leap forward is to take our computer systems from a primarily textual kind of system to a graphic and spatially oriented system. That is an important step toward the technology world we envision. And it is a logical step, when you consider that 80 percent of SCS data is spatial or geographic data. This, of course, brings us fully into the world of geographic information systems.

That is the approach we are taking. For agri-chemicals, we are working with the research community and others to build an automated multi-tiered process for analyzing agri-chemical use and assessing the impacts of alternative choices. Each successive tier provides more detailed answers, but also requires more resources to implement. Therefore, we only move on to the next tier—or level of analysis—when we are not confident that environmental risk is low. At each tier, we look at site sensitivity based on soil properties, slope, depth to groundwater, and proximity to surface water. The concept is to move to a more technologically intensive tier only if the prior tier indicates that a problem exists.

The technology is available for prescription farming—using different application rates of seed, pesticides, nutrients, water, and cultivation methods by soil and site conditions. The big question is how can the industry—meaning all sectors, ranging from the federal government to private consultants—help standardize this information so that it is readily available and affordable to all who need it?

For detailed analysis, there are many tools available. We have begun by evaluating six of the models that we felt had the greatest potential for providing guidance in agri-chemical management, especially for water quality protection.

When we started this evaluation we thought we would find the one best model that would do the complete job. Instead we found that each model does something unique, even though there may be overlap with other similar models. We have settled on two that will enhance planning at the watershed level (AGNPS and SWRRBWQ), three that are field or point specific (EPIC, GLEAMS, and NLEAP), and one for a pesticide screening model.

Now we are working toward
- automating the pesticide and nutrient management screening procedures;
- "decomposing" the technology found in comprehensive water quality simulation models into objects relating to water and atmospherics, soils and geologic, biological, and chemical processes;
- constructing a model "assembler" that will integrate objects as needed to simulate water quality effects;
- minimizing user inputs by a graphical user interface and GIS technology; and
- developing SCS water quality simulation tools for two levels of resolution—hydrologic unit scale for area, state, and national offices and field scale for field offices.

These are our challenges for the future as I see them.
- It is imperative that we continue moving into ecosystem management—a more comprehensive, holistic approach to conservation planning. We have to start our planning with the basic resources: soil, water and air. Small watersheds (traditionally no bigger than 250,000 acres [101,175 ha]) are the largest scale at which we should attempt this for now, but at some time in the future, we will have to move to watershed management that addresses bigger areas.
- To support a holistic approach, we still have a lot to do to enhance our information base so that it can be consistently applied in ecosystem planning and management.

We need to move toward integrated natural resource decision-support systems. To that end, we must
- move rapidly in supporting spatially oriented computer systems,
- strengthen and build partnerships and alliances needed to meet the challenges ahead,
- accelerate the development of user-friendly interfaces for many complex research findings and models,
- be able to identify critical areas based on biological and other natural resource data, and
- deliver services that are technically consistent in different regions of the nation.

Again, our goal is to build an integrated, geographically based technology information system that is sustainable and responsive to SCS requirements and customer expectations. I believe we are on the threshold of an exciting new chapter in total resource planning and management. ❑

Keeping agriculture viable: Industry's viewpoint

B. C. Darst and L. S. Murphy

Webster's II New Riverside University Dictionary defines "heritage" and "viability" as follows:
- Heritage—something passed down from preceding generations; tradition.
- Viability (viable)—capable of success or ongoing effectiveness; practicable.

Production agriculture could be described as a practicable tradition, because it is, at least in part, tradition. It is also practicable. Further, it links

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the past, present, and future as perhaps no other industry in the history of humankind. A piece of that linkage can be seen across today's America, as we re-evaluate crop rotation, use of cover crops, residue management, alternative methods of pest control...myriad practices, some adapted by previous generations and others which will be used by farmers of the future.

A part of the viability of production agriculture has been nutrient management. As we learned to put back into the soil its nutritional wealth, which we exported to our dinner tables, urban friends, and world neighbors, production agriculture began to build toward sustainability. Mined-out fields were no longer abandoned, requiring that virgin sod be plowed.

The lessons learned from the Dust Bowl, coupled with thousands of research studies showing the merits of proper crop fertilization and other new production technology, catalyzed the fusing of conservation and agronomic best management practices (BMPs). The results have been outstanding. Consider what has happened in the last half-century (*12*).

- The ratio of farms per American citizen has fallen from 1:15 to 1:120.
- The number of people fed by the American farmer has increased from about 20 to more than 120.
- Corn and peanut yields have quadrupled; wheat and soybean yields have more than doubled, cotton yields have tripled.

That's not the end of the story. Yields of most of our common agronomic crops are projected to double in the next 40 years (*7*). Americans can be fed, exports will be boosted, and the environment will benefit, because tens of millions of acres of our most fragile land can be returned to permanent cover. Sound nutrient management will be a major part of that scenario.

Nitrogen, phosphorus, and the environment

All the 16 essential nutrients required for food, feed, and fiber production are also protective of the environment. They promote a more vigorous, healthy crop. They reward the farmer with greater profits; they help conserve and protect our soil and water resources in several ways, by (*21*)

- promoting more massive root systems,
- providing quicker canopy development and ground cover to lower the impact of rainfall and reduce runoff and erosion,
- supporting the production of more residue, both above and below ground, to stabilize the soil,
- improving water use efficiency, and
- increasing crop resistance to stresses—drought, pests, heat, and cold.

Essential crop nutrients play a vital role in supplying us with food and in protecting the environment. However, in some cases, they can pose an environmental risk without proper management. The two nutrients most often associated with environmental risk are nitrogen and phosphorus.

This paper deals largely with concerns about nitrogen and phosphorus and with their management. It should be understood, however, that for both economic crop production and environmental protection, the nutrient management principles addressed with regard to nitrogen and phosphorus apply to all essential nutrients.

Nitrogen. When nutrient management is discussed in some quarters, it is equated to reduced per-acre rates of commercially produced fertilizer, particularly nitrogen. The assumption seems to be that there is a direct relationship between fertilizer nitrogen use and environmental damage. Facts do not bear that out, however.

Many studies have shown a positive relationship among appropriate use of nitrogen fertilizers, profitable crop production, and soil and water conservation. Others have demonstrated that nitrate-nitrogen (hereafter referred to as nitrate-N) occurrence in groundwater and surface water is a natural phenomenon. Still other studies have identified significant contents of nitrate-N in groundwater, long before nitrogen fertilization was a common practice. Selected examples follow.

- In the early 1960s, nitrate-N accumulation in plants and water was of major concern. Several studies attempted to correlate this problem with the use of nitrogen fertilizers. However, research in the midwest U.S. at that time indicated little evidence that nitrogen fertilizers were responsible for or related to high nitrate-N levels in water or in plants under normal conditions (*18, 19*).
- Research in Nebraska, evaluating the relationship between fertilizer use and water quality, resulted in the discovery of large amounts of geologic nitrate-N within the deep loess mantle stretching across the central and southwestern areas of the state. The accumulation was encountered at about 20 ft (6 m) and continued below depths of 90 ft (27 m). Levels of 25 to 45 ppm nitrate-N are common, but values to 87 ppm have been measured (*4*).
- In a recent Ohio survey, representing 34,000 rural residences from 276 counties in 15 states, results showed that nitrate-N in excess of 10 ppm—EPA standard—occurred in only 3.8 percent of the wells tested. Minimal nitrate-N contamination was found in many areas of intensive row crop agriculture, while areas of more extensive contamination occurred in agricultural and non-agricultural regions (*2*).
- A Texas survey showed that nitrate-N levels exceeding the EPA standard were prevalent in water supplies in the 1890s, more than 50 years before nitrogen fertilizer was widely used in that state. In fact, the percentage of water wells exceeding the EPA standard in the 1896-1950 period was 9.93, compared to 7.65 for the 1971-1990 period (*13, 14*).
- According to a 1992 report, nitrate-N levels in the Des Moines River in 1945 were nearly identical to today's levels. In 1945, commercially-produced fertilizer accounted for about 0.3 percent of the total nitrogen used by crops in Iowa; today it accounts for about two-thirds of the total (*9*).

To say that nitrogen fertilization is

Table 1. Increasing P rates improved wheat yields and N use efficiency.

Treatment, lb/A		Grain yield,	Plant N	N removal
N	P_2O_5	lb/A	composition, %	in grain, lb/A
75	0	35	3.67	49
75	20	53	3.69	70
75	30	60	3.70	80
75	40	70	3.97	92

Soil test: Phosphorus, Very low. Nitrogen and P knifed preplant. Nitrogen removal based on actual measurements.

Table 2. Commercial N use in the U.S., 1980-82 vs. 1989-91.

Years	Commercial N use, million tons/year
1980-82	11.4
1989-91	11.1

ruining surface and groundwater quality is no more accurate than to claim that it has no effect. There are some risks to adding nitrogen to the soil, whether the source is commercially produced nitrogen or an organic such as animal manures.

Rather than argue right or wrong, the best course of action is to link nutrient management with other BMPs for crop production systems that reward the farmer financially and protect our soil and water resources. Where the two cannot be reconciled because the plant/soil/water system is too fragile, the land should be returned to permanent cover. Even then, however, there is no guarantee that natural processes such as the mineralization of organic matter or the leaching of geologic nitrate-N will not introduce nitrate-N into groundwater systems. In fact, they will. In many cases, nitrate-N produced by the mineralization of organic matter is more likely to leach to soil depths below the root zone than that from fertilizer nitrogen, which is applied near the time the crop uses it (*3, 15*). Research has shown that organic matter can release as much as 100 lbs/acre (112 kg/ha) of nitrogen in less than four months during the summer, in areas with no crop residue or low nitrogen residue. (*5*)

Phosphorus. Phosphorus is associated with water quality primarily through the eutrophication of lakes, bays, and non-flowing water bodies. Many sources, including sewage, industrial wastes, detergents, fertilizers, soil erosion, animal manures, and plant residues contribute to phosphorus in water.

Eutrophication is a natural process which has been going on since the beginning of plant and animal life on earth. All of the coal, peat, and muck bogs in the world were created by it. The state of Minnesota alone has more than 7.5 million acres (3 million ha) of peat bogs containing 6.8 billion tons (6 billion metric tons) of peat, of which approximately 5.5 million tons (5 million metric tons) is phosphorus. That phosphorus originated from soil erosion and the decomposition of plants and animals (*17, 23*).

Soil erosion is the major pathway by which phosphorus is lost from agricultural soils. When erosion is reduced by agronomic and conservation BMPs, phosphorus loss is minimized. Leaching of phosphorus through soils into groundwater is limited because of the strong bonding reactions of phosphorus with soil compounds and soil particles. Phosphorus has a very low water solubility, but natural weathering of soil minerals and rocks does contribute small amounts to surface waters.

Terraces, contour ridges, grass waterways, and buffer strips are examples of structural techniques for erosion control. Any of these conservation practices which reduce soil erosion will also reduce phosphorus losses. Conservation tillage systems such as no-till, minimum till, and ridge till are also effective in cutting erosion losses and are practical and economical methods for farmer implementation.

Some research has shown that phosphorus concentration can be higher in runoff from fields under conservation tillage than from those with more intense tillage. The reason for this is that phosphorus is released from decaying plant residues on the soil surface (as well as other factors). But total phosphorus loss is much lower because conservation tillage is so effective in reducing runoff.

Nutrient management and soil and water conservation

The control of nitrogen and phosphorus losses is best achieved by adopting BMPs which include and combine both conservation and agronomic management. Agronomic BMPs include the use of proper fertilizer rates, timing, placement, nitrogen stabilization, nutrient balance and proper irrigation practices, variety or hybrid selection, etc.

An example of a nutrient management practice that can have direct, positive effects on nutrient use efficiency, crop yield, and the environment is the use of nitrification inhibitors in preplant nitrogen applications for corn. Nitrification inhibitors such as nitrapyrin slow bacterial conversion of ammonium-N to nitrate-N. Ammonium-N is rather stable in the soil, so potential leaching losses are minimal. In a seven-year Iowa study, nitrogen use efficiency was improved and yields were increased by as much as 16 bushels per acre with nitrapyrin in preplant nitrogen applications (*6*). With better nitrogen utilization, less would be left in the soil after the cropping season to leach with winter precipitation.

Research data from across North America emphasize the positive effects of adequate amounts of all nutrients on the ability of crops to utilize available nitrogen. In Kansas wheat research, grain yields and nitrogen removed in the grain increased with phosphorus fertilization (*10*). Results are summarized in Table 1. Nitrogen utilization improved with adequate phosphorus because of the more extensive root system resulting from better overall nutrition. In this case, nitrogen removed in the grain was actually higher than applied nitrogen rates, indicating that additional nitrogen had been supplied either by carry-over nitrate-N or mineralized organic matter. The net effect was less nitrate-N remaining in the soil for possible leaching into groundwater.

The first step toward achieving optimum nutrient use efficiency is to establish realistic yield goals—those yields which are attainable, offer acceptable economic return to the farmer, and which are most protective of soil and water resources. Production history, cost/price benefits, soil testing (soil fertility levels), and management capability of the farmer are factors which should be considered in setting yield goals.

Once realistic, attainable yield goals have been set, nutrient management (and other production management) can be put in place to support economic, environmentally-protective crop production.

Nutrient management—nitrogen.

Nitrogen is the plant nutrient most often deficient in non-legume crops. Its availability to crops such as corn, cotton, and wheat is essential to sustainable crop production. Its use in excess is detrimental to both the economic well-being of the farmer and the environment. The North American farmer is making more efficient use of nitrogen fertilization, as measured by several indicators. Since the beginning of the 1980s, nitrogen fertilizer consumption has levelled off, as shown in Table 2 (*22*).

During the 1980s, crop yields continued to climb, while principal crop acreage was reduced by the Conservation Reserve Program (CRP) and Acreage Reduction Program (ARP). The rate of nitrogen applied per acre remained fairly constant. This fact is in contrast to claims that there have been rapid increases in use.

Of the approximately 17 million tons (15 million metric tons) of nitrogen applied to U.S. crops each year, about two-thirds is commercial fertilizer nitrogen, with the remainder coming from various other sources, as shown in Figure 1 (*22*).

Non-commercial sources of nitrogen will continue to be necessary in crop production. Predicting their role in the future would be impossible without knowing how government trade policy, regulation, and legislation will affect farmer practices. What is known, however, is that all nitrogen sources impact on nitrate-N content in the soil and, therefore, the potential for contamination of groundwater, as shown in Table 3 (*22*).

Long-term research in Oklahoma, beginning in 1969, showed that nitrogen sources do not differ when evaluating residual nitrogen (amount not used by the crop). Scientists state that "regardless of the source, nitrate-N will accumulate in subsurface horizons if (your) nitrogen fertilization rate exceeds the amounts recommended" (*1*).

Results also showed that soil nitrate-N levels, measured at 6-inch (15-cm) intervals to a depth of 10 feet (3 m), were the same when fertilizer was applied to meet yield requirements of wheat as those where no nitrogen fertilizer was applied. The conclusion: If the recommended nitrogen rates

Table 3. Examples of nitrate-N leaching potential from various sources.

Research site and source of N	Nitrate-N content in soil, parts per million (ppm)
<u>Michigan State University</u>	
No N added	8
Commercial N	10
Animal manure	49
Alfalfa plowed down	62
<u>University of Maryland</u>	
Poultry manure	
(Aug to Dec)	18 (monthly avg.)
(Nov to May)	42 (monthly avg.)
Commercial fertilizer	
(Aug to Dec)	15 (monthly avg.)
(Nov to May)	15 (monthly avg.)

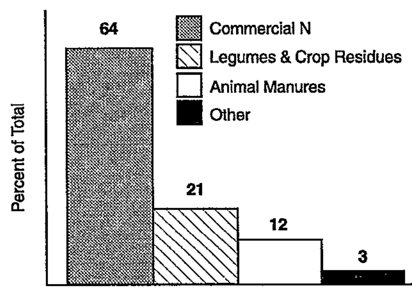

Figure 1. Percentages of total N applied to U.S. cropland by source.

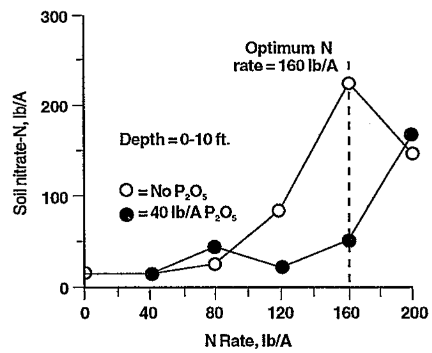

Figure 2. Nitrogen rate and P application effects on nitrate-N accumulation in the soil over a 30-year period (corn, Kansas research).

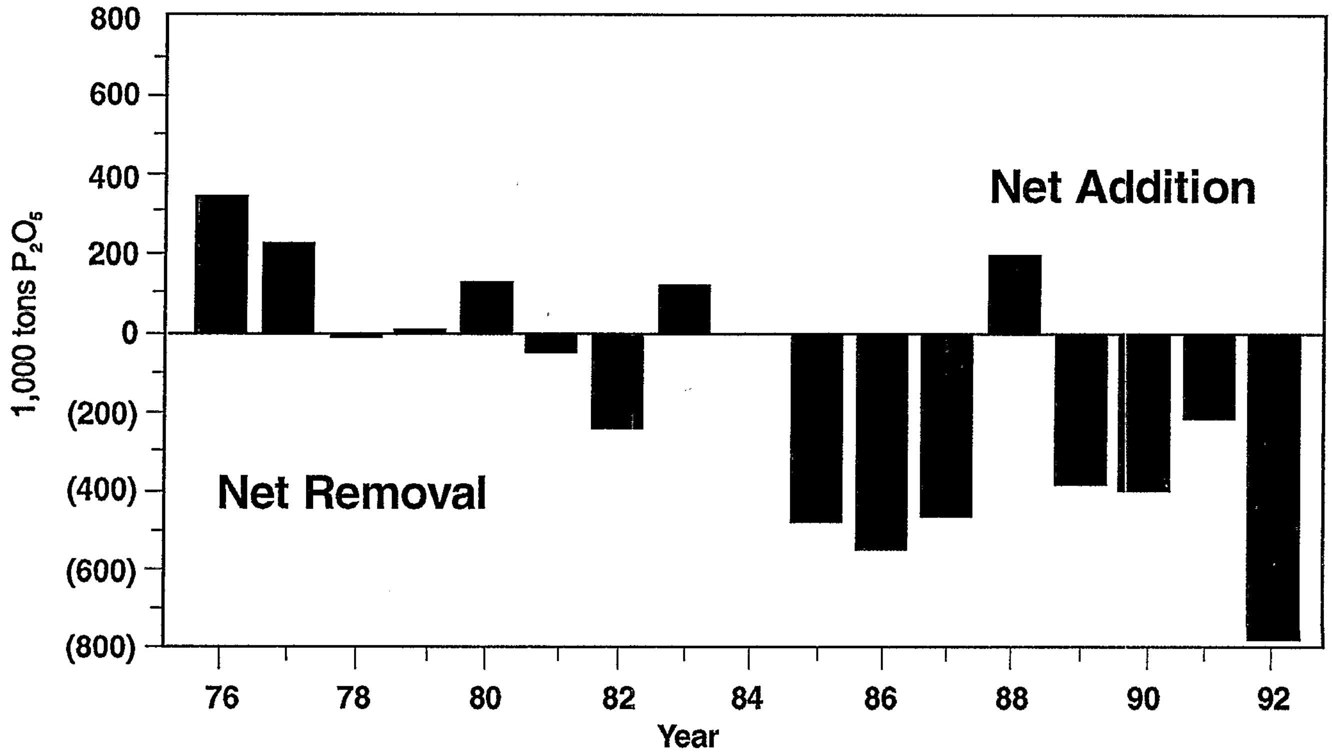

Figure 3. Net phosphate removal by corn and soybeans in the midwestern U.S., 1976-1992.

Table 4. Phosphate uptake by some common crops.

Crop	Yield level	P_2O_5 taken up in total crop, lb
Alfalfa	8 tons	120
Coastal bermudagrass	8 tons	96
Corn	160 bu	91
Cotton	1,000 lb lint	51
Grain sorghum	8,000 lb	84
Oranges	540 cwt	55
Peanuts	4,000 lb	39
Rice	7,000 lb	60
Soybeans	60 bu	58
Tomatoes	40 tons	87
Wheat	60 bu	41

Note: Phosphorus content of fertilizer is expressed as "P_2O_5" equivalent, even though no P_2O_5 as such occurs in fertilizer materials. The P_2O_5 designation is a standard expression of relative P content.

established by the Oklahoma State University soil testing program are followed, results suggest that there will be no risk of environmental contamination (*1*).

Nitrogen management, both commercially-produced and from other sources, is being researched and improved constantly. As a result, use efficiency by agronomic crops is increasing. In 1992, for example, the U.S. average corn yield was 131-plus bushels per acre (8,223-plus kg/ha), with an average nitrogen application rate of 127 pounds per acre (142 kg/ha). That translates into a use efficiency of 1.07 bushels of corn per pound of applied nitrogen, extending a record of improved use efficiency that goes back to the mid-1980s, and representing the highest nitrogen use efficiency on corn in the last quarter of a century.

What does the future of nitrogen management hold? Several management tools are now available and more are being developed that will improve crop nitrogen use. These include

- More precise timing of nitrogen fertilization, including split applications, so the growing crop has the nitrogen available when it is needed, leaving less remaining in the soil where it can pollute groundwater
- Nitrogen soil tests, which will more accurately measure nitrogen available for crop use, allowing for fertilizer nitrogen application rates that meet but do not exceed crop needs
- Nitrogen stabilization through the use of special coatings or nitrification inhibitors which hold the nitrogen in the root zone until the crop can take it up and use it
- Site specific nitrogen fertilizer applications, made possible with the use of variable rate field equipment, computers, and satellite tracking
- Balanced fertilization, using adequate levels of other essential nutrients with nitrogen to enhance nitrogen use efficiency, resulting in more profitable crop production

and the protection of soil and water resources. Figure 2 shows how balanced fertilization—using phosphorus (phosphate) with nitrogen—minimized nitrate-N accumulation in the soil. When phosphate was applied at 40 pounds per acre (45 kg/ha) and at the optimum nitrogen rate of 160 pounds per acre (179 kg/ha), residual nitrate-N levels after 30 years were comparable to those when no nitrogen was applied. However, when too much nitrogen was applied, even with phosphorus, residual nitrate-N levels were significantly higher. In this 30-year Kansas study, corn yields were also increased by an average of 24 bushels per acre per year with phosphorus (*16*). Both the farmer and the environment benefitted from balanced fertilization.

Nutrient management—phosphorus. Phosphorus is one of the three major nutrients, along with nitrogen and potassium, required in crop production. It is essential to normal crop growth; no other nutrient can be substituted for it in plant physiology. Most crops take up rather large amounts of phosphorus, as shown in Table 4 (*20*).

Until the late 1970s, farmers in the Corn Belt (Midwest) were building soil nutrient levels, including phosphorus. Since 1980, however, farmers have removed more phosphorus in corn and soybean harvests than they have been applying. In 1992, midwestern farmers applied only 75 percent of the phosphorus their corn and soybeans removed. Since 1984, they have 'mined' 3.9 million tons (4 million metric tons) of phosphate from their soils. This total reflects the deficit for phosphate fertilizer application relative to removal. Figure 3 shows that since 1980, phosphate removal has exceeded the amount added back every year except 1980, 1983, and 1988, all drought years (*8*).

Soil testing is a valuable tool available for farmers to use in assessing crop nutrient needs. It is site specific and can be combined with other management practices to formulate economically efficient and environmentally friendly fertilizer recommendations. A common misconception among those not in tune with production agriculture is that farmers have built their soil tests for phosphorus (and potassium) to the point that fertilization is no longer needed. Soil test summaries show that is not true. There are many soils across North America which test medium or less in soil phosphorus fertility that are responsive to fertilizer application. Table 5 illustrates that point (*20*).

In addition, research is showing frequent crop responses to starter fertilization, even on soils which test high or very high in fertility. Traditionally, little if any response would be expected from the crop being fertilized. Farmers were encouraged to apply nutrients at rates to offset crop removal in order to maintain the soil's productivity.

However, with today's higher yielding crop hybrids and varieties, conservation tillage, and other new or improved management practices, nutrient management is changing. Unplowed soils with residue cover stay cooler and wetter during early, initial crop growth. Applied fertilizer nutrients concentrate in the upper few inches of soil. The crop itself contributes to this stratification of fertility. All these factors tend to reduce the crop's ability to take up nutrients early in the growing season. As a result, rooting patterns change. Crops explore a lesser volume of soil for water and nutrients. Yields suffer.

Starter fertilizers place high concentrations of nitrogen, phosphorus, potassium, and other nutrients close to the young crop's developing root system. They help the crop overcome stresses such as low temperatures, wet soil conditions, and soil compaction. Understanding how limited young plant root systems are, one can see why concentrating high levels of nutrients in the root zone can boost early growth and increase the crop's yield potential. Research across North America is showing the benefits. An example of how starter phosphorus fertilizer can affect corn yield and maturity (grain moisture) is shown in Table 6 (*11*).

As new technology is discovered through research, phosphorus fertilizer management will become more efficient. With conservation and agronomic BMPs, more phosphorus will go into the production of food; less will be lost through erosion.

A look to the future

As we look to the future for direction in keeping production agriculture viable, we would be well served to glance over our shoulders, to back-breaking labor, low crop

Table 5. Soil test summaries for selected states and Canadian provinces.

State or province	Phosphorus soil test summary, percent testing medium or less
Alabama	65
Iowa	44
Nebraska	69
Ohio	32
Oklahoma	52
Ontario	52
Pennsylvania	56

Table 6. Phosphorus starter fertilizer increased corn yield and reduced soil moisture, even on a soil with a very high soil test.

Treatment	Yield, bu/A	Grain moisture, %
Without P	122	26.8
With P	145	24.3

yields, and disease- and insect-infected fruits and vegetables. Further, we must face the pressures of feeding a growing world population. The earth is now inhabited by more than 5.3 billion people. That number is expected to grow to 6.1 billion in the next seven years, and to more than 8.0 billion by the year 2025.

The effects of population pressures on the ever-shrinking land area available to food production continue. On a per-capita basis, the world had about 0.42 agricultural acre (0.17 ha) in 1980, down to 0.37 acre (0.15 ha) in 1998. If forecasters are correct, we will have only 0.32 acre (0.13 ha) per person available to production agriculture at the end of this century.

A much debated subject today is the sustainability of agriculture. Some argue that agriculture should revert to 'yesteryear,' to low input farming to achieve true sustainability. Nutrient use would be one of the inputs cut back, particularly the use of commercially produced fertilizers. Those familiar with nutrient requirements of high yield crops understand, however, that feeding the world will require larger amounts of inputs, including nutrients.

Now and in the future, the definition of sustainability—viability—must include a statement on enhanced productivity to meet increasing demands of the world's growing population and its per capita income. More intensive production will require greater amounts of plant nutrients.

Our concern should not be how much, or how little, nitrogen, phosphorus, and other essential nutrients are applied to the soil, but how, when, where, and why they are applied. To be able to answer the questions thus implied, we must look to agricultural scientists. Their research clearly shows that when nutrients are managed to build and maintain soil fertility, long term productivity can be sustained. Further, tomorrow's production agriculture can go hand-in-hand with environmental protection.

It is not enough, though, for production agriculture to be economically, technically, and environmentally sustainable. It must also be socially and politically sustainable. Consumers, elected and appointed officials, and others must be better informed, so that decisions relative to agricultural policy can be based on scientific fact, not emotion.

On one hand, consumers and special interest groups must understand that food production will never be risk-free. The potential for nitrate-N leakage into groundwater or phosphorus enrichment of surface waters exists now and will in the future. On the other hand, the farmers must continue to grow crops and livestock in ways that protect our soil and water resources. A critical part of tomorrow's production agriculture will be efficient nutrient management.

Production agriculture has changed and continues to change, mostly for the better. It is viable today and will be tomorrow. Our well-being as a world society depends on it.

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EPA's perspective—you need to protect water quality

Thomas E. Davenport

A vast majority of the nation's water resources are degraded by nutrients. Nutrients are the leading cause (55 percent) of impairment for estuaries and coastal

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waters, the second leading cause in lakes (32 percent) and rivers (28 percent). Phosphorus and nitrogen compounds from diffuse nonpoint sources are most often cited by states. Nutrient management is not just an agricultural issue. There are seven major sources of nutrients:

- Commercial fertilizer
- Manure production and disposal
- Municipal and industrial treatment plant sludge
- Municipal and industrial effluent
- Legumes and crop residues
- Irrigation water
- Atmospheric deposition

In addition, there is not just one problem associated with excessive nutrients in water. The major problem associated with excessive nutrients, particularly phosphorus in freshwater and nitrogen in saltwater, is the exacerbation of eutrophication problems in our lakes, rivers, and bays. Eutrophication is a natural process but the problem is elevated by nutrient loadings resulting from human inputs. This accelerates eutrophication, degrading water quality more quickly. In addition, nitrogen in the form of ammonia is toxic to freshwater fish and nitrate is a concern in drinking water from either surface or groundwater sources.

It is important to note that there is not one specific answer to the question of how to deal with excess nutrients. A general answer is the Best Utilization of Business and Biological Assets (BUBBA) approach. This approach recommends managing nutrients in a manner that doesn't adversely effect the environment. In plain terms, it means put on only what is needed, when it is needed, and in a form and by a method that ensures the nutrients will be fully utilized by the crop. Some nutrients will be lost through various processes, but users should focus on minimizing those losses. There is a vast array of methods for determining what is needed, when it should be applied, and how; with this information, individual nutrient management plans can be developed according to BUBBA.

Since nutrient problems impact bodies of water and are not specific to individual fields, the problems of excessive nutrients must be dealt with on a watershed basis. Unless it is related to a spill, this cumulative problem must be handled collectively by addressing all causes of the water quality problems, not just agriculture. It is well known that the condition of a body of water is a reflection of its entire watershed use and management.

When dealing with nutrient related water quality problems, two basic issues emerge: economics and environment. Economics relates to the landowner or operator's probability of making a profit. Environment issues break down into two types of problems: acute and chronic. Acute problems are those that need to be dealt with right away, such as fish toxicity and nutrient levels that exceed daily drinking water standards. Chronic problems are related to eutrophication and what it does to the water resource over time. Eutrophication causes taste, odor, and aesthetics problems, causes fish populations to change, and contributes to winter kills in many lakes due to dissolved oxygen depletion. Solutions must incorporate both economics and the environment.

There are two levels to deal with the nutrient problem: at the individual source level or geographic (statewide) level. At the individual level, selling the solution is the preferred approach because linking field economics with environmental benefit leads the individual to buy into the solution. MAX, an economic tillage computer program, is being modified to relate profit to water quality concerns and benefits. This will be a useful tool for dealing with individual fields.

At the geographic or statewide level, programs usually need to be a combination of information/education, technical and financial assistance, and in some cases, mandatory regulations. Regulations are not always necessary; the voluntary approach has worked in some cases, such as with the Great Lakes Water Quality Agreement. Several states in the Great Lakes Basin had to reduce phosphorus loading to Saginaw Bay, Lake Erie, and Lake Ontario. Without regulation, Indiana met its phosphorus load reduction goal for Lake Erie and Michigan met its goal for Saginaw Bay. These achievements were the result of a combination of cropland erosion control, nutrient management, and animal waste management practice implementation.

However, the mandatory regulatory approach will become more predominant due to the Coastal Zone Act Reauthorization Amendments (CZARA) nonpoint source requirement. CZARA requires states with coastal zone authority to develop and implement a coastal nonpoint source program. The purpose of this program is to support the implementation of specific management measures, for individual sources including cropland and livestock operations. These new state coastal nonpoint source programs must include enforceable policies and mechanisms to ensure the management measures are implemented. Region 5 of the Environmental Protection Agency is encouraging all of its states to use these management measures statewide, not just in the coastal zone. These measures make sense in both economic and environmental terms. One of the principles guiding this approach is that restoring water resources that have been impaired by nutrients is extremely costly. It is more cost effective to prevent the problem than to fix it after it occurs, and these management measures help do that. ❑

Understanding the Basics

Understanding the nutrient cycling process

J. F. Power

Nutrient cycling involves the transformation and availability of nutrients from many sources. Good soil management consists of regulating nutrient cycling in such a manner that nutrient requirements of the growing crop are met but not greatly exceeded at each stage of crop growth. This is accomplished by creating a soil microenvironment (air, water, temperature, and substrate availability within soil pores) through proper choice of management practices that controls the rate of nutrient cycling and availability as dictated by crop needs. Nutrient transformations, especially N and to a lesser extent P, result from soil microbial activity within soil pores, and are therefore mediated by the microenvironment existing within these pores. Through choice of tillage and crop residue practices, cropping systems, fertilizer practices, and related decisions, the farmer exercises some degree of control over the soil microenvironment and thus affects the transformation, availability, and potential loss of nutrients from the soil. While we currently have knowledge of many of the processes involved and factors affecting these processes, integration of all factors into an efficient management system remains very difficult and empirical. Development of an artificial intelligence system will be required to best integrate these myriad factors for all situations.

Nutrient cycles involve the transformations and availability of nutrients from many sources. Modern agricultural production practices have emphasized the widespread use of fertilizers as a source of nutrients to supplement biological sources made available through nutrient cycling. Within a generation, this approach has increased grain yields dramatically. This change has also resulted in planting less land to legumes and perennials, thereby increasing the area available for grain production. As a consequence of these developments, total grain production in many nations has increased many-fold. This has provided a means by which many nations are now able to meet their food needs for an expanding population.

This expansion in grain production capability through use of fertilizers has not been without its problems, however. There is evidence that over-fertilization has increased the concentration of many plant nutrients in both surface and ground water (*33, 39*), creating a potential health hazard, and reducing utility of many water bodies. There is also a possibility that greatly increased use of N fertilizers world-wide in the last several decades may be responsible for at least part of the increased N_2O concentrations in the atmosphere (*7*), thereby depleting stratospheric ozone concentrations. This allows more ultraviolet light to reach the earth's surface, and increases potential for skin cancer. Also N fertilizers are largely dependent on fossil fuels for their manufacture, and consequently deplete a non-renewable resource. Collectively, these and other associated problems raise the question of the sustainability of a system highly dependent upon intense fertilizer inputs. Does such a system jeopardize the conservation of soil, water, air, and energy resources for future generations?

Fortunately there are other sources of essential plant nutrients beside fertilizers. Plant-available N is derived by biological N_2 fixation, loose

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mineralization of native soil organic N, and mineralization of N contained in crop residues, manures, sludges, and other organic wastes. Likewise plant-available P can be obtained not only from acid-treated phosphates, but also from rock phosphates and other natural P-containing minerals, soil organic matter, crop residues, manures, and other organic wastes, and from secondary minerals in soils. Available K and other nutrients can be obtained from many similar sources.

Because of the many sources that may contribute to the availability of a nutrient, much of the science of crop production is involved with controlling the rate of release of nutrients from all sources in a manner that enables the plant to have a sufficient but not excessive supply of the nutrient at all phases of growth. Usually an excessive supply results in leakages from the soil-crop systems, and these leakages not only reduce economic returns, but also often end up as pollutants of air and water. Controlling nutrient availability is complicated by the fact that the crop requirement for a given nutrient constantly changes throughout the growth cycle. Achieving synchrony between crop requirement and nutrient availability is further complicated by variations in temperature, soil water content, soil aeration, and many soil properties (*30*). Consequently, controlling nutrient cycles through management practices is a difficult assignment.

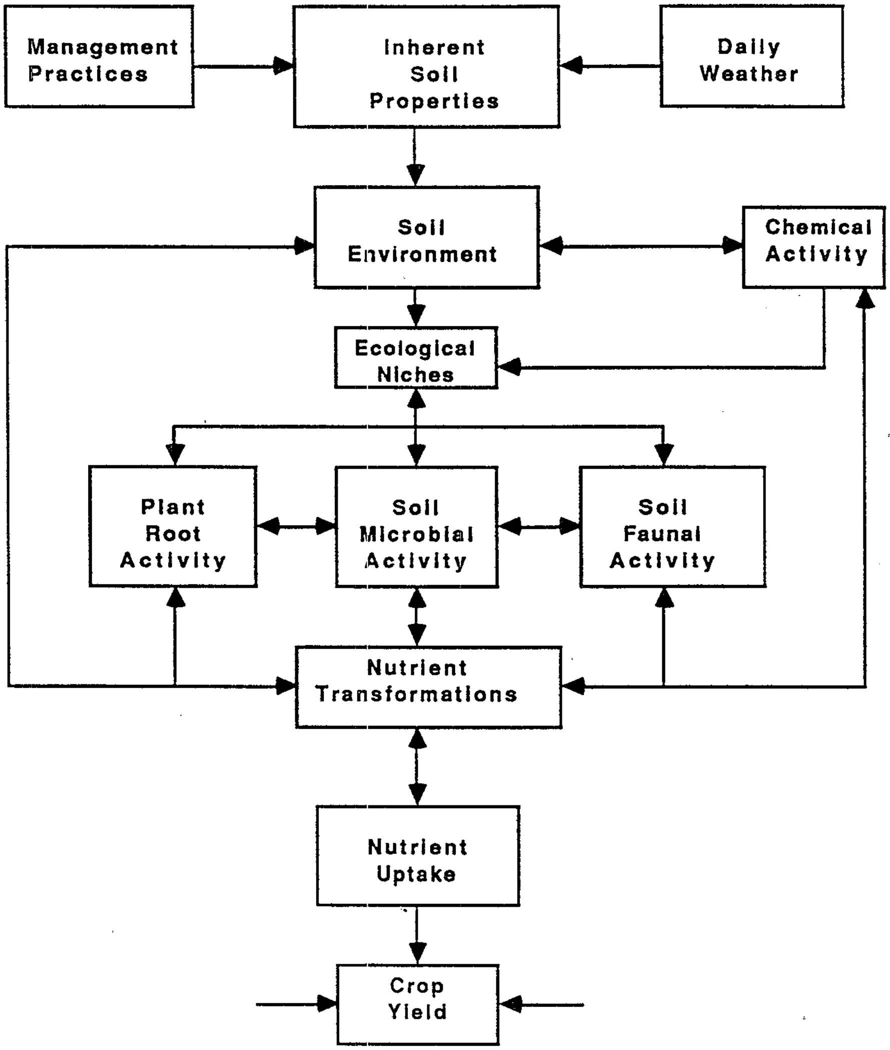

Figure 1. Flow chart relating biotic and abiotic factors to soil ecology and nutrient uptake (30).

The agricultural ecosystem

The effects of inputs into farming systems on changes in the soil environment, nutrient availability, and subsequent plant growth are shown schematically in Figure 1. For a given soil and climate input, each with its inherent properties and characteristics, the producer controls the soil environment through the selection of management practices. Soil environment factors of most concern are air (oxygen) and water regimes, soil temperature, and substrate availability. The farmer makes and executes a series of management decisions each year—choice of tillage practices, crop residue management, irrigation and fertilization practices, crops grown and cropping sequences, manuring and green manuring, weed and pest control, harvesting technique, and others. These decisions for a given soil in a given climate result in unique combinations of aeration, water availability, temperature distribution, and availability of substrates (especially soluble C utilization by microorganisms and plant-available nutrients for uptake by plant roots).

The preceding parameters of the soil environment, which are established as a result of management decisions, regulate to a large extent the chemical reactions and biological niches that occur in the soil. Chemical reactions are concerned with precipitation-solubility relations (phase changes), as well as alterations of chemical forms or species. For example, as the soil dries, many inorganic elements precipitate out of soil solution as solubility limits of the various salts are reached (*22*).

Biological niches or habitats determine the kind and numbers of living organisms in the soil. These organisms in turn affect plant root activity and microbial activity. Soil microbial and faunal activity largely determine the rates of decomposition of fresh organic matter and the availability of nutrients immobilized in organic form. Soil microorganisms live and function predominantly within the pores of the soil. These pores are also occupied by the water and air contained in a volume of soil. Consequently, one would expect that the better farm management decisions would be those in which water, aeration, and microbial activity are near the optimum combination that promotes the amount of biological activity needed to mobilize the nutrients required by the crop at that time.

The chemical and biological activity of the soil regulates, to a large degree, the nature and extent of nutrient transformations that occur (see Figure 1). In addition, changes in water and aeration regimes may result in oxidation-reduction reactions that convert certain elements from plant-available to unavailable forms (Fe, Mn, and others). Also, salt concentration of the soil solution (salinity) increases as soil water content decreases, and at sufficiently high concentrations it can affect all biological activity by altering the osmotic potential.

Finally, as indicated in Figure 1, all factors discussed ultimately affect plant growth and activity. Soil environment directly affects productivity, including plant root growth and development, nodulation, mycorrhizal infections, and meristematic activity in the crown (especially for gramineous species). Thus, the kind and magnitude of nutrient transformations that ultimately result from management decisions affect the availability of plant nutrients and subsequent plant growth. This is especially important for N since N availability is so closely tied to soil microbiology.

Table 1. Relative quantity, turnover rate, and availability of various soil organic nitrogen components of prairie soils (6).

Fraction	Total Soil N	Half-life	Mineralizable N Pool
	%	Yr	%
Plant residues			
Living	6	--	--
Dead	4	0.3	--
Microbial biomass	5	1.2	68.3
Labile organic nitrogen	65	36.0	31.3
Resistant N	20	990.0	0.4

Table 2. Effect of fallow tillage practices for winter wheat production on several soil properties and microbial biomass (9, 10).

	No Till		Sub Till		Plow	
	0-75 mm	75-150	0-75 mm	75-150	0-75 mm	75-150
Bulk density mg m^{-3}	1.29	1.30	1.25	1.38	1.25	1.31
Soil water, V/V	0.28	0.30	0.24	0.28	0.22	0.27
Water-filled pore, %	54	65	45	62	43	56
Hydraulic conductivity, mm ha^{-1}	32.0	21.9	33.0	10.1	19.4	15.4
Total N, %	0.124	0.103	0.114	0.101	0.104	0.101
Organic C, %	1.08	0.77	1.00	0.75	0.85	8.3
NH_4^+-N, kg ha^{-1}	4.6	5.2	4.0	3.8	3.5	4.2
NO_3-N, kg ha^{-1}	5.1	7.1	5.4	10.4	4.6	13.5
PMN, kg ha^{-1}(a)	52.1	45.9	47.6	50.8	43.9	47.9
Microbial biomass(b)	1.53	0.97	1.36	0.98	1.00	1.00

a Potentially mineralizable N by autoclaving

b Relative to plow treatment

Sources of nitrogen

Because of the dominance of N nutrient cycling and uptake, major emphasis is placed on it in this paper. The primary sources of N used in crop production originate from soil organic matter, residual inorganic N, biological dinitrogen fixation, atmospheric deposits, crop residues, manures, other organic wastes, and fertilizers. Relative importance of these sources varies widely in different years, locations, or cropping systems. As suggested by the flow diagram given in Figure 1, all sources must be managed in order to obtain economically profitable crop yields without experiencing unacceptable losses to the environment.

In many soils, soil organic matter is often a primary source of plant available N and other nutrients. Most of this N is immobilized as proteins and other nitrogenous compounds, often as components of dead microbial cells or sorbed on clay surfaces. This N is made available to a growing plant only through microbial degradation (mineralization) (*29*). Usually organic N comprises some 6 to 10 percent of the total soil organic matter. Often about 3 percent of the soil organic N pool is mineralized during a growing season. Thus a soil with 2 percent soil organic matter, 8 percent N in the soil organic matter component, and bulk density of 1.33 Mg m^{-3} may mineralize approximately

96 kg N ha^{-1} annually in the upper 15 cm of soil. Consequently in a fertile soil, mineralization of indigenous soil organic N is usually a major source of plant-available N (*38*).

Soil organic N is not homogenous, but rather is composed of readily labile, slowly labile, and resistant components. Chemical, physical, and functional characteristics of these components have been studied frequently (*6, 43*). Readily labile components have a turnover rate measured in weeks or months, slowly labile in months and years, and resistant in decades or centuries. Most N in soil organic matter is in the resistant form, with a much smaller fraction in the slowly labile forms. Only a few percent is in the readily labile pool, but this pool constitutes most of the N mineralized during the course of the growing season (Table 1). Nitrogen immobilized in microbial biomass may account for a large part of the readily labile pool (*29*). The resistant pool, while relatively inert, plays a major role in creating and maintaining the soil physical condition (*41*).

Residual soil inorganic N consists of ammonium (NO_4^+ and nitrate (NO_3^-) remaining in a soil after harvest of a crop or mineralized prior to planting the next crop. Often much of the residual inorganic N originates from excess applications of fertilizers and manures (*38*). This N, while readily available to the next crop, is also subject to loss by leaching or denitrification before or shortly after planting the next crop. Levels of inorganic soil N can usually be controlled through management practices if the practices used syn-chronize N availability with N uptake by the crop (*39*). Existing levels of residual inorganic soil N are frequently measured by soil testing prior to planting a crop in order to determine quantity of fertilizer or manure required by the next crop (soil testing).

Mention should be made of the non-exchangeable ammonium fraction. This N is trapped in inter-lattice spaces in 2:1 clays and is more strongly attached to clay particles than exchangeable ammonium. While this N fraction is generally considered to be unavailable to crop plants, there is considerable evidence from ^{15}N studies that an equilibrium exists between concentrations of exchangeable and non-exchangeable ammonium (*3, 27*). Because non-exchangeable ammonium may account for well over 1,000 kg N per ha in the upper meter of some soils with 2:1 clays, even a small rate of conversion of this N pool to plant-available forms could account for an appreciable part of the N requirements of a crop. Much more research is needed to understand the kinetics and role of non-exchangeable N in plant nutrition.

Atmospheric sources of N consist primarily of wet and dry deposition and gaseous ammonia absorption from (or released to) the atmosphere (*19*). The wet and dry deposition includes the various atmospheric oxides of N that are oxidized to nitrate and washed out of the air by precipitation, plus ammonia absorbed on particulate matter. Except for highly industrialized areas or near confined livestock operations, most measurements of wet and dry deposition are in the 10 to 20 kg N ha^{-1} annual range. Most of this N is in plant-available forms.

Ammonia is a highly volatile compound, and may be emitted directly from the soil following fertilization with urea or anhydrous ammonia. Also animal wastes emit NH_3 gases, as do a number of industrial processes. Consequently high atmospheric NH_3 values are often found near feedlots or industrial areas. Another major source of atmospheric NH_3 is from the anaerobic decomposition of organic matter, such as from swamp or rice paddies. In recent years there has been increasing evidence that well fertilized crop plants also emit NH_3 through their stomata during the maturation process (*21, 28*). Some studies suggest that as much as 25 percent of the total N taken up by a crop may be emitted by this means. Ammonia in the atmosphere is readily washed out by rain. Also if a plant is deficient in N, it may directly absorb atmospheric NH_3 through its leaves. Thus, most NH_3 gases emitted into the atmosphere are usually returned to the soil or crop within a few kilometers.

Crop residues are another major source of plant nutrients. In the United States, the quantity of nutrients returned to the soil in crop residues approximates that added as fertilizers. Essentially all the N returned in crop residues is in organic form so it must be mineralized by microbiological activity before becoming available for uptake by the next crop. Rate and efficiency of the mineralization process depends upon many factors—soil temperature and water regimes, C/N ratio of the crop residues, residue placement, particle size, and other factors (*32, 36*). Crop residues vary widely in C/N ratio, with higher values for residues from grain crops and generally lower values from legumes. If the C/N ratio is greater than about 30, little or no net N mineralization will occur. Tillage practices often regulate the rate at which N in crop residues is mineralized, with fastest mineralization occurring when residues are incorporated into the soil (plowing, disking).

Cropping systems largely control the quantity and composition of crop residues available to manage (*11*). Monocultures of grain crops provide only high C/N residues that contribute relatively little directly to the supply of plant-available nutrients (labile pool). They may, however, contribute appreciably to the slightly labile and resistant soil N pools (Table 1), appreciably influencing soil physical conditions and indirectly influencing microbial activity (*7, 26*). On the other hand, use of legume cover crops or legume-based crop rotations provides a variety of crop residues varying greatly in composition. Gupta and Germida (*18*) concluded that microbial (especially fungal) biomass responds rapidly to management practices, affecting macroaggregation (over 1 mm [0.04 in] diameter) more than microaggregation.

In many regions animal manures, sewage sludges, and other organic wastes also contribute greatly to the cycling of plant available nutrients. Again composition (C/N ratio) of these organic materials can vary widely, affecting rate of decomposition, availability of nutrients, and stability of soil aggregates. With livestock production systems, except for dairying, only a small part of the N fed to the livestock is physically removed in the livestock product sold from the farm (*42*). However much of the N in livestock wastes is commonly lost to the atmosphere by ammonia volatilization (and possibly denitrification) because the manures are not properly handled (*38*). It frequently happens that with intense livestock enterprises, the area available for economically suitable manure disposal is limited, resulting in manure overloading of the land. In such instances, high concentrations of nitrates in associated surface and ground waters often result (*25*).

Microbial transformations

Water, temperature, aeration, and substrate availability are the primary parameters governing microbial activity in soils. Water is often a dominant factor. These parameters therefore affect transformations of N and, to a large extent P, because most of the N and an appreciable part of the labile P in a soil are derived from the biological decomposition of organic matter (*12*). Linn and Doran (*23*) have shown that such biological processes as N mineralization, nitrification, and CO_2 production increase as the percentage of the soil pores filled with water (water-filled pore space) increases to about 60 percent (Figure 2). At higher values, rates of these aerobic processes decrease while rates of anaerobic processes (i.e., denitrification) increase. The 60 percent water-filled pore space (also 60 percent saturation) approximates water content at field capacity for most soils. From this, then, it is apparent that, as a soil dries to below field capacity, the potential rate of conversion of organic forms of N to plant-available (inorganic) forms decreases. Consequently, the rate at which indigenous organic N is mineralized and made available for crop growth decreases as the soil dries.

Mineralization of N from organic forms to soluble nitrate (NO_3^-) N is a two-step process. First, heterogeneous groups of soil organisms hydrolyze the proteins and amino acids in the organic fraction of the soil to produce ammonium N (NH_4^+). The ammonium N is then oxidized by select groups of bacteria (*Nitrosomas, Nitrococcus, Nitrobacter*) to nitrite and then to nitrate forms (*4*). Because bacteria are generally more sensitive to water deficits than are fungi, the bacteria-dependent nitrification process (NH_4^+ to NO_2^- to NO_3^-) may essentially cease to operate in a dry soil, whereas the ammonification step (organic N–NH_4^+), accomplished predominantly by more drought-tolerant fungi, may still proceed. For this reason, it is not unusual to find appreciable accumulations of ammonium N in soils after prolonged dry periods. This ammonium N is rapidly nitrified when the soil is again exposed to an environment conducive to activity of nitrifying organisms (*35*).

With alternative wetting and drying of a surface soil, especially in summer or following an irrigation, appreciable denitrification can occur under some conditions. Aulakh et al. (*2*) showed that considerable N could be lost from a no-till summer fallow field in Saskatchewan. Warm soil temperatures, coupled with a temporary reduction of water-filled pore space for a few days after a summer rain or an irrigation may create conditions in the soil favorable for denitrification (*46*). Also, wetting of the soil after incorporation of green manures may result in appreciable denitrification (*2*).

Water availability also has a similar effect on the rate of mineralization of organic sources of P, as well as for other nutrients present in organic forms. For many soils, especially those on which manuring, green manure, reduced tillage, or other such practices are employed, organic matter may be the major source for plant-available P and some micronutrients.

Management practices

As indicated several times in the preceding pages, nutrient cycling in agricultural ecosystems can be regulated to a significant extent by the soil and crop management practices employed. It should be pointed out, however, that there are limits to the degree of control possible, and that management techniques suitable for one set of soil, climate, and cropping conditions may be entirely unsatisfactory in another situation.

Several of the more common management practices used to control the cycling and availability of nutrients from various sources include cropping systems, tillage (crop residue) management, fertilizer and manuring practices, timing of cultural practices, irrigation, and others. Cropping practices affect not only the quantity of nutrients removed in the harvested crop and the quantity of crop residues returned to the soil, but also composition of the crop residues returned, time of the year they are returned, soil water regimes, and to some extent soil temperatures. Thus, cropping systems can greatly affect the availability of nutrients from the crop residues returned, as well as the rate of mineralization of indigenous soil N (*37*). Quantity of nutrients applied as fertilizer is often altered by cropping practices.

The use of legumes in a cropping system often increases the quantity of N returned in crop residues and may also increase total N uptake by crops during a cropping cycle (*31*). Rotating a seed legume such as soybean [*Glycine max* (L.) Merr.] with a cereal grain such as corn (*Zea mays* L.) usually results in greater cereal yields and greater N uptake and removal in the combined seed harvests of the two crops than would occur with a monoculture (*44*). Such a rotation results in more N being returned in crop residues, and only half as much fertilizer N is used as with a corn monoculture. Varvel and Peterson (*45*) showed that such a crop rotation often reduces residual soil nitrates after harvest, thereby reducing potential for nitrate leaching.

If a forage legume is used in a crop rotation, somewhat similar effects on N availability and use is often observed (*44*). Doran et al. (*11*) showed that, compared to a grain monoculture, a legume-based rotation

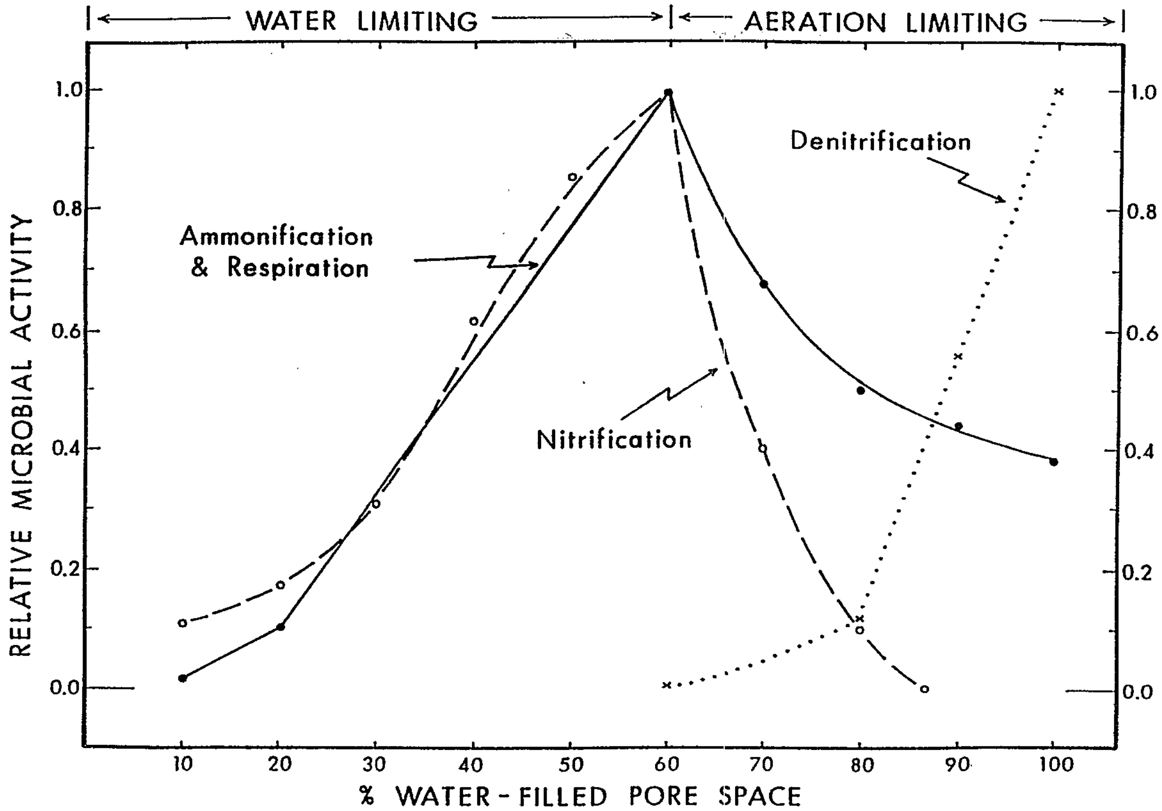

Figure 2. Relationship between several aerobic and anaerobic microbial processes and the percentage of water-filled pore space (23).

resulted in increased microbial biomass N and potentially mineralizable N. Similar results have been reported when a green manure cover crop such as hairy vetch (*Vicia villosa* L.) was used with a grain monoculture (*11*, *16*).

Choice of tillage and crop residue management practices is also a major factor regulating availability of nutrients from many sources. The net effect of crop residue management on N availability and utilization depends on many factors. In addition to tillage practices (degree of residue incorporation), these factors include N content of the crop residues (C/N ratio), time of year (precipitation and temperature regimes), quantity of residues, and to some extent, soil properties.

Crop residue management practices (achieved primarily through choice of tillage practice) greatly influence the cycling of nutrients from crop residues (*9*). By incorporating residues with plowing or disking, decomposition and nutrient cycling are more rapid. Frequently conditions are ideal for microbial activity for several days after incorporation. This results in a flush of microbial growth and rapid disappearance of crop residues. However, tillage that leaves the soil surface without residues results in rapid soil drying, greatly diminishing microbial activity. At the other extreme, no-till systems leave crop residues on the soil surface where much slower rates of microbial degradation occur. The surface mulch also reduces evaporation losses, thereby enabling this slower rate of microbial activity to proceed for a longer period. As a consequence, by the end of the season there may be little difference between no-till and bare tillage systems in total quantity of N and other nutrients mineralized (*10*). However, those nutrients mineralized with the no-till system may be better synchronized with the nutrient needs of summer-grown crops, so are utilized more effectively. On the other hand, with bare tillage nitrate is formed early in the season and accumulates in the soil before it is needed by such crops, thereby increasing risk of loss by leaching or denitrification.

These effects of tillage practices on N availability result because of the changes in microbial habitat that different types of tillage create. Doran (*9*, *10*) has shown that plowing, in comparison to no-till, usually results in fewer microorganisms and less microbial activity in the surface 0 to 75 mm (0-3 in) soil, but that this trend is sometimes reversed at lower soil depths (Table 2). Also while populations of all classes of organisms are usually increased in the surface soil of no-till, increases are particularly great for anaerobic or facultative organisms. This probably results because the microenvironment with no-till is cooler and generally less aerobic than with plowing (Table 2). Follett and Peterson (*15*) showed that concentrations of available N and several other nutrients were also greater near the surface of no-tilled than in bare-tilled soils.

Considerable research in recent years on the use of cover crops has shown that method and time of year of killing and incorporating the green manure residues also greatly affects the relative availability of N from many sources. Frye et al. (*16*) and others have shown that leaving herbicide-killed cover crop residues on the soil surface followed by no-till corn production is an acceptable practice in the southeastern United States. However in cooler, more northern regions, Power, Doran, and Koerner (*34*) found that N in cover crop residues left on the soil surface for no-till failed to mineralize in time to be utilized by the following corn crop. On the other hand, N in cover crop residues incorporated by tillage did mineralize and was used by the corn crop.

Of course, fertilizer practices also affect nutrient availability and use by crops. Included are choices of fertilizer carriers, times of application, method and placement, and use of inhibitors and coatings to regulate conversions, transformations, dissolution, and related factors. There are a number of books that discuss many of the factors controlling availability and utilization of fertilizers (*14*, *20*, *40*). The general philosophy on fertilizer N usage is to determine or estimate N availability from all other sources, estimate N requirement of the crop, and apply sufficient fertilizer N to meet any deficit that might exist between these two numbers. Usually some form of soil testing is used to estimate amount of N that will be available from residual inorganic soil N plus that mineralized from soil organic matter (*5*). In situations where a forage legume has been plowed down or where manures have been added, credits are given for additional available N originating from these sources. Gilbertson et al. (*17*) developed guidelines for calculating fertilizer N credits for manure applications.

Fertilizer management is critical for controlling nitrate pollution of surface water and especially groundwater. Any residual fertilizer nitrate-N remaining in the soil profile after crop harvest can potentially be leached beneath the crop root zone before the next crop is planted and develops an extensive rooting system. Thus it is important to apply no more fertilizer N than is required by the crop, especially in situations where leaching is likely during this non-crop period. These problems and their consequences have been discussed by many (*33*, *38*, *39*).

Summary

Nutrient management for agricultural production is a highly complex and poorly understood process. While this paper has pointed out several of the paramount factors affecting availability of uptake of nutrients from a multitude of sources, it has not addressed other factors involved or provided much quantitative information on the integration aspect. While deficiencies in knowledge required for N management are apparent, we have hardly mentioned the other nutrients involved in crop production. Likewise the multitude of feedbacks and biocontrol mechanisms involved in these biological systems have hardly been mentioned, mainly because we know so little about them. Thus it is evident that while this paper attempts to summarize knowledge on the management aspects of nutrient cycling, we realize the woeful inadequacies that still exist.

Research to date has developed many of the principles involved in the cycling, managing, and integrating of nutrient sources for crop production. As outlined in this paper, we have learned much about the various sources of crop-available nutrients, how they are transformed by soil microbial activity, and how we can manage, to some extent, these transformations. This body of knowledge is great and it continues to grow. We are also making progress on the quantification of the cycling processes. A good example is the recent recognition that percent water-filled pore space is a good predictor of type and intensity of soil microbial activity (*13*, *24*). As we continue to accumulate knowledge of this type, we will better be able to develop a much more integrative approach in managing N and other nutrients in agricultural enterprises.

Integration of these complex interactions will eventually be achieved through computer simulation modeling. Actually an artificial intelligence system will be needed because the matter is so complex with so many feedbacks and other control mechanisms involved. Add to this the literally millions of combinations of soils, crops, weather patterns, management practices, and time scales involved in agricultural production, and simulation modeling is obviously the only realistic approach to acquiring a comprehensive understanding and predictive capability. Fortunately some progress toward this goal has been made in the last decade (*8*), and we can be optimistic that we will advance rapidly toward this goal in the future.

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Understanding the nutrient management process

Douglas B. Beegle and Les E. Lanyon

Traditionally, nutrient management has attempted to optimize the economic return from nutrients used to produce a crop. The main emphasis was on the expected crop response to added nutrients. In practice however, manure has not always been applied to optimize plant nutrient use. Under contemporary circumstances manure may be applied so that nutrients are in excess of plant

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needs, so that the nutrients are not available for crop growth at the optimum time, or so that they are released into the air or water. These nutrient losses have prompted concerns about the impact of existing nutrient management on environmental quality. Leaching of excess nitrogen through the soil can increase groundwater nitrate to levels that can adversely affect the health of young children and young livestock. Surface movement of nitrogen and phosphorus in runoff increases concentrations of these nutrients in surface waters, potentially leading to eutrophication and changes in aquatic wildlife. The problems that we have with nutrient pollution are not solely the result of mismanagement by farmers but have been influenced by the evolution of our agricultural systems with no accounting for the costs of changes in environmental quality. Managing nutrients to address environmental concerns will mean more than just eliminating poor management. It will require changes in our agricultural systems. Many innovative management approaches and supportive social policies will be necessary to reconcile a highly productive, intensive agriculture with environmental protection.

Farm nutrient flows

Plant nutrient management decisions deal primarily with the flow of plant nutrients to, from, and within farms. Characterizing various patterns of farm organization can be helpful in understanding nutrient management issues and in addressing practically all activities associated with the nutrient management process for crop production and environmental protection. This is especially true in evaluating the nutrient management situation on individual farms. A major goal of nutrient management for crop production and environmental protection is the balance between agronomic crop requirement and the supply of nutrient available on the farm. Based on the evaluation of material movement, approaches to nutrient management can be developed that are sensitive to specific farm situations and the existing strategies of farm management.

Three representative examples of farm nutrient flow are illustrated in Figure 1. The managed pathways of nutrient flow on a modern cash-crop farm are shown in Figure 1a. Nutrients come on to this farm in fertilizers and other materials that are applied directly to the fields. Crops harvested from the fields take a fraction of the applied nutrients with them. When the crops are sold the nutrients the crops contain leave the farm. There is a direct connection between the flow of nutrient and the agronomic or economic performance of a farm with this pattern of organization. Traditional economic and agronomic incentives can then be effective in guiding nutrient use on these farms for crop production (and farm production) and for environmental protection. Of course, the managed nutrient paths illustrated are not the only ones nutrients can take. Significant losses from fields can occur if nutrients are over-applied compared to the crop utilization or if nutrients are otherwise allowed to be lost from the fields. The cost of practices that increase efficiency of utilization and/or reduce nutrient losses on a cash-crop farm can be at least partially offset by decreased cost in purchased fertilizer to offset the nutrient losses.

Crop and livestock farms traditionally have been viewed as producing animals or animal product outputs that result from the almost exclusive use of on-farm resources. A large proportion of the plant nutrient in the crops produced as feed for the animals are returned to the farm fields in manure from the animals. Nevertheless, fewer nutrients will be returned to the fields in the manure than were harvested in the crop, so the efficient return of nutrients to the fields is critical to maintain crop production (and farm production) on such a farm. With uniform manure distribution, nutrients are unlikely to be lost to the environment under these nutrient-poor conditions. Changes in management are therefore unlikely to be necessary to protect the environment on these farms.

The ready availability of fertilizers since the 1950s has made it possible to offset the losses of plant nutrients in animal production and manure handling from a traditional "self-sufficient" farm. If the nutrients previously available on the farm were inadequate to meet potential crop productivity, fertilizer and other plant nutrient inputs to the fields not only offset the losses of nutrients from the farm, they made it possible to build soil fertility to achieve greater potential crop production. This is the familiar nutrient response to fertilization that was so important to the rapid, widespread adoption of fertilizer by farmers.

Also, off-farm feeds can either be produced on another nearby farm and transported by the farmer to the farm where the animals are housed or they can be purchased commercially through a feed company and delivered to the farm. A key factor on modern crop and livestock farms is that the manure produced by the animals no longer must be spread on the fields where the crops were produced to maintain crop or animal production. The plant nutrients in the feed inputs can offset the losses of nutrients from the farm in the animal products or the manure handling losses as fertilizer did on the traditional farm. Accounting for all sources of plant nutrients being applied to fields becomes an important management activity to protect the environment from negative impacts associated with the overapplication of nutrients to crop fields. The on-farm resources on a modern crop and livestock farm with ruminant animals can be supplemented with fertilizer inputs directly to the fields and with off-farm feeds or other animal input. The resulting pattern of organization (Figure 1b) is significantly different from a traditional crop and livestock farm or a modern cash-crop farm.

While conditions have changed in agriculture so that intensified animal production supported by off-farm feed is possible, the changes are not just in the amounts of nutrients flowing to, from, and within the farms. The concentration of animals in larger facilities results in more manure in limited areas. The distance and amount of manure to be hauled can increase substantially if the nutrients are to be spread uniformly over potentially suitable crop areas. The farmer will generally be responsible for the costs of this additional manure hauling.

Since farms with this pattern of organization sell primarily animal products, farm performance can be different from the magnitude or efficiency of crop performance. Farm performance depends on the animal husbandry skills of the farmer and the utilization of off-farm production inputs, not just success in crop production. On a farm organized this way the decisions about plant nutrient use in the fields are not as sensitive to the economic or agronomic criteria of crop production as on the modern cash-crop farm.

Trends in animal housing and the success of crop production on cash-crop farms in specialized geographic regions have made it possible to concentrate large numbers of non-ruminant animals, such as poultry or hogs, on small land areas. Most, if not all, of the feed necessary for these animals can be economically transported to the farm where the animals are housed. Even though these farms may produce crops for off-farm sale, the land areas involved can be quite limited since the focus of the management activity is on animal production (Figure 1c). The cash-crop farm and the intensive modern livestock farm are connected by the flow of feed. However, nutrients in this flow often do not cycle back from the livestock locations to the areas of crop production. Breakdown of the nutrient cycle is a significant feature of the nutrient management situations encountered on these farms.

The difference between nutrient management on the cash-crop farm and the modern crop and livestock farm with non-ruminant animals is that the application of nutrients to the fields on the crop and livestock farm is not closely related to the major production activity of the farm: selling animals or animal products. The field-based economic and agronomic incentives that can be effective for managing nutrients on a cash-crop farm, and that will also minimize negative environmental impacts, are not as significant on the intensive livestock production-oriented farm. Further, field-based agronomic practices may be of limited effectiveness in utilizing the total quantity of nutrients on the farm because of the small land area that is necessary for animal housing. It is very likely that plant nutrient management to protect environmental quality cannot be accomplished solely on the farm where the animals are housed. Successful management of nutrients to protect the environment will depend on support from off-farm people and organizations. Neighbors with land for manure application could cooperate by providing land for manure distribution. Off-farm organizations may deal with manure hauling to locations where the manure can be used directly or transformed into another product such as compost.

The nutrient management process

Since nutrients are transferred to, from, and within farms with the movement of almost all common farm materials, such as crops, animals, and manure, nutrient management generally involves decision-making about a wide range of farm operations. These management decisions are made as frequently as several times a day to as seldom as once every five years or more. Decisions may deal with day-to-day details, such as spreading manure on a specific field on a particular day, or with the long-range future of an entire farm, such as the decision to build a manure storage unit. Nutrient management is an ongoing repetitive farm process with several key activities (Figure 2).

Since nutrient management is ongoing, an initial assessment of the farm and the potential environmental impacts of the existing farm operations is an effective starting place in many situations. Nutrient management need not start with a plan. In the assessment the approximate nutrient balance of individual fields, groups of fields that are treated similarly, or even the whole farm can be determined depending on the purpose of the assessment. The outcome of the assessment can be used as the basis for selecting options for farm nutrient management to protect the environment while producing crops and animals. The extent of nutrient management assistance required to change farm operations will also be influ-

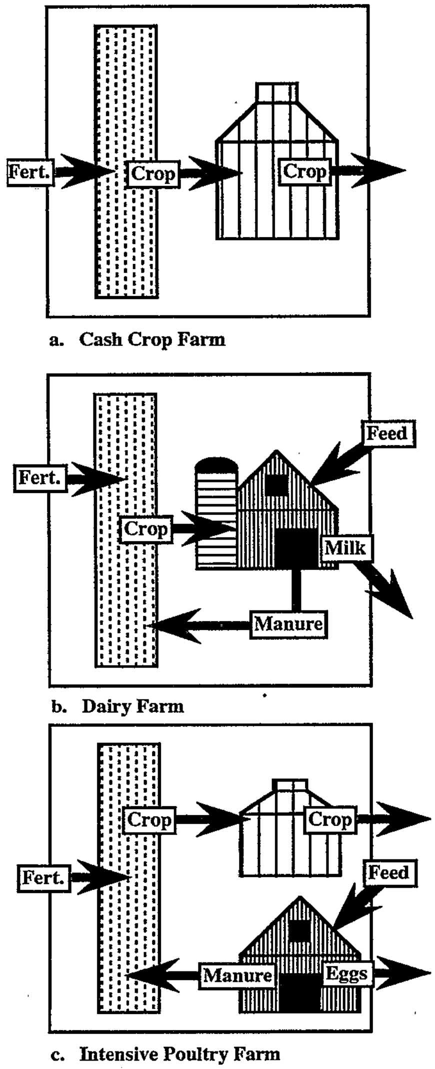

Figure 1. Nutrient flows on representative farm types.

enced by the type and extent of the options to be incorporated.

Nutrient management options can be specific practices, such as incorporating field-applied manure soon after application, identifying other landowners who may be interested in having manure spread on their fields, or more far-reaching possibilities, such as postponing a planned expansion of the livestock housing facilities on the farm. The assessment and the options selected can be the basis for many decisions that will be made in the development of a farm nutrient management plan.

Implementation of a nutrient management plan involves both the actual activities called for in the plan plus the appropriate recording of those activities so that the effectiveness of plan implementation can be assessed. The success of the management plan can be evaluated in a repeat of the original assessment.

Changes in management will generally involve a transition period from the existing to the "improved" management. The change in management could involve the adoption of new practices or require new financial arrangements to deal with the costs of implementation. The transition period can be of different lengths on different farms depending on the current status of the farm and the extent of the changes required. For those farms that successfully negotiate the transition, following nutrient management guidelines for crop production and environmental protection may simply become a part of normal farm operations in the future unless the farm operations (or environmental expectations) change significantly.

The nutrient management process can be applied at the strategic, tactical, and operational levels of management, although tactical levels may be the most common point of off-farm technical input. At the strategic level management decisions are made by the top management of the farm regarding long term goals and strategies for the operation. Examples of strategic decisions include whether to expand the livestock operations or not, or whether to acquire more land or reduce livestock numbers to achieve nutrient balance on the farm. A very broad cross-section of information is used at this level of decision making. Most of the input for strategic decision making comes from outside the farm. Information on markets for expanded production, availability of labor, or regulations regarding nutrient management would be examples of the type of information used in making strategic decisions. Thus, nutrient management goals are substantially shaped by the conditions in the surroundings of the farm, not by the actual resources or activities on-farm. If new expectations for farm performance are to be implemented, exploring the natural and social conditions within which farms must function can be more fruitful than the development of detailed practices. Practices will follow from water quality protection strategies, but practices will not mandate strategies. At best, prescribed practices will only be adopted by farmers for whom the practices are consistent with their strategies or those who are compelled to adopt them. With the difficulty in enforcing water quality protection standards for nonpoint source pollution, emphasizing and rewarding transformations in farm strategies may be the most effective approach to change.

Nevertheless, most nutrient management promotion for water quality protection emphasizes the tactical level of management. The time-frame for tactical decision making is usually from a few months to a few years. This management deals primarily, but not exclusively, with site-specific information about the farm. It is intended to implement the broad strategies outlined in strategic management. The farm nutrient management plan, in which specific nutrient allocation decisions are made for the farm, is the most common example of this level of management. When the tactical plan is the primary mechanism for implementing nutrient management for environmental protection, the possibility and consequences of accommodating the potentially different strategic goals of the farmer and society in the plan must be recognized. For instance, a farmer may not voluntarily adopt a complete nutrient management plan if the environmental protection features require contradictions with the goals of production, technology, or lifestyle that are embedded in his/her strategies. Or, if a plan is agreed upon that is on the surface consistent with the environmental protection goals and the farmer's goals, discretionary decisions will tend to favor any competing farmer goals so that implementation may be inadequate for the environmental goals.

The operational level is the most detailed level of management. At this level the tactical plan is actually implemented and decisions are made about specific tasks to be performed by the farm labor force. For example, the tactical plan may call for certain fields to receive manure at a given rate this year. The operational manager will decide on any given day who will spread manure using what equipment and on which field. This type of decision making is generally short term and requires in addition to a tactical plan, timely, very site-specific information such as weather forecasts, soil conditions, and availability of labor and equipment. Record keeping is also an important role of the operational manager. Good records of what is actually implemented on the farm are crucial for sustaining the management process. These records provide the basis for subsequent assessment of the tactical plan implementation. Discrepancies between the plan and the actual performance can be evaluated and different management options may be selected for inclusion in the next iteration of tactical plan development. Information from the tactical assessment based on these records is useful to the strategic manager for evaluating progress toward achieving the strategic environmental and production goals of the farm.

A farm production strategy assessment especially for crop and livestock farms in a production setting like Pennsylvania can be illustrated using either animal density on the farm or off-farm feed used on the farm for the animals and nitrogen fertilizer applications to corn. An assessment matrix and management option relationships based on these criteria can be used by farmers or technical support practitioners to assist in the nutrient management process for environmental protection and farm production (Table 1). From this simple assessment the strategic decision maker can evaluate factors such as the pollution potential of the operation, whether there is likely to be adequate land available for environmentally sound manure nutrient utilization, the type and extent of management assistance required for environmental protection, and possible economic implications of nutrient management for environmental protection for the farm.

Different tactical nutrient management plans will be developed depending on the preceding assessment of the farm. Low intensity farms are those where there is not enough manure generated on the farm to supply the total crop nutrient needs. Tactical plans to ensure adequate crop production and environmental protection for farms in this group would incorporate practices to maximize nutrient use efficiency on the farm. The environmental impact of any practices selected is likely to be nominal except where there is currently gross mismanagement. Consequently, changes in operations on these farms would have a small beneficial effect on the environment. While a formal nutrient management plan for environmental protection may not be required for this group, the possibility exists for positive economic benefits to the farmer based on more efficient nutrient utilization from manure that could be offset by the reduced costs of previously-utilized fertilizer. Nutrient management plans on these farms will use soil tests and manure analysis to assure distribution and timing of manure applications to maximize nutrient availability from the manure and minimize the purchase of commercial fertilizer. Examples of practices that would be appropriate on this group of farms include spring application of manure, immediate incorporation of manure, use of cover crops to scavenge nutrients, no manure spreading on legumes, and manure storage.

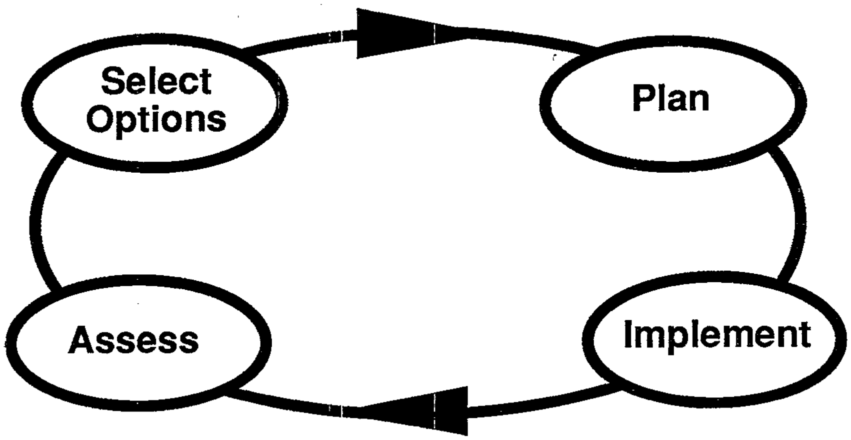

Figure 2. A schematic of the nutrient management process illustrating the four activities.

Medium intensity farms are those that generally generate enough manure to meet the total crop nutrient needs. Tactical plans to ensure adequate farm production and environmental protection would incorporate practices to maximize environmentally-safe nutrient utilization on the farms in this group. If there is enough or more than enough nutrients on the farm to meet the crop requirements, efficiency will likely be a secondary concern. The major concern will be safely using all of the manure produced. Intense management will be needed to provide the most favorable economic situation while protecting the environment. There is good potential for environmental benefits from improved management on these farms. Generally the economic impact of nutrient management for environmental protection on these farms will be small. Changes in the overall farm management, such as altering the cropping system, may be necessary strategic decisions on this group of farms. At the tactical level a detailed manure management plan will probably be necessary on these farms and will be based on nutrient balance rather than crop response. Most farmers in this group will probably want to take advantage of technical assistance from public agencies and/or private consultants in developing and implementing a nutrient management plan. The plan will use soil tests and manure analysis in conjunction with appropriate management practices to match as closely as possible nutrients available in manure with crop needs over the entire rotation. Practices such as spreading manure on legumes and not incorporating manure are examples of management options that may be appropriate for this group.

On high intensity farms, animal manure production often significantly exceeds total crop nutrient needs. Tactical plans to ensure adequate farm production and environmental protection for this group of farms will involve determining the maximum amount of manure that can be safely utilized on the farm. A substantial amount of detailed field by field nutrient management planning will not usually be necessary. In most cases the available land and the high residual nutrient levels in the soil may severely restrict on-farm use of manure. This group of farms has the highest potential for negative impacts on the environment. Alternative off-farm uses for the excess manure will need to be explored. In most instances this will mean locating a market for the manure and arranging the logistics of transportation and

Table 1. Nutrient management assessment and management options based on the potential for available soil nitrogen balance.

Criteria	Category 1	Category 2	Category 3
Farm Characteristics (Assessment)			
Animal density (Animal units/acre routinely manured)	Low (<1.25/A)	High (1.25-2.25/A)	Very high (>2.25/A)
Feed source (% Off-farm)*	On-farm (<50%)	Combination (50-80%)	Off-farm (>80%)
Non-manure nitrogen applied Nitrogen fertilizer use (lbs/A on corn)	Low to moderate (<50 to 150)	Low to high (<50 to >150)	Low to high (<50 to >150)
Management Considerations for Environmental Protection			
Adequate land available for manure spreading	Yes	Usually	No
Manure balance	Deficit	Balanced	Excess
Nonpoint source pollution potential	Low	Low to high	Very high
Assistance for: Field by field Nutrient management planning	Low to moderate	Moderate to high	Low
Assistance for: Nutrient management implementation	Low to moderate	Moderate to high	High
Source of nutrient management options	On-farm	On-farm	Off-farm
Manure management strategy	On-farm efficiency	On-farm high utilization	Off-farm distribution of excess
Manure management system	Yes	Yes	Yes
Economics of manure management	+	+ or –	–

*Feed purchased or grown on land not routinely manured.

appropriate use. Appropriate nutrient management plans should be developed for the farms where the manure is ultimately utilized. In many cases, unless a favorable marketing arrangement can developed, implementing improved nutrient management on this group of farms will have a negative economic impact on the farm. Assistance from public agencies and private consultants, manure brokers, and manure haulers will be critical to improve nutrient management for environment protection. Unfortunately, this is an area of nutrient management that is not currently well developed.

Farm nutrient management planning

Each farmer is currently involved in nutrient management. Each farmer currently has a nutrient management plan. Many of these informal or formal plans focus on providing nutrients for crop production. Some of these existing plans will also achieve environmental protection goals. Where it has been determined that a farm has a high potential for environmental impact from on-farm nutrient management or that implementation of an existing plan does not adequately protect the environment, formalizing the plan to manage all nutrient sources for crop production and environmental protection can be an effective approach to reconcile the multiple interests of society in nutrient management. Implementation of nutrient management plans for crop production and for protecting environmental quality will be most successful if the plan emphasizes modifications of the farmer's current management to meet evolving environmental expectations rather than coming up with a completely new plan that may bear little relationship to the farmer's existing management. This is why having a good assessment of the current strategy and/or ongoing nutrient management activities is so essential to achieving new nutrient management goals.

Nutrient management includes the use of manure and other nutrient sources to meet plant nutrient needs. It takes into account nutrient needs throughout the crop rotation, realistic expected crop yields, site limitations, existing soil nutrient levels, and timing, placement, and amounts of additional nutrients applied to the fields. Information required to develop these plans will vary among farms, but will likely include crop acreage, crop field histories, measured harvests or crop yield checks, amount of manure generated based on the livestock or poultry number and size and handling facilities, amount and kind of manure applied per acre, amount of purchased fertilizer applied per acre, soil test results and recommendations, manure analysis, and manure spreader calibration.

Once the net nutrient needs have been determined for individual fields or crop groups, the areas to be spread should be prioritized for manure applications. The highest priority fields to receive manure should be those determined to have the lowest residual nutrient concentrations, those in which the crop to be grown has the greatest nutrient needs, and those in which detrimental environmental effects will be minimized (no sinkholes, not a floodplain, gentle slopes, soils with low leaching potential, etc.). All remaining fields are ranked in descending order. Table 2 summarizes the factors that must be considered during the field prioritization process.

After fields have been prioritized, available manure is allocated to fields based on their ranking. The manure application priority does not determine the actual sequence of manure spreading on the fields. This operational decision is based on such factors as cropping plans, soil conditions, weather, time available, etc. at the time the manure is being spread within the context of the tactical plan. The prioritization of fields simply indicates that when all of the manure has been spread, the high priority fields will have received manure rather than the low priority fields.

The nutrient nitrogen (available or total) or phosphorus, used as a prioritizing criterion for manure application, will significantly affect manure allocation. Manure application rates to nonlegume crops based on available nitrogen are likely to be greater for a particular year than if the rates are based on phosphorus, especially if the crop is harvested as grain. If phosphorus requirements for a crop sequence including crops that will not receive manure are used as the basis of the manure application, higher rates may be possible than if based on available nitrogen. If the nutrient content of the manure exceeds the annual crop requirements of available nitrogen or phosphorus for the planned crop sequence, options must be developed to deal with the excess manure. For instance, the nutrient management plan may be altered to include more intensive crop production through doublecropping, different crop selections or harvesting methods (whole plant vs. grain), or improved crop management leading to higher crop yields. Or, options to export manure from the farm can be identified. Since nutrient management is an integral part of the total farm operation, there may also be options available in the management of the farm animals. These would include changes in the protein or phosphorus concentration of the animal rations, in the components of the animal ration to enhance the efficiency of utilization, or in facilities management to decrease the amount of nutrients in the manure.

It is not likely that it will be practical for a farmer to apply the exact manure rates calculated to balance the crop nutrient requirements for each field. However, calculating the balanced rates will provide a guide for the maximum amount of manure that should be applied. For practical operations, the calculated rates can be used to group fields and to determine the appropriate rate or rates to apply. Finally, the nutrients to be applied in manure, based on the selected application rates, must be compared to the nutrients required by the crops. Deficiencies will need to be corrected with nutrients from other sources.

Table 2. Field prioritization of manure applications.

Categorized by priority nutrient:	High priority for manure	Low priority for manure
Crop N needs	N-requiring crops	Non-N requiring crops
N requirement and residual N	Highest N requirement Lowest residual N	Lowest N requirement Highest residual N
P soil test level and K soil test level	Lowest P level Lowest K level	Highest P level Highest K level
Categorized by environmental considerations:		
Proximity to	Water bodies Sinkholes Flood plains	
Soil limitations	Leaching potential (soil hydrologic group) Erodibility and runoff (degree of slope)	
Land cover	Presence of a growing crop, crop residue or cover	
Practical limitations	Distance to manure source Neighbor concerns Land tenure	

Performance vs. BMPs

The motivations for farmers to change their nutrient management practices are many. The reasons may be economic, social, or personal preference, to name a few. As society demands more accountability from farmers, there will likely also be regulatory motivations. There are two approaches to environmental regulation. One approach is to specify what should be done on all farms as a recipe for nutrient management. Lists of required standard practices or best management practices (BMPs) such as specifying times, rates, and methods of manure application for all farmers is an example of this approach. Although this approach is relatively simple to administer, it does not accommodate specific conditions of particular farming operations or the nature, interests, abilities, or local conditions of individual farmers. Neither does this approach address needed changes in the current structure of agriculture. Closely specifying particular farming practices can also limit innovation by farmers and farm advisors in finding ways to deal with new requirements for crop production and environmental protection. Specific practices are characteristic of the operational or tactical level of management. Social expectations of farming for both farm production and environmental protection may be best represented as strategic goals, not operational specifications. Thus, rather than attempting to achieve complex goals by specifying detailed management (or behavior), alternatives that are consistent with the site-specific character of farming should be considered.

Such an approach to farm nutrient management would emphasize performance criteria for farmers to meet as part of their farm management and generate an incentive structure to recognize that performance. Performance criteria are outcomes to be achieved through nutrient management such as nutrient balance for the farm fields. These criteria are not lists of specific activities or BMPs that all farms must follow, but rather they are targets that are established and farmers and their advisors are given the freedom to develop and implement a plan integrating any practices or BMPs that are appropriate. There would be no official list of standard BMPs but rather a wide range of activities conducted on individual farms in order to meet the expectations. Carefully established outcomes can promote solutions to meet the environmental challenges faced by farmers based on local conditions while stimulating innovation at the same time. Success of this approach is predicated on the ability to deliver appropriate technical support. Clearly defined, measurable outcomes are essential to this approach to nutrient management. Incentives for meeting the performance criteria would reinforce the approach to farming that is consistent with the strategic goals of society. If the incentives that are currently in place are not revised, promoting nutrient management to protect the environment is not likely to be accepted by those producers who need to make the greatest changes to meet environmental requirements. If the current incentives were adequate for environmental protection it is unlikely that we would have the environmental problems in the first place. Teaming performance criteria with incentives could entice those who might not otherwise participate to do so. ❑

Minimizing surface water eutrophication from agriculture by phosphorous management

T.C. Daniel, A.N. Sharpley, D.R. Edwards, R. Wedepohl, and J.L. Lemunyon

Runoff from agricultural land is one of the major sources of nonpoint source (NPS) pollution. In recent reports to Congress, USEPA identified agricultural NPS pollution as the major source of stream and lake contamination preventing attainment of the water quality goals identified in the Clean Water Act (*54*). Nutrients from agricultural nonpoint sources have been identified as the main cause of cultural eutrophication in freshwater inland lakes of the U.S. and an important source of nutrients to estuaries, affecting 57 and 18 percent of impaired lakes and estuaries, respectively (*57*). With increasing amounts of phosphorus (P) control being required of point source discharges, agricultural NPSs of P are an increasing national concern. In most cases, noxious aquatic weed growth results from the addition of excessive amounts of nitrogen (N) and P (*24*). Concentrations of 0.3 and 0.01 mg L^{-1} for inorganic N and P, respectively, have been identified as critical levels expected to promote noxious aquatic plant growth in lake water (*38*, *59*). Phosphorus is the single most important nutrient to manage for controlling accelerated eutrophication in freshwater lakes (*55*). Although N may occasionally be limiting to algae during certain periods of the year, for example, when the total N to total P ratio is less than 15:1, P is still most often the nutrient of concern. Controlling P inputs to lakes is much easier than controlling N sources, as certain blue-green algae are capable of fixing atmospheric N. It is important to note that even when algal growth is limited by N, P load reduction can result in improved water quality if the load reduction is sufficiently large to drive the lake or reservoir to P limitation. In estuaries, both P and N are often limiting nutrients, with P being the limiting nutrient in the upper, freshwater dominated portions and N in the more marine dominated regions (*8*).

The relative importance of P and N to the productivity of free-flowing waters is less well understood. Bothwell (*4*) showed that although there was a relationship between peak areal biomass of periphyton communities in streams and P concentrations, P was not limiting when dissolved P (DP) concentrations exceeded 0.03 to 0.05 mg L^{-1}-levels exceeded in all but the most oligotrophic streams.

This paper will provide background information on the forms and sources of P, the importance of minimizing P in surface waters, procedures for identifying P-sensitive water bodies, and management approaches that limit P loss.

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Phosphorus chemistry of soil and runoff

Phosphorus occurs naturally in soil at levels between 300 and 1,200 mg kg^{-1}, although amounts can vary from 100 to 2,500 mg kg^{-1}. The wide variation in soil P content is a function of parent material, texture, and management factors such as the rate and type of P applied and soil cultivation. These factors also influence the amount of P in inorganic and organic forms. In most soils, 50 to 90 percent of the P is inorganic, consisting of iron and aluminum phosphates in acidic soils and calcium phosphates in alkaline soils. Most inorganic P forms are so insoluble that only a small fraction (< 10 percent) is available at any one time for plant uptake.

The major portion of soil organic P is in stable fulvic and humic compounds. More labile organic P forms, such as glycerophosphates, phosphosugars, phospholipids, and nucleic acids can be mineralized by microbial activity. Although less than 5 percent of soil organic P is usually mineralized annually, in some cases this supplies sufficient P for plant growth.

Plants absorb inorganic P from soil solution, the level of which is determined by adsorption and desorption of labile iron, aluminum, and calcium phosphates; dissolution of more soluble mineral forms of recently applied P; and mineralization of organic P. Adsorption of P by soil occurs rapidly and because of the high binding energy between soil and P, adsorption tends to dominate desorption. Thus, a general decrease in plant-available P occurs after P is applied. As the labile form of P is depleted by plant uptake, it is slowly replenished by inorganic P desorption, organic P mineralization, crop residue decay, and applied fertilizer or manure.

The loss of soil P in runoff occurs in dissolved and sediment-bound or particulate forms (Figure 1). The standard procedure to separate dissolved and particulate forms in runoff is by filtration through a 0.45μm pore diameter membrane filter. Dissolved P is comprised mostly of orthophosphate which is immediately available for algal uptake (*33, 60*). However, variable amounts of organic and colloidal P less than 0.45μm may pass through the filter and be hydrolyzed or dissolved by the strong acidic medium of the molybdate-blue procedures used for P analysis. Amounts of dissolved organic P are normally small with 90 to 95 percent DP actually bioavailable (i.e., algal available) (*22, 50*).

Sediment P includes P sorbed by soil particles and organic matter eroded during runoff and constitutes the major portion of P transported from conventionally tilled land (75 to 95 percent). Runoff from grass or forest land carries little sediment and is dominated by dissolved P. Sediment P can provide a variable but long-term source of P to aquatic biota. Sharpley et al. (*46*) found that from 10 to 90 percent of P associated with sediment runoff was bioavailable and varied as a function of watershed management.

The first step in the movement of dissolved P in runoff is the desorption, dissolution, and extraction of P from soil crop residues, fertilizer, and manure (Figure 1). These processes occur as rainfall interacts with a thin layer of surface soil (< 2 cm) before leaving a field as runoff (*40*). Once in runoff water, dissolved P can be resorbed by runoff sediment. In runoff from no-till or pasture, the sediment load is generally so low that little dissolved P is adsorbed by suspended sediment. Under these conditions, losses of dissolved P can exceed losses in runoff from conventional tilled fields with higher erosion. Rainfall that does not run off percolates through the soil profile where sorption by P-deficient subsoils results in low dissolved P concentrations in subsurface flow.

As P is sorbed by soil material, erosion determines sediment P movement (Figure 1). Sources of sediment P in streams include eroding surface soil, plant material, stream banks, and channel beds. Where there is permanent vegetative cover, such as forest or pasture, the primary source of sediment is from stream bank erosion. This sediment will have characteristics similar to the subsoil material of the area which is often of low P content. During detachment and movement of sediment in runoff, the finer-sized fractions of source material are preferentially eroded. Thus, the P content and reactivity of eroded particulate material is usually greater than source soil (*41*).

As P moves to a lake by stream flow, there is generally a progressive decrease in P load by water dilution and sediment deposition. However, P often becomes more algal available as it moves from the edge of a field to a lake as a result of these chemical and physical processes.

P sources and management considerations

Phosphorus is supplied to crops through application of both commercial fertilizer and animal manure. For both P sources, runoff losses are generally greatest in the short-term (one to three runoff events) following application with the amount of fertilizer P lost in the runoff generally less that 5 percent of that applied.

Commercial fertilizer. Loss of P in the runoff from cropland is influenced by the rate, time, formulation, and method of fertilizer application. The severity of the runoff-producing event and amount of surface cover also influence P loss. A clear relationship exists between P application rate and method and amount of P transported in the runoff. In a field and laboratory study, Römkens and Nelson (*37*) demonstrated a linear relationship between the amount of P added as fertilizer and runoff P loss. Baker and Laflen (*2*), using simulated rainfall, confirmed this work and further demonstrated the effect of fertilizer placement on runoff P transport. Concentrations of DP in the runoff from areas receiving broadcast applications of P fertilizer averaged 100 times higher than the runoff from areas receiving similar rates of P that were point-injected below the soil surface. Time of P application also influences the amount ultimately transported in the runoff. Generally, one or two runoff events account for the majority of the P lost in the runoff (*62*). If these runoff events coincide with recent application of P, regardless of the form of P, then the amount of P transported in the runoff is expected to be higher than if P applications were made during times of low runoff probability (*15*). For example, Burwell et al. (*6*) in a watershed study demonstrated that P loss in Missouri was greatest during the planting season; a time consistent with the most intense rains, P application, and minimum crop cover.

There is no intrinsic reason for

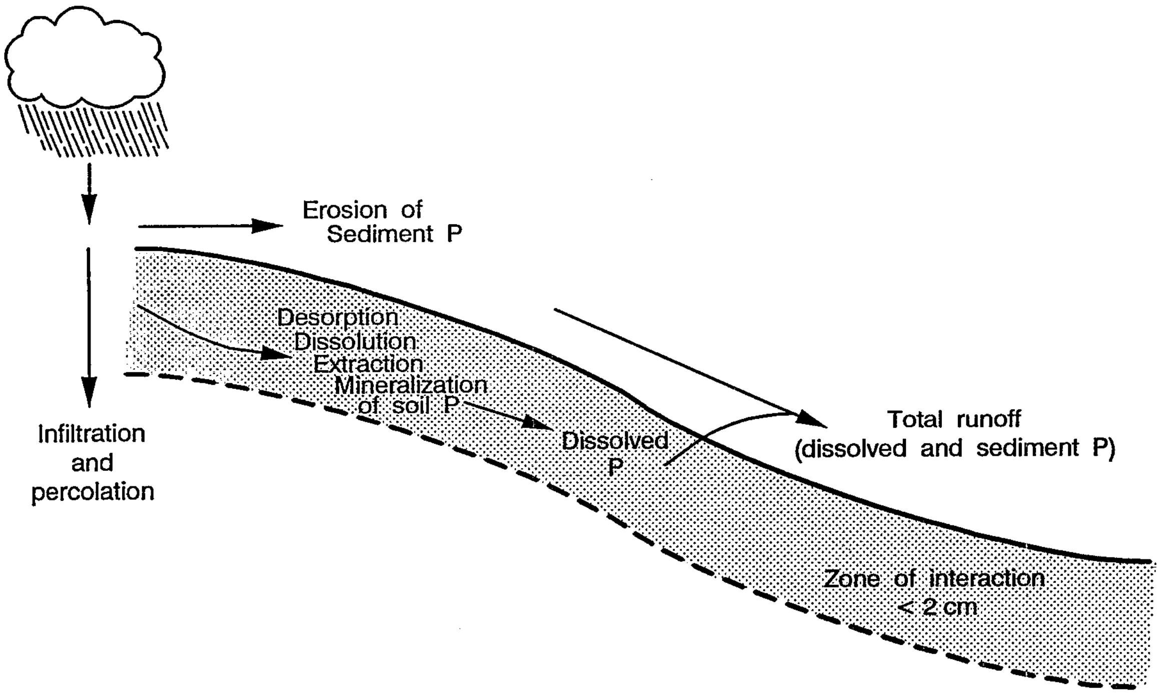

Figure 1. Processes involved in the transport of dissolved and sediment P in runoff.

long-term management of commercial fertilizers to lead to problems associated with accumulation of soil P. Commercial fertilizers allow producers the flexibility to tailor the fertilizer treatment to the specific needs of their crop, soil, and weather conditions. Application of P at rates consistent with crop needs will prevent overapplication of P and subsequent accumulation and is in the economic interest of the producer. Poorly managed application of commercial fertilizers, however, has the potential for causing accumulation of soil P and thus for promoting increased P loss. Pierzynski et al. (*34*) examined several midwestern soils and attributed soil test P (STP) levels of 218 and 246 mg kg^{-1} in a Plainfield sand (Wisconsin) and Blount silt loam (Illinois), respectively, to addition of commercial fertilizer.

Animal manure. While row-crop production in the Corn Belt can result in contamination of surface waters with sediments, nutrients, and pesticides (*20*), Duda and Finan (*11*) showed that the greatest potential for accelerated eutrophication occurs in geographic regions of intense animal production. Regions that coincide with intense animal manure production are especially susceptible to eutrophication for several reasons. Efficiency of operation requires confinement of large numbers of animal units and ultimately the production of large volumes of manure. The nutrient value of fresh animal manures averages approximately 4.3 percent N, 1.4 percent P, and 2.2 percent K (*1*). The nutrient content of slurry or liquid manures will be diluted considerably. Losses of N can occur during storage and land application, further diminishing the nutrient content of manures.

Both long- and short-term P losses are of concern in the context of manure application. The greatest potential for short-term (the first one to three storms following application) P loss occurs when the manures are surface-applied, in which case P loss is directly proportional to P application rate (*12*, *13*, *14*). Runoff P concentrations during storms that occur soon after application can be quite high; Edwards and Daniel (*12*, *13*, *14*) measured total P (TP) concentrations of 22, 29, and 12 mg L^{-1} in the first storm following application of poultry litter, poultry manure, and swine manure, respectively. Large proportions of TP in runoff from areas receiving animal manures can be in the dissolved form and available for algal uptake (*12*, *13*, *14*, *29*).

Generally manure is land applied with application rates based on N with no consideration given to the amount P in the manure. Animal manures are normally applied at rates sufficient to meet N needs of the receiving crop. Since animal manures have an average N:P ratio of 3:1 (*16*), and major grain and hay crops use N and P at a ratio of approximately 8:1 (*64*), excess P is supplied when manure is used to meet all the N needs of the crop. If application rates are adjusted for N losses via processes such as volatilization and denitrification, the excess P applied can be significantly greater. For example, if manure is used to meet the N needs for fescue production in northwest Arkansas, an excess of 40, 37, and 17 kg ha^{-1} of P will be applied using poultry, swine, or dairy manure, respectively (*1*, *19*, *53*).

Elevation of STP levels. Long-term application of fertilizer P at rates exceeding those of crop removal has resulted in elevated levels of STP, especially in areas where long-term land application of manure has been practiced. For example, in Wisconsin the average STP level for all soil tested was 48 mg kg^{-1} and for coarse textured soils used for intensive vegetable production the average STP level was 72 mg kg^{-1} (*7*). In Delaware, 65 percent of the soils tested were considered in the high range (*47*). Several midwestern soils were examined by Pierzynski et al. (*34*) and elevated STP levels were attributed to the addition of commercial fertilizer. Dairy manure application has contributed to 200 mg kg^{-1} STP levels in Wisconsin (*27*). Unfortunately, once high STP levels have been reached, considerable time is required for noticeable depletion. McCollum (*26*) estimated that without further additions of P, eight to 10 years of cropping corn (*Zea mays* L.) or soybean [*Glycine max* (L.) Merr.] would be required to reduce P levels in a Portsmouth sand from 54 mg kg^{-1} STP (Mehlich-III) to 20 mg kg^{-1}.

Relationship between soil P and runoff P. The P content of surface soil directly influences the loss of P in runoff. In fact, a highly significant linear relationship was observed between the soil test P (STP as Bray - 1 P) content of surface soil (1 cm [0.4 in]) and the dissolved P concentration in runoff from cropped and grassed watersheds in Oklahoma (Figure 2) (*44*). A similar dependence of the dissolved P concentration in runoff on the level (Bray-1) of STP was found by Romkens and Nelson (*37*) for a Russel silt loam in Illinois (r^2 = 0.81), on a Tokomaru silt loam in New Zealand by Sharpley et al. (*45*) (r^2 = 0.98, 0.1 M NaCl extractable soil P), and on water extractable soil P (r^2 = 0.61) of 17 Mississippi watersheds by Schreiber (*39*).

Vaithiyanathan and Correll (*58*) observed that the loss of P in runoff from forested and cropped watersheds in the Atlantic coastal plains was closely related to soil P content (r^2 = 0.96). In fact, the high organic P content of the forest soils (331 mg kg^{-1}; 70 percent of total P) contributed to the high organic P loss in runoff, while the high inorganic P content of the cropped soils (486 mg kg^{-1}; 75 percent of total P) resulted in a higher inorganic P loss. Other studies have also demonstrated the close dependence of P loss in runoff upon surface soil P content (*3, 35, 36, 51*).

Other factors that affect the loss of P in runoff include depth of surface soil that interacts with runoff water, the concentration of sediment in runoff, and runoff volume. Few mechanistic models have been developed to quantify these factors, so simpler, empirical models have been proposed. Using simulated rainfall, Sharpley et al. (*43*) investigated the effect of these factors on P transport in runoff. Eventually, an equation describing the kinetics of soil P desorption was proposed to predict P transport in runoff (*42*). Using this equation, Sharpley and Smith (*42*) were able to demonstrate close agreement between predicted and measured soluble P concentration in the runoff from long-term watershed studies. Other researchers have recognized the essential role of soil P concentration in developing methods to estimate P losses. Storm et al. (*48*) used a modification of the equation of Sharpley and Smith (*42*) and described particulate P loss as directly proportional, within a particle size class, to soil P concentration in a combined soluble/particulate P transport model. Wendt and Alberts (*63*) used similar methods to estimate transport of P adsorbed to soil particles and incorporated isotherms to account for adsorption/desorption dynamics. Soil P concentration was an integral input to the physically-based P transport model developed by Novotny et al. (*31*). Comprehensive hydrologic/water quality models such as EPIC (*65*), CREAMS (*21*) and AGNPS (*67*) estimate losses of P as directly proportional to P concentration in the upper layer of soil.

Priority water body selection

Identification of P-sensitive water bodies. Recently there have been several management efforts involving federal, state, and local governments in cooperation with individual citizens to manage NPS problems (*61*). Of note was a recommendation to target limited financial and technical resources on the most valuable and impaired watersheds, with additional priority on projects having strong local support.

The development of clear water quality objectives is essential. Individual lakes or reservoirs will respond differently to the same phosphorus loads because of morphological differences related to depth, water residence time, and degree of stratification. Additionally the principal use desired of a particular water body will vary and will affect the "desired" inland lake phosphorus concentration and loadings. Lakes used principally for water supply, swimming, and multi-purpose recreation will benefit from low phosphorus loadings. Lakes principally used for fish production may benefit from a moderate degree of fertility (*32*).

Approaches to developing priorities vary from state to state. Wisconsin, which has an ongoing NPS priority lakes and watershed program, utilizes an iterative process to identify lakes needing nonpoint source controls. Lakes in Wisconsin are grouped into two classes based on their sensitivity to phosphorus. Of the 15,000 identified inland lakes in Wisconsin, approximately 1,400 were targeted for phosphorus control. The principle criteria used were (a) lakes had to be greater than 10 ha (25 acres) in size to be reflective of their relative value to the state's tourism and recreation base, (b) lakes had to have flushing rates fewer than six times per year to separate them from riverine systems in which phosphorus is of lesser concern, and (c) lakes had to be deep enough to stratify. This last criterion was used to identify lakes in which internal phosphorus cycling occurs and for which most of the commonly used empirical, Vollenweider-type models were developed.

To further screen lakes for possible selection as a NPS control project a point system is used to rank lakes. Included in this ranking are factors which determine the degree to which (a) the lake's water quality is threatened; (b) the lake is able to respond or to be protected from threats if best management practices are implemented; and (c) the lake is valued as a resource. Finally, high ranking lakes are selected by a nomination process for inclusion into the NPS priority lakes and watershed program.

Once selected for a project, an iterative process is used to set achievable water quality goals for the individual lake. The most stringent best management practices (BMPs) are then implemented in the watersheds of those lakes considered exceptionally valuable and extremely sensitive to phosphorus loadings. Those less susceptible or those having designated uses more compatible with higher phosphorus loadings will have a lesser degree of critical sites or lands identified for implementation of NPS BMPs.

As Wisconsin's program has evolved it has become evident that there is a need to target and prioritize nutrient management actions within a watershed and focus on individual farms to be reflective of the needs of the receiving water bodies. As indicated earlier, application standards for animal manure have typically been N driven to be reflective of ground water contamination concerns. Similarly, control of sediment has been a priority resulting in the use of conservation tillage practices which then often require incorporation of manure or fertilizer to minimize runoff potential. Finally, individual farm management plans are then developed using sediment, N, and P as priorities.

Identification of critical areas in priority watersheds. Because P transport is controlled most effectively at the origin of the excess P, the next management step (after determining that a critical water body is P limited) should be to identify regions within the contributing watershed in which P transport reduction strategies will be most effective. These regions should subsequently be the primary focus of efforts to reduce P inputs to the P-sensitive water body by implementation of BMPs. Direct, indirect, and a combination of direct and indirect methods may be used to target regions for implementation of management options to reduce P losses from the point of origin.

Direct critical region identification refers to systematic monitoring of water body tributaries to determine relative P contributions from the various subbasins. With judicious selection of monitoring station locations, direct monitoring can identify subbasins contributing high P loads. The most apparent advantage of this approach is that subsequent decisions regarding where to focus remedial measures will be based on data rather than subjective considerations or surrogates to observed data. The disadvantages to direct critical region identification are the resources and time involved. Effective monitoring stations are expensive to establish and operate, and sample analysis costs can be quite high. Monitoring costs will increase directly with the size of the monitored watershed and the critical region resolution desired. In addition, several years' time can be required to obtain meaningful information due to the highly variable nature of NPS pollution occurrence. The resource requirements of direct monitoring for critical area identification are likely the main reason that this method is not widely used except in large watersheds.

Critical region identification is currently performed most often via indirect methods. The principle underlying indirect methods of critical region identification is to obtain a spatial representation of some index of P export; the operative assumption is that the P transport index selected is a reasonable surrogate for observed data. The criteria for critical area identification vary considerably in terms of complexity. Examples of relatively simple screening criteria include animal manure application rate, dilution, distance to nearest receiving water, and combinations of factors (*10*, *28*, *68*). Other reported screening criteria include factors such as existing facilities and attitude of the owner/operator (*52*). Heatwole and Shanholtz (*18*) reported on a procedure to rank the relative contributions of sites as a function of animal manure application rate and estimated delivery to nearest receiving water.

Advances in geographic information systems (GIS) technology have been extremely valuable in processing the multitude of data required to meaningfully characterize the P contribution potentials of subregions of watersheds. The latest advance in use of indirect methods to identify critical regions has been the linkage of spatial data on P transport factors with hydrologic/water quality simulation models (*9*, *17*, *30*, *66*). Distributed parameter models can estimate P export at the field scale, and use of GIS technology to construct the model input database can help alleviate some of the practical difficulties inherent in distributed parameter models. Indirect methods of critical region identification can be less expensive and time-consuming than direct methods and will thus probably become increasingly common with advances in prediction accuracy of hydrologic/water quality models. The dependence of critical region identification on some degree of derived data is probably the largest limitation to indirect methods. Until indirect methods are shown to give results similar to what would be obtained from direct monitoring, healthy skepticism as to whether a particular region is indeed critical may be justified.

A combination of direct and indirect methods can combine the best attributes of the two approaches to critical area identification. Limited observed data can be used to calibrate a hydrologic/water quality simulation model, and the model can then be executed on the basis of GIS-assisted input to identify regions likely to have particularly high P export. Although an uncalibrated simulation model might adequately reflect relative differences in P export from various regions, calibration is essential to accurate estimation of amounts of P transport.

Once critical hydrologic areas have been identified, the landowner, producer, and field staff need to assess the soil, hydrology, and management of individual fields to determine specific fields that have the potential for P loss. A field level assessment tool has been developed (*23*) that uses easily attainable soil, hydrologic, and management information. Using this assessment of the soil, topography, soil test levels of P, and management practices, a relative ranking procedure can be used to identify those fields that have the highest potential for producing off-site movement of P. Through this procedure, a numerical value—or P index—is assigned to each field. The process also indicates potential problem areas such as excessive erosion or manure application rates.

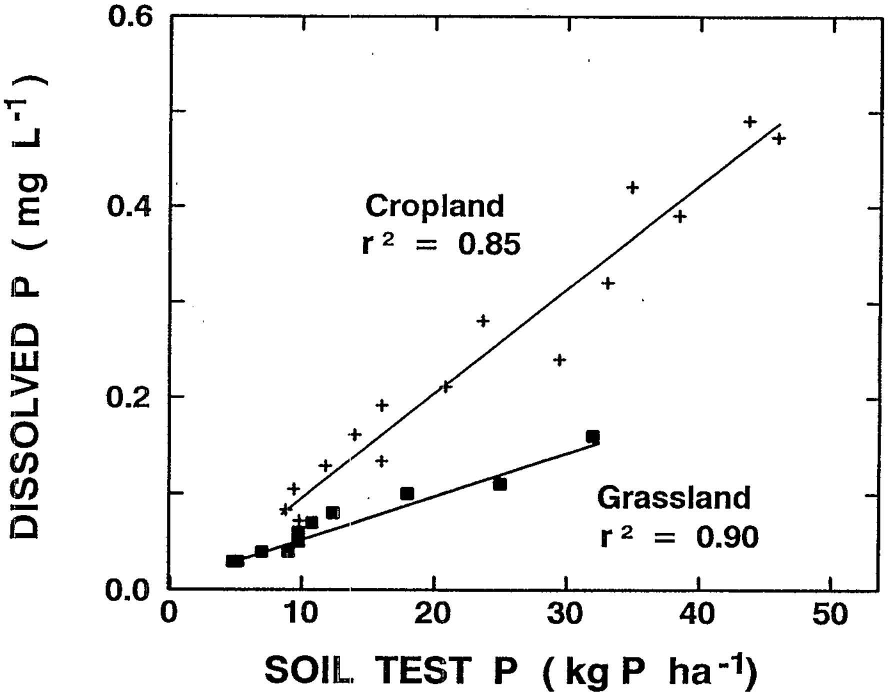

Figure 2. Effect of soil test P on the dissolved P concentration of runoff from several Southern Plains watersheds (44).

Management options for reducing P losses

Where lakes, reservoirs, or estuaries are the primary water bodies of concern, programs minimizing eutrophication from agricultural NPS pollution should emphasize limiting P inputs to surface water. In Florida, water quality management programs dealing with NPS pollution have focused on P (*25*). In Holland, the national strategy for minimizing NPS pollution, especially eutrophication due to animal wastes, is to limit entry of P into both surface and ground water (*5*).

Because STP and runoff P concentrations are related, a critical level of STP exists that results in runoff which is, on average, sufficiently high in P to cause eutrophication. State and federal water quality management agencies are attempting to identify these "cut-off levels" of STP above which no additional P should be added. Cut-off levels for soil P, along with influential chemical properties such as clay and organic matter content, need to be identified for bench-mark soils. Once identified, these levels could be a valuable tool for identifying potential P related problems associated with excess applications of either animal manure or commercial fertilizer. Developing management practices that are sequentially enacted as the STP level increases toward the cut-off level would slow down the process of restricting P application.

The first step in proper manure management is to view manure as a valuable resource that can be utilized to advantage. Alternative uses of manure should be pursued along with methods of increasing the bulk density and N content of the manure, encouraging the transport of manure from manure-rich to manure-deficient areas. However, until such methods are perfected and expanded, the predominant method of utilization will remain land application.

All fields do not contribute equally to the P load of a lake or reservoir. Therefore, if the same management practice is implemented on two different fields, the effectiveness in reducing the P load will differ. The P indexing procedure is designed to identify and rank fields for implementation of management practices. For fields with a low to moderate P index rating, flexibility exists and a wide range of management practices is available. Generally these practices are designed to reduce runoff, which is the major transport mechanism for P, and because of this they also control erosion in the process. For fields with a high P index, especially those with high STP levels, the same practices apply but less flexibility exists and more stringent approaches may be required.

Fields with low to moderate P indexes. Many management options are available for reducing P losses in the short-term following application, and all have been demonstrated to be effective under some circumstances. Options such as injection of P sources, when appropriate, can reduce the concentration of P near the soil surface. Other management options such as no-till farming, vegetative filter strips, terracing, winter cover crops, and contour farming can reduce transport of P in particulate form by reducing erosion. Strategies which reduce runoff from treated areas, such as tile drainage and impoundments, can be effective in reducing loss of DP as well as sediment P. Measures such as timing P application to avoid occurrence of intense storms and application of chemical amendments to precipitate P may also be effective in reducing P losses shortly after application, but the effectiveness of such practices needs to be better defined.

Fields with high P indexes and STP levels. The best P management plan is to prevent surface soil accumulation of P in the first place. Soil testing should be an integral part of P management to ensure that soil P levels are high enough for adequate yields and that the manure or fertilizer is applied only to fields that are P deficient, avoiding those with excessive P or those that have the potential for excessive P. If commercial fertilizer is the predominant long-term method of supplying plant nutrients, then the composition of the fertilizer can be structured to supply only the necessary amount of N and P. This approach is flexible and cost-effective to the producer. When animal manures are used as a nutrient source, less flexibility exists and a combination of manure and commercial fertilizer should be used to supply the nutrients required by the crop. Manure can be used to supply all the P required and a portion of the N needs, with the remaining N requirement being supplied by commercial fertilizer. When STP levels are between high and the cut-off level, manure application rates should be P- rather than N-based.

Cost-effective practices. Large-scale implementation of management options to reduce P loss is best approached by first constructing a framework for assessing the relationship between implementation costs and water quality benefits. While it is relatively easy to define the costs of a management practice, it is difficult to quantify the benefits that will be derived. Assessment of management practice effectiveness is difficult because of dependence of effectiveness on site-specific variables, and an all-inclusive database is lacking. Rigorous mathematical simulation models can be used to estimate management option effectiveness, but issues regarding data input requirements and output accuracy should be resolved before depending solely on models. If the effectiveness of a practice for reducing P loss from application sites can be defined, then this edge-of-field effectiveness should be translated into effects on the P-sensitive water body. This translation is best accomplished using simulation models that address edge-of-field P transport dynamics, channel flow dynamics, and the dynamics of the P-sensitive water body. A notable example of this type of combined model was developed by Summer et al. (*49*). Assuming that the first two challenges can be surmounted, there must be a relationship established between quality of the P-sensitive water body and some measure of value, so that costs and benefits are defined on a common basis. This might be the most difficult component in a framework for assessing management plans, since the value associated with a given level of quality in the P-sensitive water body depends on the use of the water body. If the water body is used solely as a water supply, then assessing its value might be relatively straightforward. If the water body is used for multiple purposes such as fishing, boating, and other uses, then the concept of value depends on intangibles and can be very subjective.

Remediation of impacted water bodies is often accomplished with expenditures of limited cost-shared public monies. Plans to improve the quality of P-sensitive water bodies thus need to focus on obtaining maximum benefits from limited public resources. To accomplish this goal, implementation plans to reduce P loading to the P-sensitive water body should initially focus on regions identified as critical. Identification of an "optimal" plan can be rather laborious, depending on the size of the area in question and on the array of potential management practices under consideration. A systematic procedure for plan development, however, will ensure that only the most effective management practices are implemented and that these practices will be implemented in locations that are most appropriate. Use of public monies to implement management practices without regard to effectiveness or where little water quality improvement is likely is a questionable public policy and will not maintain or generate broad public support.

Summary

Transport of solutes in agricultural runoff is of increasing national concern. While several pollutants are carried in the runoff, P is deemed especially important because it is the nutrient limiting growth of aquatic vegetation in most surface waters. Runoff losses of P are generally less than 5 percent of that applied with the bulk of the loss occurring in one or two events following land application. Loss of P in runoff occurs in dissolved and sediment-bound or particulate forms. Sources of runoff P include commercial fertilizers and animal manures, and the amount contained in runoff is directly influenced by management practices such as rate, method, and time of application. Runoff losses from manure are a particular concern in regions where confined animal operations exist in proximity to surface water bodies sensitive to P inputs. Soil test P levels are increasing nationally and a relationship exists between the amount of P in the soil and that contained in the runoff. This relationship requires further definition and "cut-off STP levels" need to be identified.

Limited financial and technical resources should be targeted on those water bodies deemed valuable and most likely to respond to implementation of BMPs within the watershed. State water quality management agencies need to develop clear water quality objectives for lakes/reservoirs based on intended use. Methods for identifying and prioritizing P-sensitive water bodies must be perfected and demonstrated. Once P-sensitive water bodies are known, it is necessary to identify hydrologically active areas or "hot spots" in the watershed requiring BMPs. A variety of practices exist that, when implemented, can maintain high surface water quality especially for

traditional row-crop agriculture. Less flexibility exists with land application of manure, especially on fields with elevated STP levels. Soil testing should be an integral part of manure management. Land application strategies for manure should be based on N to protect the ground water with equal consideration given to P for protection of surface waters.

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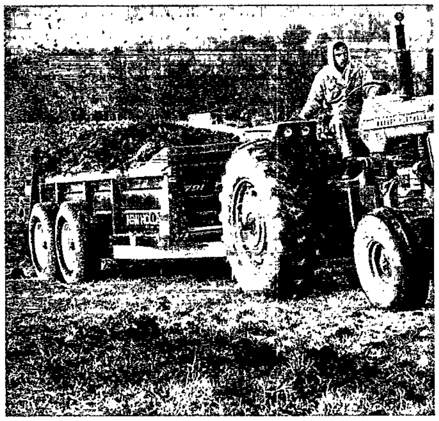

Best management practices meeting water quality goals

J. Watson, E. Hassinger, K. Reffruschinni, M. Sheedy, and B. Anthony

In Arizona, legislation was enacted in 1986, referred to as the Arizona Environmental Quality Act (*2*), to protect both surface and ground water quality from point and non-point contamination sources. A portion of the legislation addresses agricultural activities. It states that "the director shall adopt by rule agriculture general permits consisting of best management practices for regulated agricultural activities." The director, in this statement, refers to the director of the Arizona Department of Environmental Quality (ADEQ), a department in the state, newly created by the legislation.

Historically, the Arizona Environmental Quality Act was the legislative outgrowth of a response to an initiative petition produced on water quality issues. The initiative petition would have required the placing of water quality issues on the November 1986 ballot. However, water users in Arizona were concerned that water legislation might be drafted that would reflect the restrictive nature apparent in the pesticide regulations in neighboring California. Faced with the probability of a water quality initiative, the water user interests began searching for a viable alternative. Since the extremes embodied in the initiative could not be effectively argued against (due to the emotionally charged nature of the public debate) from a technical or scientific perspective, and since unrestricted discharge was unacceptable to all parties, a solution was sought in a permitting program.

A Blue Ribbon Commission had been appointed by then Governor Bruce Babbitt. This commission spent much of the second half of 1985 debating and negotiating the various issues to be included in the proposed water quality legislation. Early in these proceedings, nitrogen fertilizers and pesticides were separated as topics and assigned to separate subcommittees, as were other topics. The nitrogen fertilizer subcommittee conducted their negotiations from the perspective that "agriculture has no substitute for nitrogen fertilizers." Although this concept was not uniformly accepted in the public sessions before the Governor and the entire committee, it was not seriously challenged.

In January 1986, a draft copy of legislation entitled the "Arizona Water Quality Protection and Restoration Act" was produced. This draft, which was subsequently known as Hawke I to identify the legislator who was responsible for its introduction, introduced the aquifer protection permit procedures in the form of individual permits. However, it became apparent that the cost as well as administrative and enforcement components of the program would be exceedingly burdensome to the state if developed in the individual permit format. In response, a general permit program was developed which established an enforcement framework for a large group of similar users to follow in meeting the requirements of the law.

The concept of best management practices (BMPs) was also introduced in early January 1986. This concept was derived from the Federal Clean

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Water Act as found in the Environmental Protection Agency's rules and regulations. Since the BMP concept was a practical, fact-driven approach, it was particularly well suited for and adaptable to agriculture. The BMP concept also provided for the establishment of a level of participation and self-governance for Arizona agriculture. In addition, the BMP concept allowed site-to-site or farm-by-farm flexibility, while providing a degree of control acceptable to proponents of the initiative petition.

The Arizona Environmental Quality Act mandates that BMPs for regulated agricultural activities be adopted by rule. Complications arose, however, when an attorney general's opinion indicated that all BMPs adopted by rule, are rules, and thus must all be implemented by every producer (whether or not the combined application was rational). For example, if land levelling, high efficiency sprinkler irrigation systems, and drip irrigation systems were all considered best management practices in rule to provide efficient irrigation water application, every producer would be required to use all three methods concurrently to comply with the law. In attempting to develop the BMP program for regulated agricultural activities, this provision was found to be unacceptable. Furthermore, the rule-making process is complex, burdensome, and time consuming. In the best of circumstances rules require 12-18 months to finalize. The vesting of technical practices in rule eliminated the essential component of flexibility for successful development of an acceptable, effective, and implementable program. This constraint was overcome when the recommended BMPs for regulated agricultural activities were redefined as general goal statements, rather than specific practices, which were then adopted as rules. In this respect, Arizona's BMPs for regulated agricultural activities became program goal statements as well as rules that must be implemented. These statements not only provided direction and purpose for the program, but also incorporated flexibility into the program.

The best management practices for nitrogen fertilizer use in Arizona agriculture follow.

BMP 1—Application of nitrogen fertilizer shall be limited to that amount necessary to meet projected crop plant needs.

BMP 2—Application of nitrogen fertilizer shall be timed to coincide as closely as possible to the periods of maximum crop plant uptake.

BMP 3—Application of nitrogen fertilizer shall be by a method designed to deliver nitrogen to the area of maximum crop plant uptake.

BMP 4—Application of irrigation water to meet crop needs shall be managed to minimize nitrogen loss by leaching and runoff.

BMP 5—The application of irrigation water shall be timed to minimize nitrogen loss by leaching and runoff.

BMP 6—The operator shall use tillage practices that maximize water and nitrogen uptake by crop plants.

Similar requirements exist for confined animal feeding operations (e.g. dairies and feed lots).

Guidance practices (at one time referred to as alternative technologies) have become the specific methods which operators use to achieve the goals as stated in the best management practices and thus maintain their general permits. Since guidance practices are not incorporated into rule they can be readily modified to keep pace with changing agricultural practices and technology. Thus, guidance practices are practices that most agricultural scientists and engineers would recognize as BMPs. The following practices are examples of guidance practices for nitrogen fertilizer BMP 1.

G.P. 1.1—Sample and analyze soils for residual nitrate content.

G.P. 1.2—Test irrigation water for nitrogen content and for compatibility with ammonia containing nitrogen sources applied using fertigation.

G.P. 1.4—Use application equipment which has been properly calibrated.

G.P. 1.7—Use slow-release nitrogen fertilizers.

G.P. 1.8—Use appropriate plant tissue analysis procedures with annual and perennial crops to guide nitrogen fertilizer applications.

Compliance

For rules to be effective, they must be enforceable. Regulated agricultural activities must be conducted so as to meet Arizona's BMP rules. Any operation found out of compliance can be required to cease operation until an individual permit to operate is obtained. The process required to obtain an individual permit is so expensive due to required environmental assessments, and so lengthy (six months to a year—if everything proceeds in a timely fashion), that it is likely the operation will become insolvent before the individual permit is obtained. Furthermore, any agricultural operation that is found out of compliance is not able to access Agricultural Stabilization and Conservation Service (ASCS) cost share funds to improve their operation to assist them in compliance. The message for Arizona's agricultural producers, then, is implement BMPs to maintain your general permit at all costs.

The guidance practices used to implement the BMP rules are also a key mechanism that ADEQ has at its disposal to verify compliance with the law. An agricultural producer can be required by the Department to verify implementation of BMPs. The only rational means to do so is to produce records indicating the use of appropriate guidance practices. Further, if water quality problems exist in a locale that are attributable to agricultural activities, departmental staff can require the implementation of guidance practices that they determine are necessary to effectively protect water quality.

The Arizona Department of Water Resources (ADWR) has the responsibility for regulating the use of groundwater in the state. One of its mandates focuses on reduction of water use by agriculture. Although legislation provides for substantial penalties for noncompliance, it has seldom been necessary for the agency to mete out such penalties, since they have developed a strong educational program targeting growers. They also have substantial interaction with growers and irrigation district management through advisory committees and special projects. The success of this program, as with the BMP program, is not judged on the basis of number of fines levied, but by the fact that few compliance actions have been necessary. Success in the BMP program must be measured, not in numbers of operations closed for noncompliance (for such actions actually identify program failure if frequently needed), but in terms of compliance rates while maintaining the economic viability of the industry and the economies of the rural communities dependent upon agricultural productivity for orderly growth.

Community support

In order for any program to work effectively, various constituencies must be confident that their concerns are taken into account. The private environmental organizations must be satisfied that the regulations will effectively protect water quality; the regulatory agency staff must have clear guidelines and mechanisms available to evaluate compliance; the regulated community must be convinced that it is important to comply. While no legislation is ideal, the Arizona Environmental Quality Act and subsequently promulgated rules, have included these three entities. Their concerns are reflected in the form of the legislation and the regulations. Not only is the legislatively mandated standard stringent (aquifer protection, with all groundwater aquifers presently protected for drinking water), but the implementation mechanisms and compliance standards are practical, fact based, verifiable, and enforceable. Further, the method for compliance verification, on-site visits by ADEQ staff to operations located in areas with groundwater quality problems, provides a mechanism for meaningful dialogue between regulatory agency staff and members of the regulated community, prior to the need for compliance actions, such as cease and desist orders. This provides water quality protection without disrupting the economy of the local community dependent upon agricultural viability.

Technical inconsistencies

Arizona's legislation has some problems that should be recognized and addressed by others considering agricultural regulation for water quality protection. The nitrogen regulations are based on BMPs, which basically address the issue of mass emissions of nitrogen to groundwater. The pesticide regulations focus on concentrations below the root zone and in groundwater. In the unsaturated zone (vadose zone) between the soil surface and groundwater, the two criteria (mass emissions and concentrations) frequently are inversely related (*5*). The legislation is based on the assumption that research exists that accurately measures nitrogen and pesticide losses under management practices employed. As attested to by the recent emphasis by the U.S. Department of Agriculture and the U.S. Environmental Protection Agency to fund research regarding impacts of agricultural management practices on groundwater quality, this presumption is erroneous. The (unscientific) legal interpretation of the legislation by the state attorney general's office that all BMPs apply to all sites somewhat weakened the ability to incorporate by rule a concise list of acceptable practices. It also required substantial effort on the part of the regulatory agency staff and the regulated community to find meaningful BMPs that permitted effective and rational implementation of the legislation.

A recent research project report (*4*) on cotton in Arizona indicated that attempting to increase field irrigation efficiencies (an often-stated BMP) beyond a certain level resulted in yield reductions. Further, the differences in nitrate nitrogen losses between treatments were not statistically different due to field soil heterogeneity. Pratt et al. (*3*) found that the amount (usually the focus of BMPs) of nitrate nitrogen lost to drainage waters from agricultural fields was poorly correlated with the concentration (usually the focus of regulatory compliance programs) of nitrate nitrogen in those same waters. These examples highlight the need for care in selecting economically sustainable BMPs, as well as in identifying effective BMPs. For example, to state simply that a producer should improve the irrigation efficiency by 10 percent would result in yield losses in the case of some, and in inconsequential water quality changes in the case of others with extremely low efficiencies. Further, the specific examples of inconsequential improvement in water quality or yield losses would taint the program and bring its credibility into question.

Sustainability

The title of this paper is in some ways a misnomer. People meet water quality goals, practices don't. Effective goals are those that individuals have for themselves, not for others. Goals that are advocated for others create frustration on the part of all concerned. The regulatory agency can have desires for compliance by the regulated community, but can only have meaningful goals for themselves, not for the regulated community. Goals, by definition, cannot be statements of what another will accomplish but of what the goal-setting entity will accomplish. On the other hand, a water quality protection program can be evaluated as successful in the agricultural community when individual members of the agricultural community have established goals for their operations that are consistent with water quality protection. The distinction is absolutely critical; otherwise the standard to evaluate the success of such a program will be a moving target depending upon who (media personalities, local officials, state officials, agribusinesses, farm operators, regulatory agency staff—the list can be substantial) is establishing the criteria at a particular time. Thus an evaluation of the effectiveness of a water quality protection program for agriculture must account for what practices are implemented when "no one is looking." The nature of Arizona's implementation process (with its budget constraints) relies heavily on voluntary compliance by the majority in the regulated community (as it must if it is to be sustained in the future) with focused efforts by regulatory agency staff on problem locations and individuals who disregard the regulations.

Since grower response is such a key element to on-farm adoption of BMPs, it is helpful to ask what criteria are considered important by growers. We offer three that we consider critical. First, practices must be environmentally effective. If they cannot be shown to be an improvement (environmentally) over conventional practices presently employed, there is no scientific rationale for recommending them. This seems obvious, but frequently practices are espoused today for which no solid evidence exists regarding their effectiveness for environmental protection. To ignore this criteria is analogous to the situation in the 1950s and 1960s in which pesticide recommendations were made that were based upon the best judgment of "the pros" at the time for the purpose of controlling an important environmental problem. Today, many question the wisdom of some of those recommendations, because other environmental consequences were not considered. If we fail to obtain solid evidence regarding benefits of recommended practices, we risk not only criticism by future generations for not considering the consequences of such practices, but (even worse) we seriously risk recommending a placebo that makes the patient feel better without effectively addressing environmental consequences.

Second, practices should be economically beneficial. For a change to be sustained on a primarily voluntary basis, there should be negative economic impacts of non-implementation. A speeding ticket is a clear example of a negative economic impact. A fine for non-compliance with BMPs is another example. The problem with the ticket and fine is that they require enough regulators that a large percentage of those out of compliance will be caught. One only needs to travel the nation's highways to see the ineffectiveness of monitoring speeding (an activity that is much easier to monitor than compliance with environmental guidelines) when the regulated or monitored community remains unconvinced that maintaining the legal speed is in their best economic interests. Other social and economic pressures apparently are greater than the risk of getting caught and fined. Analogously, the risk of detection and fine may not be adequate to achieve a high degree of compliance with environmental regulations such as mandated BMPs. Therefore, the implementation of BMPs must be economically and socially beneficial to the regulated community.

Third, practices should be easily adaptable. Practice changes requiring substantial capital investment will be a hard sell. Even in cases in which a member of the regulated community invests in a capital intensive change, it does not necessarily follow that the simultaneous implementation of important management changes will ensue. Often, capital intensive changes have no substantial impact without the concurrent adoption of management changes. A prime example of this exists in Arizona. Cases can be cited in which substantial sums of money were invested in improved irrigation delivery structures, but the irrigation practices remained unchanged. Consequently, the expected savings in water costs were not realized, until the practices changed. A similar example would be purchasing new fertilizer equipment, then operating it without calibration.

Educational programs

In an effort to judge grower response to BMPs, Cooperative Extension in Arizona surveyed producers in two of the major agricultural counties of the state, Pinal and Maricopa. The Pinal county survey (*1*) was conducted in 1991, and some of the results are presented here. We found that only about 60 percent of the growers responding to the survey were aware of BMPs being mandated. Of those aware of BMPs, most were using plant and irrigation management practices that would be identified in Arizona as acceptable guidance practices (e.g. soil testing for nitrogen, plant tissue testing for nitrogen, irrigation scheduling with real time weather data, etc.) for the purpose of meeting BMPs.

The low percentage of respondents who were aware of state mandated BMPs was somewhat surprising since the survey followed two years of media attention, a state level grower advisory committee effort to include grower concerns in the BMP formation, and combined agricultural industry, cooperative extension, and ADEQ meetings about BMPs. It was clear that some key elements must be missing from the educational endeavor to find such a low awareness level, after such a high profile effort. At least three missing elements of the educational program were identified. First, a clear demonstration of environmental need and benefit was missing. Solid data did not exist that clearly supported that specific agricultural practices were degrading groundwater quality, or more importantly, that alternative practices would protect groundwater quality to an extent greater than already existed. A second missing element was a "buy in" by county extension personnel and SCS county staff. In general, a conviction did not exist that there was an agriculturally created water quality problem. Without supporting scientific evidence, there was no compelling reason for these educators and technical support staff to encourage BMP adoption. A third missing element was the lack of local on-farm demonstrations of practices that were known to reduce the potential for degradation of groundwater quality.

In response to these needs, cooperative extension has initiated on-farm demonstrations highlighting the possibility of water and nutrient losses below the crop root zone, with a particular emphasis on early season losses. The ADEQ has funded a demonstration and research project on BMPs through the University of Arizona Cooperative Extension and Experiment Station, and two Hydrologic Unit Area projects were initiated in the state as cooperative efforts between Cooperative Extension, SCS, and ASCS. The Arizona Departments of Environmental Quality, Water

Resources, and Agriculture have participated in the planning of these two projects. A substantial contribution has been made to these projects from individual agricultural cooperators, advisory committee members, and irrigation districts, as well. The agricultural community involvement is characterized by a desire to define the problem specifically and promote effective solutions. There is a strong desire that the regulatory process be consistent with scientific findings. It is hoped that the interaction of the regulated community with the regulatory, educational, and technical assistance organizations will enhance the understanding and adoption of effective and sustainable practices that protect water quality.

Summary

A successful regulatory program is often evaluated in terms of how many citations were handed out or how many fines were imposed. In truth, a successful program accomplishes its mandates in a manner that maintains economic viability and builds a sustainable base of support. To do so, it must be conducted by staff who are scientifically competent, who can develop confidence in their credibility by a number of constituencies, and who are provided with the necessary tools (including budgetary support) to implement the program. The regulated community must be involved in appropriate aspects of the program to maintain the program's visibility. The key ingredients in all aspects of a successful program are individuals; individuals in a regulatory agency who can make a program work in spite of political maneuvering in legislative bodies and in their agency or other agencies; individuals in the regulated community who are willing to take the bull by the horns and become proactive for the good of their industry; and individuals to provide education and technical assistance who are willing to deal with the problems of helping the regulated community implement needed practices. Arizona has been fortunate to have the involvement of such individuals in the development of its BMP program. Its long term viability and success will depend primarily upon the commitment of the state's citizens and their elected representatives to make the program work.

There are some negative aspects of the legislation and BMP program. Many of the members of the agricultural community would consider Arizona's Environmental Quality Act of 1986 to have been so divisive that it should not be recommended as a model for other states to use. The nature of the process by which it was formulated created many of the inconsistencies within the legislation. Legislative oversight, or the lack of it, can be a problem. Agency directors (and there have been three in six years) have difficulty obtaining legislative attention to funding requirements, except when a last minute budget is being fought over.

The challenge to educational and technical assistance agencies has been and will continue to be to develop meaningful programs that are both scientifically correct and consistent with regulatory requirements. Standard practices and data interpretation methods need to be developed against which other practices and result interpretations can be compared. When technical inconsistencies between the BMP program and the pesticide program appear, the goal of minimizing groundwater pollution will necessarily drive the educational effort. However, this can result in mixed signals to the regulated community. Strong interaction between the regulated community, the regulatory agency, the technical assistance agencies, and the educational agencies will be important to prevent misunderstandings and misconceptions.

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Tools to aid management: The use of site specific management

S. Kincheloe

Best management practices (BMPs), maximum economic yields (MEY), and sustainable agriculture are terms that should be part of your vocabulary. In the proper context, BMPs, MEY, and sustainability are not terms in conflict. On the contrary, BMPs lead to MEY and MEY leads to sustainability, both environmentally and economically.

Put another way, the primary objective of a sustainable, efficient agricultural system is to provide an economical, safe supply of high quality food and fiber, with adequate and responsible protection of the environment. It is this combination of

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productivity and responsibility that most accurately describes the term "sustainable agriculture."

What are best management practices? Best management practices are those practices that have been proven in research and tested through farmer implementation to give optimum production potential, input efficiency, and environmental protection. A BMP for one location is not necessarily the same for another—they vary for different crops, soils, and climates. BMPs are very site specific. Past research, farmer experience, and knowledge of uncontrollable factors, such as soil and climate, are valuable tools in arriving at the BMP recommendation for each particular site. BMPs involve both soil conservation and agronomic practices. It is the combination of these BMPs that assures a highly efficient and productive cropping system, one that preserves the soil for future generations. Most scientists agree that farmers must build a system of BMPs or refine the current system to be both profitable and the best possible steward of the soil.

Best management practices must be site specific for each field—even areas within those fields. General categories of practices are usually recommended, but within these categories, each farmer must develop the most efficient use of inputs.

Here are examples of BMP categories:

Cultural practices
- Variety/hybrid selection
- Crop rotation
- Intercropping
- Conservation tillage

Pest management
- Use of resistant cultivars
- Use of pest management dynamics
- Integration of techniques
- Integrated pest management

Water management and conservation
- Scheduling irrigation
- Eco-farming/moisture harvesting
- Crop selection

Sound fertility programs
- Soil and plant tissue testing
- N credit for legumes/residues
- Placement/timing/rate
- Use of residues/manures/sludge

One BMP that is generally recognized as environmentally sound is soil testing. It will continue to be extremely important that farmers base their fertility programs on a good soil testing program.

Most of these examples are not new. The idea is simply to maximize the efficiency of all inputs and manage steps to produce the highest yield at maximum profit, which in turn enhances environmental stewardship.

MEY is achieved through the use of BMPs and precision management. This includes using the latest agronomic technology for each productive cropping system. Dedicated production agronomists have put together the kinds of technology that give greater consistency to high yields. This "reproducibility" has given confidence that efficient new MEY systems which lower unit production costs are real today and will be improved tomorrow. The most striking feature of each MEY system developed is the need to integrate all controllable inputs at optimum levels for the crop and site. When using MEY technology, farmers should add soil conservation practices which best fit their particular situation. Together, these two objectives give farmers the best opportunity to increase profits in an environmentally responsible manner.

By definition, sustainable agriculture is a production system of BMPs that properly utilizes inputs, both those produced on the farm and those purchased externally, in the most efficient, responsible manner to improve productivity and maximize profitability (MEY) from a farming operation, while minimizing any adverse effect on the environment. Recent applications of technology have offered profound progress in achieving MEY and sustainability. Through the integration of off-the-shelf innovations, the implementation of MEY can be enhanced. Some of these innovations are computers, radio receivers, global positioning satellites, and intensive soil testing. The integration of these and other components into a production system for greater efficiency has resulted in a number of different terms to describe it. Some terms are precision farming, computer aided farming, variable rate technology, farming by the foot, and site specific management. The following discussion should provide an overview of this management process called site specific management.

Research has documented that wide yield variations routinely occur in fields that have always received the same inputs. Much of the variability is due to different soil types. However, significant variability is found within soil types. This is true because human activities have had a more profound effect on nutrient level variability than the natural, inherent variability of soil type. Growing economic and environmental concerns are causing some farmers and researchers to take a closer look at individual fields when applying inputs.

Recent production developments have focused on the benefit of dividing a field into small units for more intensive, site specific management. This procedure is called the grid sampling approach. The field is subdivided into small cells of about 2.5 acres (1 ha). Soil sample cores are collected within the cell and consolidated for analysis. The soil samples are summarized and nutrient management maps created. With this approach, it is recognized that nutrients such as nitrogen, phosphorus, and potassium vary independently of soil type, map units, and of each other. Fertilizer rates and chemicals then are varied based on the nutrient management maps developed.

The major advantage of the grid system is that it considers both the soil type and field history differences. Another advantage of the grid system is that the intensive soil sampling provides the best soil testing program most farmers have ever had.

Intensive soil testing is at the heart of this system. Individual soil samples are taken from each grid of approximately 2.5 acres (1 ha). The soil test results are entered into computer mapping software. The computer is used to develop digitized field maps by combining grids with similar nutrient levels. At this point, fertility management is possible on a more site specific basis. The fertilizer rate can be varied according to the nutrient maps using manual methods such as spot spreading, double spreading, and manually manipulating the controls on spreaders.

Even more important today is the pressure being placed on the agricultural community to develop high-tech, innovative procedures to replace more traditional farming techniques. The concept of site specific management (or variable rate technology, computer aided farming, precision farming, or whatever the term used to describe the concept) does address the current issues of the day comprehensively. By understanding the characteristics of a field in detail and relating these features by geographic location, the farmer can focus on areas that need attention and treat them according to yield potential. Yield potential is shown through soil types and the nutrient grid maps.

Successful implementation of site specific management relies on the farmer treating each soil type or each grid area individually instead of treating the entire field as a single management unit. Obviously this shift in management approach can lead to increased productivity because a field is farmed according to the potential of each small grid area.

Innovative farmers are beginning to break away from traditional production practices. Space-age ideas and equipment and computer and communication systems are helping farmers move into these high-tech methods of crop production, achieving maximum economic yields and reducing potential environmental impact. Dead reckoning and radar gun systems mounted on field equipment have been particularly useful in establishing the sampling grids. Likewise, they have been helpful in positioning equipment in the field.

However, even more sophisticated technology is being used. It is called Global Positioning Satellite systems. Global Positioning Satellite systems have the greatest potential for use in positioning fertilizer spreaders and other farm equipment in the field at exactly the same location, time after time. Another feature is that exact geographic locations can be determined at any time as the equipment moves across the field.

Global positioning systems are a 24-hour, worldwide, all-weather network providing precise navigation information to earth-based computer systems within meters of its target. GPS, as it is called, is a U.S. government navigation system operating from a constellation of 24 satellites. Used primarily for government activities, this highly accurate positioning system is now open to civilian use. Because of its precise positioning of both moving and stationary objects, the system can be used to provide the missing link in agricultural input applications—the capability to position farm equipment precisely in the field relative to the digitized soil nutrient maps, maps developed from intensive grid sampling.

The satellites send radio signals at precise intervals. Receivers on the ground measure the delay of signals from four or more satellites. With the aid of computers and these radio signals, the distances and relative positions are calculated. The net result is fertilizer spreader trucks with radio receivers and computers that can update their position as frequently as every second. This location information is combined with computerized fertility field maps to adjust fertilizer applications by varying the mixtures and rates.

The use of variable rate fertilizer spreaders or "blend on the go" spreaders enables this concept to work. These spreaders, with onboard computers and radios, have up to six compartments of different dry fertilizer materials. The computer controls how the materials are mixed as well as the application rates. It also senses the location of boundaries on the digitized map relative to the precise location in the field.

Dry fertilizer alone is not the only aspect of site specific management. The first variable rate liquid spreader was used in the U.S. for the first time during the 1992 season. The principle is the same as with dry fertilizer. This unit has only one tank so the rate of only one liquid mix can be varied through sets of triple nozzles across the length of the spray boom. However, the unit has been modified by adding an additional tank so that two different fertilizer mixes can be varied.

The true test of the benefit of such a management system is crop yield. Thus, the most recent step in this site specific management system is the development of monitors mounted on harvesting equipment that record yield using the same digitized maps. A number of different types of monitors are being used for the first time. Controllers and monitors for variable rate anhydrous ammonia, herbicides, seed planters, liquid and dry fertilizer, and yield are now available and operational on a limited basis. Obviously, the ideal system would be the use of all these in the same field and on the same farm.

By using both computer mapping and satellite navigation tools, the farmer will be able to apply inputs to only those soils and areas which can make the best use of the inputs. The concept of "farming soils, not fields" allows for precise farm management practices by correlating soil data and equipment positions. Future models from continued research of this new technology will make use of more detailed information about climates and soil types. It is difficult to correlate farmers' inherent understanding of their fields and specific crop needs. Even though farmers know that there are areas which consistently do not produce good yields in a field, they usually cannot accurately define the boundaries of these areas.

This site specific technology can help farmers match the genetic potential of specific crop varieties with soil potential. The growers' production challenge is, therefore, threefold:

1. Agronomically sound management.
2. Profitable production systems.
3. Environmentally responsible soil stewardship.

In the final analysis, science-based technology, advanced mechanization and crop management techniques, together, are tools—powerful tools—with remarkable potential for change in our global food production systems. ❑

Nitrogen testing for optimum management

D. H. Sander, D. T. Walters, and K. D. Frank

Nitrogen testing for optimum production requires a means to predict or monitor crop N needs both to maximize profitability and to prevent environmental damage. The complexity of the nitrogen cycle and the uncertainty of climatic effects on crop performance and N availability make N testing a formidable task. We address the current technology for N testing and the problems as well as future promises of this technology.

Developing an ability to predict nitrogen (N) requirement of crops has been an important issue ever since N fertilizers became widely available after World War II (*15*).

Prior to the development and availability of synthetic N fertilizers, the N requirement for cereal grains was met through crop rotation with legumes and the judicious use of manures and other organic wastes. In these cropping systems, N was seldom in excess supply for two primary reasons. It is well known that N_2 fixation associated with legumes decreases as soil N supply increases and since large livestock confinements were rare, manures were generally lacking for individual farmers compared to crop N needs. Therefore, excessive N application causing environmental problems was limited to a few point sources.

With the advent of synthetic N fertilizers, farmers soon began to overestimate crop N requirements, and because of low N costs, tended to apply excessive N rates in the hope of producing additional yield and profit. This resulted in nitrate-N contamination of ground waters especially in areas of high water tables or on sandy soils where nitrate-N can be easily leached below the root zone. There is some doubt that even economic optimum yields can be produced without some contamination of groundwater (*6, 9, 18*).

Methods of predicting crop N needs through soil and plant analysis have been widely published in research and technical journals for well over 40 years. Much has been learned about the chemistry and biology of N transformations in the soil and crop N needs. While early research objectives were to develop N tests to predict optimum application rates and profitability, adoption of this technology was hampered by the very low cost of N fertilizers. Increased interest in N fertilizer efficiency in recent years has been driven by public concern about pollution of ground and surface waters. This has made it mandatory to justify the N recommendation system in both economic and environmental terms. In addition, with recent increased emphasis on nutrient management plans, it has become essential that those making these plans have an understanding of nitrogen testing. The objective of this paper is not to do a comprehensive literature review, but to provide an overview of the basis for fertilizer N recommendations and to discuss their limitations. A number of reviews of soil N testing have been previously published (*5, 7, 14*).

Nitrogen testing systems

There are basically two N testing systems available to predict crop N requirements. One is based on an estimate of the amount of N present in the soil that will be available to the crop. The other is to analyze the crop for N needs. Neither is easy because of the many factors that affect N availability and plant performance.

Nitrogen is quite unstable in soil. Its availability is also a function of soil temperature, water content and microbial activity, which determines the amount and rate of available N mineralized from organic matter and crop residues.

Soil testing

Early research in soil testing concentrated on determining the potential ability of the soil to mineralize available N from organic matter. However, correlations between crop response to applied N with total N and/or organic matter content have been generally poor (*16*). While mineralization rate tests correlated well in the 1950s, increased carryover of residual N from fertilizer N use decreased the value of these tests. It was soon discovered that a measure of residual nitrate-N carryover from fertilizer N was a quick and practical means of predicting fertilizer N needs. By 1970, many laboratories changed to using residual nitrate-N in the root zone or some prescribed soil depth as a standard soil test for available soil N.

A primary problem with using residual nitrate-N in the root zone as a measure of N availability is that nitrate-N is highly mobile and moves with water. Soil type and the amount of water percolating through the root zone determines the amount of nitrate-N that will be leached from the root zone. The nitrate-N content of the soil is only a measure of N availability at the time the sample is taken. It does not indicate or measure the ability of the soil to mineralize available N, which can be very important on soils that receive organic residues or manures (*13*). In addition to leaching losses, there are also gaseous losses of N from the soil. Nitrate-N is lost as various N oxides when the soil has a low oxygen content such as when soils are water-logged. Nitrogen is also lost through volatilization where ammonium N is changed to ammonia. These gaseous losses can be substantial (*10*). Volatilization losses of fertilizer ammonium and urea N can be well over 50 percent of that applied. Leaching can also be a major loss pathway, especially on sandy soils.

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Published as Journal Series No. 10430, Agricultural Research Division, University of Nebraska.

Because of the many factors affecting soil N availability, N recommendations may vary from state to state and from one laboratory to another. Users of N recommendations need to recognize that because of all the factors affecting both soil N availability and fertilizer N performance, predictability of actual fertilizer N crop requirements is highly variable. While techniques for using soil residual N testing are difficult nationwide, the N recommendations based on these soil tests are being researched and improved in a number of states.

Actually the most widely used method of recommending N is to simply use a factor times the expected yield. This method of determining N requirement completely ignores any variability of available N in the soil. The factor 1.2 is often used since it reflects an average amount of applied N needed to produce a bushel of corn. While this gross method is still widely used, it is gradually being replaced or modified by soil nitrate-N tests.

Soil tests to estimate residual nitrate-N in the root zone have been in use for the past 20 years, primarily in states west of the Missouri River where precipitation and leaching are relatively low (*7*, *22*). The probability of high leaching load in regions east of the Mississippi River is believed to limit the use of fall and spring soil nitrate-N as a measure of N availability. However, root zone nitrate-N has correlated well with yield response to applied N in Wisconsin (*3*). Recent research in Vermont and Iowa has shown that a soil test for soil nitrate sampled prior to sidedressing on corn (pre-sidedress nitrate test-PSNT) has shown good correlation with yield response to applied N (*2*, *12*).

A major problem with the practical acceptance of soil nitrate-N soil sampling has been the sample depth required to represent the available N in the root zone. Most states in the semi-arid areas have recommended sampling depths from 0.6 to 2 m (2-6 ft). This depth recommendation has generally limited acceptance of root zone soil nitrate-N analysis, because of the difficulty in obtaining a sample. The recent PSNT test has been correlated to 0.3-m (1 ft) samples, which allows hand sampling. Samples deeper than 0.3 m normally require hydraulic sampling equipment which limits sampling to soils where crops are not actively growing. While PSNT soil sampling deeper than 0.3 m results in improved correlations, the advantage has been small and probably is not worth the effort (*1*).

Table 1. Effect of different mathematical models relating corn grain yield to applied N on the average optimum N rate, R^2, and yield at recommended N. Average across 25 N rate experiments in Nebraska, 1988-1992.

Model	Optimum	Ave R^2	Yield at recommended N rate
	kg N ha^{-1}		Mg ha^{-1}
QUAD	162	0.51	10.85
QUAD PL	177	0.52	10.79
LIN PL	127	0.49	10.79
MITS	194	0.50	11.29

Plant analysis and sensing

It is obvious that nutrients absorbed by the plant are available. Therefore, direct evaluation of the plant as an indicator of nutrient availability has always been attractive. Much research on plant analysis over the years has, however, failed to provide a better system of recommending N needed for optimum yields than has soil analysis. The primary problem with plant analysis has been that plants may absorb much more N than is actually required for optimum yields. This luxury consumption makes it difficult to determine true critical levels. Another major problem is that by the time the need is apparent, it may be too late to apply N.

Recently, research has shown that corn leaf chlorophyll content increases in relation to applied N similar to grain yield (*11*). This has led to the use of chlorophyll or "greenness" sensing as a means of determining when corn will respond to or needs additional N fertilizer (*21*). This technology is especially suitable for sprinkler irrigated corn where N can be applied as needed through irrigation water. While still in the research phase, chlorophyll sensing promises a system of increasing N fertilizer efficiency beyond what can currently be done with soil nitrate-N sampling alone. By using this technique, N deficiencies can be detected early enough to allow correction of the problem with fertilization. However, the technology has limitations for dryland crops because of the need for precipitation soon after N application in order to obtain N uptake. The need to apply N in tall crops such as corn also may limit the use of leaf sensing under dryland conditions.

Making a fertilizer N recommendation

While N recommendations are not made uniformly across state lines and vary from crop to crop, the Nebraska algorithm for corn may be used as an example of how a N recommendation is made. This algorithm is based on a total of 81 N rate experiments on irrigated and dryland corn located across the state of Nebraska (*8*). Nitrogen recommendations for other crops in other states as well as in Nebraska may be based on more or less data. Recommendations may be based on relatively little actual field correlation and calibration data. The Nebraska algorithm for a fall or spring soil nitrate-N sample is as follows:

N REC, kg ha^{-1} = 39.2 + 21.4(Y) − 8.96 (mg kg^{-1} NO_3-N) -2.5 (OM)(Y) minus other N credits

where

Y = grain yield, Mg ha^{-1} (5 year average + 5 percent)

NO_3-N = soil NO_3-N concentration averaged over at least 60 cm, mg kg^{-1}

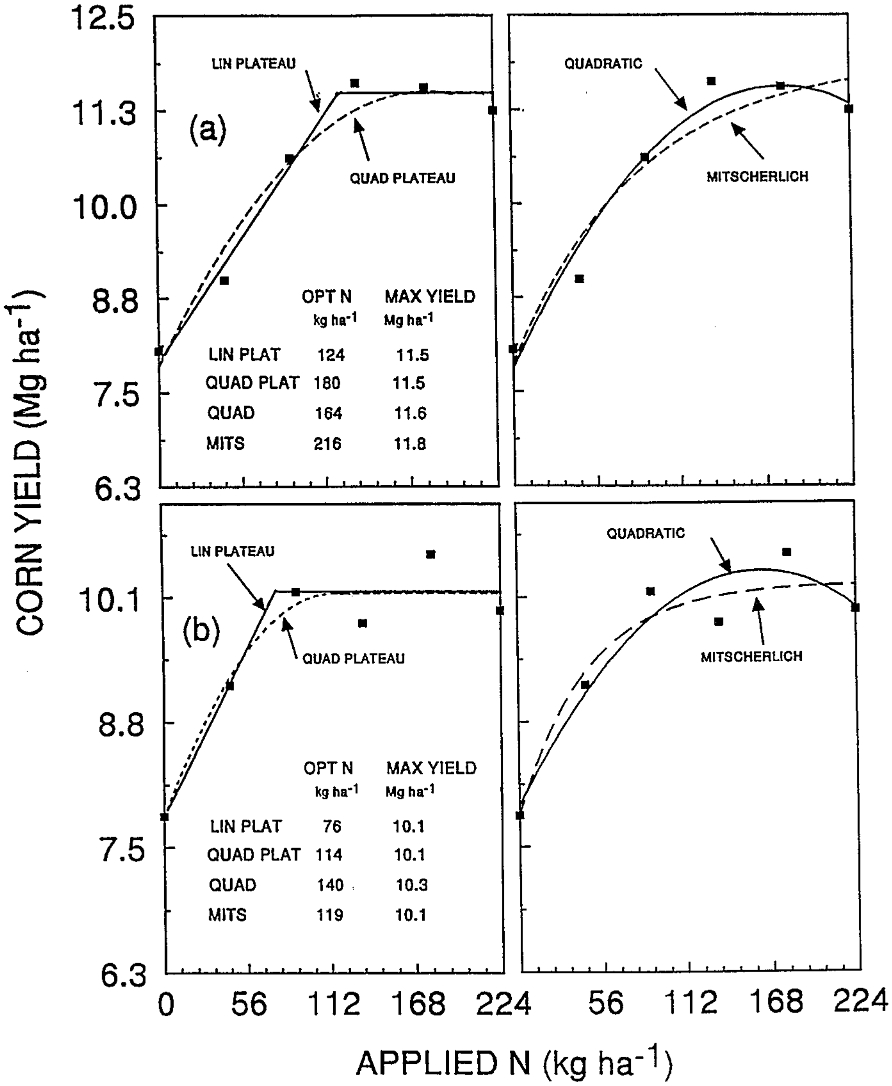

Figure 1. Effect of model selection in determining the optimum (OPT) and maximum (MAX) corn grain yields on two locations (a) and (b) in Nebraska.

OM = soil organic matter content in percent

Other credits include subtracting N for previous legumes; N in irrigation water; and N in manure.

The algorithm is easily used to calculate a N recommendation, either by computer or calculator or by hand. For example, a soil with a 11.0 Mg ha^{-1} (175 bu $acre^{-1}$) average yield; an average soil nitrate level of 8 mg kg^{-1} (8 ppm); and a soil organic matter of 3 percent with no N credits would have a N recommendation of 120 kg N ha^{-1} (107 lbs N/acre).

It is apparent that the algorithm has simplified a very complex and dynamic soil N supplying system. It is also apparent that the N recommendation will be the same regardless of future weather or other management variables such as hybrid selection, tillage, seeding rates, time of N application, and a host of other factors that influence the final yield obtained. The N recommendation is made only on the basis of expected yield, soil nitrate-N, and organic matter content. It is normally made before the corn is even planted. Actual yield may be zero because of drought, hail, insect or disease attack, or a combination of all of these. The major factor, weather, is nearly impossible to predict very far in the future. The N recommendation has to be based on what has happened on average in the past. Since yield is a major factor determining the N requirement of a crop, irrigation removes a major yield limitation affecting N recommendations. However, because dryland yields are highly variable, the accuracy of the recommendation may vary, reducing recommendation accuracy considerably from year to year. This variation actually increases the need for soil nitrate-N testing for dryland in order to evaluate N carryover for the following crop.

Other N credits such as N in irrigation water, cereals following legumes and manure application can greatly affect the recommendation. Irrigation water N has been found to substitute essentially equal to fertilizer N. While irrigation water application rate is unknown at N application time, irrigation water N content in 22.5 cm (9 in) of water is subtracted directly from the N recommendation in Nebraska. Legume credits usually involve corn following soybeans or alfalfa. Most recommendations credit 45 to 56 kg N ha^{-1} (40-50 lb N $acre^{-1}$) for soybeans and 112 kg ha^{-1} (100 lbs N $acre^{-1}$) for alfalfa. Credits for manure normally require a N analysis with credits based on expected mineralization rates, which varies according to kind of manure and method of handling.

How good is the N recommendation?

Effect of model selection. From 1988-92, 25 N rate experiments were completed in Nebraska on irrigated corn to study the value of PSNT under Nebraska conditions. These experiments were used to determine how well we can predict the fertilizer N requirement with our present algorithm. The first step in this process is to determine how much N is needed at each site for optimum profit. Figure 1 shows the response curve for two sites (a and b). It is apparent from looking at the yield response to applied N, that some curve smoothing is required to determine the optimum N rate. There are generally four models that are used to fit yield response curves: linear-plateau, quadratic-plateau, quadratic, or Mitscherlich. The selection of the best model to use is not an easy decision (*4*).

Figure 1 shows the variation in the optimum N that one would conclude was required for each of two sites using the four different models discussed above. Optimum N rates were determined for the Mitscherlich and quadratic functions by determining the N rate which maximized profit at a given cost/income ratio ($98.42 per Mg of corn and $0.33 per kg N). For the linear and quadratic-plateau, optimum N was determined statistically. For example, in Figure 1b the optimum N rate was 76 (68), 114 (102), 140 (125), and 119 kg N ha^{-1} (106 lb N $acre^{-1}$) for the linear-plateau, quadratic-plateau, quadratic and the Mitscherlich model, respectively. In Figure 1a and, on the average, for the 25 sites (Table 1), the linear-plateau consistently had the lowest optimum N, followed by the quadratic, quadratic-plateau, and the Mitscherlich. Similar to the findings of Cerrato and Blackmer (*4*), the R^2 (coefficient of determination) and maximum yields determined by each model are very similar, except the Mitscherlich was somewhat higher.

Even though the N optimum for the linear-plateau averaged 36 kg N ha^{-1} (32 lbs N $acre^{-1}$) less than the quadratic, 50 kg N ha^{-1} (45 lbs N $acre^{-1}$) less than the quadratic-plateau, and 67 kg N ha^{-1} (60 lbs N $acre^{-1}$) less than the Mitscherlich, all models had very similar R^2 values—a common statistical measure of how well the model fits the data. Our purpose in showing these discrepancies between the commonly accepted models is not to provide a solution to the problem, but to show how difficult it is to determine the optimum N application rate even with replicated N rate experiments. Fortunately, since the response curve is relatively flat on top, this error does not generally result in large yield losses or grossly excessive N recommendations. However, Cerrato and Blackmer (*4*) determined from their data analysis that if the optimum was based on the linear-plateau model and the quadratic-plateau was the correct model, the producer would have lost $47.00 ha^{-1} ($18.95/$acre^{-1}$) by under-fertilization of N. If the optimum was based on the quadratic model in their data, and the quadratic-plateau model was correct, the producer would have lost $16.00 ha^{-1} ($6.45/$acre^{-1}$) from over-fertilization. This is without any consideration for any environmental damage that might result from the excessive N application.

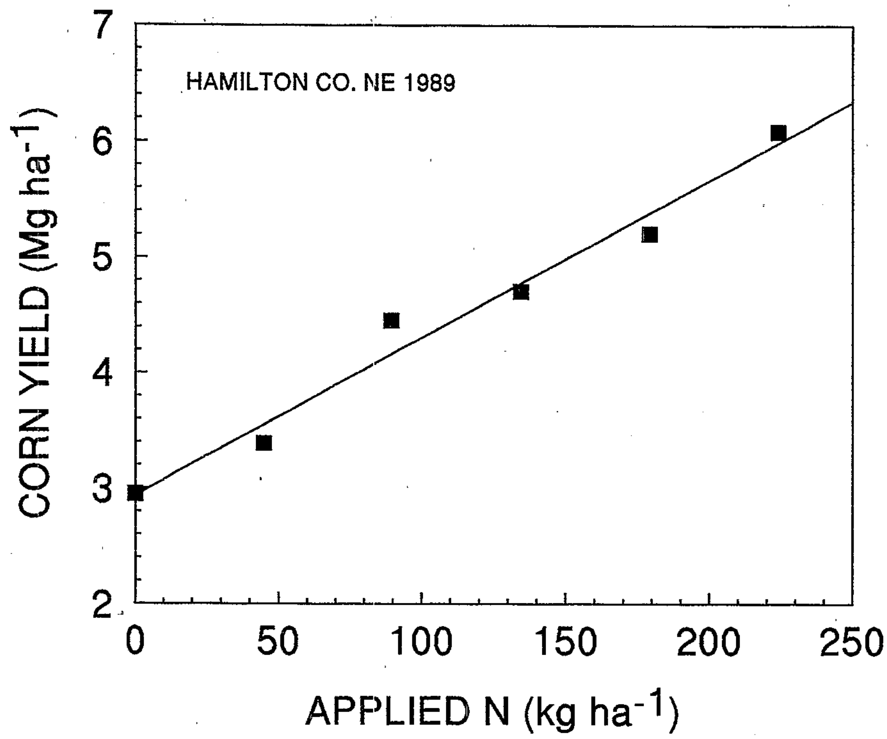

Figure 2. Corn grain yield in relation to applied N showing linear yield response from N rate experiment in Nebraska, 1989.

As more research data is collected to improve present N recommendations, it is clear that response model evaluation is an important factor in N recommendation development, because the N rates calculated from these models are used to derive the N recommendation algorithm.

Effect of soil available N supply. Some of these factors have already been discussed, such as leaching of nitrate-N and mineralization of N after soil sampling, which is especially important following cover crop incorporation or manure application. The reasoning behind PSNT is to evaluate available N status after spring leaching and mineralization have occurred with time remaining to apply any needed N.

Additional factors include spatial variability of soil nitrate, which is generally increased with fertilizer N application and by poor irrigation water distribution. Even nitrate-N distribution in the root zone may influence soil nitrate effectiveness since nitrate enters the root primarily by mass flow in water. Nitrate deeper in the root zone may have low availability if root development is maintained in surface soil when frequently wetted by precipitation or irrigation water. Methods of tillage or degree of residue incorporation can also greatly affect mineralization.

Effect of fertilizer efficiency. All nitrogen recommendations must assume a certain average effectiveness of the fertilizer N being applied. Nitrogen recommendations based on

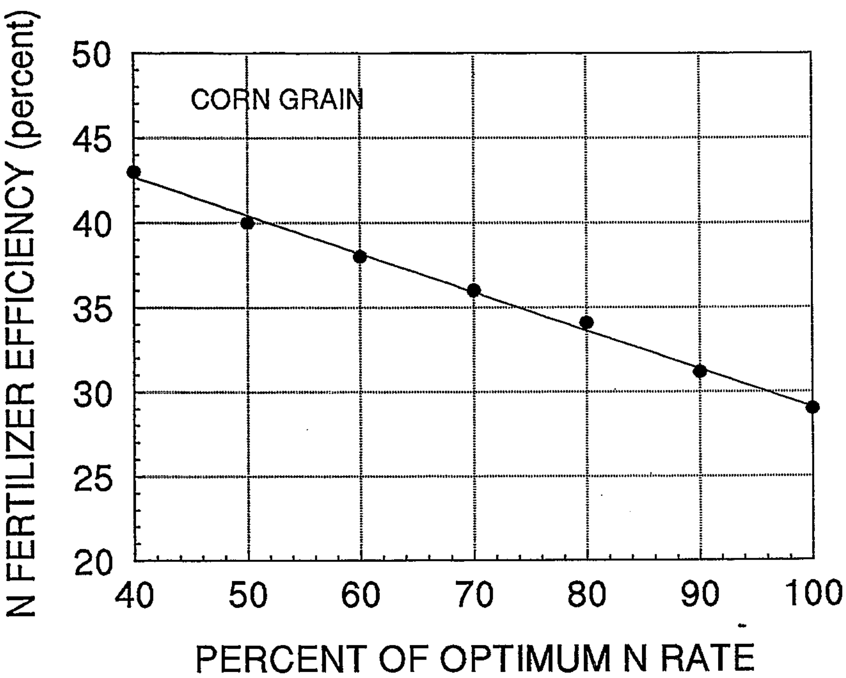

Figure 3. Corn grain fertilizer N efficiency as affected by percent of optimum N rate averaged across 10 locations in Nebraska, 1988-1990. Optimum based on \$98.42 Mg^{-1} of corn (\$2.50 bu^{-1}) and \$0.33 kg^{-1} N (\$0.25 lb^{-1} N).

field calibration experiments necessarily reflect the average N fertilizer effectiveness of all experiments in the database. Calibration experiments often utilize ammonium nitrate as a preplant application to standardize the N source and method of application. However, there is a mass of data to show that N fertilizer effectiveness can vary widely depending on many factors. Varying amounts of fertilizer N may be lost by leaching, denitrification, and volatilization, depending on the temperature and precipitation that occur after application. Sources of N also vary in their susceptibility to be lost by leaching or by gaseous mechanisms.

Fertilizer N may also be effectively removed from the available N pool by immobilization in crop residues depending on residue kind and degree of incorporation.

A well-known means of increasing N fertilizer effectiveness is to delay application time until the crop is approaching maximum N uptake. Maximum N fertilizer effectiveness usually occurs with sidedressing row crops, topdressing small grains, and applying through irrigation water.

Fertilizer N efficiency is also influenced by such factors as insects, disease, plant genetics, and environmental factors affecting plant health, and therefore, potential yield. All of these factors affect yield response to applied N and one or more of the factors is probably the reason for linear response to applied N such as shown in Figure 2. The various factors that affect N fertilizer efficiency result in above ground N uptake efficiencies for corn of only 50 to 60 percent. Because of the law of diminishing returns, N use efficiency declines rapidly as the optimum N rate is approached (*6*). In Nebraska, average irrigated corn grain N efficiency averaged only 30 percent at the optimum N rate (Figure 3). This data also showed that even decreasing the optimum N rate to only 50 percent of optimum increased corn grain efficiency to only 40 percent. This indicates that since most N recom-mendations attempt to recommend at the optimum economic rate, about 60 percent of the fertilizer N for irrigated corn is either lost in gaseous forms, leached, or remains in the soil as root and stover residues, immobilized as organic forms or as available inorganic N.

Effect of soil sample variability. Any discussion of the factors affecting soil test N recommendations is incomplete without some recognition of soil sample variability (*19*). Soil sample nitrate-N variability can greatly affect the N recommendation. Variation can be several hundred percent, depending on soil property variation, i.e., texture, organic matter content, past fertilizer history and distribution, precipitation, and past crop yields. Poor recommendations because of soil sample variability can only be controlled by obtaining adequate sample numbers that represent the area to be fertilized. One needs to always recognize that soil nitrate-N analysis will vary vertically and horizontally as well as in time. Soil nitrate-N content is not static, but dynamic and constantly changing. This change is affected by all factors that influence nitrate-N loss and accumulation in the soil.

Taking soil samples as suggested by the various soil testing laboratories and state extension services normally provides soil nitrate-N analyses that have errors in recommendations at a level commensurate with errors from other factors that effect N recommendations.

How good are N recommendations? It is probable that most N recommendations based on present soil testing procedures are no better than ± 20-30 percent of the actual N need due to the many unpredictable factors that affect N availability to the plant. However, N recommendations based on soil nitrate-N is the best tool we currently have for recommending N fertilizer under most conditions. It is certainly both economically and environmentally superior to using a factor times yield goal to predict N needs, a method that is still widely used. The value of the soil nitrate-N test increases greatly as residual soil N increases to levels where no yield responses occur. At these high levels, soil nitrate-N based recommendations go to zero, while the factor method continues to recommend excessive rates of N. Soil nitrate-N testing is especially important for dryland cropping where yield expectations are often unpredictable. Soil nitrate-N testing in these situations can substantially reduce the following crops' N fertilizer recommendation and improve profitability as well as reduce nitrate-N contamination of ground and surface water.

The ability to establish a realistic yield expectation is certainly a major factor affecting the N recommendation. Even under irrigation, climatic conditions may increase or decrease the yield by 30 percent which means a yield goal of 11 Mg ha^{-1} (175 bu $acre^{-1}$) may actually range from 8 to 14 Mg ha^{-1} (127 to 223 bu $acre^{-1}$). A 3.1 Mg ha^{-1} (50 bu $acre^{-1}$) variability translates into about a $\pm$ 67 kg ha^{-1} (60 lb N $acre^{-1}$) variation in N requirement.

New technology

In many respects, it appears possible that relatively little improvement can be made in N recommendations using current soil testing practices for available N where adequate databases exist. However, research can fine-tune the soil test system, which certainly can be made more site specific. It is difficult to know what impact better knowledge can have on recommendation accuracy—for example, how N is immobilized and released from residues and how nitrate-N at various depths in the root zone affects N availability. In addition, little is known quantitatively of how N affects cereal yields depending on time of N uptake. Expanded research programs can certainly provide better N recommendations when the existing database is small or non-existent, but it must be recognized that the problem is a difficult one and large improvements are limited by factors that either cannot be controlled, are difficult to measure quantitatively, or are unpredictable.

The PSNT soil test is an example of refining the soil nitrate test to account for changes in soil nitrate-N status after the crop is established. By waiting until June to take soil samples, most mineralization and leaching has probably occurred and time remains for sidedressing or applying N in irrigation water. The test appears to do well in differentiating whether corn will respond in yield to applied N or not. A soil test of 21 to 26 ppm in a 0.3-m (1 ft) sample is currently the critical level for determining whether to apply N. How much N to apply when the test is below 21 ppm is still being researched.

The newest technology and probably the one with the greatest promise for irrigated corn is chlorophyll sensing (*17, 20, 21*). Chlorophyll content can now be sensed by a small portable meter that senses leaf color, which is closely related to chlorophyll content. This method potentially allows one to directly determine the relative N sufficiency of a crop in time to apply corrective action. Research has shown that corn chlorophyll readings as early as the sixth leaf stage are as accurate as soil nitrate-N tests in separating responsive from non-responsive sites (*17*). This method has promise, especially for irrigated corn where N can be applied in later stages of growth, providing a method of "spoon feeding" N according to need (*21*). Plant sensing with variable rate technology coupled to pivot irrigation systems promises to provide a N management system that has the potential to improve N fertilizer efficiency over current best N management practices.

Summary

Predicting the N requirements of a crop is quite difficult because of the many factors affecting availability of N already present in the soil and N that may be added as fertilizer. It is difficult for one mathematic function to predict N need for even one crop grown under widely varying conditions of climate and soil. However, soil nitrate tests of either the root zone to at least a 0.6-m (2 ft) depth prior to planting, or in early June (PSNT) to a depth of 0.3 m (1 ft) offer much improvement over using a factor times the expected yield. Certainly model fitting limitations, weather, pests, and variable fertilizer N effectiveness limits predictive ability of soil tests. However, there is little doubt that such tests can help prevent over-fertilization, which has been a major factor in elevated nitrate-N levels in our groundwater. New plant sensing techniques promise to increase N fertilizer efficiency greatly, especially under irrigation where N can be easily applied late in the growing season. Plant sensing coupled with fertilizer variable rate technology could result in significant improvement in fertilizer N use efficiency, and thereby, reduce environmental contamination and increase profitability for producers.

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Managing Animal Wastes

Agricultural waste management planning

William H. Boyd P.E.

An agricultural waste management system (AWMS) is a planned system in which all necessary components are installed and managed to control and use by products of agricultural production in a manner that sustains or enhances the quality of air, water, soil, plant, and animal resources.

In the U.S. Soil Conservation Service (SCS), AWMSs are planned under the umbrella of a Resource Management System (RMS) (Figure 1). A RMS is a unique combination of practices and management systems that, when applied, will protect the resource base and environment. It provides solutions to all identified resource problems and meets both the decision maker's and public's resource use, conservation, and maintenance objectives. Therefore, an AWMS is a subsystem of a RMS that deals with an agricultural waste problem. In solving an agricultural waste problem, an AWMS will interface or relate to other sub-systems in an RMS, such as a cropping system or a water management system.

The major objective in planning an AWMS is to help the producer achieve wise use of natural resources. Because of the number of alternatives to be considered, the planning process is often complex; however, the AWMS selected should be as simple and easily managed as possible. The key to doing this is to involve the decision maker in the planning process.

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Resource considerations

SCS soil conservationists work with decision makers to help them recognize the nature, extent, and importance of the five resources—soil, water, air, plants, and animals (Figure 2).

Soil. The soil is often the medium used in the final assimilation of many of the agricultural waste products. The application of organic agricultural wastes benefits soil condition by improving tilth, decreasing crusting, increasing organic matter, and increasing infiltration. Waste must be applied to the soil so that the waste constituents do not exceed the soil's capacity to absorb and store them. Application of wastes at a rate that exceeds the soil's infiltration rate can result in unwanted runoff and erosion. When this occurs, plant nutrients in solution and those attached to the soil particles along with bacteria, organic matter, and other agricultural material may be transported to the receiving water.

Water. Maintaining or improving the quality of surface and groundwater is an important consideration in planning an AWMS. Potential groundwater contaminants from agricultural operations include nitrate, salts, waste pesticides, and bacteria. Potential surface water contaminants from agricultural operations are nutrients, organic matter, and bacteria. The usual objective in planning an AWMS is to exclude clean water and capture polluted water for treatment or storage for subsequent use when conditions are appropriate.

Air. An AWMS often has an adverse impact on the air resource, so planning must consider ways to minimize degradation of air quality. Objectionable odors from confined livestock, waste storage areas, lagoons, and field application of wastes must be considered in plan-

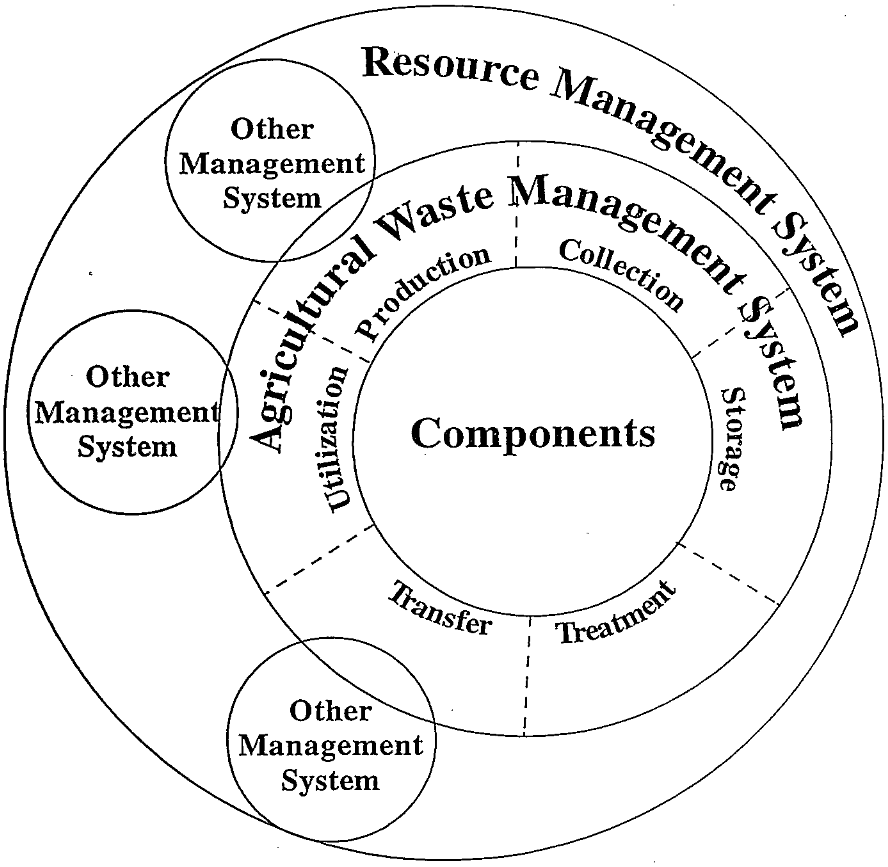

Figure 1. Relationship of an agricultural waste management system other management systems, and the resource management system.

ning an AWMS. Emissions of ammonia and gases from livestock operations are associated with acid rain. These types of emissions are also coming under scrutiny for their contribution to other environmental concerns, such as the greenhouse effect/global warming. Air movement, humidity, and the odors air may carry from the AWMS must be considered. Windbreaks, screens, or structure modification may be required to create conditions that minimize the movement of air.

Plants. Plants are used to recycle nutrients, screen undesirable views, channel or funnel wind, reduce noise, modify temperature, or prevent erosion. Plants selected for an AWMS must be adapted to the site conditions. If wastes are applied to agricultural fields, the application must be planned so that the available nutrients do not exceed the plants' need or contain other constituents in amounts that would be toxic to plant growth.

Animals. Obviously, an AWMS for a livestock enterprise must be planned to be compatible with the animals involved. A healthy, safe environment is essential for domesticated farm animals. Structures are planned both to protect the AWMS components from the animals and the animals from the components. Planning should also consider hazards from disease, parasites, and insects. The impact on wildlife also must be considered. Pollution of receiving water can have a significant effect on animals. Organic matter can drastically reduce dissolved oxygen levels in a stream, and high ammonia concentrations can kill fish. In addition, water with excess nutrients, or contaminated by agricultural chemicals, or polluted by bacteria can result in an environment that has a very negative effect on animals.

Human considerations. In addition to the resources, the social, cultural, and economic effects of alternative AWMSs on the human environment are considered. SCS provides assistance to help the producer comply with federal, state, and local laws, rules, and regulations, and to take into account such factors as financial status and management capabilities.

The planning process

Planning an Agricultural Waste Management System (AWMS) involves the same process used for any type of natural resource management system. The steps in this planning process are (1) identify the problem; (2) determine the objective; (3) inventory the resources; (4) analyze the resource data; (5) formulate alternative solutions; (6) evaluate alternative solutions; (7) determine a course of action; (8) implement the plan; and (9) evaluate the results of the plan. Following is a discussion of the planner's activities and responsibilities in each planning step as it relates to an AWMS.

Identify the problem. Decision makers must know what problems, potential problems, and federal, state, and local laws and regulations affect their operation. This information can help them recognize the need to develop an AWMS that will protect the resource base.

Determine the objectives. To plan an AWMS that is acceptable and will be implemented, the planner must determine the decision makers' objectives early in the planning process. The objectives greatly influence the type of AWMS planned. For example, the type of AWMS planned would be significantly affected if the decision maker's primary objective is to use the waste for power generation rather than for land application. A decision maker's objective to bring the operation into compliance with laws and regulations may result in an AWMS that is not as extensive as one where the objective is to minimize the effect on the environment and enhance public acceptance of the system. A decision maker's objective to minimize management efforts would result in an AWMS significantly different from one that would emphasize the role of management.

Inventory the resources. After the objectives are determined and documented, it is time to inventory the resources. The planner must assure that the resource inventory data are complete to the extent that they can be used to develop alternatives for a proposed AWMS. This requires an inventory based on compilation of data from many different sources. Some of the required data can be physically measured. For example, the number of acres available for land application of waste often can be determined from a map. Other needed data, such as the level of management, are less tangible and must be determined based on observation, discussions with the decision maker, and judgement of the planner.

Analyze the resource data. This can be best accomplished by viewing an AWMS as having six functions. The inventory data are categorized into one of the six functions and then interpreted, analyzed, and evaluated in preparation for developing alternatives.

Formulate alternative solutions. Alternative AWMSs are formed based on the analysis of the inventory data as cataloged into one of the six functions of an AWMS. A more complete discussion of these six functions is presented in the next section.

Evaluate alternative solutions. Alternative solutions need to be evaluated to determine if they meet the objectives, solve the problem, and are socially, culturally, and economically acceptable.

Determine a course of action. If the preceding planning elements are properly carried out, the decision maker will have all of the information available, including the private and public objectives, on which to make the needed decision. The decision should be based on whether the alternative is cost effective, environmentally sound, and socially acceptable.

Implement the plan. Well planned, economically sound, and acceptable plans have a much greater likelihood of being implemented. Decision makers ultimately have almost total control over implementation. The planner can help decision makers by providing approved detailed construction drawings and specifications for facilities, specific operation and maintenance plans for each component, and information on cost sharing programs, low interest loans, and other opportunities or conditions, such as pending laws, that may affect the decision to implement the AWMS installation.

Evaluate the results of the plan. Changing demands, growth, and technological advances create a need to evaluate an AWMS to update objectives and modify plans. Plans developed but not implemented within a few years must be reevaluated. This requires repeating some or all of the planning elements to maintain a viable plan. The implemented AWMS may need to be fine-tuned not only because of technical advances, but because of what the decision maker has learned about the system. This planning element gives the planner an excellent opportunity to gain experience and knowledge that will be useful when providing planning assistance to other decision makers.

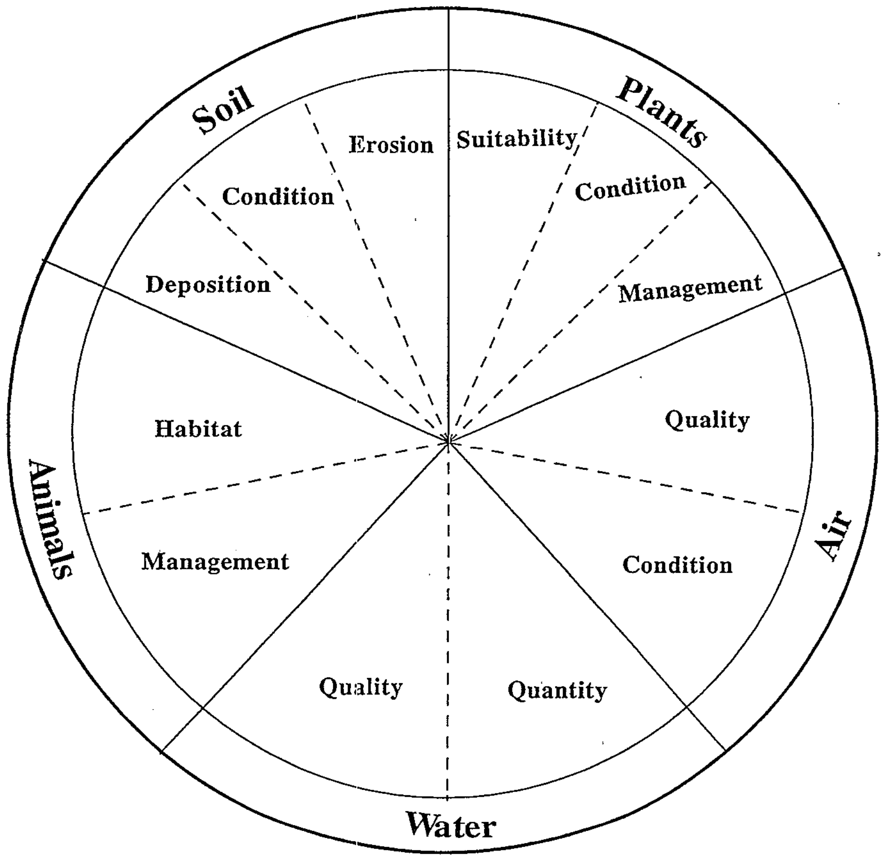

Figure 2. Resource considerations.

The total systems approach

Agricultural waste management

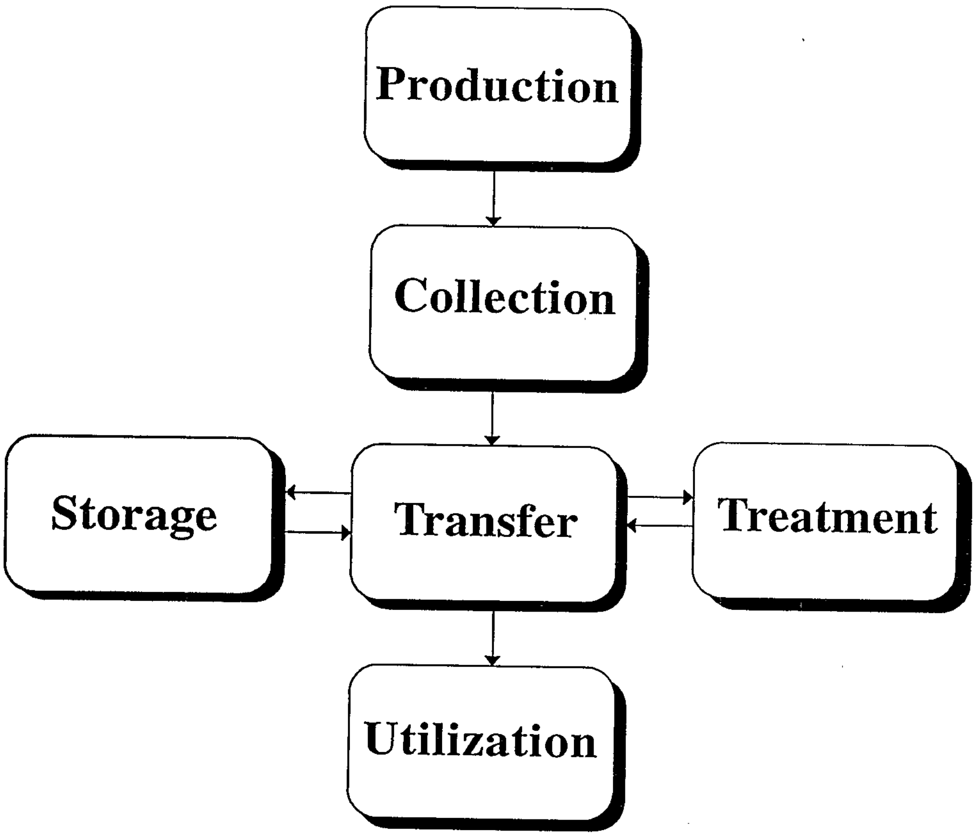

Figure 3. Waste management system functions.

system alternatives are developed using the total systems approach. A total system accounts for all the waste associated with an agricultural enterprise throughout the year from production to utilization. In short, it is the management of all the waste, all the time, all the way. A total system for the management of agricultural waste consists of the following six basic functions: (1) production, (2) collection, (3) storage, (4) treatment, (5) transfer, and (6) utilization (Figure 3). For a specific system these functions may be combined, repeated, eliminated, or arranged as necessary.

Production refers to the amount and nature of agricultural waste generated by an agricultural enterprise. Waste requires management when enough is produced to become a resource concern. A complete analysis of production includes the kind, consistency, volume, location, and timing of the waste produced. The production of waste should always be kept to a minimum. For example, a large part of the waste associated with many livestock operations includes contaminated runoff from open holding areas. The runoff is reduced by restricting the size of open holding areas, roofing part of the holding area, and installing gutters and diversions to direct uncontaminated water away from the waste. A proverb to remember is, "Keep the clean water clean." Leaking watering facilities and spilled feed also contribute to waste production. These problems are reduced by careful management and maintenance of feeders, watering facilities, and associated equipment. The waste management system also accommodates seasonal variations in the rate of production, and considers fixed expansion of the operation. A record should be kept of the data, assumptions, and calculations used to determine the kind, consistency, volume, location, and timing of the waste produced.

Collection refers to the initial capture and gathering of the waste from the point of origin or deposition to the collection point. The AWMS plan identifies the method of collection, location of the collection points, scheduling of the collection, labor requirements, necessary equip-ment or structural facilities, manage-ment and installation costs of the components, and the impact that collection has on the consistency of the waste.

Storage is the temporary containment of the waste. The storage facility of a waste management system is the tool that gives the manager control over the scheduling and timing of the system functions. With adequate storage the manager has the flexibility to schedule the land application of the waste when the spreading operations do not interfere with other necessary tasks, when weather and field conditions are suitable, and when the nutrients in the waste can best be used by the crop. The storage period is determined by the utilization schedule. The waste management system plans identify the storage period, the required storage volume, the type of storage facility, the estimated size of the facility, the location of the facility, the installation cost of the storage facility and the cost of management, and the impact of the storage on the consistency of the waste.

Treatment is any function designed to reduce the pollution potential of the waste, including physical, biological, and chemical treatment. It includes activities that are sometimes considered pretreatment, such as the separation of solids. Plans include an analysis of the characteristics of the waste before treatment and a determination of the desired characteristics of the waste following treatment; the selection of the type, estimated size, location, and the installation costs of the treatment facility; and the management cost of the treatment process.

Transfer refers to the movement and transportation of the waste throughout the system. It includes the transfer of the waste from the collection point to the storage facility, to the treatment facility, and to the utilization site. The waste may require transfer as a solid, liquid, or slurry, depending on the total solids concentration. The system plans include an analysis of the consistency of the waste to be moved, method of transportation, distance between points, frequency and scheduling, necessary equipment, and the installation and management costs of the transfer system.

Utilization is the recycling of reusable waste products and the reintroduction of nonreusable waste products into the environment. Agricultural wastes may be used as a source of energy, bedding, animal feed, mulch, organic matter, or plant nutrients. Properly treated, it can be marketable. The most common practice is to recycle the nutrients in the waste through land application. A complete analysis of utilization through land application includes selecting the fields, scheduling applications, designing the distribution system, selecting necessary equipment, and determining application rates and volumes, the value of the recycled products, and the installation and management costs associated with the utilization process.

The functions are accomplished by implementing and managing individual components. The components may be an interrelated group of conservation practices, such as a waste storage pond, roof runoff water management, diversion, and waste utilization. Push-off ramps, manure pumps, transport equipment, grade control structures, and vegetative treatments are examples of components that support the function.

The waste management plan

The best waste management system is of little value and has the potential for much harm if it is not properly managed and maintained. Also, the owner of the waste management system is often subject to fines and litigation if unable to provide documentation for the rationale of the plan and the procedures followed in operation and maintenance. For this reason it is recommended that the owner be provided with the following set of documents which constitute the waste management plan.

- A narrative description of the management of the waste from production to utilization.
- A set of "as build" plans and construction specifications for the components installed to implement the plan.
- A copy of pertinent correspondence including agreements and permits.
- A written operation and maintenance plan describing the upkeep and management of the system and the individual components in a safe manner so that it functions as intended throughout its design life.

Properly done, the AWMS plan guides the actions of the producer in a way that enables the producer to utilize the waste while protecting the natural resources. ❑

Best management practices for livestock production

L. M. Safley, Jr. P.E.

Livestock production is a major component of agriculture in the U.S. However, the livestock industry faces significant environmental challenges, which have risen from increased public awareness and desire by the public for aesthetic and environmental protection. On one hand, fewer people in the U.S. are directly involved with livestock production and there is less sensitivity to the problems that livestock producers face. On the other hand, there is a trend to develop larger, more sophisticated livestock production facilities which can be more visible. Livestock producers must develop strategies for managing waste materials in a manner that will minimize the potential for offensiveness and environmental degradation.

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This paper will identify several management practices that livestock producers should consider carefully. Because each livestock enterprise is unique, there is no one specific waste handling system that will meet all needs. Rather, a specific set of management practices must be adopted by each producer.

Primary environmental concerns

There are two primary environmental concerns facing livestock producers, nutrients and odor.

Many livestock producers import the majority of feed materials consumed on a given site. Only a portion of these nutrients are retained by the animal. The remaining nutrients pass to the waste treatment/storage system where additional loss can occur. The nutrients left after waste treatment should not exceed the assimilative capacity of the receiver site.

Some odor can result from livestock production. When odor causes neighbors to initiate litigation and/or production restrictions, livestock producers face real problems. Livestock producers will have to locate future facilities in low population density areas or develop technology for superior odor control.

Developing a waste management system

During the planning of any livestock enterprise considerable thought should be given to developing an appropriate waste management system. The system must accomplish the following:

- timely waste collection
- adequate waste treatment and/or storage
- efficient land application
- utilization/management of nutrients

It is important for the producer to realize the capabilities and flexibility of a waste management system prior to committing the resources to develop it. All system components should be designed with the producer's objectives in mind. The producer must also be aware of the operating costs associated with the waste management system:

- Processing waste
- Land application of waste
- Equipment maintenance
- Planting and harvesting crops
- Waste analyses
- Record keeping

Site selection

A waste management system must be developed around a given tract of land. Each tract of land has its own set of attributes. Site selection is probably the most critical element in developing a livestock enterprise. A number of factors that should be considered when evaluating a site relative to waste management are discussed below.

Geology

- Are there any limitations to constructing lagoons or earthen storage basins (e.g. depth to bedrock, Karst areas, excessive sand)?
- What is the clay content of the soil?
- How deep is the water table? Does it vary throughout the year?

Land

- How much land is available for applying waste materials?
- What types of crops can be grown?
- Is the land adequate to accommodate all of the nutrients to be applied?
- What is the background level of soil nutrients?

Location

- What is the proximity to wells, streams, ponds, churches, businesses, schools, and residences?
- What type of agriculture is practiced adjacent to the site (livestock, row crop, etc.)?
- Are the neighbors sympathetic to livestock production?
- How visible will be the livestock production facilities, the lagoons or waste storage units, and the land that will receive the waste?
- What is the likelihood of future development within two miles of the site's boundaries?

Climate

- What is the mean ambient temperature by month? What is the mean monthly rainfall?
- What is the prevailing wind direction?
- What is the natural air drainage pattern (especially for conditions of calm wind and high humidity)?

Prior to purchasing a tract of land a careful appraisal should be made of the site considering the factors identified above.

Livestock nutrient production

The quantity of nutrients excreted by livestock is directly influenced by diet. This is a very important observation for two reasons. First, reduced nutrient excretion implies increased nutrient utilization for a given level of performance and this translates into reduced production cost. Second, a reduction in the amount of nutrients produced reduces the amount of land required for application of manure.

Probably the simplest example of the impact of managing feed nutrients relative to manure nutrients can be seen in a model of nitrogen utilization by a mature lactating cow. Equation 1 predicts the nitrogen in manure as a function of nitrogen intake and milk production:

$$N_{manure} = N_{feed} - N_{milk} \quad [1]$$

This model was first suggested and validated by Boussingault (*2*) for maturing lactating dairy cattle being fed a ration to maintain body weight. The model is now accepted as the basis for nutrient balance research in all mammals (*12*, *16*). Using the model, Safley, Westerman, and Barker (*13*) determined that approximately 75 percent of the ingested feed nitrogen was excreted for mature, lactating dairy cattle.

Schatzchen and Kuhl (*14*) have estimated that 76 percent of the feed nitrogen in a large swine facility was excreted.

The simplest way of reducing manurial nutrients is to improve feed efficiency. This can be accomplished by reducing feed loss or altering the ingredient blend in feeds. For example, a 5 percent feed loss in swine production translates into an increase in excreted volatile solids of approximately 46 percent (Earth, 1985).

European research (*7*, *9*) has suggested several possibilities for reducing nitrogen in swine manure. The first option is to improve efficiency. A reduction in feed conversion of 0.5 units translates into a 10-15 percent reduction in nitrogen excretion. Another option is that of phase feeding. In phase feeding, finishing swine are fed a reduced protein diet as they approach market weight. Another option is to balance a ration using synthetic amino acids. This has the impact of reducing the protein in the ration. Using soybeans as the principal protein source will lead to "over feeding" of certain amino acids (lysine, tryptophan, threonine, etc). It may be possible to reduce nitrogen excretion in urine by more than 25 percent if synthetic amino acids are used. However, economics will dictate the feasibility of this option. Hall et al. (*5*) have found nitrogen excretion reductions in the range of 40 to 50 percent with the use of feed grade amino acids with no apparent reduction in animal performance.

Nitrogen is not the only nutrient of concern to the environment. Phosphorus is also coming under increased scrutiny. The state of Ohio now suggests that manure applications should be made on the basis of meeting crop phosphorus needs. This typically increases the amount of land required by 50 to 100 percent as compared to nitrogen. Only 14-15 percent of the phosphorus in a corn-soybean ration is available to finish swine (*3*). The remainder is excreted in the feces. Research has indicated that the addition of microbial phytase has increased phosphorus utilization (*4, 6, 8*). This could lead to reduced amounts of excreted phosphorus and other nutrients (calcium, etc.).

Lindemann (*10*) has conducted research in Virginia on reducing nitrogen and phosphorus excretions from swine. Large differences have been found in feed efficiency within a given herd of swine that exhibit similar growth rates. This would suggest the need for evaluating the genetic potential of livestock for nutrient utilization efficiency. Other ideas being considered include split-sex feeding and changes in diet to match environmental conditions. Lindemann et al. (*11*) has suggested that the addition of chromium to swine diets can improve feed efficiency by approximately 6 percent and at the same time accomplish improvement in carcass measurements.

Research on reducing nutrient excretion has been conducted with caged layers (*15*). It was determined that the use of methionine along with reduced protein inputs could reduce nitrogen excretions by 16 percent. Reduction in phosphorus levels in the diet also lead to significant reductions in excreted phosphorus.

There has even been discussion of developing "designer" grains that would be more digestible (Charles Murphy, University of Maryland, 301-504-5560) and, therefore, reduce nutrient excretion when fed to livestock.

Nutrient losses during collection, treatment, storage, and land application

A critical element required in the evaluation of a given site is an estimate of the quantity of nutrients that will be produced by the waste system. An appreciable amount of the nitrogen in manure can be lost (become unavailable) in certain waste management components (anaerobic lagoons, irrigation, etc.). Considerable quantities of phosphorus can be concentrated in the sludge in lagoons that is only periodically removed. It is a good idea to seek the advice of professionals that routinely work in livestock waste management when developing an estimate of the effective amounts of nutrients that must be managed from a given livestock enterprise.

Waste management plan

Every livestock enterprise should develop a comprehensive waste management plan. This may be a requirement of the permitting process. Development of a waste management plan typically identifies most potential problems associated with a given enterprise. Such knowledge is essential. A well-developed, well-executed waste management plan is one of the livestock producer's most valuable tools.

The following should be included in waste management plans:

Livestock population. Identify the type, number, and mean live weight of the livestock. This information is essential to any planning process.

Schematic of production facilities. All production facilities should be identified on a site sketch. All waste management system components (pipes, storages, etc.) should be identified.

Facility map. A map should be prepared that identifies the boundaries of the enterprise and the surrounding land. Often a USGS topographical map can be used. An ASCS aerial map may also be useful.

System design. A file should be initiated that will contain information on any professional design work (SCS, Cooperative Extension Service, private practice engineers, equipment manufacturers, etc.) that has been done on the waste management system. This may include the design work done on lagoons or other components. In addition, literature, specifications, and other information on any manure management system equipment (pumps, spreaders, etc.) should be retained for ready reference.

Permit file. A copy of any permit materials and related correspondence should be maintained in a separate file. The producer should be thoroughly familiar with all requirements (especially reporting) of the permit.

Waste management calendar. Every livestock enterprise should have some type of calendar that identifies pertinent waste management activities: permit renewal, reports due, analyses schedules, estimated dates of waste application, etc. Someone should be responsible for making sure that the calendar activities are appropriately managed.

Land receiving waste. A map should be prepared that identifies each field that will receive waste. Each field should be uniquely identified to facilitate communication. The cropable acreage, soil type, and any agronomic limitations (seasonal high water, excessive slope, etc.) should be identified. A table should be prepared that identifies all of the fields.

Cropping plan. A cropping plan should be developed that identifies the acreages of crops that will be produced for a given year. It is a good idea to have at least a preliminary plan for the crops to be produced for one to two subsequent years. This will aid in managing crop rotations. The potential nutrient uptake (N, P, and K) of each crop should be identified. This information should be available from the Cooperative Extension Service. A simple computation should be made to determine the probable amount of each nutrient that should be assimilated for all of the crops that will receive waste during the year. These figures can be compared with the estimates of nutrients that will be applied routinely during the same time period. The goal is to have sufficient land to utilize the nutrients produced.

Field records. An annual record should be maintained for each field that includes the following information:

- crop grown
- yield
- important crop dates—planting, harvesting, waste application, etc.
- amount of waste applied
- application of any commercial fertilizers

Waste production and characteristics records. A file should be established that records the amounts of waste materials that are removed from storage/treatment. This can be compared to the records being maintained for land application. Periodic, representative waste samples should be collected and analyzed. Copies of the lab reports should be retained and used to determine the quantities of nutrients removed/land applied. Typical analysis parameters include

- TKN—total Kjeldahl nitrogen; includes organic nitrogen and ammonia nitrogen
- Ammonia-N—ammonia nitrogen; can be readily used by plants
- Nitrate-N—nitrate nitrogen; can also be used by plants; an analysis for nitrate-N is needed only if the waste has been treated aerobically
- P—phosphorus
- K—potassium
- TS—total solids

Soil and crop samples. Representative samples of crops from each field should be collected and analyzed. This information, along with the yield, can be used to estimate crop nutrient uptake. At the end of the growing season, soil samples should be collected from each field that received waste during the year. The analytical results should be compared to those from previous years for a given field. The above information can be used to evaluate the effectiveness of the waste management scheme and changes can be made as needed.

Monitoring well records. If monitoring wells are required by a permit, the sampling schedule should be closely followed. It is a good policy to collect water samples periodically from existing wells in the vicinity of the livestock production facilities and the fields that receive waste. Well water samples typically are analyzed for nitrate nitrogen and pathogenic bacteria.

Permits for waste management systems

Several states now require livestock producers to obtain permits for waste management. Much of the information identified above typically will be required. The permitting process (collecting the information needed and evaluation by regulatory agency) can be time-consuming. In many cases the permit has to be issued prior to construction. Therefore, producers should investigate the requirements of the permitting agency in a given state and plan accordingly.

Once the permit has been received, the producer should read it thoroughly. Most states allow a period of review and discussion before the permit is final. In some cases it may be in the best interest of the producer to challenge certain assumptions (nutrient uptake, etc.) used in developing the permit. However, the producer typically will have to support his/her position thoroughly.

Nutrient management

For planning purposes the phosphorus and potassium in livestock waste can be considered equivalent to that found in commercial fertilizers. However, not all of the nitrogen that is applied can be considered plant available. Frequently a decision has to be made with regard as to how the nutrients in livestock will be managed since the concentrations of the individual nutrients are rarely in the required proportions. Therefore, some nutrients may be applied in excess. Phosphorus and potassium are frequently applied in excess of immediate crop needs when using livestock waste as the sole source of nutrients. This is not necessarily bad. However, annual soil samples should be taken from all fields receiving livestock waste to see if nutrient imbalances are developing.

The following equation can be used to estimate the plant available portion of the nitrogen in livestock waste:

$$PAN = (MR \times (TFN - NH^3\text{-}N)) + ((1-VR) \times NH^3\text{-}N) + NO_3\text{-}N$$

where

PAN—plant available nitrogen

MR—mineralization rate (organic nitrogen converted to inorganic nitrogen)

TKN—total Kjeldahl nitrogen concentration

NH^3-N—ammonia nitrogen concentration

VR—volatilization rate; amount of ammonia nitrogen lost during application

NO_3-N—nitrate nitrogen concentration

Laboratories can differ in the reporting units used, which can be confusing. The producer should request that the analytical reports be prepared using units that are most useful to the producer. Frequently laboratories use the concentration units of ppm (parts per million) or mg/l (milligrams per liter). These terms are the same for liquid samples (as received basis).

There is some debate with regard to what value for MR should be used. In general, the fresher the waste material the higher the MR. The MR for freshly excreted waste typically ranges from 0.35 to 0.5. Waste that has been through some type of treatment (aerobic or anaerobic) will have a lower MR—typically 0.2 to 0.35. The IF can also vary. For injection of waste the IF is in the range of 0.05 to 0.10. For irrigated lagoon liquid the IF is typically assumed to be 0.5. It is suggested that the Cooperative Extension Service be consulted with regard to appropriate MR and VR values for a given system and climate.

Estimates of nutrient application should be taken from published sources during the initial planning process. As soon as waste material is removed from a facility, representative samples should be collected and the information used to determine actual application rates. Apparently similar waste systems have been found to have significantly different waste characteristics. This difference is a function of variation in management and feeding programs. A database of waste characteristics should be developed for a given enterprise. This information is essential to proper waste management.

Odor management

Some odor is a natural part of livestock production. Given this fact, it would be best to locate livestock production facilities away from potentially complaining neighbors.

Odor should always be a primary siting consideration. However, there is almost always the potential for someone being offended. Odors can come from production facilities as well as waste treatment/storage units. Sometimes it is difficult to determine the exact source of odor.

Odor management as a part of waste treatment begins with design. Underdesigned lagoons will generate more odor than properly designed lagoons. The additional cost associated with larger lagoons can be offset by the reduction in odor potential.

There are numerous products on the market that make claims regarding odor control/reduction. However, few, if any, of the manufacturers of these products can support their claims with scientific evidence.

Floating covers have been placed over a few lagoons to help reduce odor. However, this alternative should only be considered as a last resort due to the expense of the covers. However, if an anaerobic lagoon must be covered, the cover design should allow for harvesting of the biogas. There is some potential for utilizing biogas as a fuel. However, the economics of covering anaerobic lagoons for biogas collection and utilization have not been fully developed.

Other important best management practices

Visual buffers. Visual buffers can reduce complaints from neighbors and passersby. Such buffers should be established prior to or during construction. If possible, locate waste management systems using natural visual buffers (trees, topography, etc.).

Vegetative buffers. Vegetative buffers should be implemented around all fields receiving waste. Vegetative buffers will reduce the potential unanticipated runoff leaving the field. All waste application systems should be planned to promote rapid incorporation of the waste into the soil. Vegetative buffers serve mainly as a second line of defense. They can help strip nutrients from the runoff.

Appropriately designed treatment/storage units. Some producers want to determine the size of treatment and storage components using the smallest possible recommendation. This typically can lead to problems with odor, excessive nutrient and sludge buildup, and application scheduling.

Runoff control. Absolutely no runoff that has passed through feedlots or otherwise made contact with livestock manure should flow into any waterway or drainageway. Collection ponds and vegetative buffers should be used to help manage runoff.

Soil Conservation Service BMPs

The USDA Soil Conservation Service Best Management Practices (BMPS) typically associated with livestock production are identified as follows:

SCS Practice Name	Code
Compost facility	317
Conservation cropping sequence	328
Conservation tillage	329
Contour farming	330
Controlled drainage	335
Critical area planting	342
Dike	356
Diversion	362
Fencing	382
Field border	386
Filter strip	393
Grassed waterway	412
Heavy use area protection	561
Irrigation water management	449
Lined waterway or outlet	468
Mulching	484
Nutrient management	590
Pasture and hayland management	510
Pond	378
Pond sealing or lining	521
Roof runoff management	558
Sediment basin	350
Structure for water control	587
Subsurface drain	606
Field ditch	607
Main or lateral	608
Terrace	600
Underground outlet	620
Waste management system	312
Waste storage pond	425
Waste storage structure	313
Waste treatment lagoon	359
Waste utilization	633
Water and sediment control basin	638
Water table control	641

Summary

Livestock waste management systems must be developed for individual enterprises. Adequate planning, development, and implementation of a waste management plan will allow producers to operate in ways that minimize the potential for environmental degradation and protect the investment made in the entire production facility. Producers must exercise the initiative and be willing to commit the needed resources to manage livestock waste.

Reducing the quantity of nutrients excreted by livestock will positively impact profitability and reduce the potential for environmental problems.

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Methane production from animal wastes

Andrew G. Hashimoto, Thom G. Edgar, and Hiroshi Nakano

The anaerobic digestion process has been used since the early 1900s primarily to treat sewage. Methane was a by-product that was occasionally used to heat buildings or generate electricity. The renewed interest in anaerobic digestion has been directed toward evaluating its feasibility for converting biomass feedstock into energy. In the U.S., initial efforts to commercialize anaerobic digestion technology for converting biomass to energy and other products have been primarily focused on livestock enterprises. This paper describes general considerations for commercializing this technology and describes our efforts to design and construct a centralized anaerobic digestion facility to convert dairy manure into electrical energy and fertilizer.

General considerations

Most commercial anaerobic digestion systems are operated at mesophilic temperatures (90° to 95°F) with retention times ranging from 0.25 to 0.45 lb (0.11-0.2 kg) volatile solids (VS) per ft^3 per day. Methane production rates from these systems range from 0.8 to 1.2 ft^3 (0.02-0.03 m_3) CH_3/ft^3 day digester.

Both upright steel tanks and trench-type, plug-flow digesters have been used. The type of digester has no apparent effect on the design retention time or loading rate.

Typical capital cost for major components of a manure digestion system are: manure preparation and storage, 16 percent; digester, 42 percent; engine-generator, 30 percent; and miscellaneous, 12 percent. These are general guidelines and the relative percentages can vary considerably. For example, the engine-generator can be up to 50 percent of the total cost for small plants, and the manure preparation and storage component may be much higher if sludge thickeners or size reduction equipment are needed.

Products. Biogas is being used in various ways. The majority of plants convert biogas to electricity. However, several plants use the biogas as boiler fuel for a steam flaker, dehydrators, meat packing plant, or alcohol still.

The ultimate use of the biogas should be based on local energy demands and relative values of the different forms of energy. If there is a large local demand for thermal energy, then this alternative is generally the most economical since the capital and operating costs for engine-generator sets can be avoided. However, for the majority of plants and most on-farm applications, biogas production generally exceeds the farm's thermal energy demand during most of the year, and it is not economical to store biogas for seasonal use. Thus, many farmers have decided to convert biogas into electricity.

Electricity generation is attractive because the biogas can be converted as it is produced. This alleviates the need to store the biogas for long periods, and any excess electricity can be sold to an electrical utility. The price received from the sale of electricity varies considerably between states and utilities. In most cases, the utility pays only a fraction of the rate they charge farmers for the use of electricity. Thus, it is important to use as much of the generated electricity on the farm as possible and minimize the amount sold to the utility. To accomplish this, farmers may elect to manage their energy demands to match their energy production (load leveling) and/or produce energy to meet periods of high energy demand (peak shaving).

Digester effluent is being used in several different ways. The predom-

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inant uses are as fertilizer, livestock feedstuff, and livestock bedding. The digestion process does not affect the concentration of the major nutrients (nitrogen, phosphorous, and potassium). Thus, the digester effluent has the same fertilizer value as the influent manure, although some farmers feel that the effluent is a better fertilizer because a higher portion of the total nitrogen is in the more readily available ammonia form.

Digested solids are being separated by centrifuging, screening, and/or pressing. In some cases, mildly cationic polyelectrolytes are being used to increase solids capture efficiency. The solids are being used as livestock feedstuff or bedding.

The value of the digester effluent as a livestock feedstuff ranges from $20 to $100 per ton. These values were generally estimated by the value of the feedstuff that the digested solids replaced in the ration, with some discount for the lower digestibility of the effluent solids. Using digested solids for bedding is gaining popularity in dairy operations because of the increasing cost of traditional livestock bedding.

Incentives. Several state and federal incentives are available for using anaerobic digestion systems. The Oregon Department of Energy offers a 35 percent Business Energy Tax Credit for equipment and installation costs, and a Small Scale Energy Loan Program that will finance projects like these at interest rates below commercial rates. An additional 10 percent federal pollution tax credit is available. The proposed federal investment tax credit would also be an incentive to construct these systems. In addition, accelerated depreciation schedules may be available. The Public Utilities Regulatory Policies Act of 1978 states that all utility companies must purchase electric power from private facilities at an avoided-cost rate.

Barriers to commercialization. Most of the firms that build digesters feel that the major barrier to commercialization is financial rather than technical. The economic conditions in the U.S. during the 1980s (low energy prices and high interest rates) have caused some enterprises to delay installing anaerobic digestion systems. Other enterprises wishing to install digestion systems have not been able to secure financing because of the perceived high risk of these systems. With the recent improvement in the economy and examples of successful anaerobic digester operations, more interest has been generated for installing these systems. Also, recent projections about energy shortages by the end of this century has renewed interest in alternate energy sources.

Even if an anaerobic digestion system is economically feasible for a livestock enterprise, other factors must be considered before installing a system. The additional labor and management needed to operate and maintain the system must be considered in relation to other labor demands of the enterprise. For a fairly well automated plant, one or two hours per day would be sufficient to monitor the operation of the plant. However, when more sophisticated management strategies are imposed, such as generating electricity only at high demand periods, more time must be devoted to the operation of the plant.

Effluent from the digester must be handled and ultimately disposed of in an environmentally sound manner. Although the digestion process removes most of the organic matter in the manure, the effluent from the digester still contains many of the other nutrients and oxygen demanding substances that must be disposed of properly.

In summary, it is clear that methane can be recovered from livestock manure. The major questions are whether the process is economically feasible for a particular farm and if the process fits in with the overall operational objectives of the farm. The process appears to be feasible for only relatively large farms. However, the need for alternative sources of energy will become more acute in the next decade and this may improve the economic feasibility of the process for smaller farms.

Tillamook feasibility study

Background. Tillamook County is located on the northwest coast of Oregon and is the largest producer of milk and shellfish in the state. Approximately 30 percent of all Oregon dairies are located in the county. The dairy industry contributes about $62 million from milk production alone to the local economy. All but two of the dairy farms in the county are members of a dairy cooperative, the Tillamook County Creamery Association (TCCA).

With the expansion of the Tillamook Creamery in 1990 to double (or more) its previous cheese production capacity, the opportunity exists for the members of the TCCA to increase the county's milk production. However, before the 191 area dairies can increase their dairy herd size, the problem of manure management must be addressed. With the current cow population already producing about 195 tons of total manure solids daily, there is a history of water quality problems in the county watersheds. There are concerns about pathogens attributable to livestock and other sources. Intermittent elevated coliform counts in the oyster harvesting areas of Tillamook Bay have resulted in fishing closures of the bay and fines to the TCCA.

Nitrogen is also perceived to be a potential threat to public health. Estimates indicate that the nitrogen loading rate to the agricultural pasture lands of the county is approaching agronomic limits. The region's high rainfall (more than 90 inches [229 cm] annually), poor draining soils, and high water table pose environmental limits on agricultural practices that cannot be easily improved by conventional methods. Any plan to increase animal numbers significantly must include alternatives of managing manure. Waste management alternatives must responsibly account for pathogens and nitrogen in excess of the crop uptake rate. The stream bacteria standard is 200 fecal coliforms (FC)/100 ml and the bay standard is 14 FC/100 ml. Even after dilution from rainwater, fecal coliform counts from 1,000 FC/100 ml to over 6,000 FC/100 ml have been measured during the fall months in Tillamook area waterways (*2*). Progress has been made in recent years with improving manure management in area dairies, but the fecal coliform problem is not yet fully resolved.

Because of these concerns, a feasibility study (*1*) was conducted by Oregon State University (OSU) and supported by the Tillamook Methane Energy and Agricultural Development Committee (MEAD). We estimated the total county cow population to be 26,000 head of 1,400 lb (635 kg) cow units. Sixty-four percent of the cows (118 dairies) are located within 10.5 miles (17 km) of the Port of Tillamook Industrial Park, the preferred site for the proposed facility. Within 10 miles (16 km) of the town of Cloverdale, but as far as 26 miles (42 km) from the port site, are 58 dairies with 28 percent of the county's herd. Finally, 14 producers with 8 percent of the cow population are within 5 miles (8 km) of the village of Nehalem but more than 28 miles (45 km) from Tillamook.

A number of scenarios were evaluated to assess the economic feasibility of constructing one or more centralized anaerobic digestion facilities. The scenarios included: constructing one plant (Port of Tillamook) up to three plants (Port of Tillamook, Cloverdale, Nehalem); cost of transporting the dairy manure to the plant(s); plant size to handle maximum projected manure production or only a portion of the current manure production; effluent handling alternatives; and conversion of effluent solids into a slow-release fertilizer.

Summary. Remedying the manure management problems of Tillamook County dairies with a centralized, county-wide waste-treatment system will necessitate undertaking a rather complex and comprehensive activity, requiring participation and cooperation among many area dairy farmers, governmental agencies, and residents. Economies of scale could allow area dairies to benefit from sharing in a common, management-intensive waste-treatment system, as opposed to multiple, individual dairy systems. Installation of one or two methane production plants, including lagoon storage and solids recovery facilities central to Tillamook and Cloverdale, to serve all the dairies in the county is technically feasible for treating and reducing pathogen and nitrogen levels in county watersheds. This, in turn, would permit area dairies to expand their milking herds to meet the Tillamook Creamery's production capacity while realizing increased income per dairy.

Unisyn pre-construction study

Because the feasibility study showed promising results, the MEAD committee contracted with Unisyn Biowaste Technology (a subsidiary of Washington Energy Company, Seattle) to examine and report on issues critical to the implementation of the project. The subsequent Preconstruction Report (*3*) showed that the patented biowaste technology developed by Unisyn would effectively address the environmental issues facing the Tillamook dairy industry at a cost within the range determined by the OSU feasibility study. By participating in the project, farmers could expect to increase milk production and overall farm revenue, while easing the environmental pressures inherent in increased land application of manure.

Summary highlights. The analysis showed that the facility would relieve the pressure to land-apply manure during periods of high manure accumulation and rainfalls (during the winter months). After digestion and effluent processing, the liquid effluent would contain only 25 percent of the nitrogen in the fresh raw manure and almost none of the fecal bacteria normally present in untreated manure.

Financial analysis showed that the projected operating cost to the farmer for hauling manure to be less than $2 per ton of untreated manure. Total cost for a design capacity of 121,000 gallons (458,033 l) per day including site preparation, equipment, buildings, construction management, financing, design and technical fees, permits, bonding, start-up and commissioning costs) would be between $12 and 15 million.

The field survey of 30 farmers indicated high receptivity to the project and the perceived need to address the problems of excess manure for the long-term health of the Tillamook dairy industry.

Market research demonstrated a high receptivity to the concept of a slow-release, recycled fertilizer product associated with the Tillamook name. This receptivity should create a high first-purchase demand. Performance and price of the product will dictate long-term success.

Capital requirements were estimated to be $3.8 million in equity and $10.5 million in debt. A significant portion of the equity would need to be in the form of public grants. Unit price for by-product sales are projected at 6¢ kWh for electricity, $250 per blended ton of fertilizer, and $40 per package ton of soil amendment.

Available parcels within the Port of Tillamook Bay Industrial Park are recommended as the best siting choices.

Odors associated with land application of the liquid nutrient were projected to be greatly reduced compared to the application of raw manure.

Project components. Manure will be transported to the plant by tanker and/or dump truck depending on manure solids content. Priority will be given to farms within a 10-mile (16 km) radius of the plant. An entity responsible for assuring a minimum volume supply of feedstock throughout the year will be identified.

The major feedstock for the facility will be dairy manure. Waste cheese whey and other sludges may be accepted. If necessary, an incentive system for farmers to maintain high-solids manure would be developed.

Biogas will be sold to the Tillamook People's Utility District (PUD) to generate electricity. Waste heat from the generator will be used to heat the digester, and to supplement the drying system for fertilizer production.

Centrifugation will be used to separate solids, which will be dried into a final product of bagged fertilizer. The product will be sold in high-value retail markets as well as commercial applications such as golf courses, and for institutional and agricultural uses.

Liquid will be returned to farmers or to adjacent port property for irrigation. If necessary, the nitrogen value will be decreased further by lagoon storage. Pathogens and weed seeds will be monitored and controlled to assure a clean effluent to area farmers.

Digester operations, including transportation and waste contracts with farmers will be the responsibility of the Soil and Water Conservation District. The fertilizer facility and its products are proposed to be the responsibility of the TCCA and Unisyn as 50-50 private venture partners. The energy facility would convert biogas from the treatment facility into saleable electricity and would be solely owned by the PUD. An advisory board would be composed of a voting member from each entity to direct and inform the operator coordinating the three facilities. The operating partner is proposed to be Unisyn, to oversee and manage the day-to-day activities at the combined facilities.

Herd size. The initial survey of farmers interested in sending their manure to the plant resulted in a total herd size of 10,000 dairy animals. On average, most of the farmers would like to increase their herd size by 43 percent over the next five years. A major constraint to such expansion is the current limit on available land for manure application.

Financial. The financial prospective for the initial plant is as follows:

- Plant capacity-121,000 to 145,000 gallons (458,033-548,883 l) of manure input per day
- Plant production-13,700 to 16,400 tons (12,435-14,886 metric tons) of blended fertilizer annually; 4.8 to 5.8 million kWh of net electrical production; 11,350 to 13,600 tons (10,302-12,345 metric tons) of soil amendments annually; 330 to 400 tons (300-363 metric tons) of grit annually; 29.4 to 35.4 million gallons (111-134 million l) of liquid nutrient annually
- Capital cost-$14.0 to 17.8 million
- Operating revenue at year 3 - $4.4 to 5.2 million
- Operating expense at year 3 - $3.0 to 3.5 million
- Direct payroll (excludes contract hauling)-$0.5 to 0.6 million
- Annual farmer's service charge-Less than $2.00 per ton of manure

Current project status

After acceptance of the Unisyn Pre-Construction Study by the MEAD Committee, development of the project focused on two issues, organization development and financing.

Organizational development. The recommended organizational structure was developed to meet a number of objectives. These objectives include matching ownership with individual organizational mission; matching ownership with financing capabilities; recognizing community-wide environmental benefits; and linking public and private entities.

The Tillamook County Soil and Water Conservation District (TCSWCD) and the PUD are currently negotiating an Inter-Governmental Agreement that will allow the PUD to operate the TCSWCD portion of the project. The TCSWCD will retain final authority over decisions affecting digester operations. The TCSWCD has the mission of protecting the soil and water resources of the county, as directed by the local dairy farmers and has state-granted authority to raise funds to meet its mission. The PUD has organizational depth, staffing, and administrative support services. By combining the two public entities for the development of the facility, the project has the capability of developing faster, involving the right segments of the community, and simplifying the public-private contract.

Unisyn and the TCCA are also discussing the potential for the joint venture fertilizer facility that will take the solid by-products from the digesters and form, package, and market fertilizers and soil amendment products. The joint venture entity would contract with the TCSWCD/PUD. The advantage of the joint venture would be to combine a number of organizational assets that add value to the marketing of the fertilizer products.

Financing. The Pre-Construction Study outlined a combination of financing sources, including public revenue bonds, private equity, and government grants.

A number of state agencies have been approached by the MEAD Committee. Preliminary indications are that the agencies are interested in the project and have the capability to provide revenue bonds for the project.

Private equity contributions to the project are being discussed between the private parties.

Grants are currently being proposed to a number of federal agencies for specific portions of the project. In October, the U.S. Congress funded $750,000 to initiate the project in 1993.

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Proper animal manure utilization

Alan L. Sutton

Livestock and poultry producers are considering the manure management system in their operations seriously today for two reasons: the need for efficiency of operation to increase profitability and the need for environmental responsibility. Several alternatives for manure collection, transport, storage, treatment, and utilization are available which are environmentally sound and can reduce the cost of production. In addition, proper management and

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Journal Paper No. 13953, Purdue Agricultural Research Programs, Purdue University, West Lafayette, Indiana 47907. Mention of product trade names does not mean endorsement or exclusion of other similar products by Purdue University.

Table 1. Comparative cost between swine lagoons and pit systems when all costs and benefits are compared. (1)

System		Cost - $/head capacity 600-head capacity	1,000-head capacity
Pit storage	Concrete pit	$3	$3
	Concrete slats	5	5
	Tanker system w/injectors	5	3
	Tractor	2	2
	Labor	1	1
	Total cost	$16/hd	$14/hd
	Nutrient returns	$9	$9
	Net costs	$7/hd	$5/hd
Lagoon	Concrete floor	$2	$2
	Recycle system	1	0
	Lagoon	3	3
	Irrigation	3	2
	Labor	1	1
	Tractor	1	1
	Total cost	$11/hd	$9/hd
	Nutrient returns	$2	$2
	Net costs	$9/hd	$7/hd

planning of a manure system is imperative for it to be used successfully. Following is a brief discussion of some problems facing the livestock industry related to manure management, solutions with proper management techniques, and research needs.

Pollution concerns

The potential contribution of animal agriculture to environmental pollution has been under scrutiny recently. Reports indicate that agriculture is the one of the biggest contributors to water pollution and animal production is a major component. Animal agriculture can contribute to pollution in three ways. First, water pollution can be caused by direct runoff after field application of manure or by contaminated water from open feedlots; by leaching caused by excessive nutrient applications or leaking earthen manure storages; and by direct runoff into poorly sealed wellheads. Second, air pollution can be caused within the buildings and during land application from odors and gasses created by manure decomposition, microbial agents, and dust from feed systems and the animals. Third, soil pollution can be caused by applying extremely high rates of nutrients to the land (through manure) and creating an imbalance of nutrients that can cause poor plant growth.

Proper land application of manure with efficient crop utilization offers the most environmentally safe use of manure. However, there has been concern about lack of uniformity in nutrient application and reported soil compaction problems with heavy application equipment. Some livestock operations do not have sufficient manure storage capacities or enough land to apply manure for maximum nutrient utilization. Excessive nutrients in livestock and poultry diets, and poorly operated feed delivery systems can result in excessive nutrients being excreted in manure that must be applied to the land.

Because of isolated cases of pollution and the perceived threat of animal agriculture's contribution to nonpoint source pollution, the possibility of stricter environmental regulations is evident. The major focus of regulations, at the federal, state, and local level, is to control runoff, control odors, have sufficient storage and land available for timely application of manure, and apply manure at agronomic rates. The goal must be a complete environmentally-sound manure management plan which is unique for each and every livestock and poultry producer.

Solutions

The goals of a manure management plan are to control and utilize the available manure nutrients from a livestock operation, reduce the costs and enhance the beneficial returns from the system to the enterprise, and maintain an optimum environment. Table 1 shows an example of the comparative costs (based on 1992 prices) between slurry pit and lagoon systems for two pork production operations of different sizes. Credit for fertilizer use of manure nutrients can reduce the manure system costs, especially with larger operations. In addition, due to a greater nutrient value of slurry manure, the system cost per head-capacity was reduced as compared to the earthen lagoon system. With earthen systems, proper management practices and design of facilities to control, store, and apply manure also are necessary.

Available nutrients from manure produced on the operation can be effectively utilized in a productive cropping program or processed and utilized in a non-polluting manner. In cases where there is not sufficient land available for crop utilization, agreements with neighboring land owners should be arranged. Information needed to develop a manure nutrient management plan includes crop nutrient needs; manure nutrient content to be applied; previous crop grown on the land site; soil characteristics and test results (cation exchange capacity [CEC], pH, phosphorus [P], potassium [K], and other minor elements); amount of manure applied on the field previously; and method and time of application of the manure.

Manure nutrient content

Nutrient levels in manure can vary considerably depending upon composition of the diet fed to the animals, system and length of time of storage, and the amount of water, bedding, or feed spillage in the manure. Producers have had little confidence in maximizing the nutrients in manure because there has not been an easy method for analyzing nutrient contents. Mixing liquid manure through mechanical agitation is the best means of obtaining a uniform sample of manure for laboratory analysis and being assured of a uniform application of manure nutrients applied to the soil. Manure analyses (dry matter, pH, total N, ammonium N, P, and K) should be conducted on manure from different storages over time until the nutrient content and variability of the manure on the farm has been firmly established. Analyses should be done routinely as a check or when a significant change in management of the operation takes place, i.e., changing the composition of the diet or addition of waterers.

A quick on-the-farm nitrogen test can be used to estimate available nitrogen in manure. This test, available in a kit, N-Meter (Agros, Kallby, Sweden), takes only five minutes and results can be used to adjust application rates when there is considerable variation in manure nitrogen content due to incomplete agitation or when changing manure storage locations, i.e. farrowing, nursery, growing-finishing. N-Meter values with estimated available N values were compared from various manures incubated in soil and the results were very similar (Sutton, 1993, unpublished data). Table 2 shows a comparison of available N in selected duck and swine manures. Westerman et al. (*13*) showed similar results comparing various types of manure for available N values with these methods.

The system and length of storage primarily affect the nitrogen content of manure. Long-term storages such as lagoon systems result in less organic nitrogen and more ammonium nitrogen. However, with increased length of storage, more ammonium nitrogen is volatilized into the atmosphere. The least amount of nitrogen loss is found in slurry storages for liquid manure systems and manure pack or litter systems for solid manure systems. P and K are not lost prior to land application unless there is runoff from an uncovered feedlot. Collection and storage of feedlot runoff is necessary and this dilute waste has some N, P, and K content that is generally irrigated onto cropland. In a lagoon system, most of the P (50-80 percent) and 50 to 75 percent of the K settles in the bottom of the lagoon. This is recoverable only when the sludge in the lagoon is removed. Table 3 summarizes the range of N, P, and K losses as affected by manure storage systems.

Table 2. Comparison of nitrogen meter values with laboratory available nitrogen estimates*

Manure type	Number	Nitrogen meter	Available nitrogen
	(n)	(lb/1000 gal)	
Liquid duck pit	8	23.3	25.8
Liquid swine pit	21	21.8	26.4

*100% ammonium N plus 30% organic N.

Table 3. Nutrient losses from animal manure as affected by method of handling and storage. *

Manure handling and storage method	Losses N	Losses P	Losses K
	(%)		
Solid systems			
Daily scrap and haul	15-35	10-20	20-30
Manure pack	20-40	5-10	5-10
Open lot	40-60	20-40	30-50
Deep pit (poultry)	15-45	5-10	5-10
Liquid systems			
Anaerobic deep pit	15-30	5-10	0-5
Above ground storage	5-25	5-10	0-5
Earthen storage pit	20-40	10-20	10-20
Lagoon	70-80	50-80	50-80

*Based on composition of manure applied to the land vs. composition of freshly excreted manure, adjusted for dilution effects of the various systems.

Due to the organic nature of animal manures, specific management practices must be used to maximize the value of manures as a nutrient resource. Nitrogen in manures can be lost by volatilization, denitrification, and leaching when applied to the soil. Early work in our laboratory determined that considerable nitrogen can be lost very rapidly by volatilization when surface-applying manure with a tanker wagon or irrigation system (Table 4). Most of the ammonia nitrogen loss takes place within 48 hours after application (*2*). Higher pH manure such as lagoon effluent, poultry manures, and veal calf manures volatilize more rapidly than manures with a pH below 7.0.

Incorporation of manure is important to conserve and utilize its full fertilizer value. This is especially important if the manure is applied in the spring or summer when temperatures are warm. Ammonia loss from surface-applied manure is greater during warm temperatures, and days with lower humidity and more air movement. In contrast, incorporating manure in the soil, whether by direct injection or by a tillage practice, will reduce ammonia loss significantly. Other advantages to incorporation include reduced runoff potential and odors. Comparing injection versus surface applications on corn yields showed an average advantage in corn yields of 23.5 percent (range 9.8-43.6 percent) for injection. (*11*).

Crop nutrient needs

Application rates of manure must be based upon the nutrients available in the manure and the nutrient requirements of the crop using realistic yield goals based on experience from farm history. Recommended nutrient needs should be adjusted based on P and K soil tests and whether a legume was grown on the land the previous year. The carryover of nitrogen from previous years of manure application should be estimated and manure application rates adjusted. The range of N carry over from legumes can be 20 to 30 lb N per acre (22-34 kg/ha) for soybean up to above 80 lb N per acre (90 kg/ha) for a good stand of alfalfa forage. With this information, the nutrient needs of the crop can be calculated precisely and over-application of N can be avoided.

Due to the organic nature of manure, considerable biological transformation takes place in the soil. Nitrogen mineralization and immobilization and the relative amount of N available for plant use depends upon the carbon to nitrogen ratio in the soil along with the contribution from the manure source. Nitrogen can be tied up in the organic matrix to a great extent and increased soil microbial activity results when manures are incorporated in the soil. With the increased microbial activity, there is a potential for increased release of N in the inorganic form. Unless the N is retained in the ammonium form, which is firmly attached to the soil particle, the N is converted to the nitrate form and potentially leached. If the soil is saturated with water, the nitrate form can be converted to nitrous N gas and volatilized (denitrified). In either case, nitrogen is lost from the soil and is unavailable for plant use. It has been estimated that only 3 to 35 percent of manure nitrogen and about 50 percent of fertilizer nitrogen is used for plant growth (*3*, *6*).

The challenge of nutrient application, whether from manure or commercial fertilizer sources, is to have nutrients available at the stage of growth when the plant needs them most. In the case of corn, P is required just after germination and for early growth. But in the case of nitrogen, little nitrogen is needed by the young plant. Considerable nitrogen is needed during the reproductive stage, i.e., silking, tasseling, etc. Manure is usually applied in the spring or fall, prior to the growing season or after harvest. Thus, considerable N can be lost before the plant can utilize it unless the N is stabilized in the soil.

Table 4. Nitrogen losses from animal manure to the air as affected by method of application.

Method of application	Type of manure	Nitrogen loss*
		(%)
Broadcast without incorporation	Solid	15-30
	Liquid	10-25
Broadcast with incorporation†	Solid	1-5
	Liquid	1-5
Injection (knifing)	Liquid	0-2
Irrigation	Liquid	30-40

* Percent of total N in manure applied which was lost within three days after application; wind and temperature effects may increase losses.

† Incorporation within a few hours of application.

Field and laboratory research studies have shown that nitrification inhibitors can stabilize the nitrogen in manures by keeping the N in the ammonium form through suppression of the soil-borne Nitrosomonas bacteria (*8*). Retained nitrogen in the soil, increased grain yields, tissue nitrogen levels, grain protein levels, and less incidence of disease have been recorded by using nitrification inhibitors with commercial fertilizers (*4*) or manures (*7*, *9*, *10*, *11*, *12*). As a result, the nitrogen in the manure can be fully utilized for greater efficiency and there can be greater confidence that the nitrogen placed in the soil is there to be used by crops. The water pollution potential of the manure nutrients applied is greatly reduced. This positive effect has been most significant for summer or fall applications prior to the next year's crop season, or if the soil is saturated with water in the spring. Increased corn yields from the use of nitrification inhibitors have ranged from 5 to 53 percent for fall applications, 5 to 15 percent for spring applications, and 3 to 15 percent for summer applications (*11*). In addition, the greatest benefit of the nitrification inhibitors is realized when the nitrogen rate applied is near the nitrogen requirements of the crop. This also allows the producer to enhance the nutrient potential of the manure, realize reduced fertilizer costs, and apply manure at a lower rate which will reduce the build-up of other nutrients in the soil. Using nitrification inhibitors increases management flexibility for land application since manure can be applied in the fall, when the soil is in better condition to handle heavy equipment and when labor and equipment may be more readily available.

When manure is applied to meet the nitrogen requirement of the plant, there will be an over-application of P and K which will build up in the soil. The producer must decide either to apply this higher rate and rotate the fields to receive manure about every three or four years, or reduce the rate of application and supplement with additional nitrogen. Enriching the manure with anhydrous ammonia and applying the manure at a lower rate has been done successfully (*10, 11*). This practice can be accomplished by using an asparger tube in the tanker wagon or within a manure discharge pipe during loading of the manure into the tanker wagon (*5*). The major benefits of enriching manure with nitrogen are balancing the manure nutrients to meet crop nutrient needs while lessening the buildup of nutrients in the soil, fewer trips required across the field, and greater efficiencies of nutrient utilization from the manure sources.

The use of rapid transport trucks with wide or flotation-type tires for manure application results in less soil compaction under a variety of soil conditions. Some custom haulers apply 24 hours a day to remove manure from livestock pits. The trucks have powerful vacuum pump systems which allow for greater solids removal from pits. Agitation pumps are available to agitate manure in the pits for three to four hours before application to provide a more uniform application of nutrients to the field. Reliable custom applicators calibrate their equipment, thus application rates for specific crop needs can be implemented. This bulk hauling system allows for application on fields a greater distance from the building in a reasonable amount of time. In most cases, custom applicators should be considered as a viable option because of the efficiencies and services provided.

Another application alternative is the large self-propelled semi-truck tanker units used to haul large volumes of manure to distant fields where the liquid manure is loaded into smaller machines for field application. Some producers use two semi-tanker units to reduce the amount of down time with loading and unloading in the field. Another method is to locate a portable fireman's tank in the application field. A semi-truck fills the portable canvas storage unit. The application machine then loads manure directly from the canvas fireman's tank. This system can be temporarily located at any field site.

Calibration of equipment is necessary to ensure the desired manure application rate. Calibration can be accomplished simply by determining the weight, in the case of solid manures, or volume, in the case of liquid manures, applied to a certain area. The width of the application swath and distance and speed traveled during application are required for the calculation. By determining the amount of manure applied to a given area at a certain speed, one can calculate the speed required to apply a desired amount of manure, assuming that the rpm of the tractor and pressure in the tanker wagons are similar.

In Denmark, an N-Dos Meter (Samson Co., Bjerringbrø, Denmark), has been developed for control of nitrogen application to the land by adjusting the flow rate of manure from a tanker wagon during land application. Possibly this type of equipment and technology will be developed and expanded to deliver accurate amounts of nutrients to the land during manure applications.

Other management techniques to evaluate nutrient needs in the soil include the use of the pre-sidedress nitrate test. This on-the-farm test measures soil nitrate levels when the corn is about 8 to 12 inches (20-30 cm) tall to determine the need for additional sidedress nitrogen. This technique is important if manure has been applied in the fall or summer previous to planting and if a nitrification inhibitor was not used to stabilize the nitrogen.

Research needs

There are several areas in manure management requiring additional research and implementation. These include efforts in developing genetically engineered microbes to decompose manure solids and control odors and development of odor control additives more efficiently, either for addition into animal diets or through direct addition to manure storage. There is a need for more precisely controlled manure application systems to assure uniform application of manures to the land. There is a need for continued work on the control of nitrogen in the manure storage systems and after application to the soil so that it will be available for plant uptake. Research is needed to improve the efficiency with which animals digest and utilize feed, thereby reducing nutrient output in manure. Considerable research is being conducted to determine the efficiency of feeding phytase enzymes to reduce P output in manure and balancing the amino acid requirements of monogastries to reduce N output in manure. Investigations of methane production efficiencies and recovery of nutrients for other uses, such as refeeding, bedding, or soil amendments are needed. Development of computer systems to assist producers in manure management planning are now available and will need to be refined as more research information is generated.

Maximum benefits/reduced costs

Maximum benefits of the manure management plan are realized when manure is applied to low test soils, applied under optimal soil conditions, applied to well drained soils, applied to productive crops, and when nutrient application levels are balanced with the needs of the crop. Reduced costs are realized when producers develop a manure management plan, reduce fertilizer usage, implement the best management practices, and keep good records. Proper design and management of manure systems are the keys to enhancing potential nutrient benefits, reducing costs, and making a positive environmental impact. Through future technological developments and implementation, producers will be able to utilize animal manures more precisely on a "prescription" basis.

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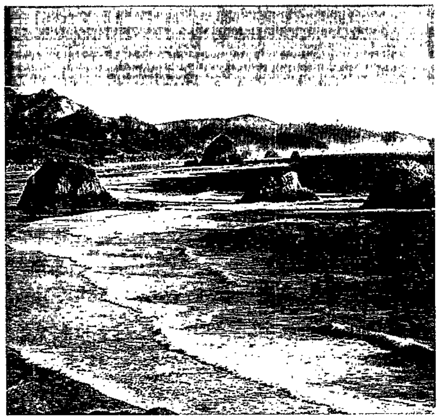
Coastal Zone Act Reauthorization Amendments of 1990 (CZARA)



Nutrient management measure to be implemented in the coastal zone

Anne C. Weinberg

Several of the articles in this special issue refer to the nutrient management measure which is one of the management measures to be implemented under section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA). CZARA requires states and territories (hereinafter referred to as States) with approved coastal zone management programs to submit "Coastal Nonpoint Pollution Control Programs" to the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) for approval. These state programs are to employ initial, technology-based "management measures" throughout the coastal management area, to be followed by additional measures, where necessary, to address remaining, known water quality problems.

CZARA required EPA to publish (and periodically revise thereafter), in consultation with NOAA, the U.S. Fish and Wildlife Service, and other federal agencies, management measures guidance for sources of nonpoint pollution in coastal waters. In January 1993 EPA published "Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters" (*1*). Coastal states and territories will need to develop Coastal Nonpoint Pollution Control Programs to implement the approximately 55 management measures in this guidance.

Following is a copy of the nutrient management measure in the "Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters" (*1*):

Develop, implement, and periodically update a nutrient management plan to (a) apply nutrients at rates necessary to achieve realistic crop yields, (b) improve the timing of nutrient application, and (c) use agronomic crop production technology to increase nutrient use efficiency. When the source of the nutrients is other than commercial fertilizer, determine the nutrient value and the rate of availability of the nutrients. Determine and credit the nitrogen contribution of any legume crop. Soil and plant tissue testing should be used routinely. Nutrient management plans contain the following core components:

- Farm and field maps showing acreage, crops, soils and water bodies.
- Realistic yield expectations for the crop(s) to be grown, based primarily on the producer's actual yield history, State Land Grant University yield expectations for the soil series, or SCS Soils-5 information for the soil series.
- A summary of the nutrient resources available to producer, which at a minimum include
  - Soil test results for pH, phosphorus, nitrogen, and potassium;
  - Nutrient analysis of manure, sludge, mortality compost (birds, pigs, etc.), or effluent (if applicable);
  - Nitrogen contribution to the soil from legumes grown in the rotation (if applicable); and
  - Other significant nutrient sources (e.g., irrigation water).
- An evaluation of field limitations based on environmental hazards or concerns, such as
  - Sinkholes, shallow soils over fractured bedrock, and soils with high leaching potential,
  - Lands near surface water,
  - Highly erodible soils, and
  - Shallow aquifers.
- Use of the limiting nutrient concept

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to establish the mix of nutrient sources and requirements for the crop based on a realistic yield expectation.

- Identification of timing and application methods for nutrients to provide nutrients at rates necessary to achieve realistic crop yields; reduce losses to the environment; and avoid applications as much as possible to frozen soil and during periods of leaching or runoff.
- Provisions for the proper calibration and operation of nutrient application equipment.

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A new approach to runoff—state coastal nonpoint pollution control programs

Ann Beier, Steven Dressing, and Lynn Shuyler

States, local governments, farmers, foresters, developers, and others will soon be faced with new requirements to control nonpoint source pollution—that is, the pollution that results when rain or snow moves pollutants like nutrients and sediments, heavy metals, bacteria, and pesticides from sources such as farms, urban areas, and marinas into surface water and groundwater. In November 1990, Congress, recognizing that nonpoint pollution is a key factor in the continuing degradation of many coastal waters, enacted section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA) (codified as 16 USC s. 1455b).

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CZARA requires that states and territories with approved coastal zone management programs (see Figure 1) submit Coastal Nonpoint Pollution Control Programs (coastal nonpoint programs) to the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) for approval. States that do not submit approvable programs will lose a portion of federal funding provided by section 319 of the Clean Water Act and section 306 of the Coastal Zone Management Act.

The coastal nonpoint programs required by CZARA, although building on existing programs, are not intended to represent "business as usual" for addressing nonpoint pollution. Rather, CZARA provides an innovative approach to controlling nonpoint pollution. First, the programs are truly joint programs—state section 319 lead agencies (generally water quality agencies) and coastal zone management agencies are to work together to develop and implement the programs. EPA and NOAA are jointly responsible for providing assistance to the states and for approving the programs.

Second, the programs will employ initial, technology-based "management measures" throughout the coastal management area, to be followed by additional measures, where necessary, to address remaining known water quality problems. Unlike existing nonpoint programs, a baseline level of pollution prevention or control will be required. Finally, CZARA requires insurance, in the form of state enforceable policies and mechanisms, that both the technology-based and additional nonpoint source controls are fully implemented.

EPA and NOAA have published two documents to assist states and others in meeting the new program requirements (58 Fed. Reg. 5182, January 19, 1993). The first document, "Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters," is EPA's guidance on the best available and affordable technologies to restore and protect coastal waters from nonpoint source pollution. The second document, "Coastal Nonpoint Pollution Control Program—Program Development and Approval Guidance" was developed by EPA and NOAA as a road map for states to develop the coastal nonpoint programs required by CZARA in a timely and resource-efficient manner.

Management measures guidance

Under section 6217(g), Congress required EPA, in consultation with other federal agencies, to develop guidance specifying "management measures" to control coastal nonpoint pollution. Management measures, or "g" measures, are defined in the law as "economically achievable" (affordable) measures to control nonpoint pollution in coastal waters which reflect the greatest degree of pollutant reduction achievable through the application of best available technology, siting criteria, operating methods, or other alternatives. EPA developed this guidance with assistance from NOAA, other federal agencies including the U.S. Department of Agriculture (USDA) and the U.S. Army Corp of Engineers (COE), and a number of state experts.

Although this article focuses only on the agricultural management measures, the guidance document specifies measures for each of five major categories of nonpoint pollution: agriculture, forestry, urban (including new development, septic tanks, roads, bridges, and highways), marinas and recreational boating, and hydromodification. A chapter describ-ing the ways that wetlands and riparian areas can be used to prevent nonpoint pollution is also included.

Each chapter (corresponding to the major nonpoint source categories) sets forth the management measures that must be incorporated into state programs. The chapters also describe some of the management practices that may be used to achieve each measure; activities and locations for which each measure may be suitable; and information on the cost and effectiveness of the measures and practices. Descriptions of proper operation and maintenance of measures are included.

The management measures are described in terms of integrated systems of practices rather than discrete best management practices (BMPs). Many of these systems include activities to reduce the generation of pollutants—a pollution prevention approach—as well as actions to keep the pollutant from reaching surface water or groundwater. Measures range from more traditional activities, such as erosion and sediment control, to more comprehensive strategies, such as watershed planning to help minimize urban runoff.

Management measures for agricultural activities

The management measures apply to the primary agricultural nonpoint pollutants: nutrients (particularly nitrogen and phosphorus), sediments, animal wastes, salts, and pesticides. The guidance specifies the following management measures for agricultural activities:

Sediment and erosion control. The goal of this measure is to minimize the delivery of sediment from agricultural lands to receiving waters. Landowners may choose either to apply the erosion component of the U.S. Department of Agriculture's Conservation Management System through such practices as conservation tillage, strip cropping, contour farming, and terracing, or design and install a combination of management and physical practices to remove settleable solids and associated pollutants in runoff delivered from the contributing area for storms up to and including a 10-year, 24-hour frequency. In the first case, erosion control on the land is combined with sediment delivery control to reduce both erosion and sediment delivery; in the second case only sediment delivery control is explicitly addressed, although erosion control methods can help achieve this measure as well.

States are to apply this measure to activities that cause erosion on agricultural lands including cropland, irrigated cropland, range and pasture, orchards, permanent hayland, and land used for specialty crop and nursery crop production.

Confined animal facility control. Two different management measures apply to confined animal facilities (feedlots) depending on the number of animals at a particular facility. Neither of these measures applies to facilities that are currently required by federal regulation (40 CFR 122.23) to apply for and receive discharge permits. A confined animal facility is defined as a lot or facility (other than a facility for aquatic animal production) where animals have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period, and crops, vegetation forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility.

The management measure that applies to all new confined animal facilities and to larger existing facilities (see EPA's "Guidance Specifying Management Measures..." for size cutoffs) is to limit discharges from confined animal facilities to surface water by storing both the facility wastewater and runoff caused by all storms up to and including the 25-year, 24-hour frequency storm. To protect groundwater, it is recommended that storage structures have either an earthen lining or plastic membrane lining, be constructed with concrete, or be a storage tank.

For smaller, existing facilities, the management measure is to design and implement systems that collect solids, reduce contaminant concentrations, and reduce runoff to minimize the discharge of contaminants in both facility wastewater and runoff caused by all storms up to and including a 25-year, 24-hour frequency storm. Storage is not required. Systems must be implemented that substantially reduce significant increases in pollutant loadings to groundwater.

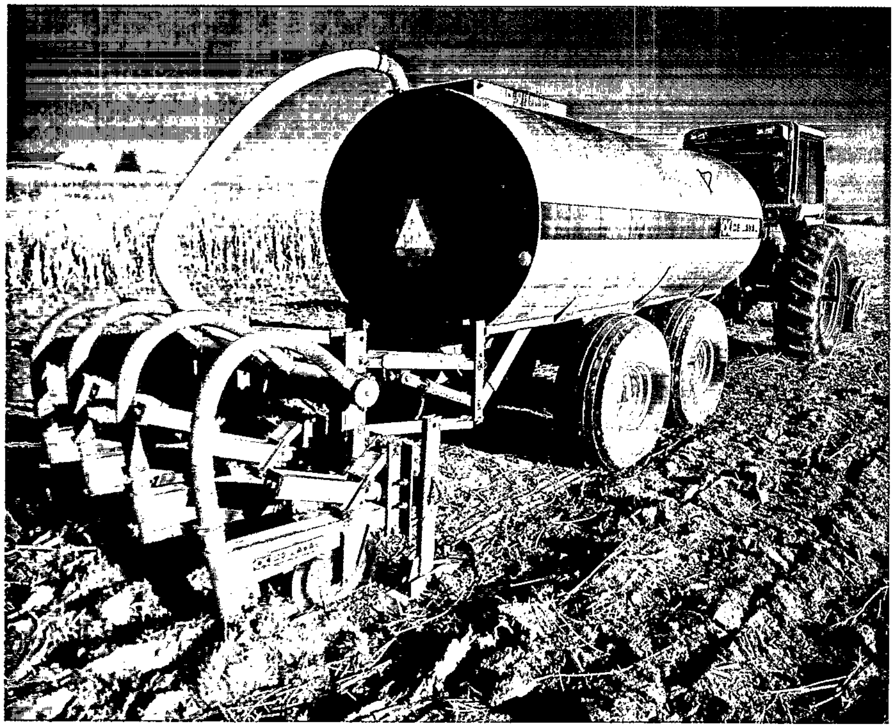
Both confined animal facility measures require management of stored runoff and accumulated solids through an appropriate waste utilization system. Neither measure, however, specifies required methods for animal waste management.

Soil Conservation Service

Figure 1. No-till cropping practices are recomended to meet the erosion and sediment control management measure.

Nutrient management. This measure calls for development, implementation, and periodic update of a nutrient management plan to apply nutrients at rates necessary to achieve realistic crop yields, improve the timing of nutrient application, and use agronomic crop production technology to increase nutrient use efficiency. Nutrient management is designed to prevent pollution by developing a nutrient budget for the crop, applying only the types and amounts of nutrients necessary to produce a crop based on realistic crop yield expectations, and to identify and address environmental hazards and concerns on the site (e.g. land near surface water, highly erodible land, and shallow aquifers).

Pesticide management. This measure is designed to minimize ground-



Soil Conservation Service

Figure 2. Subsurface injection of manure prevents runoff of manure and may be used to achieve the goals of a nutrient management plan.

water and surface water contamination from pesticides. The measure is to be achieved by evaluating pest problems, previous pest control measures, and cropping patterns; evaluating the soil and physical characteristics of the site (including pesticide mixing and storage areas); using integrated pest management strategies (IPM) such as improving the timing and efficiency of application; improving calibration of pesticide spray equipment; and using anti-backflow devices on hoses used for filling tank mixtures.

Livestock grazing. The focus of the grazing management measure is on the riparian zone, although the control of erosion from range and pasture land above the riparian zone is also encouraged. Sensitive areas such as streambanks, wetlands, estuaries, ponds, lake shores, and riparian zones are to be protected by reducing the physical disturbance and direct loadings of animal waste and sediment caused by livestock through a variety of livestock management practices ranging from excluding livestock from sensitive areas to using improved grazing management systems, such as herding. Erosion is to be controlled on upland areas by either implementing the range and pasture components of a USDA Conservation Management System or by maintaining range, pasture, and other grazing lands in accordance with activity plans established by either the U.S. Department of Interior's Bureau of Land Management or USDA's Forest Service.

Irrigation. This measure promotes an effective irrigation system that delivers necessary quantities of water yet reduces nonpoint pollution to surface water and groundwater. The measure calls for operation of existing irrigation systems so that the timing and amount of irrigation water applied match crop water needs. This requires, at a minimum, the accurate measurement of soil-water depletion volume and the volume of irrigation water applied, and uniform application of waters. The measure specifies that backflow preventers for wells are necessary when chemigation is used. The measure recognizes that state water laws may conflict with the measure and will take precedence over it.

State program guidance

As described above, the management measures guidance will be implemented through new state coastal nonpoint pollution control programs. EPA's and NOAA's recently released "Program Development and Approval Guidance" describes what needs to be contained in each state program for approval by EPA and NOAA. States will have to address issues such as where the program will operate geographically, how management measures will be selected and implemented, and how the program will be coordinated with other existing federal, state, and local programs.

State programs must include management measures "in conformity" with those specified in EPA's management measures guidance. In general, the presumption is that states will implement all the management measures for each of the source categories (e.g., agriculture, forestry), and subcategories (e.g. grazing, harvesting) described in the management measures guidance. However, states have the opportunity to exclude nonpoint source categories and subcategories in certain situations. States may exclude certain sources if they can demonstrate either that the category, subcategory, or specific source is (a) neither present nor reasonably anticipated in an area, or (b) does not, individually or cumulatively, present significant adverse effects to living resources or human health. Exclusions will most likely apply on a watershed or local basis.

States must also provide information on how they will ensure the implementation, operation, and maintenance of the measures. States will need to ensure the implementation of management measures through the use of enforceable policies and mechanisms. These can range from traditional regulatory activities (such as permits) to incentive programs (such as state or local cost-share, tax credits) provided that the state has back-up authority to ensure that measures are implemented within the timeframe specified by EPA and NOAA.

In addition to implementing the technology-based management measures, states must also describe their process for implementing "additional measures" those measures necessary to achieve and maintain water quality standards, where the "g" measures alone are inadequate. These additional measures will be determined by the state.

Schedule

States have until July 1995 to submit programs to EPA and NOAA for review. The federal agencies have until January 1996 to review the programs. Once approval is granted, states have three years (until January 1999) to implement the "g" measures and an additional two years (through January 2001) to assess the effectiveness of the "g" measures in achieving water quality standards. States then have three more years (until January 2004) to implement additional measures, where necessary to attain or maintain water quality standards.

Funding

Congress has authorized $12 million a year for states' development and implementation of the CZARA requirements. However, to date, actual Congressional appropriations for this purpose have totaled less than $2 million annually for the 29 coastal states; $4 million is available for FY 1994. Funding for program implementation is available under section 319 of the Clean Water Act. In addition, cost-share funds under USDA's Agricultural Conservation Program can be used by farmers to implement the management measures, unless installation is done on an involuntary basis. The USDA-ASCS has established a policy that governs such situations (NOTICE ACP-239).

If a state does not submit an approvable coastal nonpoint pollution control program, EPA and NOAA are required to withhold a percentage of state grant funds under section 319 of the Clean Water Act and section 306 of the Coastal Zone Management Act.

Soil Conservation Service

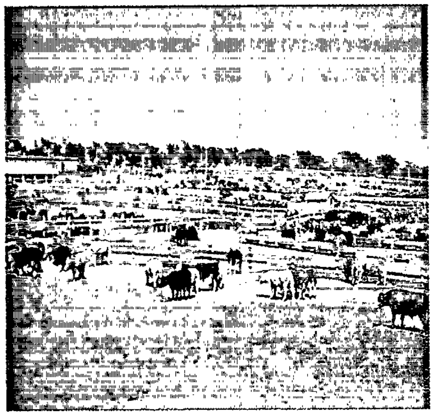
Figure 3. Providing alternative water sources is a practice to achieve the grazing management measure.

Conclusion

What will the new coastal nonpoint programs mean for state governments and agricultural producers? First, the management measures are to be implemented through new state coastal nonpoint programs and thus the states will bear a major responsibility for both developing the program and implementing it. State water quality and coastal zone management agencies have until July 1995 to develop these programs. Coordination with existing programs will be a key to successful program development and implementation. States are now beginning to evaluate existing programs and, where necessary, create new programs and authorities to meet the CZARA requirements. State officials are required to involve the public throughout the program development process, and there will be opportunities for the public to discuss potential new state requirements.

Although all coastal states will be responsible for ensuring that the management measures are implemented, there is flexibility in how states may develop and implement particular program components. States may adopt a variety of approaches to meet CZARA requirements, and of course, much depends on the nonpoint source control activities already underway. Thus, it is difficult to anticipate and predict exactly how individuals or businesses in any particular coastal state will be impacted. In some areas the requirements for confined animal facilities may far exceed existing levels of control. However, in general, for agricultural producers, state coastal nonpoint programs will most likely require an acceleration of implementation of practices that are already widely employed throughout the agricultural community. Practices such as conservation tillage for erosion control and nutrient management plans are likely to become the norm in coastal areas. ❑

State/Regional Experiences



California's experience with a voluntary approach to reducing nitrate contamination of groundwater: The Fertilizer Research and Education Program (FREP)

Jacques Franco, Stephan Schad, and Casey Walsh Cady

Densely populated California supports the fifth largest agricultural economy in the world. It produces billions of dollars of agricultural produce annually while its population grows rapidly. California's cities and rural areas are competing for land, water, and other natural resources.

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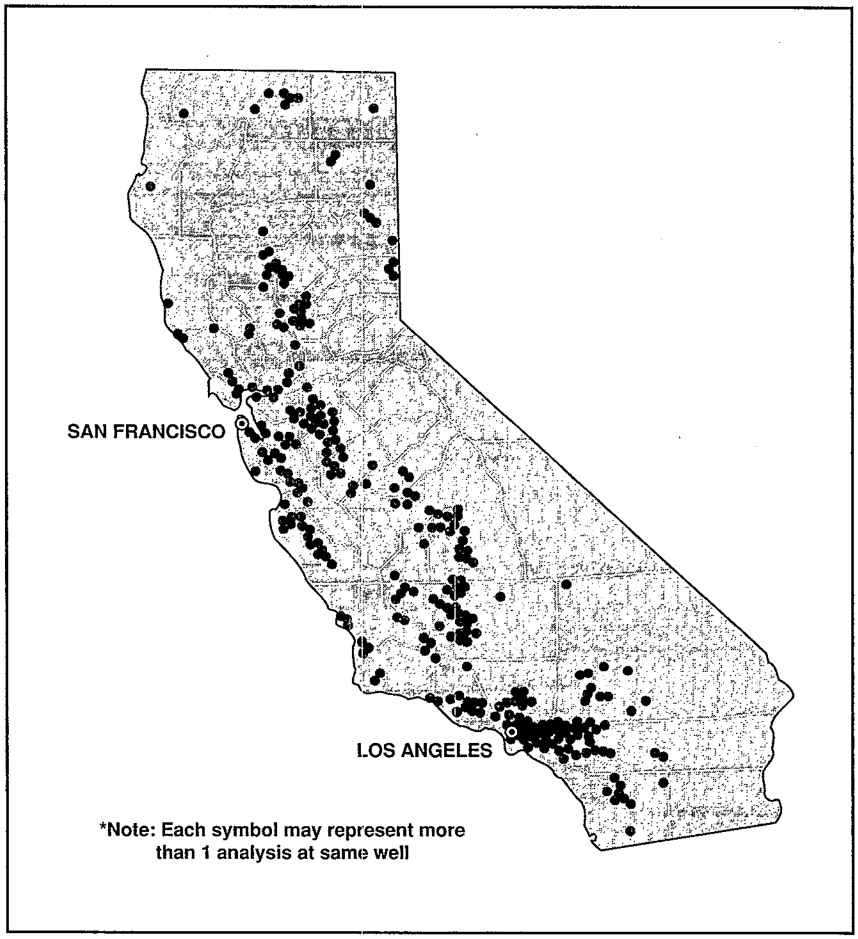
Growers are being increasingly viewed as contributors to environmental degradation. One particular concern is agriculture's impact on groundwater quality. Many of California's farmers apply fertilizers, specifically nitrogen, to their high value crops. Nitrogen not taken up by plants or trees can convert to nitrate and end up in the groundwater. According to the California Department of Health Services, more public supply wells in California have been closed due to violation of the nitrate drinking water standards than from any other contaminant (*1*). The current public health standard for acceptable drinking water in California is 45 mg/l (45 parts per million) of nitrate. The Environmental Protection Agency reports that hundreds of wells in various areas of California exceed this level (see Map 1). In total, 10 percent of the water samples taken from 38,144 California supply wells showed nitrate concentrations exceeding the state's maximum contaminant level of 45 ppm, according to a 1975 to 1987 survey (*2*). In one specific area, the Metropolitan Water District of Southern California estimates that about 4 percent of its annual production has been lost to nitrate contamination, while only 0.5 percent has been lost to organic contamination to date (*3*).

Although nitrate is a natural component of living systems, too much nitrate can cause health problems. One well-known potential threat is the relationship between high nitrate levels in drinking water and a rare infant disease called methemoglobinemia (blue-baby syndrome). In the stomachs of very young babies, nitrate can convert to a related compound (nitrite) that interferes with the blood's oxygen-carrying capacity. Cancer and birth defects are other concerns, although no firm link has been established.

There is also an economic dimension to the problem. When nitrate in a public water supply reaches or exceeds the 45 mg/l standard, costly measures are necessary. The well may have to be deepened or closed down, a different water source may have to be acquired for blending, or expensive water treatment may be required. For example, one southern California water district has estimated that wellhead nitrate treatment costs about $375 per million gallons (*4*). In 1986, public water systems in California applied to the State Department of Health Services for more than $48 million to correct nitrate violations (*4*). The total cost was undoubtedly larger since many water agencies used other sources of funds to address the problem.



Map 1. Well locations where nitrate levels have been recorded at 45 mg/l or greater during the period 1975-1987. (EPA STORET SYSTEM, 1988)

The Fertilizer Research and Education Program (FREP)

California's state government has only recently begun to address nitrate contamination from agriculture. In 1988, the Director of the California Department of Food and Agriculture (CDFA) appointed a Nitrate Working Group to study the nitrate problem relating to agriculture in California (see Map 2). After analyzing 12 years of well data, the Working Group developed recommendations which still form the basis of FREP's mission (*3*).

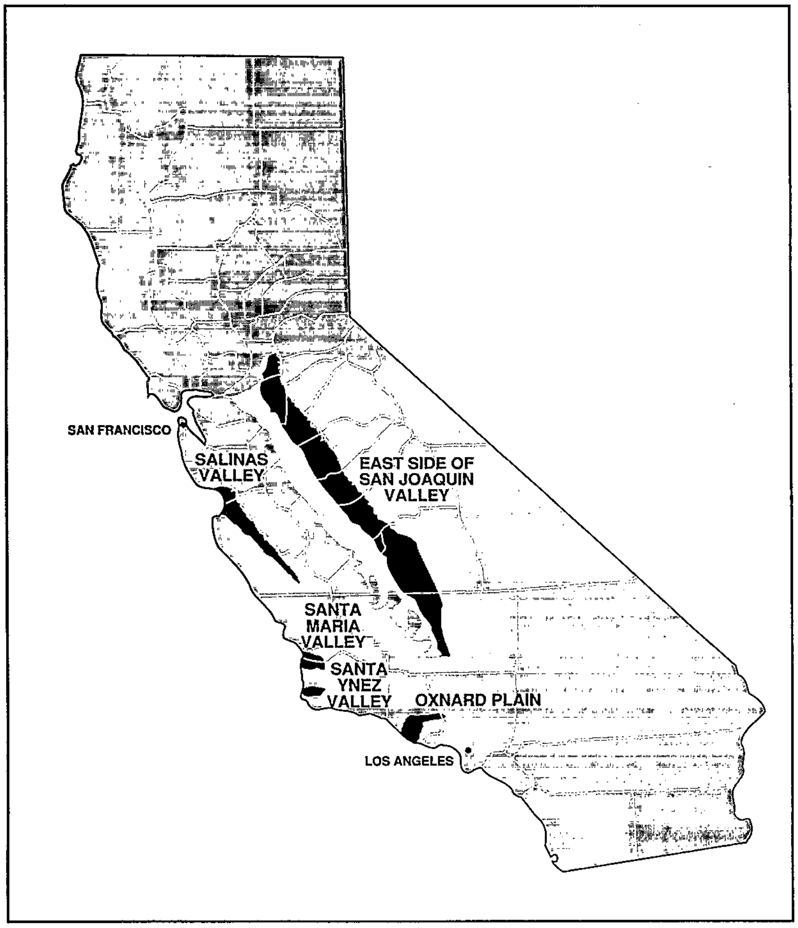
The Nitrate Working Group recommended that CDFA identify and prioritize nitrate-sensitive areas throughout California and develop research and demonstration projects to reduce agriculture's contribution to ground-water contamination from fertilizer use.

The first step in implementing these recommendations was to decide which locations in the state should be given highest priority. Two conditions indicate an urgent problem: (1) a high level of nitrate contamination in groundwater and (2) a population that depends on that water for drinking. Those two conditions depend on various factors. To determine nitrate sensitivity of an area, FREP expanded on a list of criteria originally prepared by University of California soil scientists (*5*, *8*).

1. In terms of groundwater use, nitrate concentration is critical if groundwater is used for domestic or animal consumption.
2. Sandy or other coarse-textured soil types transmit water downward more rapidly, and nitrate along with it.
3. Inefficient irrigation practices may lead to deep percolation which increases the leaching of nitrate.
4. Types of crops most likely to increase nitrate leaching are those that need heavy nitrogen fertilization, have high economic value, are not harmed by excess nitrogen, and tend to take up a smaller fraction of the nitrogen applied.
5. A climate with high total rainfall, concentrated heavy rains, and mild temperatures lead to more nitrate leaching.
6. Distance between root zone and groundwater: The closer plant roots are to the groundwater table, the more readily nitrate enters drinking water.
7. Potential impact: Nitrate contamination of drinking water becomes more immediate the more people depend on it as their sole drinking water supply.

Early activities. Using the nitrate sensitivity criteria listed above, FREP chose three areas to begin initial field activities in 1990: the Salinas Valley in Monterey County, eastern Stanislaus and Merced Counties, and the Fall River Valley in Shasta County. The goal of all these projects is to develop and extend information to growers on improved farming practices. These improved ways of fertilizing, irrigating, and managing crops are designed to fit local resource and farming conditions, reduce nitrate leaching, and improve growers' profits.

Salinas Valley. The Salinas Valley in coastal central California produces more than a quarter of the nation's fresh vegetable crops, while depending almost entirely on groundwater, not only for irrigation but for domestic and industrial water use as well. About 150,000 people use Salinas Valley groundwater as a drinking water source. According to a 1987 report by the Monterey County Water Management Agency, almost half of the wells sampled in unconfined



Map 2. Generalized map of nitrate sensitive areas in California.

aquifers of the Valley had nitrate levels above the 45 mg/l standard (6). Irrigated farms are a major source of that nitrate.

FREP was invited by the Salinas Valley Nitrate Advisory Committee (NAC) to help address the pressing local nitrate problem. Pooling resources with the State Water Resources Control Board, the Monterey County Water Resources Agency, the lettuce industry, and University of California Cooperative Extension, FREP funds a number of projects which research and demonstrate improved farming practices.

In one Salinas project, a team of growers and researchers are improving nitrogen uptake efficiency in vegetable crops. The project also demonstrates winter cover cropping practices compatible with vegetable production methods.

Stanislaus and Merced Counties (San Joaquin Valley). On the eastern side of the San Joaquin Valley, particularly in Stanislaus and Merced Counties, many farming areas are sensitive to nitrate groundwater contamination. Local soils tend to be sandy or coarse, with little or no layering to restrict downward water flow. Tree crops grown in this area require high inputs of nitrogen but their nitrogen uptake efficiency is relatively low. Water delivery systems tend to be less efficient, which increases deep percolation. Throughout the San Joaquin Valley, dairying, with its associated problems of manure disposal, is a large and important industry.

FREP is supporting research to develop strategies to reduce potential nitrate leaching in almonds and peaches, and to improve plant nitrogen monitoring techniques in orchards. One research project is developing diagnostic tools and sampling procedures to assess nitrogen status in tree crops.

Fall River Valley. Although this small farming region in northeastern California is not high in statewide agricultural importance, it was selected for a pilot project because of its small, confined aquifer and its unique combination of rural residences in close proximity to agricultural production. The Fall River Valley produces livestock, alfalfa, potatoes, grain, and specialty crops such as strawberry plants. A recent survey of local wells showed that about 40 percent had nitrate levels in excess of 45 mg/l.

Here, FREP works with the Fall River Resource Conservation District, the Regional Water Control Board, and other agencies. In the first phase of this project, roughly 20 wells throughout the region are being monitored. Information is collected not only on nitrate levels but on patterns of land use, population, agriculture, and geology. Nitrate data is being correlated with proximity of leach fields, type of agriculture, soil type, and depth of wells. The second part of the project is developing best management practices, primarily for potatoes and strawberries.

The Competitive Grants Program. In 1990, the California state legislature authorized an increased tax assessment on fertilizer sales to support research and education projects to advance the environmentally safe and agronomically sound use and handling of fertilizer materials. This legislation was proposed and supported by California's fertilizer industry and the California Department of Food and Agriculture. FREP has managed these funds through a competitive grants program.

A review committee, which includes growers, fertilizer industry representatives, state government representatives, and University of California scientists, selects and recommends funding for projects. At the same time, since people from different areas of expertise participate in the review, FREP uses this process as an opportunity to identify new areas of research and outreach.

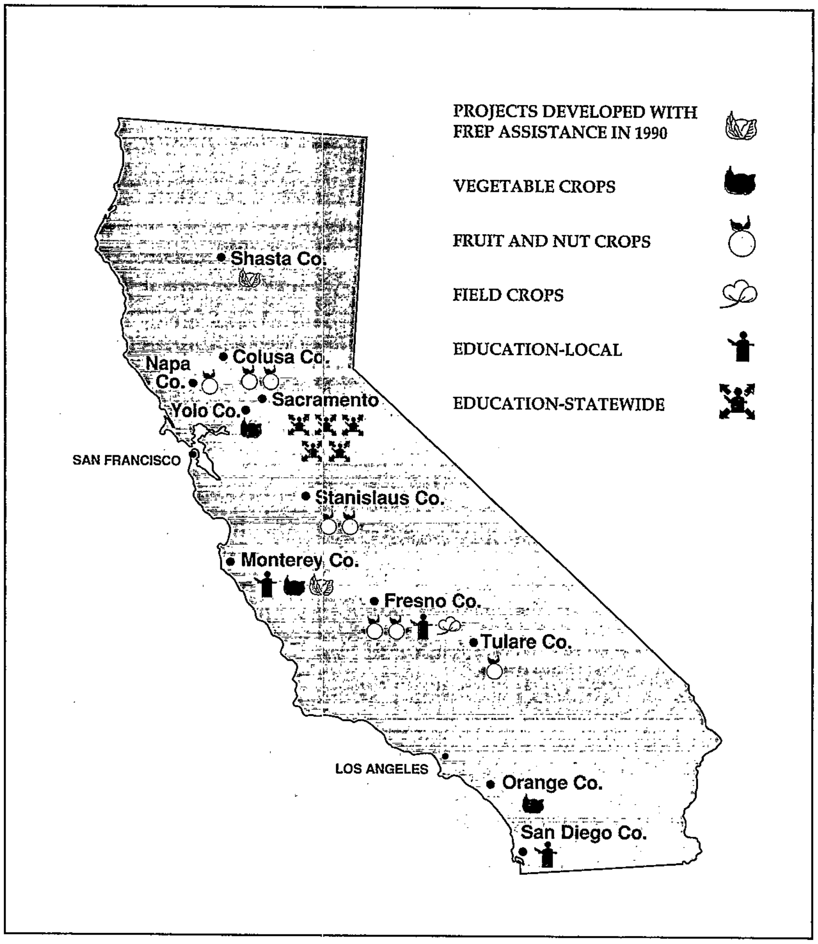
The purpose of the competitive

grants program is to generate specific information and practices that can be used on farms to reduce the downward flow of nitrate while maintaining productivity and the economic viability of the farms. Our current research portfolio includes projects on almonds, citrus, stone fruits, lettuce, cotton, and grapes. Many of these projects are being carried out on growers' fields, thereby incorporating their views and practices into the project management. Educational projects include fertilizer management training for small and ethnic minority farmers, videotapes on best management practices, and agricultural curricula for secondary school teachers (7, 8) (see Map 3).

Public service and outreach. FREP also has a mission of outreach. It serves as a clearinghouse to improve information exchange among individuals working on California's nitrate groundwater problem related to fertilizer use. It facilitates access of local agencies, growers, and agricultural service suppliers to federal, state, and other resources. Both technical assistance and funding are provided (see Chart 1).

The program is currently developing a computerized information system (FREPIS) which includes a computerized system to store, process, and produce resource materials and publications; baseline information on fertilizer use statistics and farming practices for target crops, and a collection of technical articles, potential sources of funding, directories of technical expertise, and regulatory and legislative analysis and information. With this structure, growers, industry, and extension experts will be able to easily access current information and locate support services.

The FREP staff also helps organize field days, workshops, and grower meetings; works with media; and helps develop and distribute information on specific best management practices for a variety of California's crops.



Map 3. FREP project sites 1990-1992

Reflection on our experience

Relative to California's large agricultural industry and the extent and complexity of the fertilizer and groundwater situation we are addressing, FREP is a small program. Four years of this voluntary nitrate management program have not fundamentally changed fertilizer management practices. However, FREP offers an approach that actively involves all key parties who have a stake in addressing the nitrate problem. Nevertheless, it is too early for a formal evaluation of the program. In the following, we would like to look at the distance we have covered so far, as well as at the road still lying ahead.

Progress to date. We believe that FREP has done a few things well. For example, FREP brought together growers, industry, the university, and government, as partners who can constructively address the nitrate situation. Since these parties have an opportunity to participate actively in FREP's work and governance, we have developed realistic and practical approaches to deal with the nitrate problem. Out of the same partnership, our non-regulatory approach is more palatable to growers than regulation imposed by outsiders.

Another clear benefit from FREP activities is that the value of the adaptive research and information gained through our activities will increase, if fertilizer use becomes regulated. In the worst of cases, this information would help guide legislation toward an effective and practical control of fertilizer use that hopefully will minimize costs to growers. We feel that our work grows in value as the debate around groundwater quality heats up.

Early results from some FREP-sponsored projects show great promise. These projects have the potential to increase the efficiency of fertilizer application, and reduce

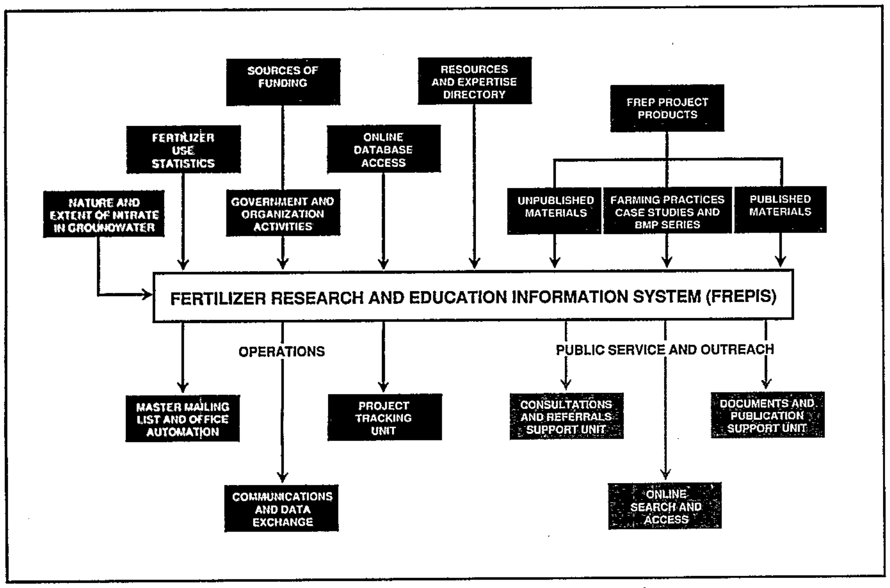


Chart 1.

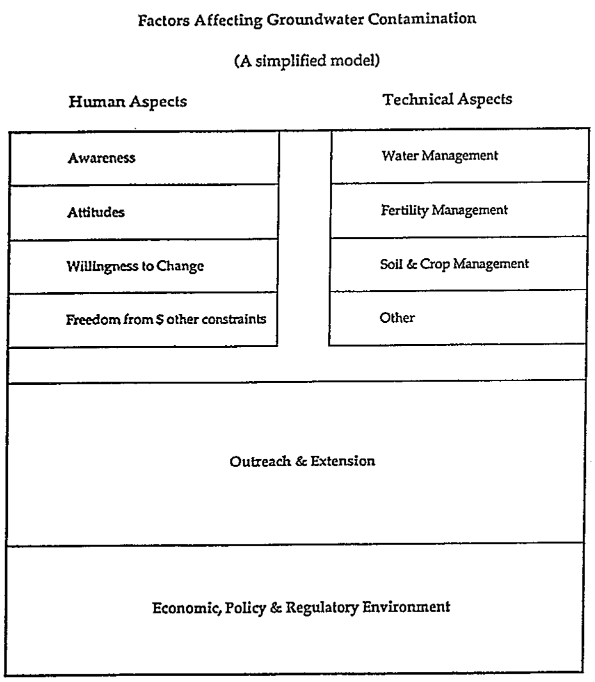


Chart 2.

nitrate contribution to groundwater. For example, one project that shows how growers may replace regular soil fertilizer applications with foliar applications is being quickly adopted by citrus growers. If this practice is widely adopted, it clearly will increase grower returns and may prevent up to 10,000 tons of elemental nitrogen from ending up in groundwater every year. In addition this practice may also reduce the use of insecticides; a clear example of a "win-win" situation.

Finally, FREP's mere presence has helped increase key players' awareness of the nitrate in groundwater situation. We have observed increasing activity by various grower groups and public entities in this area. This increased activity probably can be related in part to FREP's presence and activities.

Continuing challenges. After four years of work, what are some issues which continue to challenge us?

California's multitude of crops and climates has certainly posed a big challenge to our program. With hundreds of crops planted between the coast and the mountains, it is impossible to develop adaptive research and outreach projects to address all situations effectively; therefore our approach to this basic constraint has been to concentrate on those farming systems that pose the highest potential threat (*3*, *7*) and where payoffs appear most promising.

Working at a meeting-point between California's state government and the fertilizer industry sometimes reveals differences in perspectives. On one hand, we have seen both parties successfully working alongside each other in areas where goals and perspectives are clearly complementary. On the other hand, our program's goals, which have been embraced by a majority of the fertilizer industry's leadership, have yet to be translated into clear incentives to their workforce, particularly to the sales people.

Our other major cooperator, the University of California Cooperative Extension Service (UCCE), poses a similar "institutional" challenge to FREP's objectives. Priorities of UCCE and the University rest on plant improvement and protection, not as much on plant nutrition. Faced with budget cuts, the University dedicates fewer resources to fertility issues and is losing expertise that is not being replaced. Also, extensionists work in a research-biased environment. Education and outreach activities often fall victim to the infamous "publish-or-perish" situation.

New social values placed on agriculture challenge FREP and farmers alike. Society used to expect high productivity and efficiency from farmers. Now, farmers are asked to balance productivity against environmental quality. Society and its institutions have yet to define where that balance lies. From a grower's point of view, this new set of social values is less clear and allows more room for interpretation than the old goal of maximum production. At this time, neither institutional nor market incentives seem to delineate "optimal" agricultural practices.

From some growers' perspective, these new demands are incompatible with the high agricultural productivity from which we all benefit. Fertilizer is inexpensive relative to other production inputs, for many of California's high value crops. The potential savings from reduced fertilizer use may be perceived as not worth the increased risk of potential yield or quality loss. Given the uncertainties of crop production, applying more fertilizer than may be needed is a rational management strategy (*9*). Over-applying fertilizer probably is seen by many growers as an inexpensive insurance program. This situation could be changed only if food prices were to reflect the environmental costs associated with crop production. For that reason, farmers probably hesitate to venture into risky or unproven practices when their foreign competitors may not be held to the same environmental performance standards.

Finally, we recognize that an effective interface with growers is a critical and ongoing challenge. Practitioners should have a major role in shaping our program. However, it requires a sustained effort to maintain active grower participation. This is not surprising in light of our previous discussions regarding the relatively low priority of fertilizer management in relation to the many other issues confronting growers. Although FREP has encouraged growers to propose and actively participate in the projects we support, so far, growers play an indirect role in formulating the questions some FREP projects are addressing. So, while farmers still participate in most of the projects, their participation has not been as active as we would like it to be.

The outlook. We are committed to improving our "close to the customer" position, and use as much input as we can from our clientele. Growers participate in reviewing project proposals we receive and help evaluate research results. Commodity Research Boards cooperate with us in various projects. By involving practitioners, we can keep our work practical and relevant to our clientele. We will continue to strengthen grower participation at all levels of our program's activities.

At the same time, we are turning our attention to fertilizer salespeople and production advisors. We realize that their advice strongly influences growers' decisions on fertilizer management. An important step in that direction is the Certified Crop Advisor program currently being developed by the California Fertilizer Association, the American Society of Agronomy, and state agencies, and supported by FREP. This important program is increasing the technical proficiency of individuals that help growers make fertility related decisions.

As part of our effort to better understand and serve our clientele, FREP is attempting to address the human aspects of adoption of agricultural practices (see Chart 2). We realize that before growers modify their farming practices, they first need to become aware of the effect of their practices on groundwater quality. A good understanding of grower attitudes, their willingness to change, and the constraints they face is required to develop effective programs. By integrating these social and behavioral components of decision making, our projects will yield information which has a better chance of widespread adoption.

Looking to the future, we hope that our approach will prove effective. We will continue to nurture the partnership between industry, government, and growers—a partnership that focuses on prevention and active grower participation. We will continue to support a partnership for adaptive research and demonstration of practices that are good for the environment as well as the pocket book. In the long run, the true test of FREP's effectiveness will be whether we can sustain a targeted effort which brings tangible results and is regarded as credible by our clientele and the general public.

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A local agency's approach to solving the difficult problem of nitrate in the groundwater

Ron Bishop

Central Platte Natural Resources District (NRD), located in south-central Nebraska, is one of 23 NRDs across the state. Natural Resources Districts are local units of government charged with the responsibility of conservation, wise development, and proper utilization of the natural resources. They are responsible for a host of activities dealing with soil, water, and other natural resources.

This paper is about the management of groundwater quality within the Central Platte NRD. Of the 13 different NRD purposes outlined in Nebraska Statutes, two deal directly with groundwater quality: purpose No. 6, "the development, management, utilization and conservation of groundwater and surface water," and purpose No. 7, "pollution control."

Groundwater quality problems are not new to the Central Platte valley. As early as 1961, 11 years before NRDs were created, the University of Nebraska Extension Service documented cases of groundwater nitrate above 10 ppm in Merrick County in the eastern part of the Central Platte area.

The NRDs across Nebraska were formed July 1, 1972, and, partly because of those earlier indications of groundwater nitrate in Merrick County, one of the first actions of the Central Platte NRD was to form a water quality committee. The efforts of that committee resulted in a contract with the Conservation and Survey Division of the University of Nebraska at Lincoln to conduct a baseline study of groundwater quality across the Central Platte region.

The results of the study, published in 1974, indicated that the groundwater nitrate problem was not unique to Merrick County. About half the district had nitrate levels at less than 2.5 ppm but the other half had significant amounts of nitrate in the groundwater. Approximately 20 percent of the NRD, extending from Kearney in the central part to Columbus in the northeast corner, had groundwater nitrate that exceeded 10 ppm.

The 10 ppm is significant because the U.S. Public Health Service as well as EPA has established 10 ppm nitrate/nitrogen as the maximum allowable concentration in drinking water for humans and animals. Levels above 10 ppm can lead to methemoglobinemia, or "blue baby" syndrome as it is commonly called. Infants, especially infants under six months of age, are particularly susceptible to methemoglobinemia. The ingested nitrate reduces the oxygen carrying capacity of the blood (thus causing the blue tinge to the skin) and can lead to brain damage or death in severe cases.

The NRD and the Cooperative Extension Service in 1974 started a project in Merrick County to study methods of extracting nitrate from groundwater through irrigated corn production. That same year, the NRD, in cooperation with the Department of Agricultural Engineering at the University also conducted a study to determine what contribution septic tanks made to groundwater nitrate.

The septic tank studies, completed in 1975, indicated that while septic systems can be a contributing factor, especially in development areas that have a concentration of septic systems for sanitary disposal, septic tank leaching could not be a primary source of groundwater nitrate in the Central Platte valley. The NRD also continued the studies with the Extension Service, looking at methods of extracting nitrate from the groundwater through corn production in 1975 as well as 1976 and 1977.

In 1977 the NRD entered into a second contract with the Conservation and Survey Division of the University of Nebraska to carry out a study to determine the original source of the nitrate in the groundwater. The study was completed in 1978 and identified commercial fertilizers applied to irrigated croplands as not the only, but the major, source of groundwater nitrate in the Central Platte valley.

Commercial fertilizers applied to the fields were leached below the root zone and into the groundwater aquifer by rainfall and over-application of irrigation water. In 1978 the Conservation and Survey Division conducted a third study concerning carbon content of groundwater and a fourth study looking at atrazine in groundwater within the NRD. Then in 1979 the NRD entered into still another contract with the Conservation and Survey Division to study chemical seepage, primarily nitrate seepage from irrigation tailwater recovery pits. The study was to determine what contribution the pits made to groundwater nitrate problems. Also in 1979 the NRD, working in cooperation with the Extension Service, Agricultural Stabilization and Conservation Service (ASCS), and the Soil Conservation Service of Hall County applied for and received a grant through the State Department of Environmental Control with cost-share monies through ASCS, that enabled the NRD to establish the Hall County Water Quality Special Project. This was a major research and demonstration project covering 65 square miles (168 km^2) in an area of Hall County that had high nitrate and varying soil types.

The program got under way in 1980 and was carried out for the next four cropping seasons. The objectives of the project were to study ways to impede the leaching of nitrate into the aquifer from fertilizer applications, to improve the water quality by mining groundwater with high nitrate content, and to demonstrate that nitrate may be managed efficiently and effectively while maintaining crop yields.

In 1984, 10 years after the first baseline study, the NRD did another inventory of groundwater nitrate. The

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inventory indicated that the areas of high nitrate had grown in size, and it showed that the average concentrations continued to increase over time.

The average nitrate concentrations of groundwater in Buffalo County had increased from 2.4 ppm in 1961 to an average of 7.3 ppm by 1984 and in Hall County it increased from 1.5 ppm in 1961 to 10 ppm by 1984. In Merrick County, where the levels had averaged 7.7 ppm in 1961, they had increased to the point where the average nitrate concentration in groundwater was 16 ppm, 60 percent greater than the U.S. Public Health Service recognizes as the maximum safe level for human or animal consumption.

All of the investigations, demonstrations, and research that were conducted between 1973 and 1983 showed that the quality of the groundwater in the Central Platte region is impacted by three things: residual nitrate, irrigation water, and fertilizer applications.

Residual nitrate can impact upon groundwater because it is the nitrogen in the root zone left over after the crop is harvested that is available to leach into the groundwater supply.

Irrigation water also has an impact on groundwater quality. First of all, the nitrogen content of the irrigation water and then the rate at which we apply the irrigation water affect groundwater. Over-application of irrigation water leads to leaching the nitrogen down below the root zone and eventually into the groundwater aquifer.

Finally, fertilizer applications have an impact on groundwater quality. The rate at which commercial fertilizer is applied can have an impact. Putting on more fertilizer than is needed or can be utilized by the crop means more nitrogen available to be leached down below the root zone. The form of the nitrogen fertilizer, whether it is in a leachable form or not, can have an impact, and the time of year that the fertilizer is applied can have an impact. Fall applications of nitrogen fertilizer means that the "opportunity time" for it to be leached below the root zone and into the aquifer is extended.

The Hall County Water Quality Special Project was completed in 1983. In 1984 the Central Platte NRD, the Soil Conservation Service, and the Cooperative Extension Service entered into an agreement to continue and expand the program of utilizing "best management practices" that were found to be most effective in the Hall County project. A full-time employee was hired to work with farmers, fertilizer dealers, soil testing labs, and the public to promote sound nitrogen management. Six demonstration fields were set up on farms in Buffalo, Merrick, and Hall Counties the first year. The employee working on the program took deep soil samples for analysis on each of the demonstration fields.

Historically only a small percentage of the cropland fields were tested each year for residual nitrate and most of those that were tested only had samples taken of the top seven or eight inches. The demonstrations and the soil sampling that have been done since 1984 as well as the soil sampling from the Hall County Special Water Quality Project indicated that a large volume of residual nitrate available to the crop is missed in those shallow samples. As an example, an 8-inch (20-cm) sampling in Buffalo County of the fields involved in the demonstration plots would have indicated an average of 17.5 pounds (8 kg) of nitrogen available per acre. However, a sampling of the root depth to 4 feet (1.2 m) indicates that in fact an average of 125 pounds (57 kg) of nitrogen per acre was available on those same fields.

The employee also took water samples each year from each well that was involved in the demonstration fields.

Additional nitrogen for the crop is also available in the irrigation water from those high nitrate areas. Irrigation water from a well testing 25 ppm nitrate/nitrogen is making 50 pounds (23 kg) of nitrogen available to the crop for every 9 inches (23 cm) of water applied.

Looking at the averages over the four counties in which demonstrations were held during the 1984, 1985, and 1986 cropping years, we find that the three-year average for each county ranged from a low of 90 pounds of nitrogen available per acre (101 kg/ha) in the soil and water to a high of 166 pounds per acre (186 kg/ha) in Buffalo County.

In addition to taking and analyzing the soil samples and analyzing nitrate in water that is available for the crop, the project employee also scheduled the irrigation applications, then checked yields on each of the demonstration fields at harvest time. The results of the yield checks indicated that applying additional nitrogen does not result in higher yields. Typical of the findings is a 1984 demonstration field study in Buffalo County in which the recommended commercial fertilizer (N) amount, after taking into account the nitrogen available in the soil and in the water, was a nitrogen application of 150 pounds per acre (168 kg/ha). The field was stripped out into test plots with some of the plots having applications of the 150 pounds that was recommended, and some strips 40 pounds per acre (45 kg/ha) less at 110 pounds per acre (123 kg/ha), and other strips 40 pounds more than the recommended at 190 pounds per acre (213 kg/ha). A yield check at the end of the year indicated that the 150 pound recommended rate maximized yields at 187 bushels per acre, but the application of 110 pounds, 40 less than recommended, yielded within one bushel of the recommended amount and in fact out-yielded the plots with 190 pounds of nitrogen by two bushels per acre.

Another field study in Merrick County conducted in 1984 showed basically the same results with 56 pounds of nitrogen per acre (63 kg/ha) yielding within one bushel of those plots on which 225 pounds per acre (252 kg/ha) of nitrogen had been applied.

In 1986 the Nebraska legislature expanded the authority and responsibility of natural resources districts by adding to the management area authority the ability to require "best management practices" and "education programs designed to protect water quality."

The Central Platte Natural Resources District Board of Directors felt that the

NRD was in an excellent position to develop a reasonable and effective program for groundwater quality management, so they adopted a program that establishes management areas based on the seriousness of the groundwater nitrate problem. Phase I areas are those areas where the average groundwater nitrate level is between 0 and 12.5 ppm.

Originally in a Phase I area the only regulation was the requirement that fall applications of commercial nitrogen fertilizer be banned on the sandy soils. The rest of the Phase I program was a combination of voluntary cooperation, research and demonstration, and information and education. Effective January 1, 1992, two new requirements were added. First, all operators using nitrogen fertilizer on corn or sorghum must become certified by attending a two and a half hour educational class on fertilizer and water management with recertification required every four years. Second, the NRD now bans fall nitrogen applications on the heavier soils until after November 1 each year.

Phase II areas are areas where the average nitrate concentration in groundwater is from 12.6 to 20 ppm. In a Phase II area the programs and regulations established in Phase I continue and there are additional requirements or regulations imposed upon operators. Irrigation wells are required to be sampled and analyzed for nitrate each year, deep soil analysis for nitrate is required on every field every year, and in addition to the ban of fall applications of fertilizers on sandy soils, the fall applications are permitted on heavier soils only after November 1, and require the use of an approved inhibitor. Each operator is also required to submit an annual report to the NRD. Additional regulations effective January 1, 1992 include furnishing a certification from the dealer that an inhibitor was used when required and a requirement that all irrigation water applications be metered. The reason for the metering can be seen by looking at the results and records of some of the demonstration fields. Irrigation water applications on two different fields of corn in the same county during the same year can range from 9.6 inches (24 cm) to 38.5 inches (98 cm).

Phase III areas have been established recently in the NRD. Phase III areas have an average nitrate concentration of greater than 20 ppm. In a Phase III area the programs and regulations that were started in the Phase I and Phase II areas are continued and in addition, two more regulations are imposed dealing with fertilizer applications. First, the commercial nitrogen fertilizer applications are banned on all land in the fall and winter and second, when those commercial nitrogen fertilizer applications are made in the spring, the NRD requires either a split application or the use of an approved inhibitor.

Phase I areas cover about 80 percent of the NRD and about 50 percent of the irrigated cropland. Phase II areas cover some 225,000 acres (91,058 ha) extending from approximately Kearney on the west, eastward across the valley to the eastern end of the NRD near Columbus. The four Phase III areas scattered across the eastern half of the NRD cover some 250,000 acres (101,175 ha) of land.

The purpose of the groundwater quality management program that the Central Platte Natural Resources District has adopted is really two-fold. The first purpose is to clean up our groundwater supplies since each of the 115,000 residents of the NRD rely upon that groundwater as a source of drinking water. The second purpose is to accomplish groundwater cleanup in such a way that we do not have a detrimental impact upon the irrigated agriculture economy that is so important to the Central Platte Valley of Nebraska.

The results from the first four years of the program are very encouraging. Nitrate levels, that averaged 19.0 ppm over an area of 500,000 acres (202,350 ha) and were increasing at the rate of 0.5 ppm per year up through 1987, have not only stopped the increase, but have declined at an average annual rate of 0.25 ppm per year. ❑

Nutrient management legislation in Pennsylvania

Douglas B. Beegle and Les E. Lanyon

In the spring of 1993, the Pennsylvania state legislature passed and the governor signed the Nutrient Management Act into law. Before this legislation was passed, problems with nutrient pollution were handled primarily under the Clean Streams Law. This law basically states that if a farmer is following practices in the Department of Environmental Resources (DER) publication *Manure Management for Environmental Protection*, no special permits or approvals are required for manure utilization on farms. The Nutrient Management Act is the first law in Pennsylvania to directly affect nutrient application on farm fields. This article summarizes the main provisions of the Act.

Purposes

The purposes of this legislation as stated in the Act are as follows:

- Establish criteria, planning requirements, and an implementation schedule for nutrient management control on certain agricultural operations that generate or use manure.
- Provide for development of an educational program on nutrient management.
- Provide for development of technical and financial assistance for nutrient management and alternative uses of animal manure.
- Require DER to assess the extent of other nonpoint sources of pollution.

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Who will be affected?

The Act states that "concentrated animal operations" will be required to develop and maintain a nutrient management plan. Concentrated animal operations are defined as operations where the animal density exceeds two animal units per acre on an annual basis. An animal unit is 1,000 pounds of live weight. Thus, for example, a 1,300-pound dairy cow is 1.3 animal units; 333 chickens weighing 3 pounds each is 1.0 animal unit; and 5 hogs weighing 200 pounds each is 1.0 animal unit. Which acres will be counted in calculating the animal density is unclear, but presumably acres available for manure application will be counted. The worksheet contained in Table 1 can be used to estimate the animal density on your farm (See Table 1).

To calculate the animal density on your farm, insert the total animal units (AU) calculated in Table 1 into Table 2 along with the number of acres available for manure (See Table 2).

The actual calculations used in the regulations may be different from those used in these tables, but these figures will give farmers an idea of where they stand.

The criterion of two animal units per acre is a fairly high animal density. Farms with a higher density are likely to have more nutrients than can be utilized safely by crops on the farm. Thus nutrient management plans often will not only include detailed plans for on-farm manure utilization but also may require plans for moving some manure off the farm.

Plan development, approval, and implementation

A certification program will be developed by the Pennsylvania Department of Agriculture and all plans will have to be written by certified nutrient management specialists. Farmers may become certified to write their own nutrient management plans. Details on what will be required for certification have not yet been developed.

Plans required under this legislation must be submitted to the local conservation district or other designated authority for review. Existing operations which have more than two animal units per acre will have one year from the time the regulations are adopted to submit their plans for approval. New operations or operations that expand and then have more than two animal units per acre must submit a plan within three months of the time when regulations are adopted or prior to the start of operations, whichever is later.

Conservation districts will have 90 days to act on the plan. If the plan is not approved, the operator has 90 days to submit a revised plan. Plans must be implemented within three years. This implementation deadline can be extended by two years if substantial capital improvements are required for implementation.

The animal density criterion is not to be construed as prohibiting development or expansion of agricultural operations that exceed the criterion. It just means that these operations will be required to have a nutrient management plan.

Any farm that violates the Clean Streams Law also must have a nutrient management plan. Farms with fewer than two animal units per acre will be encouraged to have voluntary nutrient management plans. Plans can be transferred to subsequent owners of an operation.

Authority under the Act

The State Conservation Commission—the authority for this Act—is charged with the following:

- Develop regulations, within two years of the legislation being passed, that establish minimum criteria for nutrient management plans. The following criteria were specified in the Act:
  - identify the nutrient of concern, which is nitrogen for at least the next five years
  - establish procedures to determine acceptable application rates for manure
  - establish record-keeping requirements for land application and nutrient distribution
  - identify recommended best management practices (BMPs)
  - establish minimum standards for storages
  - establish conditions under which plans must be amended
  - establish criteria for emergency situations
- Continually evaluate emerging technologies for use as BMPs.
- After five years, reevaluate the criterion for "concentrated animal operations."
- Develop and implement an educational program on nutrient management.
- To the extent that funds are available, provide financial assistance for implementation of nutrient management plans.
- Administer this Act. Administration and enforcement can be delegated to local conservation districts with adequate programs and resources for implementation.

Nutrient Management Advisory Board

The Act establishes a Nutrient Management Advisory Board to review and comment on all regulations, criteria, and policies of the Conservation Commission related to the Nutrient Management Act. The board members will include

- farmers (5)
- nutrition specialist
- feed industry representative
- fertilizer industry representative
- commercial lenders representative
- local government representative
- university agronomist
- hydrologist
- citizen representatives (2)
- environmental representative

Financial assistance

To the extent that funds are available, the Conservation Commission will provide financial assistance in the form of loans, loan guarantees, or grants for implementation of nutrient management plans for existing operations. A special nutrient management

Table 1.

Animal operation(s)	No. animals (annual average)	x	Animal weight	÷1000=	Animal units
Example: Cows	100	x	1300	÷1000=	130
		x		÷1000=	
		x		÷1000=	
		x		÷1000=	
		x		÷1000=	
				Total	

Table 2.

Total AU	÷	Acres available for manure	=	AU per acre
	÷		=	

fund will be established for this purpose. To receive financial assistance under this Act, a farm must have an approved nutrient management plan.

Enforcement

An authorized agent of the Conservation Commission or conservation district will be able to conduct investigations of agricultural operations and take action necessary to enforce the Act. Civil penalties of not more than $500 for the first day of each offense and $100 for every additional day of continuing violation can be assessed by the Conservation Commission. The amount of the penalty will be determined by the gravity of the violation, potential harm to the public, potential effect on the environment, willfulness of the violation, previous violations, and economic benefit to the violator for failing to comply. In the case of a violation which causes no harm, a warning may be issued in lieu of a penalty.

If a violation occurs in an operation where a valid nutrient management plan is being fully and properly implemented, the farmer will be exempt from penalty, and the liability for any damages will be limited.

Preemption of local ordinances

No ordinance or regulation of any political subdivision may prohibit or in any way regulate practices related to the storage, handling, or land application of animal manure or nutrients if the local ordinance or regulation is in conflict with this Act or its regulations. This includes ordinances related to construction, location or operation of facilities used for storage of animal wastes or nutrients. Local nutrient management ordinances can be adopted, but they must be consistent with this Act, and their requirements can be no more stringent than the requirements under this Act. Finally, no local penalty can be assessed for a violation where a penalty has already been assessed under this Act.

Other nonpoint sources of potential nutrient pollution

While this Act deals only with regulation of nutrient management on concentrated animal operations, the Pennsylvania Department of Environmental Resources is charged with assessing the extent of the impact of other potential nonpoint sources of nutrient pollution on the environment, including

- assess the impact of on-lot septic systems on nutrient pollution problems and make recommendations within one year.
- assess the impact of improper water well construction on nutrient pollution problems and make recommendations within one year.
- assess the impact of nonagricultural use of nutrients on nutrient pollution and make recommendations within two years.
- assess the impact of storm water runoff on nutrient pollution problems and make recommendations within one year.
- assess the impact of atmospheric deposition on nutrient pollution problems and make recommendations within two years.

Perspective

This Act is expected to have an impact on a small but significant number of farms in Pennsylvania. However, all farmers and agricultural industries have a stake in protecting the environment from potential agricultural nutrient pollution. Even though a formal, approved nutrient management plan is not required of most farmers under this law, all farmers already have a nutrient management plan that guides their nutrient management activities. Most of these plans are based on optimizing the economics of their production systems. An effort should be made to review each plan regularly, not only from an economic and agronomic perspective but also from an environmental perspective, and to make modifications to reduce potential environmental damage. ❑

Evolution of nutrient management in the Chesapeake Bay region

Russ Perkinson

The Chesapeake Bay is the largest and most productive estuary in North America. The bay produces half of the blue crabs and one quarter of the oysters harvested in the U.S. The main stem of the bay is about 200 miles (322 km) long and varies in width from 3 to 30 miles (5-48 km), with a surface area of 2,200 square miles (5,698 km^2). Nine major rivers draining 64,000 square miles (165,760 km^2) empty into the bay.

There has been a heavy emphasis placed on agricultural nutrient management as a method of reducing nitrogen and phosphorus loadings in the bay. In 1982 the results of a six-year study were published by EPA. The study was authorized by Congress at a cost of $27 million to identify the causes of declining water quality in the Chesapeake Bay. In the bay, acreage of submerged bottom grasses, a vital habitat for many forms of bay life, had declined sharply over the last two decades. Previously, vast acreages of submerged grasses had been documented back to colonial times. The study concluded that three primary factors were contributing to the bay's decline: excessive sediment loads; excessive levels of nitrogen and phosphorus; and toxic contaminants. It is interesting to note that of the toxic compounds found in the study, agricultural pesticides were not found to be a significant factor in the decline of the bay.

High nutrient levels in the bay result in excessive growth of phytoplankton, tiny plants which grow suspended in water. At low to moderate populations, the phytoplankton benefit bay life by providing a food source to animal forms. At high populations, the phytoplankton growth clouds the water, reducing light transmission to the bottom grasses which reduces their vigor or results in death of the grass beds. As the phytoplankton die, the decomposition process decreases dissolved oxygen in the water, which directly stresses higher forms of marine life.

Nutrient reduction strategies must focus on both nitrogen and phosphorus levels in the Chesapeake Bay region. In the fresh water tributaries, phosphorus is generally the limiting factor to phytoplankton growth. However, in the salt water areas of the bay, nitrogen is the limiting factor in the summer months when most phytoplankton growth occurs, while phosphorus may be the limiting factor in other seasons.

Agriculture's contribution to the nutrient enrichment of the bay is significant. As long as a significant agricultural industry has existed in the bay watershed, it has contributed nutrients to the bay's waters. However, as the agricultural industry became increasingly specialized and the population base in the area grew, nutrient inputs to the bay increased. In evaluating the evolution of agricultural practices over the past few decades, it is interesting to observe that nitrogen deficient corn is rare in most years. Thirty or more years ago, corn plants exhibiting mild nitrogen deficiency symptoms were likely the rule rather than the exception.

Following the six-year EPA study, models were used to assist in the determination that a 40 percent reduction in controllable nutrient loads in the bay would be necessary to return it to an acceptable condition. In 1987, the Governors of Maryland, Pennsylvania, and Virginia, and the Mayor of Washington, D.C. signed the second Chesapeake Bay Agreement which committed the jurisdictions to meet a 40 percent reduction in controllable nutrient loads.

During the mid-1980s, the Bay states developed or expanded agricultural BMP cost-share programs as a means of reducing agricultural impacts on the bay. In each state, the lead agency which operates agricultural BMP programs also plays a major role in nutrient management. In Pennsylvania and Virginia, overall direction and field delivery of nutrient management programs are the responsibility of the natural resources agencies which rely partially on conservation districts, while Maryland's program is led by the agricultural agency with field delivery through Cooperative Extension. Many similarities exist in the nutrient management programs of each state, yet each has initiated innovative approaches.

Pennsylvania

Nutrient management on a statewide scale in the Bay region first began in Pennsylvania in 1985 when an innovative, fully integrated farm planning program was established for animal waste management. Landowner/district agreements are formed which require the installation and maintenance of all practices in the contract and the implementation and maintenance of a nutrient management plan. In return, practices are cost-shared at 80 percent, up to $30,000 per farm. Agreements have been established on 616 farms in the Bay watershed. Approximately $2 million annually is budgeted for these agreements. Pennsylvania State University staff provides training to the 38 conservation district technicians who develop the nutrient management plans. The Pennsylvania Department of Environmental Resources funds the district positions and the cost-share programs and maintains a staff of six engineers who design animal waste structures and other BMPs.

Proposed legislation in Pennsylvania would require nutrient management planning on high density livestock farms if enacted. Nutrient management ordinances currently exist in two counties and numerous townships across the state.

Pennsylvania has been a leader in

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the water quality research pertaining to nutrient management. For example, some of the early work on the presidedress nitrate test for corn was initiated in Pennsylvania.

Maryland

Maryland initiated the nutrient management program in 1989. Currently, 20 nutrient management "consultants" are housed in Cooperative Extension offices in the state. The consultants develop nutrient management plans for farmers and conduct educational activities including field days and demonstrations. The supervision of day-to-day activities is by county Cooperative Extension unit directors and the program technical direction originates from the University of Maryland. The positions are funded through the Maryland Department of Environment (MDE) and the Maryland Department of Agriculture (MDA), with the MDA Office of Resource Conservation formulating strategic program direction. To date, nutrient management plans have been developed on 175,671 acres (71,094 ha) by the consultants.

Innovative programs in Maryland include a Nutrient Management Consultant Certification Program offered by the MDA Office of Resource Conservation. The program is aimed at private and public sector personnel who may develop nutrient management plans. Groups targeted for certification include employees of the retail fertilizer industry, sludge contractors, private consultants, and government employees. The first test was held in January. Of the 121 people who applied for certification, 83 (68 percent) passed the exam. Nutrient management agencies in Pennsylvania, Maryland, and Virginia cooperated in the development of a bank of test questions to be used in nutrient management certification programs. New sewage sludge regulations being developed in Maryland will require nutrient management plans developed by sludge contractors for sites to receive sludge applications.

Virginia

Virginia's statewide nutrient management program also was established in 1989. The Division of Soil and Water Conservation, in the Department of Conservation and Recreation, is the lead non-point source pollution management agency and operates the nutrient management program. Ten nutrient management specialists develop nutrient management plans and conduct educational programs across the state. These specialists have developed more than 800 nutrient management plans on 180,000 acres (72,846 ha) of cropland. Nitrogen and phosphate use reductions are estimated at 4.4 million pounds (2 million kg) and 3.9 million pounds (1.8 million kg) respectively from the planning activities.

Innovative programs in Virginia include several incentive and regulatory programs. A state tax credit on nutrient management-related farm equipment was enacted in 1990. The state tax credit is 25 percent of the purchase price or $3,750, whichever is lower, on manure spreaders, fertilizer applicators, and tramline equipment that meet established criteria. To claim the credit the farmer must have a nutrient management plan approved by the local conservation district in place. A plan must also be developed for farmers receiving state animal waste storage cost-share assistance.

Regulatory programs requiring nutrient management include Virginia Pollution Abatement (VPA) permits and the Chesapeake Bay Preservation Act. VPA permits, issued by the State Water Control Board, which include a nutrient management plan are required on farms with 1,000 animal units that have liquid or semi-solid manures. The Chesapeake Bay Preservation Act requires soil and water quality conservation plans in 31 coastal zone counties if farmers want to reduce required 100 foot (30 m) buffers around surface waters to 25 feet (8 m). These plans include nutrient management, soil erosion, and IPM components. In addition, several counties in the state also have poultry ordinances which require nutrient management plans.

Summary

Although each state is using various methods to deliver nutrient management programs, many program components are the same and the states have cooperated extensively. The nutrient management coordina-tors from each state meet quarterly to exchange ideas and work on common projects. As a result, content and format of nutrient management plans are similar across the jurisdictions. The group has developed uniform criteria and standards for nutrient management plans and the framework for a nutrient management certification program for each state. In addition, the states cooperated in the development of a pool of 600 test questions for use in nutrient management certification programs in the Bay area. Regional training materials are being developed for use in nutrient management certification programs. In order to realize the goal of nutrient reduction in the bay, the states must continue to invest in research, cooperate extensively, and develop creative program strategies.

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Nutrient management in Idaho

R. L. Mahler and F. G. Bailey

As Idaho's major industry, agriculture accounts for 36 percent of the states' total gross product. Farm sales directly account for 21 percent of the gross product with an additional 15 percent attributed to food processing. More than 12,000,000 acres (4,856,400 ha) of cropland and hayland are found in the state. About 4,000,000 acres (1,618,800 ha) are irrigated (*2*).

The irrigated lands are the most intensively managed and most productive, resulting in the widespread axiom that water is the lifeblood of Idaho. On an average day 23,000,000,000 gallons (87,064,000,000 l) of water are used in the state (*5*). Dividing this by Idaho's current population of 1,060,000, per capita water use is 22,000 gallons/person/day (83,279 l/person/day), the highest per capita water use rate in the U.S. More than 97 percent of the state's water use is attributed to agriculture. Most of the irrigation water comes from rivers, but Idaho is also the country's fourth largest user of groundwater. Groundwater comprises only 22 percent of Idaho's total water use, but it accounts for nearly 95 percent of the state's drinking water.

Many Idaho crops are intensively fertilized with nitrogen (N), phosphorus (P), and sulfur (S). Nitrogen application rates range from 100 to 480 lbs/acre (112-538 kg/ha) on irrigated land and from 25 to 140 lbs/acre (28-157 kg/ha) on rainfed cropland. Phosphorus is applied to roughly 30 percent of Idaho's cropland each year at rates ranging from 20 to 70 lbs/acre (22-78 kg/ha). Sulfur is applied to about 35 percent of Idaho's rainfed cropland each year at rates between 10 and 25 lbs/acre (11-28 kg/ha). Potassium is annually applied to less than 5 percent of the cropland in the state. More than 85 different crops are grown in Idaho. Major crops include potatoes, barley, wheat, sugarbeets, dry beans, alfalfa, sweet corn, and onions (Table 1).

Based on regional and national information, poor N management can impair both groundwater and surface water. Conversely, poor P management primarily impairs surface water. Since soil erosion is the major mechanism by which P enters surface water, its control will provide environmental protection from P-containing fertilizers. Best management practices to control erosion in Idaho have been encouraged for years. However, few practices to discourage N leaching through soils and into groundwater have been utilized to date.

Nitrogen leaching is a concern in Idaho, particularly in irrigated areas of the state, as locations of prime aquifers and intensively managed farmland often coincide. In many areas water tables are within a few feet of the soil surface. The Idaho Division of Environmental Quality and U.S. Environmental Protection Agency are concerned that agriculture may contaminate aquifers with nutrients, particularly N. Of particular concern are dairy operations and irrigated fields receiving large amounts of commercial N fertilizers.

Nitrogen use efficiency (NUE) is often used as a measure of the efficiency of nutrient management. NUE can be defined as the percent of N applied to the land that actually ends up in the plant. In Idaho, NUE ranges from 10 to 80 percent depending on both the crop grown and the level of management. NUE averages about 50 percent in Idaho. The lower the NUE value, the greater the likelihood that a significant portion of the applied N may end up in the groundwater.

The relatively low NUE values observed across Idaho can be attributed to one or more of the following factors: poor irrigation water management, incorrect rates of N applied to fields (usually too much N), poor environmental conditions (weather), improper agronomic practices, and/or an inadequate research database resulting in incorrect fertilizer application rates.

In Idaho, nutrient recommendations are research-based for major crops. The University of Idaho has published fertilizer guidelines for 34 of the state's 40 most important crops. These fertilizer guidelines are based on soil test correlation research and depend on soil sampling. In addition, tissue analysis for nutrient management can be used throughout the season for some of the most intensively managed crops like potatoes and sugarbeets.

Best management practices (BMPs) for N management in Idaho should include one or more of the following practices: soil sampling, fertilizer recommendations based on the soil sample and research data, split applications of N fertilizer, nutrient credits for plow-down residues of legumes and applied manures, use of nitrification inhibitors, manure management, irrigation water management, use of slow release N fertilizers, crop rotation selection to maximize NUE, and variable fertilizer management within a single field (*4*).

Nitrogen management in Idaho crops

Three crops are introduced to examine the current status of N management in Idaho. These crops are onions, potatoes, and winter wheat.

Onions. Onions are a high value, intensively managed, irrigated crop grown primarily in southwestern Idaho. Under current management conditions NUE ranges between 15 and 40 percent. Current N management is far from optimum as N application rates are based primarily on tradition even though a research-based onion fertilizer guide is available for grower use (*1*). Nitrogen is applied in split applications; however, total amounts of N applied over the growing season often exceed 300 lbs/acre (336 kg/ha). The high market value of onions results in farmers

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Table 1. Acreage, production, and ranking statistics for major Idaho crops in 1992.

Crop	Acreage	Production	Ranking of states
Potatoes	405,000	122,175,000 Cwt	1
Sugarbeets	207,500	5,070,000 Ton	2
Peas	80,000	1,501,000 Cwt	2
Lentils	47,000	621,000 Cwt	2
Barley	1,370,000	59,250,000 Bu	3
Hops	4,200	5,431,000 Lb	3
Mint	16,000	1,375,000 Lb	3
Onions	8,000	4,880,000 Cwt	3
Spring wheat	971,000	32,660,000 Bu	6
Dry beans	246,000	2,932,000 Cwt	6
Sweet corn	130,000	180,000 Ton	6
Alfalfa hay	1,110,000	3,914,000 Ton	8
All wheat	1,852,000	81,660,000 Bu	8
All hay	1,420,000	4,294,000 Ton	15

Table 2. Nitrogen use efficiency values in winter wheat production as affected by annual precipitation when all nitrogen is applied at planting.

Precipitation zone (inches)	Nitrogen use efficiency (percent)
16 to 18	65
18 to 20	58
20 to 22	50
22 to 24	42
24 to 26	34
> 26	21

ensuring that adequate N has been applied to their crop, even at the expense of the environment.

A survey conducted in 1992 found virtually all onion fields were subjected to soil and/or tissue sampling (*7*). Average N application rates to onion fields in this survey was 297 lbs/acre (333 kg/ha). The N was applied in three to four split applications over the growing season.

Nitrogen use efficiency in onions is low for several reasons. The major problem with N management in onions is related to over-irrigation and the fact that the effective rooting depth is only 12 to 16 inches (30-41 cm). Combined with the fact that onions do not tolerate dry soils, excess irrigation water often leaches N below the root zone. Consequently, a "catch 22" situation occurs where N is repeatedly applied to onions after irrigations to replenish the previously leached nutrient. The net effect is low NUE and nitrate contamination of groundwater.

Nitrogen use efficiency in onions can be improved using a three-pronged approach. First, soil samples should be collected from each field prior to planting. The applied N should be based on the onion yield potential and the University of Idaho fertilizer guide for onions. The N fertilizer should be applied as a slow release material or in several multiple (6 to 10) small increment applications over the course of the growing season. Second, irrigation water management should be improved to reduce leaching potential. And third, the N status of the onion plants should be monitored throughout the growing season using tissue sampling and analysis. The N applied during the growing season should be based on needs determined from the plant nitrogen status.

Potatoes. Potatoes are Idaho's largest cash crop. Potatoes are grown under irrigated conditions throughout the southern part of the state. This high value crop currently receives intensive N management with help from private consultants. Under superior management NUE can approach 75 percent (*8*, *9*). Nitrogen management is intense in potatoes because either a lack of or an excess of N will reduce crop yields and impair crop quality. Excess N results in vegetative plant growth at the expense of tuber growth.

Nutrient management for potatoes is well refined. Excellent soil and plant tissue test correlation databases exist for the Russet Burbank potato (*6*). Growers routinely apply a portion of their N requirement prior to planting. Virtually all the potato cropland in Idaho is sampled for a soil analysis prior to planting. The N applied is based on a soil sample and the research database in the University of Idaho Fertilizer Guide for potatoes. Additional N is applied in the irrigation water in small increments throughout the growing season as needs are determined by weekly plant tissue analysis. This spoon-feeding of N throughout the growing season based on need results in relatively high NUE values.

Nutrient management can be further enhanced in potatoes with better irrigation water management. Since potato roots are concentrated in the upper two feet of the soil profile it is easy to leach nitrates below the root zone.

Growers currently use superior nutrient management in potatoes because the economics of potatoes make it pay. Potatoes are probably the most efficiently managed crop for N in Idaho. Realistically, N management cannot be further enhanced without a better irrigation water management program.

Winter wheat. Dryland winter wheat is grown extensively in northern Idaho. The crop is grown where annual precipitation ranges from 18 to 35 inches (46-89 cm). Winter wheat yields exceeding 100 bushels/acre are quite common. Nitrogen applications range from 75 to 150 lbs/acre (84-168 kg/ha). Even though wheat is a low value crop when compared to irrigated potatoes or onions, the high yield potentials attainable in northern Idaho encourage moderate to intensive nutrient management. Currently, NUE in winter wheat ranges from 35 to 60 percent, with an average value of 45 percent in northern Idaho. Nitrogen use efficiency values are higher in the lower precipitation regions (Table 2).

Ideal nutrient management BMPs for winter wheat in northern Idaho include all of the following: soil sampling prior to seeding; basing N application rates on soil analysis, realistic yield goals; and University of Idaho fertilizer guides, and split N application between the spring and the fall in areas that receive more than 22 inches (56 cm) of annual precipitation.

Approximately 40 percent of the wheat fields currently have soil samples taken prior to seeding wheat. The recommended soil sampling depth is 5 feet (1.5 m); however, less than 25 percent of the fields are sampled to a depth greater than 2 feet (0.6 m). In fields which are not sampled, N application rates are often based on historical application rates. Fertilizer recommendations are based on the University of Idaho Fertilizer Guide for winter wheat (*3*). Split applications of N improve NUE in the higher precipitation areas.

As a rule plant tissue analysis on dryland wheat is not performed during the growing season. Thus an initial soil sample is the only measure of nutrition. Recent studies of drain tiles have shown that a significant amount of N is leaching during the winter and spring periods, particularly in areas where fall N is applied (Mahler, unpublished data).

Idaho nutrient management specification

In 1990 the U.S. Department of Agriculture's Soil Conservation Service (USDA-SCS) in Idaho began the development of a nutrient manage-ment specification for the SCS field office technical guides. The intent was to establish technical quality criteria for protecting water quality. The practice was written to be voluntary; however, the management guidelines were to be designed so that all environmental concerns were adequately addressed. An initial committee consisting of representatives from SCS, University of Idaho, USDA-Agricultural Research Service, Idaho Soil Improvement Committee, private consultants, industry agronomists, fertilizer dealers, and producers was put together in the spring of 1990. The committee developed Idaho's nutrient management specification. More than 90 percent of the document was put together with unanimous consensus. However, when an issue or a numerical value could not be resolved by consensus, SCS made the ultimate decision. The specification requires use of the latest research and technology and uses the University of Idaho crop fertilizer guides as the basis for fertilizer recommendations. This document has received wide-spread exposure in Idaho and has generated much controversy. The document is not perfect, but it is an excellent starting point for nutrient management programs in Idaho. The goal of the committee was to develop guidelines whereby producers, the fertilizer industry, and conservationists could position themselves to meet water quality needs without having to be regulated. The nutrient management specification has five parts: (1) a general specification section, (2) N, (3) P, (4) organic wastes and manure, and (5) operation and management. The general portion of the Idaho nutrient management specification contains the following:

- Soil sampling will follow the guidelines in the University of Idaho Cooperative Extension System Bulletin No. 704 titled "Soil Sampling."
- The soil sampling depth for each crop will follow the guidelines contained in the current crop fertilizer guides developed by the University of Idaho and cooperating agencies.
- Plant tissue sampling methods and analysis procedures will follow current University of Idaho or industry guidelines for individual crops.
- Soil laboratory analysis will be according to accepted industry methods and standards.
- Growers will establish realistic yield goals for each crop and each field. Yield goals will be based on crop yield history and the planned management level.
- Nutrient recommendations will be based on the crop fertilizer guides or locally supported databases.
- The grower will maintain a record for each field showing the crop sequence, crop variety, soil test data, kind and amount of nutrients applied, special application practices, and crop yields. These records begin with the practice and will be maintained for at least a five-year period or until the grower no longer manages the field.
- Irrigation water management is required on irrigated cropland. Irrigation water management will be applied to meet the Irrigation Water Management No. 449 Practice Standard and Specification.
- Periods with high leaching potential will be identified for each field.

In addition to the general part of the nutrient management specification both N and P are further addressed. The N section is of particular interest and contains the following:

- Nitrogen applications will be based upon a current soil test or plant tissue analysis. The minimum will be one soil test per year prior to planting.
- A yearly nitrogen management plan will be developed for each field and crop. The plan will include as a minimum:
  - previous crop variety
  - current crop variety
  - current yield goal
  - current soil test data including the amount of available nitrogen in the soil
  - an estimate of the amount of nitrogen in organic matter to be available during the crop growth period
  - amount of supplemental nitrogen to be applied to the crop in order to meet production goals and residue decomposition needs (This includes

nitrogen from chemical fertilizers, manures, organic wastes, or other sources.)
  - special application practices or materials needed on the field to meet water quality objectives including timing of application, multiple applications, side-dressing, banding, foliar feeding, fertigation, stable forms of nitrogen, nitrogen inhibitors, or needed changes in crops or crop sequence
- The maximum amount of nitrogen applied to each crop in a given year will not exceed 1.2 times the amount recommended in individual University of Idaho Fertilizer Guides unless additional soil tests or plant tissue analyses show a need. Additional nitrogen applications will follow recommendations based on the new soil test and/or tissue analysis data.
- The following limitations apply to cropland fields where the water budget shows more than 8 inches of water leaching below the root zone:
  - Crops following alfalfa or clover will be limited to high nitrogen use crops such as small grains, corn, or potatoes that efficiently utilize nitrogen fixed by the legume.
  - Fall nitrogen applications will be planned to avoid high concentrations of mobile nitrogen in the soil during the normal winter-spring high leaching periods.

The most controversial portion of the entire N management specification is the N limitation which states that N application cannot exceed 1.2 times the amount of N as recommended by University of Idaho fertilizer guides.

The phosphorus portion of the specification states

- Phosphorus applications will be based on current soil test or plant tissue analysis and the University of Idaho fertilizer guides or locally developed databases. A minimum of one soil test per field is required before applying phosphorus.
- Phosphorus may be applied so that one application will meet phosphorus requirements for several years.
- Phosphorus will be soil incorporated where a potential exists for surface runoff and soil erosion before the next tillage operation. Phosphorus may be applied during active crop growth with sprinkler irrigation systems if plant tissue analysis indicates a need and if no surface water runoff occurs from the target area.

Although somewhat controversial, this voluntary nutrient management specification has several positive aspects. Perhaps most important is that the plan is research-based. Nitrogen management relies on University of Idaho fertilizer guides. In addition, there is adequate flexibility for growers to supplement original nutrient applications with justification based on additional soil and/or plant tissue tests during the growing season. And last, this plan is based on a combination of proven N management BMPs.

The down side of the nutrient management plan is that under conditions of poor management a grower must spend more money for diagnostic purposes to justify additional fertilizer applications to fields. The plan also assumes that the University of Idaho fertilizer guidelines are up-to-date. This requires a university commitment to a continuous soil test correlation research and extension program. This may be difficult in light of the fact that the University of Idaho soil fertility program has been reduced by 50 percent over the last 15 years.

The fact that this plan is a voluntary effort will allow refinement with time. Some states have already enacted laws limiting fertilizer use in especially vulnerable areas. The authors of this paper predict, however, that sometime in the not-too-distant future nutrient management planning will no longer be voluntary unless producers and the fertilizer industry are willing to apply fertilizer according to research-based technical criteria such as the Idaho Nutrient Management Specification.

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Innovative local dealer nutrient management programs—How they work

John E. Culp

Tennessee Valley Authority (TVA) and the National Fertilizer and Environmental Research Center (NFERC) in Muscle Shoals, Alabama, have a unique position in the agribusiness community. TVA/NFERC

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interacts with fertilizer dealerships, providing them with information about new products and processes and ways to increase the efficiency of growing crops, and environmental information about their businesses and operations. Therefore, NFERC can have a significant impact on how the dealer manages the nutrients he/she markets to the farm community. Here we discuss innovative local dealer nutrient management programs.

The NFERC programs that deal with nutrient management involve containment of the nutrients at the dealer site to prevent contamination of the air and of surface and groundwater, development and evaluation of more efficient and environmentally friendly fertilizer processes and products, and development and evaluation of agricultural practices and soil testing procedures to make more efficient use of the nutrients applied.

A major objective of NFERC is to promote more efficient and environmentally acceptable use of plant nutrients to benefit U.S. farmers and consumers. Our efforts in the environmental area are to help maintain a competitive, sustainable, and environmentally acceptable U.S. agriculture. We are doing this through three program activities: containment, research and development, and technology transfer.

The idea behind the containment program is to show fertilizer dealers how to prevent point source pollution from contaminating surface water, groundwater, and the air. In our containment and compliance program, we are establishing 20 model site demonstrations (MSDs) across the country to introduce technologies to help dealers contain potential pollutants onsite. The idea is to develop containment systems at retail dealer sites that get raw materials in and send finished products out. Everything else stays onsite.

The model demonstrations are located in areas of high fertilizer use. They are established to provide other dealers from the surrounding areas with an actual operating facility where they can see how to install secondary containment and prevent point source pollution. This is information they can take home and use.

Fertilizer and agribusiness associates and regulatory officials also are encouraged to cooperate in this program. These sites are real-life solutions to dealers' problems of how to install containment at either an existing or new site.

The dealer pays all construction costs, keeps records, and divulges how much is spent on containment. TVA/NFERC provides engineers and drawings and conducts educational programs at the site. Cost of containment structures run from $75,000 to more than $350,000.

After the construction is completed, an open house is held to help the dealer show customers, business associates, legislators, and regulators how he/she is being a good steward of the environment. Following are highlights from model site demonstration facilities in Oregon, Maryland, and Florida. Each uses different construction materials and a different approach to solve similar problems.

Manager Dennis Reich started from the ground up, building a state-of-the-art fluid fertilizer plant in a rural area of Oregon. The plant was fully contained to protect the environment. The entire tank farm was lined with a hypalon liner and covered with gravel. This was less expensive than concrete, but concrete was used in the load pads and under the fluid mixing system. Proper attention was given to sloping the "load-out" and transfer areas so any major spills could drain into the tank farm dike and could be recovered. Proper management of piping also was made to detect leaks and to move any fluids from leaks or spills into a sump and holding area for reuse in formulations, land applications, or other disposal methods.

Another model demonstration site is Willard Ag Service in Frederick, Maryland. This business is located in downtown Frederick and was especially sensitive to potential pollution that could result from accidents or rinsing operations. They primarily mix and distribute fluid fertilizers. Concrete dikes were installed around the tank farms, leak detection systems were installed, and materials transfer points were contained using a combination of concrete and asphalt. The transport areas in and around the plant were covered with asphalt and sloped into a containment area. Congressional members and staff from Washington and state regulatory officials visited during the open house to learn how the industry is responding to environmental issues and protection.

About 150 fertilizer dealers, customers, business associates, and regulatory officials attended the model site open house in January at Ranch Fertilizer in Okeechokee, Florida. Ranch Fertilizer is a large operation—last year it moved about 100,000 tons (90,720 metric tons) of fertilizer, about 80 percent solid and 20 percent fluids. The company is situated adjacent to a creek that flows into Lake Okeechobee. Fertilizer has been sold from this site for many years. Recently, the Florida Department of Environmental Regulation had cited them for increasing the N and P levels in the creek which flows directly into Lake Okeechobee. Management at Ranch immediately began to install additional secondary containment and to cap the site and prevent any further nutrients from entering the ground. TVA personnel provided technical input into the design of containment and storm water management. Monitoring of the site and the creek will continue for years to provide data on the time required to lower the nutrient content leaving this facility. Results have already been and will be useful in determining how to handle other sites in Florida.

The model site demonstration program is proving to be an excellent educational tool in helping the industry and environmental officials conduct scientific-based environmental protection programs. Several dealers have said what they learned at the model sites has saved them money by causing them to change or modify their containment design to one that was more efficient and less costly.

The other part of the containment program involves environmental site assessments. The idea is to provide dealers with information on changes that should be made to enable them to keep their raw materials and products onsite.

In addition to the containment work just described, TVA/NFERC also assists in research to develop technologies to help prevent and solve environmental problems. Major emphasis is in three areas: agricultural, chemical and biochemical, and chemical engineering.

One approach to increasing nitrogen efficiency is being able to determine how much residual nitrogen remains in the soil and is available for the growing plant. TVA over the years has cooperated with various land-grant universities to develop such a test. A test has been available and is in use now in the relatively dry (0-8 inches [0-20 cm] rainfall per year) areas of the country. Results have not been as consistent in the wetter areas of the country which are generally areas east of the Mississippi River.

This then gives you a brief sketch of the cooperative work going on between TVA, the dealers, and others to improve nutrient management techniques. Cooperative research technologies, development, and finally technology transfer are all keys in this effort. ❑