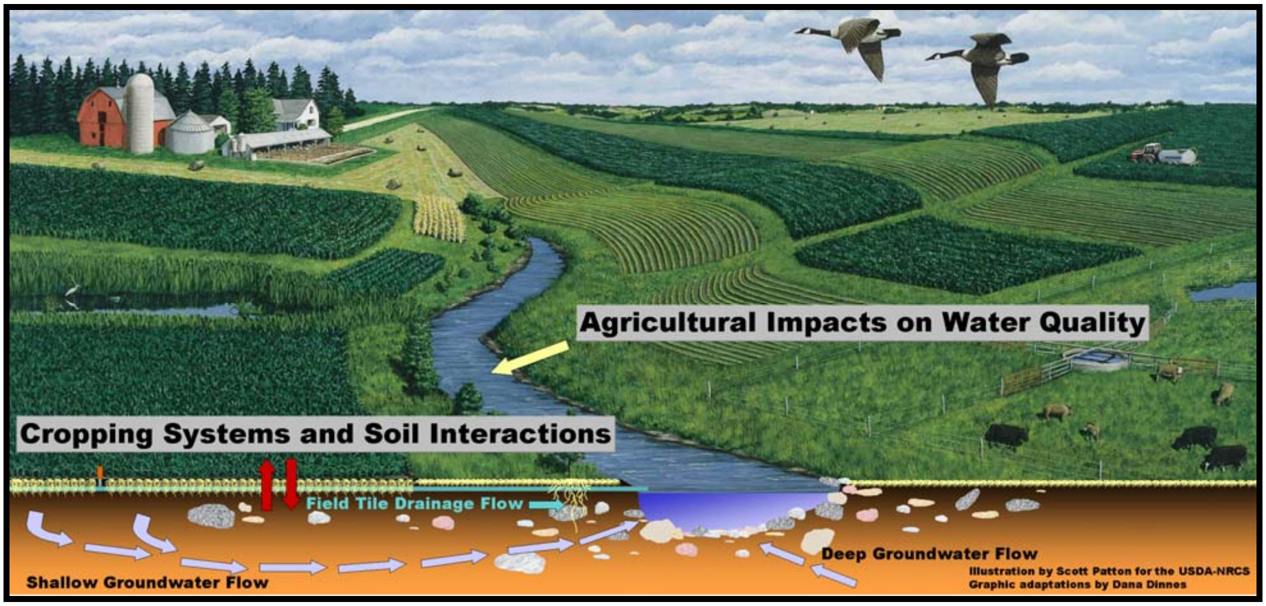
Assessments of Practices to Reduce Nitrogen and Phosphorus Nonpoint Source Pollution of Iowa's Surface Waters



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Executive Summary

Advancements in scientific technologies and research over the past century have brought about a better understanding of the connections of water quality with livestock, wildlife, humans and the health of aquatic and terrestrial environments. The resulting knowledge of the ill effects of contaminated water resources led to the Clean Water Act of 1972 and its later revisions.

The requirements set forth by the Clean Water Act for states to meet targeted water quality standards have been set in motion. The first and usually easiest type of water pollution to address is point source (areas of confined and discrete conveyance), for which standards and management practices have been in implementation now for a number of years across the nation. The more difficult type of water pollution that yet needs to be addressed is nonpoint source (NPS). NPS pollution is defined as being any source of water pollution that does not meet the definition of point source. In general, nonpoint sources are diffuse across a landscape and occur at intermittent intervals, due mostly to weather-related events. Examples of NPS pollution are contaminated urban and agricultural runoff and leachate waters, flow from abandoned mines and atmospheric deposition of contaminants directly to waterbodies.

Agriculture greatly dominates land use in Iowa: over 90% of the state's land area currently is in agriculture production. It is not surprising then that agriculture is the dominant contributor to NPS pollution within the state. Nitrogen (N) and phosphorus (P) plant nutrients have been identified as contaminants of surface water throughout the Midwest. Although agriculture may comprise the largest contributing portion of the state's total NPS pollution, the remaining portions (urban and industrial) must also be addressed to achieve the reductions in contamination necessary to meet the requirements of the Clean Water Act. Therefore, the entire state of Iowa will need to be evaluated to determine and prioritize existing and potential NPS pollution at-risk areas.

Presented within this document is an introduction and background of the factors that impact NPS nutrient pollution of Iowa's surface waters. The intent of the background information is to provide the reader with a working knowledge of natural and human-induced factors that influence NPS nutrient pollution, being: landscape; climate; carbon, N and P cycles and ratios; and, land and water use management. This is followed by a discussion of the principles and functions of NPS pollution management practices and the importance to evaluate research results by the spatial and temporal aspects of the experiments.

Principle functions and responses of the environment to natural and human-induced disturbances are consistent over time. The designs of NPS nutrient management practices are based on these principles and are summarized below.

- The closer bedrock lies to the land surface the greater the risk it poses to water quality.

- Land management practices that reduce the volume, speed and concentration of runoff flow can reduce erosion potential.
- The coarser the overall soil texture, the faster the soil's water infiltration rate.
- Increased runoff flow results in decreased ground water flow, and vice-versa.
- The greater the amount of tillage induced soil disturbance, the greater the potential for total P losses.
- Preventive practices cost less than remedial practices to meet the same water quality goal.
- The solution to pollution is not dilution: the solution is prevention.
- Reduced nutrient load equals reduced risk.
- Improving the timing of nutrient application and matching the amount that is available with crop demand can improve yield and water quality.
- Improved on-field water storage reduces potential NPS pollution.
- Increased plant cover and decreased soil disturbance results in decreased erosion.
- Mobile sediments and nutrients deposited and retained on the land will decrease NPS pollution.
- Greater off-field water storage capacity results in less potential streambank and channel erosion.
- Greater off-field nutrient storage capacity leads to a greater opportunity to prevent the nutrients from entering surface waters.
- The greater the biological nutrient pool, the better synchronization of nutrient availability with crop demand and/or potential ability to capture nutrients transported off-field.
- Reduced nutrient availability during periods of little to no crop demand results in reduced risk of NPS pollution.

Conservation practices are based upon two types of NPS management strategies, preventive and remedial. Preventive refers to not creating, or at least minimizing the probability of creating, a NPS nutrient pollution problem. This can be accomplished for instance by buffering the environment to destructive forces and limiting contamination threats. Preventive measures typically cost less than remedial because it is easier to prevent a problem from occurring than it is to fix the problem after it has been created. However, there will be cases where preventive practices alone will not meet future water quality standards. In such cases, remedial treatment practices will need to be added to create an effective overall strategy. Remedial practices are typically located between the nutrient source area and a surface waterbody to intercept, store or alter nutrients, thus rendering them unavailable, at least for an appreciable period of time.

Following the background section are water quality impact assessments of conservation practices to manage NPS N and P nutrient pollution. For each conservation practice the assessments identify mechanisms of nutrient reduction and removal, current documented degree of success, applicable conditions, conditions that limit its function, and sources of its variability in performance. Seventeen different nutrient reduction and removal mechanisms have been identified each for soluble and insoluble forms of N and P, being:

Reduction and Removal Mechanisms of Soluble Nutrients

1. Decreased artificially drained soil volume
2. Decreased exposure of nutrients to leaching by preferential flow of soil water through soil macropores or leachate diversion
3. Denitrification (nitrate-N only)
4. Dilution
5. Improved adsorption to soil matrix
6. Improved balance of nutrient application rate with crop demand
7. Improved synchronization of nutrient fertilizer availability with crop demand
8. Increased crop growing season for greater utilization of available nutrients
9. Increased crop nutrient use efficiency (crop assimilation)
10. Reduced applied nutrient load
11. Reduced in-field volume of runoff water
12. Reduced rate of nutrient mineralization (mainly for N)
13. Reduced soluble nutrient fraction within runoff water
14. Reduced volume of runoff water reaching surface waters
15. Reduced volume of shallow ground water drainage
16. Temporary nutrient sequestration in soil organic matter
17. Vegetative assimilation

Reduction and Removal Mechanisms of Insoluble Sediment- and Particulate-Bound Nutrients

1. Dilution
2. Improved balance of nutrient application rate with crop demand
3. Improved stabilization of soil surface to impede wind and water erosion detachment and transport of nutrient enriched sediment and particulates
4. Improved synchronization of nutrient fertilizer availability with crop demand
5. Improved water infiltration and nutrient adsorption to soil matrix
6. Increased crop growing season for greater utilization of available nutrients
7. Increased crop nutrient use efficiency (crop assimilation)
8. Reduced applied nutrient load
9. Reduced erosion and transport of nutrient enriched sediments and particulates
10. Reduced fine-particulate nutrient fraction in runoff water
11. Reduced in-field volume of runoff water
12. Reduced nutrient solubility to soil water and surface water
13. Reduced soil nutrient mineralization rate (mainly for N)
14. Reduced volume of runoff water reaching surface waters
15. Temporary nutrient sequestration in soil organic matter
16. Trapping and retention of transported nutrient enriched sediments and particulates
17. Vegetative assimilation

Information for the background and assessments was assimilated from many sources, being preexisting federal government publications (i.e., the USDA NRCS Iowa Field

Technical Guide, EPA national management measures to control NPS pollution guides, etc.) to scientific texts and research journal articles.

Finally, the Summary and Conclusions present a compilation of the assessments' estimated long-term impacts on N and P NPS pollution and provide perspectives that are meant to serve as guidance on how to devise and implement comprehensive conservation management plans, along with suggestions for further research to resolve gaps in current knowledge. Estimates for potential reductions of NPS losses were based upon total N (TN) and total P (TP) nutrient forms to reflect the balance of all potential losses and gains in N and P transport to surface waters and because water quality standards are to be determined by the total nutrient forms. Research has shown that some of the existing conservation practices can significantly reduce NPS N and P contamination of surface waters. Most notable among these practices are those that function to considerably reduce both TN and TP losses, which are cover crops (50% for TN and TP), diverse cropping systems (50% for TN and TP), in-field vegetative buffers (25% TN, 50% TP), livestock exclusion from stream and riparian areas (30% TN, 75% TP), and riparian buffers (40% TN, 45% TP). Other practices that offer appreciable reductions in NPS TN loss are N nutrient timing and rate conservation management (15-60%) and wetlands (30%). Additional practices that also can significantly reduce NPS TP loss are moderately reduced tillage practices (50% compared to intensive tillage) and no-tillage (70% compared to intensive tillage, 45% compared to moderately reduced tillage), terraces (50%), seasonal grazing (50%), and P nutrient knife or injection application (35%). These conservation practices should be prioritized for additional research funding and farmer adoption depending upon if one or both nutrients pose NPS loss risks on their lands.

Although a number of these practices may substantially decrease NPS nutrient loss, a single practice alone may not be able to reduce these losses to the extent necessary to meet water quality standards, particularly for critical source areas. Comprehensive conservation management plans may often require the adoption of both preventive and remedial practices. For a remedial field-edge conservation practice to function successfully it is critical to implement in-field conservation practices that are designed to increase soil water storage (thereby reducing runoff and leaching water volumes) and reduce N and P mass transport. For example, concentrated runoff flow from fields entering riparian buffers and wetlands may exceed these practices' storage and treatment capacities and then directly enter surface waters. Including in-field buffers, terraces and meadow crops will reduce runoff volume and help to maintain any runoff that does occur as diffuse flow. Critical source areas of NPS N and P loss can vary from each other in location. Nitrogen loss is generally more diffused across the landscape since it is dominated leaching while P loss tends be at high risk from highly erodable areas and near stream channels, which are usually more isolated than leach prone areas. Strategies to reduce N and P NPS losses may at times require the application of different conservation practices for the two nutrients.

Designing successful comprehensive conservation management plans requires a number of considerations. An order of tasks is recommended here to guide the adoption, implementation and validation of conservation practices for reducing N and P NPS pollution, being:

1. Delineate Iowa's varied agroecoregions.
2. Identify the critical source areas and associated characteristics that pose high risks for N and P loss.
3. Identify the characteristics of the remaining areas and the associated degrees of N and P loss.
4. Determine water quality standards (end points that must be met) that preserve the integrity of aquatic ecosystems and meet the requirements for each waterbody's designated use.
5. Identify where each conservation practice is applicable and prioritize by highest probability to reduce nutrient losses.
6. List suites of conservation practices designed to meet water quality standards and maintain the integrity of field-edge remedial practices during peak events.
7. Apply policies, education and programs that address social and economic concerns for the adoption and implementation of conservation practices.
8. Provide assistance to farmers in designing comprehensive conservation management plans on an individual basis and in coordination with whole watershed management plans.
9. Monitor water quality to document the performance of the implemented conservation practices, determine if water quality goals are being met and guide further actions if necessary.

Some of the above tasks suggested to guide effective implementation of conservation practices are already in use, but unfortunately not always in a coordinated manner among the various government agencies. Other aspects have not yet been adequately addressed, but are critical to the success of the entire process. Social and economic studies are greatly needed to determine existing barriers to public adoption of conservation practices to help identify new policy options that may overcome the barriers. Also, education programs need to be developed and instituted for all residents from primary school through adult age groups. Knowledge leads to awareness that may then motivate changes in behavior, which is critical to achieve rural and urban support, cooperation and compliance with future water quality programs.

There are two basic philosophies and structures of conservation practice program policies with advantages and drawbacks to each model. The advantage of the monetary subsidies model to provide motivation for voluntary adoption is that those that adopt the supported practices generally do so without complaint and implement the practices correctly. Two major disadvantages are that it is very costly to taxpayers and that in the decades that this model has been in use it has rarely achieved adoption at scales sufficient enough to significantly improve water quality. A second option is the performance-based model. The basic premise of a performance-based model is for government to require that water quality standards be met, but allow the landowner and/or operator the flexibility to choose and implement their choice among a suite of conservation practices that are appropriate to the characteristics and N and P NPS pollution risks that exist on their lands. There are merits to this approach. Allowing the landowner and/or operator such flexibility would result in more willing cooperation and proper implementation of adopted practices than by a purely mandatory approach. The drawbacks are that it may still be costly to taxpayers depending upon if and how program subsidies are structured and that it may take much longer to meet water quality standards because time frames for adoption would likely be longer than with compliance demands from mandatory programs. A successful example of the performance-based model with an added component of local regulation has been in existence for over 30 years in Nebraska, called the Nebraska Association of Resource Districts (NARD). A locally elected Board of Directors governs each district that must maintain water quality to state and federal standards. If water quality standards are not being met, then the Board of Directors have the power to assess fines to landowners that do not manage theirs lands with approved conservation practices. This is a viable option for the state of Iowa to consider adopting. It will likely limit public defiance and discord since penalties for non-compliance are assessed by local residents, not state or federal agencies that are frequently viewed as being removed from the affected area and people.

Analyses of the extensive information used to develop this document generated many recommendations to guide future efforts. Updates to this document should include results from environmental models verified and validated for uncertainty, evaluations of applicable practices that have been researched and developed in other countries, and to address streambank/channel cutting processes and corrective practices. The assessments revealed many gaps in research and recommendations to resolve the most significant issues are as follows:

- More long-term watershed scale studies are needed of all conservation practices.
- All conservation practice research projects should determine nutrient losses from both runoff and leaching pathways to provide more complete information of water quality impacts.
- Further evaluation and development of plant species and varieties to provide more suitable cover crop options in the Upper Midwest.
- Development of markets, storage technologies and low cost equipment options to support adoption of diverse cropping systems.
- Additional in-field buffers research to quantify variability in performance with time and differing climatic conditions, and with both diffuse and concentrated flow.
- Further research of strip tillage nutrient application, minimal disturbance manure injection and other nutrient placement method effects on water quality that include continuous monitoring over long time periods.
- Begin research of precision farming technologies as to their impacts on water quality since one of the primary goals of precision farming methods is to improve crop nutrient use efficiencies.
- The Iowa P Index must be researched to determine its effects on NPS P loss to surface waters.
- The water quality benefits must be quantified for rotational, management intensive and seasonal grazing systems and livestock exclusion from stream riparian areas in Iowa and the Upper Midwest.

- Further research needs to provide a better understanding of riparian buffer nutrient transport and reduction processes and to determine optimal designs tailored for site-specific conditions.
- Encourage policy makers and administrators to support changes in how environmental research is funded and structured. Environmental research could be more efficient in terms of funding and time if projects were designed in a holistic manner.

An important question facing the people of Iowa is, “Do we have the courage and determination to work together as a functional society to confront and correct the causes of NPS pollution within our state?” To do so means that each person that owns or operates any land must look at their activities and change practices that cause off-site losses of sediment and N and P nutrients. It also means that we need to assist and support others in implementing change on their Iowa lands when the magnitude and cost of change threatens their livelihoods. This will require new and innovative approaches in financial support, but also offers the potential to strengthen healthy and productive ties between individuals and groups that will improve communities. Cooperation and coordination among local, state and federal agencies, state universities, and agricultural and non-profit organizations in this endeavor can greatly accelerate progress. The first step will be for all to agree on the need for improved water quality, and then work toward this common goal through active participation.

It must be remembered that one cannot expect change without first performing change. When determining what and where to enact changes, one must choose the applicable practices that have shown the greatest potential for achieving success. All Iowans will share in the benefits of improved water quality, and all Iowans must share the responsibility to make it a reality.

This is to be a “living” document, meaning that the content within will change over time as future editions are printed. This is necessary in order to incorporate new findings from future scientific research of N and P NPS pollution management practices.

Assessment of Practices to Reduce Nitrogen and Phosphorus Nonpoint Source Pollution of Iowa's Surface Waters

General Introduction

The quality of Iowa's water resources is an important issue for the state's citizens for many reasons and has received much attention in recent years. Our livelihoods are intimately dependent upon the quantity and quality of Iowa's water resources. Drinking water, whether it is from surface or subsurface sources, is the most common and important use for all Iowans since it directly affects our health. We also require treated water for household use, such as for washing and hygiene. Many Iowans regularly use surface waters for recreation. The term "primary recreation contact" refers to swimming in a waterbody without risk of adverse health effects to humans. Secondary recreation contact refers to potential health risks from incidental contact or ingestion of water as a result of activities, such as fishing and boating. Use of streams and lakes for these activities is therefore dependent on the quality of the waterbodies. Iowa's aquatic and terrestrial wildlife require adequate water quality to provide their needed habitat and resources for survival. Industry and commerce require large volumes of treated and untreated water to support their activities. In addition to drinking and household uses, urban areas also demand water for lawns, gardens, golf courses, and wastewater treatment. Rural farmsteads have much the same needs for water as urban residences, though the wastewater treatment methods may differ. Agriculture greatly depends upon water resources for crop and livestock production.

Water pollution sources have for legal purposes been divided into two areas, point and nonpoint. The legal definition of point source pollution in Section 502(14) of the Clean Water Act of 1987 is "… any discernable, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft from which pollutants are or may be discharged." Point source pollution is contamination that is generated by an internal process or activity (not from effects of weather) and is from an identifiable location. Examples of point source pollution may be municipal and industrial wastewater facilities, ground coal storage areas, hazardous waste spill areas, and runoff or leachate from solid waste disposal and concentrated animal feeding confinement sites. Nonpoint source (NPS) pollution is defined as being any source of water pollution that does not meet the definition of point source. In general, nonpoint sources are diffuse across a landscape and occur at intermittent intervals, due mostly to weather-related events. Examples of NPS pollution are contaminated urban and agricultural runoff and leachate waters, flow from abandoned mines and atmospheric deposition of contaminants directly to waterbodies.

Agriculture greatly dominates land use in Iowa with over 90% of the state's land area currently in agriculture production. It is not surprising then that agriculture is the dominant contributor to NPS pollution within the state. Nationwide, the 1996 National Water Quality Inventory notes that of the waters surveyed 40% of the rivers and 51% of the lakes were impaired due to excess nutrients. These plant nutrients (i.e., nitrogen, N, and phosphorus, P) have also been identified as common contaminants of surface water throughout the Midwest. Although agriculture may be the largest contributor, urban and industrial sources must also be addressed to achieve the reductions necessary to comply with the Clean Water Act. Therefore, the Iowa Department of Natural Resources must take a holistic approach to reduce NPS pollution and help all Iowans address the problems of impaired water quality.

The entire state of Iowa will need to be evaluated to determine and prioritize existing and potential NPS pollution areas. Once the critical source areas are identified, the most appropriate management practices can be determined and implemented where needed. There often will not be a single management practice that will provide adequate protection of NPS nutrient pollution to surface waters from each critical source area. Instead, several practices may be required. A variety of practices already exist that can be combined to provide a comprehensive conservation management plan that will be aimed at achieving both environmental and economic goals.

The requirements set forth by the Clean Water Act for states to meet targeted water quality standards have been set in motion. All Iowans will benefit from improved water quality. Those benefits include safer drinking waters, cheaper water treatments, better recreational opportunities, and more robust economies that will result from making the state more attractive for people and businesses to stay and move here. If we fail to accomplish this important challenge by our own voluntary actions and fail to adopt what Aldo Leopold called a “Land Ethic,” it is inevitable that the necessary actions for change will be forced upon all of us.

First presented is a background of the factors that impact NPS pollution of Iowa’s surface waters. The intent is to provide the reader with a working knowledge of natural and human-induced factors that influence NPS nutrient pollution, being: landscape and climate effects; carbon, N and P cycles and ratios; and land and water use management. This is followed by discussions of the principles and functions of NPS N and P management practices and the importance to evaluate research results by the spatial and temporal aspects of the experiments. Next, water quality impact assessments of conservation practices to manage NPS N and P pollution are presented. Research has shown that these practices have the potential to reduce the NPS contamination of one or more of the four constituents identified by the EPA’s and state’s Total Maximum Daily Load (TMDL) programs. Currently, those pollutants are total nitrogen (TN), total phosphorus (TP), turbidity (i.e., suspended particles and sediment), and chlorophyll *a* (one component of chlorophyll substances present in aquatic plants and algae). The assessments will address each practice’s current documented degree of success, applicable conditions, conditions that limit its function, and sources of its variability in performance. Information for the background and assessments was assimilated from many sources, from preexisting federal government publications (i.e., the USDA NRCS Iowa Field Technical Guide, EPA national management measures to control NPS pollution guides, etc.) to scientific texts and research journal articles. This document will finish with an overall summary of the assessments and concluding remarks that are meant to serve as guidance on how to put plans into action and for areas of further research that have the highest probabilities to meet water quality goals. The Appendices include a glossary of technical terms and reference lists for the background and assessments sections. USDA-ARS National Soil Tilth Laboratory and Iowa State University scientists have provided reviews of this report.

This is to be a “living” document, meaning that the content within will change over time as future editions are printed. This is necessary in order to incorporate new findings from future scientific research. Advancements can be made with additional research for improving the design, implementation and maintenance of NPS nutrient management practices to optimize their performance. However, at this time we do have extensive knowledge of how the physical, chemical, and biological components of the natural environment and human activities can affect NPS nutrient pollution of surface waters.

Background of Natural Environment and Human-Induced Effects on Nonpoint Source Nutrient Pollution of Surface Waters

To understand how a nonpoint source (NPS) pollution management practice functions, the variability in its effectiveness, and the likelihood that the practice will improve water quality, requires at least a basic knowledge of our environment. Once this is accomplished, one can then begin to evaluate and identify the best-fit NPS management practices that will offer the highest probability of improved water quality. There are and will always be areas where future research will provide new knowledge that advances our understanding of how the environment functions, which will lead to new and refined practices. However, scientific research from the past two centuries has provided us with knowledge of many functions and responses of the environment to natural and human-induced disturbances, which are constant over time. The designs of current NPS management practices are based on these principles. When addressed in the following background text, these principles are shown in ***bold italics***. Discussion will begin with the most basic factor that influences water quality, namely the landscape, then proceed to climate, nutrient cycles and ratios, land and water use management, principles and functions of NPS management practices, and finish with an explanation of the importance to evaluate research results by the spatial and temporal aspects of the experiments.

Landscape Factors

Geology

The physical structure of our land, properties of the materials on and within the land, and resident biological systems are a few of the primary factors that affect water quality. The histories of geologic events that shaped landscapes are quite varied across the U.S., which has led to efforts to identify and map these characteristics. In Iowa, several landforms have been delineated. The unique geologic setting associated with each landform can impact water quality, from the type of soils present to the depth to bedrock.

In *Landforms of Iowa* (Prior, 1991), seven different landforms were identified within the state (Fig. 1), being: the Des Moines Lobe, Loess Hills, Southern Iowa Drift Plain, Iowan Surface, Northwest Iowa Plains, Paleozoic Plateau and Alluvial Plains. The geologic events that formed each landform differ and Prior (1991) presents this information in detail. For purposes of this document, it is important to note that each landform presents different potential impacts on water quality. For example, the Paleozoic Plateau consists of relatively thin soil profiles overlying limestone bedrock. Many sinkholes and subsurface fissures in the limestone bedrock exist that can rapidly convey leached and runoff contaminants to ground water resources. The Loess Hills, being light windblown silt deposits with steep slopes, are very erosive and can contribute large loads of sediment to streams, especially when the soil is tilled and has little vegetative or residue cover. The Iowan Surface, Southern Drift Plain, and Northwest Iowa Plains all have significant portions of area that have sufficient slope for erosion to be a major threat when disturbed by tillage. The Iowan Surface also has areas of poorly drained flat landscape, which is predominant in the Des Moines Lobe and Missouri and Mississippi Alluvial Plains. Artificial field tile drainage lines and drainage ditches were installed over much of these landforms to enable row cropping. Across the entire state, there are approximately 7,790,000 tile-drained acres and 800,000 miles of tile drainage lines. Water flow patterns (hydrology) changed dramatically as a result and created a greatly increased risk for leached contaminants to quickly enter surface waters (see the Hydrology section for further explanation).

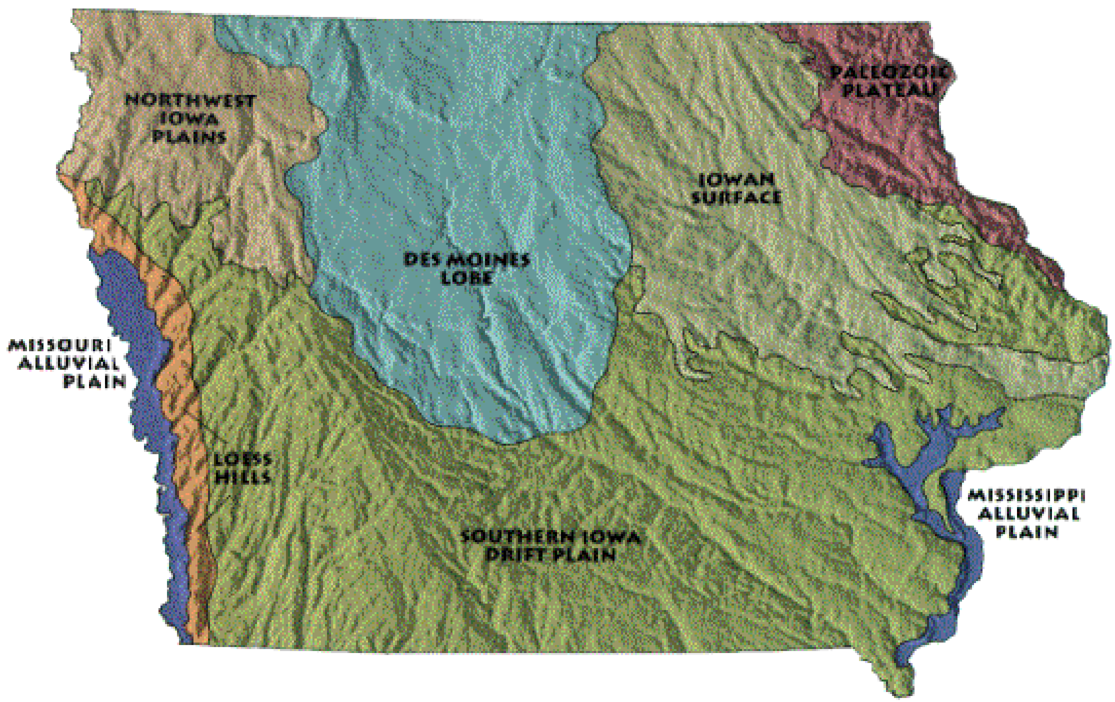

Fig. 1 Landform regions and surface topography of Iowa. *Illustration by Patricia Lohmann from Prior, 1991. Landforms of Iowa. Pg. 31. University of Iowa Press. Iowa City, IA.*

Any landform's underlying and exposed bedrock influence water quality by characteristics that can either help to protect water resources or pose a threat to them. For instance, shale bedrock forms a solid barrier (also called a confining layer) to water percolation since it is relatively impervious and has few vertical fractures. Ground water percolating from above will accumulate above the shale and move laterally. This characteristic slows water movement causing the ground water to have a longer residence time within the soil profile as long as it lies relatively deep below the soil surface. A longer water residence time increases the likelihood of contaminants being filtered from the ground water by adhering to soil particles before it eventually flows into a surface waterbody. This then gives soil bacteria more time to either assimilate (incorporating the material into its cellular structure) or break down the contaminant, which can improve water quality. Any bedrock material that is prone to vertical fractures, such as limestone, can pose a threat to water quality because it does not provide an impermeable layer and can quickly conduct any contaminants transported by infiltrating water to surface and ground water resources. ***The closer bedrock lies to the land surface the greater the risk to water quality***. The karst topography of northeast Iowa, with its shallow and exposed limestone bedrock and resulting sinkholes, is a classic example of this situation. Thus, the type and spatial location of bedrock are two of the physical attributes within a landform's given drainage area - or watershed - that impacts water quality.

A watershed refers to a physical component of our environment, being the entire surface area (or basin) that contributes surface and subsurface drainage water to a particular waterbody. The term "hydrology" refers to the patterns of water flow within an area and is the physical characteristic that identifies individual watersheds. Therefore, any given point of land is part of a watershed, and the size of a watershed depends upon the waterbody of reference. For example, the watershed area of a headwater stream (also called a "first order stream") is only a portion of a larger stream's watershed that the headwater stream flows into (the larger stream then being a second order stream). On a larger scale, the Des Moines River watershed is a fraction (or sub-basin) of the Mississippi River watershed. A single watershed may consist of a variety of landscape features. Floodplains, bluffs, glacial till plains, rolling glacial moraines, and deep loess hills are just a few of the landscape features within the Mississippi River watershed.

Topography

Watershed boundaries and the direction of water flow are determined by a landscape's topography. Slope and slope length are two important characteristics of landscape topography that impact water quality. The degree of slope and slope length influences the amount and intensity of runoff water from any precipitation or snowmelt event. Runoff water flow increases in speed and volume as slope increases in angle and length. This results in runoff with greater flow energy and in turn can increase soil erosion. Runoff that collects in a channel or gully prior to entering a permanent surface waterbody is called concentrated flow, which can be difficult to manage and poses a large erosion threat. A landscape that is relatively flat and lacks gullies will have more surface ponding in closed depressions (i.e., prairie potholes), and runoff is spread over a larger area (diffuse). Diffuse runoff has less energy than concentrated runoff, though the volume may not differ. Therefore, ***land management practices that reduce the volume, speed and concentration of runoff can reduce erosion*** (see Land Use and Management for further discussion). In addition to factors of slope and slope length, runoff and erosion are also impacted by soil type properties and characteristics.

Soil

A specific soil type's impact on water quality is determined by its properties. Soil type and its associated properties are the result of the following five soil forming factors:

parent material, climate, topography, biology, and time. The pH (a measure of hydrogen ion concentration) of a soil is a product of soil forming factors. The pH scale ranges from 1 to 14, with 1 being the highest acidic level, 7 being neutral and 14 the highest alkaline level. Soils formed from granite rock and/or under forest vegetation tend to have an acidic pH (values roughly from 4.5 to 6.9) and soils formed from basalt rock and/or under grass vegetation tend to have neutral to slightly alkaline pH (values from 7 to 8). Accumulations of salts can result in alkaline soil pH levels above 8 and are very difficult to manage for plant production. Soil pH is the primary factor that determines the solubility, or availability, of nutrients, which influences crop production and the risk for NPS pollution of water resources by the movement of nutrients.

Most nutrient elements are at peak availability between pH values 6.5 to 7, which is why the most important soil fertility factor for crop producers to manage is soil pH. Below pH 6.5, P availability dramatically decreases. Nitrogen availability is relatively stable over a wide range of pH levels. The dominant forms of both N and P and the transformations of those forms vary depending upon soil pH, which influences potential losses of N and P. Transformation of the plant-available N form of ammonium to nitrate (called nitrification) occurs at higher rates with soil pH levels that are near neutral to slightly alkaline (6.6 to 8.0) than at more acidic pH levels (<6.6). This is because the bacterial groups that perform the transformation function better at near neutral pH than in acidic conditions. As will be discussed in more detail later, nitrate is much more of a leaching loss risk to water resources than is ammonium. Phosphorus availability is reduced when it combines with iron and aluminum in acidic soil conditions, and with calcium in alkaline conditions. Therefore, P availability can be manipulated to some extent by managing soil pH along with some elements. Nutrient availability is also influenced by the ability of a soil to hold a given amount of nutrient compounds, which is largely a factor of soil texture.

Soil texture is classified by a soil's particle size fractions (sand, silt and clay). In general, ***the coarser the overall soil texture, the faster the soil's water infiltration rate***. For soils that are dominated by sand sized particles, leaching of contaminants to shallow ground water is more of a concern than runoff. A soil with high clay content has a slow water infiltration rate, which will result in less leaching, but more runoff. Soil texture can also relate to soil fertility, particularly in Iowa. Soil fertility is the ability of a soil to hold and supply nutrients for plant growth. Most plant nutrients are ions with a positive charge (cations), and since opposite charges attract, fertility is measured by the amount of negative charge sites on the surface of soil particles (cation exchange capacity, or, CEC). There are two general types of clay minerals - 2:1 and 1:1 - referring to the composition and arrangement of clay mineral layers. The 2:1 clay minerals have greater fertility and are the predominant type of clay minerals in Iowa. Sand sized particles have less surface area by volume than silt, and silt less than clay. Soil fertility tends to increase with greater particle surface area size by volume because there is a greater potential for negatively charged sites to exist. Iowa soils have moderate to fine texture. Soil organic matter (SOM) also has a high CEC, and so increases the fertility of soil, depending upon on soil pH, along with improving many soil physical properties. The former tall grass prairies, soil parent materials (e.g., glacial till and loess), gentle slopes and climate interacted over time to give Iowa soils a moderate to high percentage of SOM. The combined attributes of 2:1 clay minerals, moderate to fine texture and high SOM contents are why Iowa's soils are considered to be some of the most fertile in the world. One of the few detriments of high fertility soil is that when such a soil is eroded and transported to a surface waterbody it can contribute a large amount of contaminants, such as nutrients and pesticides.

The most fertile portion of a soil is at and near the surface, commonly varying in depth from an inch to a foot or more. Dark soil color is indicative of high SOM and nutrient contents. Fine textured surface soil particles and partially decomposed plant organic matter holds greater amounts of nutrients than larger sized soil particles and soil aggregates. Being of less density than the aggregates and exposed at the surface, the fine surface particles and plant organic matter are the first portion of the soil to be dislodged and transported with any erosion event. The process of surface material with high nutrient content being preferentially eroded and transported before heavier soil particles in runoff is called enrichment.   Enriched runoff occurs within the first stages of any erosion event and is the initial portion of runoff to enter surface waters. This presents a two-fold problem. First, even small erosion and transport events can contribute appreciable amounts of nutrients, especially P, to surface waterbodies. Secondly, these preferentially eroded surface sediments and organic matter constitute the most productive portion of farmland. Thus, erosion of Iowa's soils results in degradation of both Iowa's environment and long-term economic well-being. The frequency and degree of erosion events that occur are not only a function of soil properties and characteristics, but also of how water moves through a given area.

Hydrology

Hydrology refers to the patterns of water flow on and through a watershed area over both space and time. All of the natural geologic and soil factors already discussed, plus others that will be later, interact to determine a watershed's hydrology. Any natural or human-induced change on a landscape has the potential to affect a watershed's hydrology and risk of NPS pollution. Although gaining a comprehensive understanding of a watershed's hydrology is very difficult due to the many influential factors, there are a few basics that apply universally. Water inputs move on or through land area by two basic methods; either by ground water flow as water infiltrates through the soil profile, or by runoff water flow over the land surface when part or all of the precipitation is not able to infiltrate. In general, ***increased runoff results in decreased water infiltration and storage, and vice-versa***.

Land management practices that increase water infiltration will result in increased ground water flow and reduced runoff. Conversely, land management practices that reduce water infiltration (whether intentional or not) will reduce the fraction of precipitation that becomes ground water flow and increases the runoff fraction. Relating this situation to NPS pollution, areas with good water infiltration rates and/or level topography will be more susceptible to problems from leached contaminants moving with ground water flow, predominantly being negatively charged ions (i.e., nitrate). Areas with poor water infiltration rates and/or steep sloped topography will have a greater problem with contaminants that are held at or near the soil surface and moved with runoff water flow, predominantly being positively charged ions (i.e., P, ammonia, pesticides). Runoff water reaches surface waterbodies in a matter of minutes to hours, while ground water flow to surface waterbodies (termed baseflow) may range from minutes to many years. There are several implications of these highly variable residence times for these two sources of surface water that influence water quality. First, runoff can deliver NPS contaminants quickly to surface waterbodies, especially if there are few structures to slow its delivery either via retention (i.e., wetlands) or frictional surfaces (i.e., vegetative buffers). For streams, this may present acute contamination problems. In lakes and reservoirs, it would add to chronic contamination since the water in such standing waterbodies can have long residence times. Secondly, the baseflow fraction may either dilute or add contaminants to a surface waterbody depending upon the residence time of the baseflow within the soil profile and the soil conditions at the time the water began to pass through the soil (time zero). If there was a high amount of nitrate present in the soil at a time zero of 1973 – whether from N fertilization, N mineralization of SOM, or both – and the residence time of the baseflow is 30 years, then the baseflow may be a significant source of nitrate to a surface waterbody in 2003. If there was a small amount of nitrate present in the soil in 1973, a surface waterbody's baseflow fraction may be transporting little nitrate and would have a dilution effect. The important issue with the baseflow fraction is that it presents a lag period in its effects on surface water quality. Changes in land management practices today may reduce NPS contamination from the runoff and shallow ground water (such as field tile drainage) and improve surface water quality relatively soon. However, highly contaminated baseflow that originated many years ago but is just now entering surface waters will diminish the current benefits of those management changes. Nonetheless, the long-term benefits from improved land management would not be reduced since baseflow that originated after implemented changes will improve surface water quality in the future.

Geologic events and resulting landscape attributes form the base of the many natural factors that impact NPS pollution and surface water quality. This geologic base becomes altered over time from the effects of weathering, such as by water and wind erosion. The extent and types of weathering are dictated by climate and climatic changes over time.

Climate Factors and Impacts on Soil Biology

Precipitation

It is easy to envision the importance of precipitation in regard to both physical landforms and the resident biological systems when one considers the major factors that determine differences between ecosystems such as arctic, alpine, rainforest, savannah, grassland and desert. The amounts, intensities and patterns of precipitation vary significantly among these ecosystems, leading to variable risks of NPS pollution.

In Iowa, the annual distribution of precipitation is not equal, with a majority of the annual rainfall occurring in spring and early summer (Fig. 2). The distribution of rainfall events that deliver relatively high amounts of precipitation (peak events) is generally similar to the distribution of annual total rainfall (Fig. 3). Knowing that nitrate is easily leached and carried with infiltrating water, Figs. 2 and 3 indicate the periods of time when nitrate is at its greatest risk to off-site transport. If soil conditions are favorable for the accumulation of nitrate and there is little to no active plant growth, which is common in spring for row crop fields, then the months of April through June pose the greatest risk of nitrate contamination to water resources. However, this is only a generality. Risk of nitrate contamination depends upon many factors and can be considerable at other times of the year. For instance, if N fertilizer is applied to a cornfield prior to planting at an average rate for Iowa and is followed by an event such as summer drought or disease that limits the ability of the corn crop to take up the added N and N naturally released from SOM, then a large amount of nitrate may be present in the soil after harvest. It is not uncommon in Iowa to have a wet fall, so if this follows the previously described conditions, large amounts of nitrate can be leached and enter surface waters in the fall.

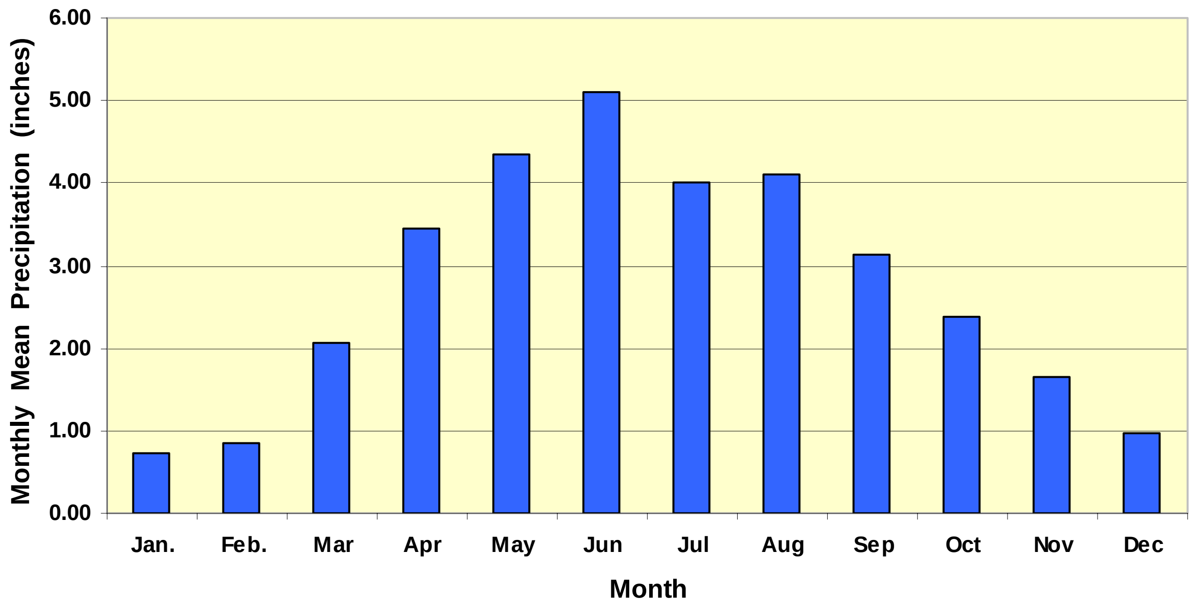

Fig. 2 Fifty-year monthly mean precipitation at Ames, Iowa: 1951-2000.

† *Data from Iowa State University Climatology website at:* http://mesonet.agron.iastate.edu/climodat/table.html

Although the number of peak events shown in Fig. 3 is a small fraction of lesser rainfall (non-peak) events, the peak events can contribute the major fraction of annual NPS pollution to surface waters. Many of the non-peak rainfall events may result in little to no runoff and water infiltrating below the plant root zone to leach nutrients. The non-peak rainfall events that do result in runoff can carry high concentrations of nutrients due to the preferential transport of enriched materials, as discussed above. But the total amount, or load, depends both on the concentration of the contaminant and the volume of water that enters a stream or lake. The probability and total load of a NPS pollutant carried in runoff and/or leached water reaching surface waterbodies increases with increasing intensity and amount of precipitation per event. So the total annual amount of runoff, leached water and NPS pollutant load frequently is dominated by the peak event source fraction of total annual precipitation. The amount of runoff and water leached below the plant root zone also depends upon the soil conditions just prior to the rainfall event (especially soil moisture content), plant and residue cover, and the degree of plant water demand at the time of the event (discussed in more detail in the Vegetation and Water Use Section).

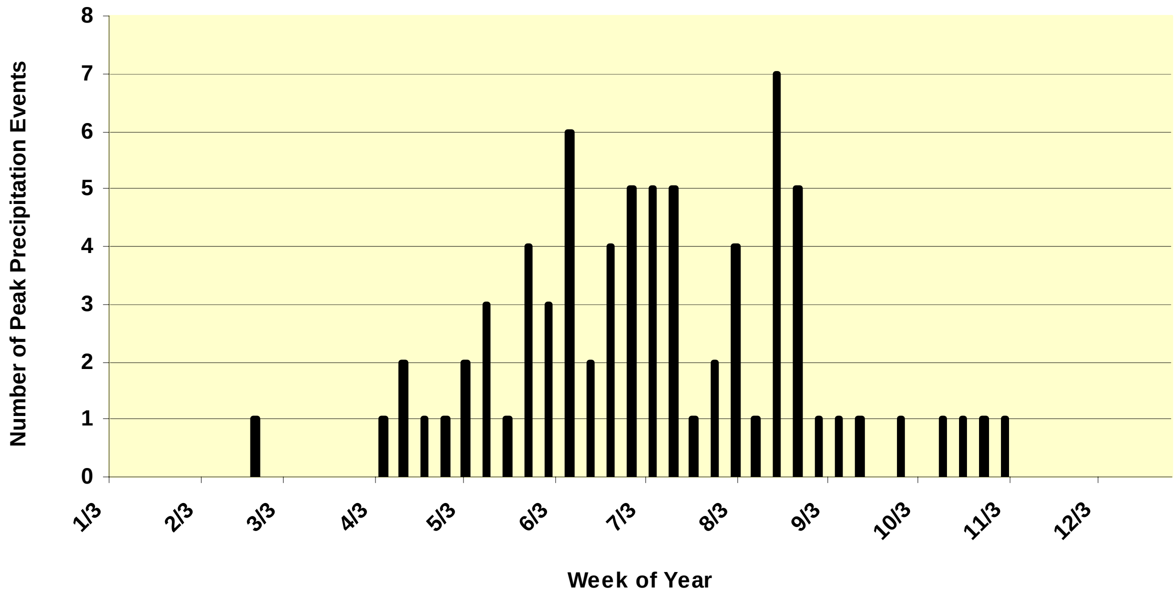

Fig. 3 Fifty-year peak precipitation events[1] by week at Ames, Iowa: 1951-2000.

1 Peak precipitation event defined as total precipitation > 2.00 in/day.

† *Data from Iowa State University Climatology website at:* http://mesonet.agron.iastate.edu/climodat/table.html

When rainfall occurs at times of little to no plant cover or active growth, there is a greater chance for runoff and leaching losses of contaminants. The probability of negative impacts from rainfall events decrease when peak plant demand for water and nutrients, and plant canopy cover, is more in synchrony with peak rainfall events and patterns. Peak rainfall and snowmelt events also have a much greater impact on streambank erosion and streambed channel cutting than non-peak events. Most watersheds' hydrologic characteristics allow for the non-peak event flow contributions to streams to be distributed over a relatively long period of time. But, peak rainfall and snowmelt events commonly overwhelm a watersheds' ability to store and slowly release water to streams. Large volumes of runoff then enter streams in short periods of time, quickly accelerating streamflow rate. Streamflow energy is then greatly increased and can result in massive erosion of streambanks, particularly banks that are steep and unprotected by rock or vegetation. Additionally, high-energy streamflows can resuspend any sediment in the streambed and cut deeper channels, further increasing sediment load and transport within the streams.

While the characteristics of precipitation are major factors of NPS pollutant transport, the amount of a particular nutrient form available for transport depends upon many factors and their complex interactions. Precipitation influences two of those factors, soil moisture and aeration status (level of available oxygen), which impacts the activity of soil microbes. Although most people only become aware of some negative effects of microbes, such as infectious diseases, life on earth would not be possible without the other functions they perform. Microbiologists commonly call microbes “little bags of enzymes,” referring to microbes’ critical role in the cycling of elements. Microbes (bacteria, fungi and algae) are responsible for a majority of chemical and nutrient transformations in soil and water through their diverse metabolisms that allow them to thrive under many conditions.

Soil moisture content affects microbes and the biochemical reactions that they perform. There are two general groups of microbes that are identified by their type of metabolism, aerobes and anaerobes. All fungi and many bacterial species are aerobes, which require free oxygen for respiration. Some species of bacteria are anaerobes, requiring the absence of gaseous oxygen, and instead, respire a variety of compounds. As soil moisture content decreases, aeration is increased, leading to more available oxygen. Any disturbance – biological or mechanical - that mixes the soil and temporarily increases soil to surface atmosphere contact increases available oxygen content in the zone of disturbance. So, tillage and earthworm activity creates a more aerobic soil environment, though this effect of tillage is only temporary (discussed later in the Land and Water Use Management Section). Because soil water displaces available oxygen, increases in soil moisture leads to more anaerobic sites within the soil. When the soil profile is saturated the entire soil environment becomes anaerobic. Although oxygen levels increase with decreases in soil moisture content, aerobic microbes do require water to grow and function. Overall microbial activity (including both aerobic and anaerobic groups) is optimal at a soil moisture content termed field capacity, being the maximum amount of water a soil can hold without gravitational drainage occurring. A second basic difference between the aerobic and anaerobic microbes is that when all conditions are constant other than oxygen status, the aerobic metabolism functions at a higher rate than the anaerobic metabolism. This means that microbial biochemical transformations of nutrients and other compounds occur faster in aerobic rather than anaerobic conditions. Another primary climatic factor that affects the physical and biological components of ecosystems is temperature, which plays a key role in the amounts of certain nutrient forms that are available and at risk for off-site transport to water resources.

Temperature
Temperature (or thermal energy) affects the physical, chemical and biological characteristics of soil. A few examples of physical and chemical characteristics affected by temperature are soil volume, pressure, Brownian movement (vibration of ions), diffusion of ions in soil water and water structure. As temperature increases, ions increase in movement, which results in increased volume, pressure, diffusion and chemical reaction rates. Temperature also has indirect effects on soil chemical reactions and transformations by its influence on plant and microbial metabolic rates.

Plants have developed diverse metabolisms and life cycles to minimize competition for available resources. One of the variable aspects of plant metabolisms is related to the temperature ranges where each general type of metabolism is most active. Cool season plants are most active during the spring and fall seasons, and relatively inactive during the heat of the summer. Warm season plants are most active during the summer and less active in the spring and fall. In combination, these two plant groups are able to uptake available soil water and nutrients during most of the year. When grown separately by location (i.e., field monoculture stands), there are significant time periods when available soil water and nutrients cannot be used by plants. This situation leads to increased risk of NPS nutrient pollution by seasonal periods, which is described in more detail in the Land and Water Use Management Section. Microbes have also evolved groups that vary in their optimum temperature ranges of metabolic activity.

Temperature affects the rate of microbes' metabolic activity because their internal temperature is not self-regulated. Some groups of bacteria have become specialized to be able to thrive in low temperatures (slightly below to above freezing), and others to thrive in very high temps (near boiling point). Other than these few exceptions, microbial growth and metabolic (biochemical) reactions are generally very slow at 32^o F, and then increase dramatically from 50^o F to 77^o F. From 77^o F to 95^o F, microbial growth and activity functions at its maximum capacity if all other needs are not limited (i.e., oxygen level, carbon or energy source, nutrients). Above 95^o F, biochemical reaction rates dramatically decrease, which will kill most microbes. These general effects of temperature on microbial activity interact with other factors that ultimately determine the rates of nutrient transformations and availability, which are integral parts to the cycling of nutrients and elements.

Nutrient Cycles and Ratios

Carbon Cycle
Microbes both take up and incorporate nutrients into their tissues (called immobilization) and release nutrients (called mineralization) either as byproducts of their biochemical reactions or upon rupture of their cells at death. For all living organisms, carbon (C) is the primary building block for cellular structures. With the exception of the few groups of microbes that can derive energy from inorganic compounds lacking C and photosynthetic organisms (i.e., plants, algae and bacteria having chloroplasts), C-based organic compounds are the energy sources for most other organisms. For example,

energy stored in the carbon-hydrogen (C-H) bonds of sugars, carbohydrates and proteins of plants is fuel for animals and a majority of the microbes (i.e., fungi, protozoa and most bacteria). Also, cell walls are composed of chains of C molecules. Carbon compounds are also a common byproduct of aerobic and anaerobic metabolisms, although the resulting compounds will vary. An example is aerobes respiring carbon dioxide (CO_2), while some anaerobes produce ethanol (C_2H_5OH) from their ability to perform fermentation.

Carbon cycles between the biological, soil, atmospheric and aquatic components of the global environment through biogeochemical processes. Biogeochemical processes refer to transformations that occur biologically, physically and chemically. Some of the C transformations result in C being stored for varying periods of time in one or more of the physical components, thus being a “sink” of C. Plants serve as a C sink through their uptake of CO_2 during photosynthesis and incorporation of the C in plant tissues. Other transformations release C from one component to another, the former being a “source” of C to the latter. In the example of CO_2 respired into the atmosphere from microbes as they decompose SOM, the C source to the atmosphere is SOM with the C transformation performed by microbial respiration. Other C transformation pathways are gas exchange between the atmosphere and surface waters, cycling of C among aquatic organisms and deposition of organic residues in the beds of freshwater and marine waterbodies.

Other than N-fixation and a few other metabolic processes (i.e., enzymatic reactions), organisms obtain nutrients containing N, P and other elements either through their uptake of C compounds or water. Therefore, C transport and transformations within the soil plays a major role in the availability of these nutrients to plants and microbes, having implications for management options to reduce NPS pollution of N (discussed later).

Nitrogen Cycle

Like C, N exists in many forms and has a very complex cycle, flowing between terrestrial, aquatic and atmospheric environments (Fig. 4). The presentation of this topic will be limited to the most pertinent aspects relating to N NPS contamination of water resources. Several forms of N can readily enter the atmosphere from terrestrial and water environments such as ammonia, nitrous oxides and dinitrogen (N_2). All gaseous N forms combined equate to roughly 78% of the earth’s atmosphere. Dinitrogen is neutral in terms of environmental impact, but ammonia and nitrous oxides are detrimental since they are some of the greenhouse gasses that have disturbed global climate patterns due to trapping heat within the atmosphere. Because of its negative charge, nitrate (an anion) is easily transported with water infiltrating through soil to surface and ground water resources. High concentrations and loads of nitrate have significant environmental and economic consequences, which is explained later in this section. Ammonium’s positive charge (a cation) allows it to attach to soil particles’ negatively charged sites. Ammonium can also transform to ammonia, then being able to volatilize if exposed to air, and both N compounds can enter water when soil particles are eroded and transported to water resources. In an aquatic environment, ammonia can only volatilize to the atmosphere from the very surface of the water. Ammonia is stable in the water column below the water-air interface and is toxic to aquatic organisms even at low concentrations. Although there are some negative environmental effects of N, it does serve important roles. Nitrogenous compounds of DNA and RNA nucleic acids, amino acids, amino sugars and proteins are vitally important to cellular function, which explains why N is a primary nutrient element for all organisms.

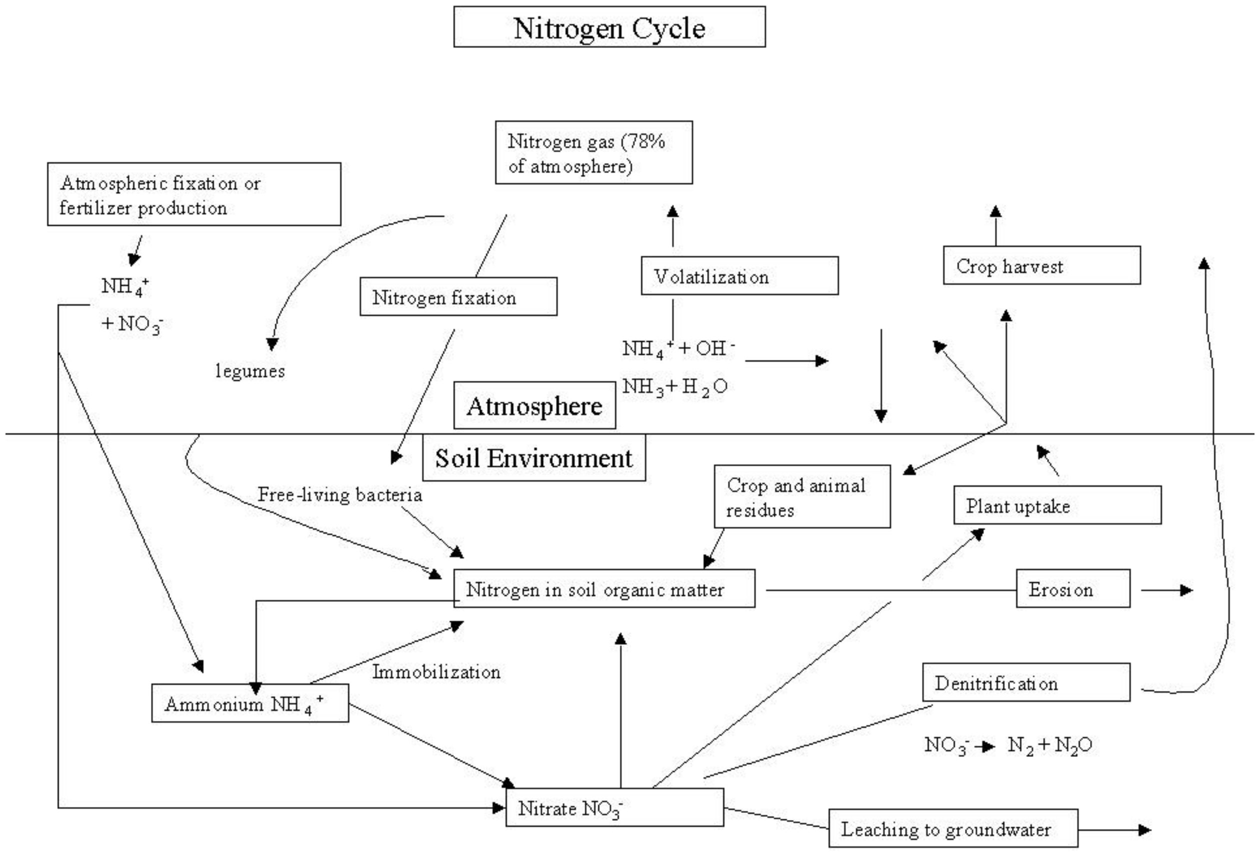

Fig. 4 The nitrogen cycle.

The nitrogenous compounds of organisms, whether released while alive (i.e., animal manures and plant root exudates) or upon death, and SOM are sources of N nutrients for future generations. However, these organic N compounds are not directly available for plant uptake, first needing to go through the microbial degradation processes of N mineralization to be transformed to the inorganic N form ammonium. Ammonium is one of the three inorganic forms of N that plants and microbes can recycle into new cellular tissues, the others being ammonia and nitrate.

Only carbon, hydrogen and oxygen are of higher demand to animals and plants than N. Plants and microbes can directly obtain N through a process called N immobilization. Immobilization of N involves the incorporation of available inorganic ammonia, ammonium and nitrate into amino acids to either build proteins or provide energy. Plants are able to absorb ammonia from the atmosphere during the day and incorporate it into amino acids. At night, plants lose ammonia from leaf surface tissues to the atmosphere. The balance of these plant losses and gains of ammonia-N is a net gain of N in the plant tissues from emergence to maturity, but much ammonia is lost back to the atmosphere when the plant shoot residue decays. Both plants and microbes compete for ammonium and nitrate in the soil. Ammonium is more directly incorporated into amino acid structures than nitrate, but microbes typically out-compete plants for the ammonium because their immense numbers allow them to exploit a greater portion of the soil profile. Other N immobilization processes also exist to further impede plant uptake of ammonium. As previously mentioned, the negative charge sites on soil particles can form an ionic bond with the positive charged ammonium ion, particularly with 2:1 clay minerals that have a high CEC and can hold the cationic ammonium within interlayer areas. Soil organic matter can also adsorb ammonium due to its high CEC. While there can be intense competition between plants and microbes for available ammonium, some plants and bacteria have evolved a mutually beneficial relationship that reduces this competition for N.

A few groups of plants, such as legumes and alders, can obtain N indirectly through a symbiotic relationship with specific species of bacteria by a process called N-fixation. In this relationship, plants harbor aerobic bacteria within nodules in their root systems. The benefits bacteria receive from the plant include a somewhat protected environment (compared to ambient conditions within the soil), oxygen transported from the plant shoot to the nodule, and energy produced by the plant from photosynthesis. The bacteria have the ability to break the strong triple bond between the two N molecules of atmospheric dinitrogen, and can then provide N nutrients for their needs and those of the plant. Agriculturalists of some cultures recognized this trait of legumes many centuries ago. Despite not understanding the precise metabolic pathways and relationships, they added legumes to their cropping systems to improve the production of other non-leguminous crop plants such as wheat. However, if the inorganic ammonium and nitrate forms of N are present within the root zone, the plant will slow or cease transport of oxygen and energy compounds to the N-fixing bacteria and preferentially utilize the free inorganic soil-N. This occurs because energy costs to the plant are much less to uptake the available inorganic N forms than to support the N-fixing bacteria. Therefore, the only critical period of potential NPS N pollution from legume production is the time frame between the removal or killing of the legume crop to when the succeeding crop has established a root system to uptake N mineralized from the decaying legume roots (management practices exist to minimize this threat and are discussed in the Assessments of Nitrogen Management Practices section). Legume roots are just one organic source present within the soil from which microbes are able to mineralize N, releasing plant-available ammonium-N. Another major organic source of N is SOM.

The potential impact of N mineralized from SOM can be illustrated by estimating the amount of plant-available N associated with SOM in many Midwestern soils. For a given climatic region, assuming 2% of the total organic N in the surface foot of soil is mineralized annually, a soil with 1% SOM content could be expected to mineralize approximately 40 lb N per acre each year. With a general 3% average SOM content for most Iowa soils, this amounts to 120 lb N per acre being gradually released over an entire year's growing season. It is important to remember that these are general estimates because the amount of organic N made available through mineralization processes will vary greatly over time due to factors such as temperature, precipitation and tillage. However, because of their high SOM levels, this estimate illustrates that Iowa soils have a high potential for providing N to plants throughout the entire growing season. Once ammonium is mineralized from legume and other organic residues, a specific group of bacteria can compete with plants for this N source and transform both ammonium and ammonia to a much more mobile N form.

Under soil environmental conditions that are typically favorable for aerobic bacteria, two groups of bacteria can quickly convert available ammonical-N forms to nitrate by the processes of nitrification. The first group of bacteria use the ammonical-N forms as energy sources, transforming it to nitrite (NO_2^-). The second bacteria group then uses nitrite as an energy source and transform nitrite to nitrate (NO_3^-). Once this process is complete, nitrate then can build up within the soil and pose a threat to water resources with any subsequent rainfall event since it is so readily leached.

In high concentrations and loads, nitrate can cause impairment to water resources in several ways. Nitrate-N concentrations in excess of the USEPA maximum contamination limit (MCL) of 10 ppm for drinking water may pose risks to humans and livestock. Many Iowa streams commonly have nitrate concentrations that exceed the 10 ppm drinking water MCL, which has cost some communities millions of dollars for nitrate removal or to provide alternate drinking water sources. Numerous studies have shown significant edge-of-field losses of nitrate. One example is an Iowa study where scientists found average nitrate-N concentrations of 21 ppm in subsurface drainage water leaving fields planted to corn/soybean or corn/oat rotations. Similarly, for the Walnut Creek watershed located near Ames on the Des Moines Lobe, other scientists reported flow-weighted nitrate-N concentrations in field and county agricultural drainage lines that were often greater than the EPA 10 ppm MCL for drinking water, especially from April through July. Nitrogen loadings to the Mississippi River and its tributaries have also been identified as a cause of degradation in freshwater and marine ecosystems. Elevated N concentrations have altered natural aquatic plant, animal and microbe population dynamics, aggravated occurrences of hypoxia (low dissolved oxygen concentration of < 2 ppm), and sped the process of eutrophication in the Gulf of Mexico. Growth of algae and other microbes in most saltwater systems is limited by N concentrations. As N concentrations increase, more algae and microbe growth is supported when water temperatures are warm. This leads to hypoxic conditions because as aquatic primary producers die and fall to the bottom of the water column, bacteria decompose the primary producers' residues and deplete oxygen to the point of suffocating aquatic fauna (i.e., fish, mussels and invertebrates).

Leaching is just one fate of nitrate in the N cycle: nitrate can go through a process called denitrification that transforms nitrate to other N compounds that are gaseous and then enter the atmosphere. Bacterial, physical and chemical processes can cause denitrification. Under anaerobic (no free oxygen present) soil and water conditions with adequate C sources, time and favorable temperatures, nitrate can be reduced by various groups of bacteria to the nitrite (NO_2^-). Nitrite is highly reactive by microbial, physical and chemical processes, which transform nitrite to gaseous N forms of nitrous oxide (N_2O) and dinitrogen (N_2). For the groups of bacteria that contribute to denitrification, C forms that are easily utilized by the bacteria is a key factor that determines the amount and rate of these N transformations. Soil and aquatic conditions that either lack in C sources or have only C sources difficult for bacterial metabolisms to utilize will not support active microbial denitrification. The upper portions of soil profiles typically have greater amounts of readily decomposable C (SOM and plant residues) and therefore can better support microbial denitrification than portions deeper in the profile that tend to have little available C. Also, a wetland will only adequately support microbial denitrification if it has an appreciable amount of plant residue C sources. Denitrification can begin near 40^{o}F and continue up to a limit of roughly 165^{o}F, with the rate increasing with rising temperature. Time is also an important factor. If nitrate laden water flows relatively fast through the zone of active denitrification - having a short residence time - bacterial, physical and chemical denitrification processes will have limited opportunity to transform nitrate to gaseous N forms. These naturally occurring transformations that remove nitrate from surface and shallow subsurface waters reduce the threat of NPS nitrate contamination of other surface waterbodies. However, denitrification also represents a lost N resource and economic losses for farmers when the nitrate originates from agricultural fields because a crop did not utilize this N.

An often overlooked aspect of N cycling that affects farmer economics and the environment is N use efficiency of various crop management systems. The very dynamic nature of the N cycle does make managing N nutrients for crop production difficult, but it also indicates the importance of efforts to optimize crop N use efficiency due to the many possibilities for N losses from fields. Due to the high N requirement for plants, N is frequently added to agricultural fields as manure fertilizer or various commercial fertilizer forms to support cropping systems that alone cannot sustain optimum yields. The row crop corn-soybean rotation is such a cropping system, with corn having a high demand for N and soybean not being able to provide enough N itself to sustain optimal corn yields. Other crop rotations can provide enough N inputs to the soil to self-sustain optimal yields of each crop within the rotation, but this requires that at least one of the crop plants to fix N from the atmosphere in appreciable amounts to support other crops with high N requirements.

Optimizing plant N use efficiency also requires proper management of other nutrients, particularly the major nutrient P. To be able to optimally manage P, one must first have an understanding of how P cycles within the environment.

Phosphorus Cycle

The P cycle is less complicated than those of C and N because P lacks a gaseous phase (Fig. 5). Therefore, P nutrients cannot be lost to the atmosphere, a fact that has both positive and negative consequences. On the positive side, plant P use efficiencies can be relatively high since there is a lower potential for losses from the soil than exists for N. On the negative side, if and when P concentrations in surface waters become high enough to cause environmental problems, there are fewer options to reduce P contamination than there are for N.

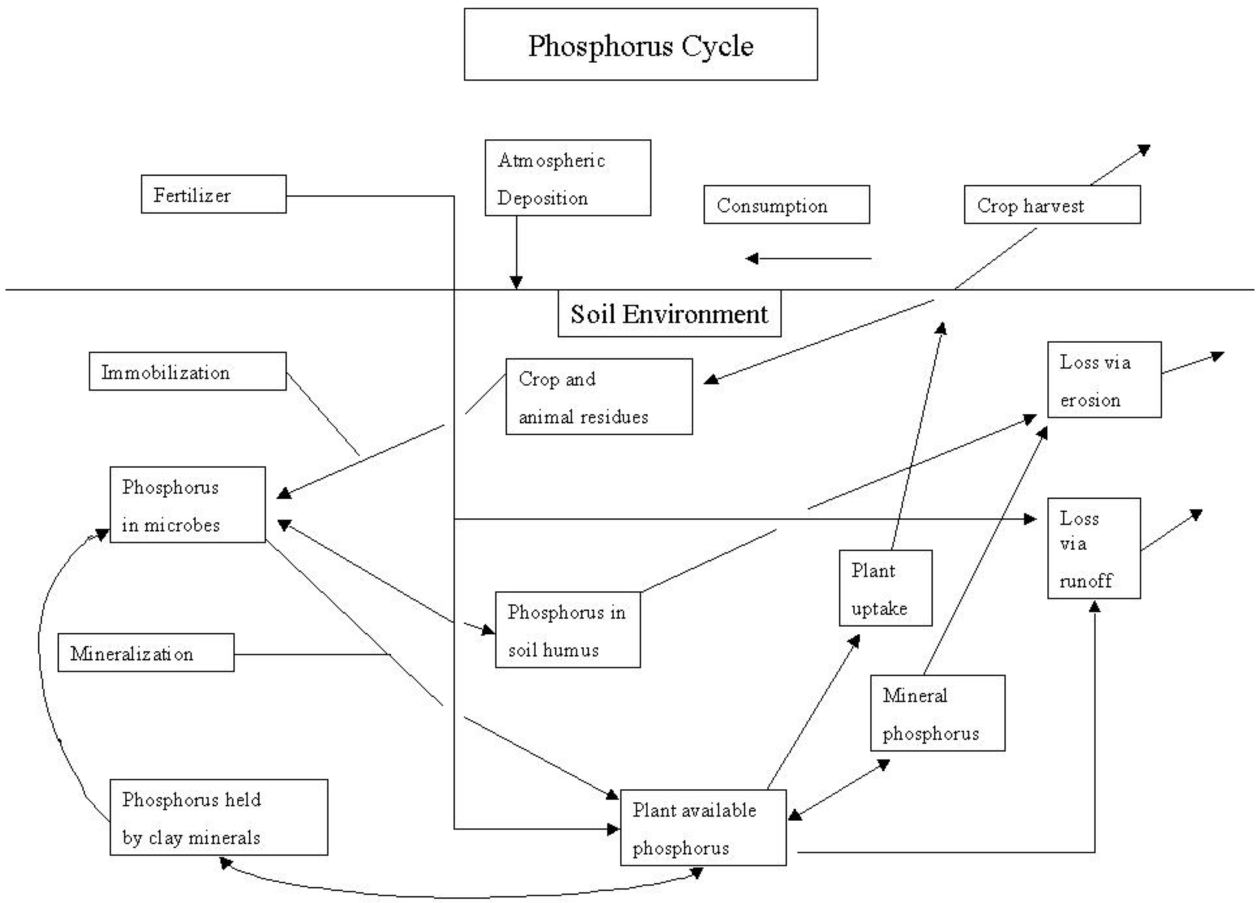

Fig. 5 The phosphorus cycle.

Phosphorus is highly reactive, forming compounds with iron, aluminum, calcium, fluorine and other elements that are not readily water soluble. Although much of the P in the soil environment is bound to soil particles, P in organic and reactive inorganic forms does dissolve in soil water at low concentrations and then is available for plant and microbial uptake. Plant roots and soil microbes are both involved in the release of soil P, mostly through dissolving the mineral P (e.g., appatite) by the production of carbon dioxide and organic acids. Organic P held in SOM, manures and plant and microbe cells typically comprises 1/3 to 1/2 of the total P pool in many soils. Soil microbes play an important role in P cycling and plant P nutrition because they add to the pool of available P by decomposing organic P.

The concentration of dissolved and biologically available P in soil water is positively correlated to the amount of available P measured by standard soil tests in nearly a 1:1 ratio, at least up to a rather high upper limit. So, if soil-test P increases by 50%, then the dissolved biologically available P concentration increases by 50%. Above the aforementioned upper limit, being approximately 600-800 mg soil-P to 1 kg soil, the amount of dissolved P to soil-P test becomes dramatically greater than 1:1. Plants accumulate P to concentrations of 50-100 times greater than in the soil solution, thus moving P from rooting depths within the soil profile to the surface when incorporated in shoot tissues. When the plant dies, its shoot residues either remain on the soil surface, or are incorporated in the upper soil profile with tillage. Microbes decay the plant residues, mineralizing the organic P to inorganic forms. Since inorganic P is very reactive, it then binds mostly to the smaller size fraction of soil particles at or near the surface. So over time, this process causes an accumulation and enrichment of P at or near the soil surface. Applications of P fertilizers and manures to the upper soil profile further add to this scenario. Surface water runoff then has the potential to transport large amounts of P to surface waters because it contacts a P rich zone and the smaller particle size fraction of soil is eroded preferentially to the larger and heavier soil particles that have a lower P content. In terms of total P (dissolved P and soil-bound P), runoff erosion typically contributes the greatest amount of P to surface waters. However, other P transport mechanisms can contribute P to a degree that can cause eutrophic conditions in surface waters. In the past, P carried by soil water leaching to surface waters was considered to be insignificant. As soil test P levels have increased over the past few decades in some agricultural soils, dissolved P concentrations in leached subsurface flow have occasionally been measured that are high enough to cause impairment of surface water quality from this source fraction alone. In this situation, efforts aimed solely at reducing runoff and erosion P will not be sufficient to reverse P impairment of surface waters. The P loads within the soil must also be reduced.

Phosphorus has several fates once it enters the aquatic environment depending upon its form. Particulate P may be deposited with sediments in stream or lake beds where it may either be stored and unavailable (a P sink), or dissolve and become available (a P source), depending upon the physical and chemical properties of the system. Dissolved reactive P (also referred to as soluble P) may either be adsorbed by sediments or assimilated by algae and aquatic plants. Growth of algae and aquatic plants in most freshwater systems is limited by P concentrations. Like N in saltwater systems discussed above, as dissolved reactive P concentrations increase, more algae and aquatic plant growth is supported when water temperatures are warm. This can lead to eutrophic and hypoxic conditions in freshwater systems. In addition to causing fish kills, it also can cause fish population changes. Rough fish species are more tolerant to low dissolved oxygen conditions than game fish and can then dominate a freshwater body. Phosphorus may eventually leave a particular waterbody by flow transport, especially during high flow periods, or by deep burial within bed sediments. High flow periods can also add P to a particular waterbody, continuing the cycle.

Carbon, Nitrogen and Phosphorus Ratios

All forms of life require balanced nutrition for proper growth, development and maintenance. This balance, or ratio, of available nutrients is also critical to how elemental nutrients cycle in the environment. Just as a corn plant may experience reduced yield due to a deficiency of a single nutrient such as N, so too may microbes be limited in being able to perform transformations of other nutrients. A soil's microbial community is constantly changing, with growth, death and associated nutrient flows and transformations occurring simultaneously. The overall effect of these dynamic processes at any given point in time has been shown to depend upon the ratios of nutrient elements.

Net immobilization, mineralization or relative balances of available N are all closely tied to the amount of available C in the soil. When plant residues with C:N ratios greater than 20-25 parts C to one part N (20-25:1) are added to the soil, available inorganic N and N released from SOM is immobilized during the first few weeks of decomposition. Eventually, as residue decomposition proceeds, the C:N ratio will begin to approach that of soil organic matter (10:1), microbial populations will decrease, and N from plant residues that was taken up by the microbes will once again be released into the soil. At C:N ratios between 10:1 and 25:1, there will essentially be a balance between amounts of N immobilization and mineralization. Therefore, one factor that influences the amount of N that is available to a crop and at risk to off-field losses is C, another is P.

Imbalances in the amount of available C, N and P in a soil to crop requirements of these nutrients can increase the risk of NPS nutrient contamination to waterbodies. Most animal manures have N:P ratios of 3:1 or less, while crop N:P requirements typically range from 5:1 to 7:1. If manure is applied to the soil on the basis of crop N needs, then P is being applied above that which a crop will utilize. With time, manure applied on the N basis will lead to enrichment of soil-P and increase the risk of NPS P contamination to surface waters.

Alterations in the N:P ratios of natural aquatic systems have been implicated in impairments to these resources. Nitrogen fixing algal species are able to thrive in freshwater lakes, therefore N does not limit their growth. Since P is the nutrient of next highest demand, freshwater primary producers (algae and other phytoplankton species) are typically P limited in their growth. As P loading to freshwater systems has increased to and beyond the point of causing eutrophication, the demand for dissolved silica (Si) in these waters by phytoplankton also increased. Many phytoplankton species (i.e., diatoms, foraminiferans, etc.) assimilate Si into their cell walls to create a protective shell, changing the Si from a dissolved to a solid phase. Upon death, phytoplankton fall out of the water column and deposit the Si in freshwater bed sediments where it becomes unavailable. Therefore, in eutrophic and hypereutrophic fresh waterbodies large amounts of Si are then removed from the aquatic environment. This N:P:Si ratio disturbance in freshwater lakes has led to other impairments in the marine ecosystems that receive flow from these freshwater systems.

In recent decades, the N:P:Si ratio in the Gulf of Mexico has been dramatically altered, having negative impacts on that ecosystem. Marine phytoplankton have a cellular N:P ratio of 16:1 (called the Redfield Ratio). In a natural undisturbed marine ecosystem, the N:P ratio is less than 16:1, which means that phytoplankton growth is limited by N nutrients. Also, N fixing algae are limited in growth due to other natural conditions, further restricting primary production due to low N levels in undisturbed marine ecosystems. As nitrate loads have increased over the past several decades (4 to 7 fold) to the Gulf of Mexico, the N:P ratio has approached 16:1, where N is no longer limiting phytoplankton growth. This has resulted in large algae blooms, leading to depleted oxygen (hypoxic) conditions as previously described. At the same time, the dominant phytoplankton species have changed in response to changes in the N:Si ratio of the Gulf of Mexico. Due to prevalent eutrophic freshwater lakes in the Mississippi River Basin, dissolved Si levels have decreased by nearly 50% over the past few decades, paralleling the increased N loads during the same time period. With N no longer limiting phytoplankton growth and limited Si availability, the previously dominant diatom phytoplankton species (having high Si requirements) have been displaced by other algal species that can cause massive blooms, leading to hypoxia during summer months.

Nutrient ratio relationships allow manipulating the availability and soil pool of some nutrients by managing other nutrients. For instance, N can be added to a soil without shifting soil C:N ratios towards net mineralization if the added N is complexed with C. Composting of N sources with C substrates such as wood chips or straw will result in a soil amendment that will have a C:N ratio similar to that of SOM (10:1). The compost amendment will have the effect of increasing the SOM pool that will release the added N through mineralization slowly over time. This offers a crop N supplement that is in more synchronous availability to crop needs, instead of the large flush of available N with regular commercial and manure N fertilizers that commonly leads to increased N losses. One of the functions of a cover crop is to incorporate available inorganic N that remains within the soil after harvest of a primary crop into an organic form, thus manipulating N availability to be more in-tune to a succeeding crop's needs. Although adding C with P fertilizer additions does not appreciably alter P availability, P can be managed to some extent by complexing it with iron, aluminum or calcium. The stability of these P compounds depends upon soil pH and aeration. In aerobic conditions, P bound to iron and aluminum oxides are stable at acidic pH levels, and P bound to calcium is relatively stable at alkaline pH levels. However, anaerobic conditions (i.e., water saturated) cause iron and aluminum oxides to dissolve - iron oxides being more susceptible to dissolution than aluminum oxides in these conditions - releasing P to the soil solution or water in the beds of surface waterbodies. It is important to note that forming such P compounds may be difficult to balance with crop needs and these P management practices may be more applicable tools for municipal waste systems than for agricultural production.

Managing nutrient availability to optimize crop production and nutrient use efficiency, and to minimize the risk of NPS nutrient pollution, involves an understanding of the physical, chemical and biological factors of nutrient cycling at the microscale. However, the knowledge and management of microscale factors must be combined with that of the macroscale to adequately address the full scope of NPS contamination of water resources. Macroscale NPS risk management encompasses field and landscape use activities that influence soil, water and plant interactions.

Land and Water Management

One of the most important factors to reduce NPS pollution that must be managed is water movement from the land to surface waterbodies (see the Hydrology Section for details), which includes both overland and subsurface flow. Overland runoff is the primary P transport pathway, while subsurface flow is the primary nitrate transport pathway. Methods designed to reduce runoff and stream volume, reduce water flow energy (flow concentration and speed) and increase a land's water storage can reduce the NPS contamination risks of these pathways. Management of biological, soil and water resources at the field and landscape scales are essential to performing such tasks.

Soil and Water Management

Concentrated runoff poses the greatest threat for erosion. The physical laws behind this scenario are fairly easy to understand when one considers the entire volume of sheet or rill overland flow spread over a wide area becomes gathered into a small zone. A large amount of energy that once was diffused over the wide area is now funneled into a small, narrow strip. Alteration of a landscape's degree of slope and length of slope is one management tool that can help to limit concentrated flow.

To some extent, the degree of slope and slope length can be managed physically by constructing terraces. Properly designed and placed terraces will reduce the degree or angle of slope and slope length, thus decreasing runoff energy by reducing its speed. In turn, reducing the speed of runoff results in reduced flow volume due to a larger fraction of the water infiltrating into the soil profile. Also, a terrace system should function to distribute any runoff over a wider area, thus diffusing the runoff and altering it from concentrated to sheet or rill overland flow. This function is critical to optimize the performance of other NPS pollution management practices, such as riparian buffers.

Most low relief row-crop fields within Iowa have been installed with various types of artificial drainage to alleviate periodic conditions of excess soil moisture that hinder field operations, which has had both positive and negative effects on NPS nutrient pollution. Artificial drainage (tile drainage lines, drainage wells and drainage ditches) affects hydrology by increasing the speed with which water moves off the landscape by short-circuiting natural water flow into shallow ground water. The improved surface drainage reduces the risk of overland flow that can result in sediment erosion and total P losses to surface waters. It was believed in the past that tile drainage P contamination of surface waters was insignificant. But with an upward trend in soil test P levels of agricultural over the past few decades and the common presence of non-buffered surface tile intakes, recent studies have documented tile drainage water P levels that were high enough to cause surface water impairments even in the absence of runoff event P contributions.

Artificial drainage influences other aspects of nutrient transport by reducing the amount of water that can be stored on the landscape, which has increased NPS pollution of leachable nutrients, most notably, nitrate. In balancing these considerations, there is not typically a high degree of risk for sediment erosion from low relief ag fields since many of the tiled areas were formerly closed depressions (potholes), or infrequently had concentrated runoff events. But, the potential for nitrate leaching has dramatically increased for many agricultural fields. This is because improved drainage allowed an increase in row-cropped acres of annual crop species at the expense of perennial species, the fraction of precipitation infiltrating the soil and transporting nitrate increased, and soil conditions became more aerobic. Remembering that aerobic conditions result in greater microbial activity than anaerobic, there is increased SOM-N mineralization and transformations to nitrate with improved drainage.

Tillage also creates a more aerobic soil environment in the zone of soil disturbance, though the effects are only temporary. The net result of tillage is an increased aerobic microbial activity leading to elevated mineralization of SOM-N. However, depending on tillage to release N for crop production is generally not a wise soil management practice. From a soil quality perspective, it reduces the benefits of SOM such as CEC, soil structure, and water retention capacity merely for the release of plant-available N. Depending on seasonal weather patterns of temperature and rainfall, tillage during autumn or early spring can cause N mineralization too early and increase the potential for nitrate leaching before subsequent crops have an opportunity to assimilate the N released by these processes. The reason why the aeration effects of tillage are temporary is due to the damage that tillage causes to soil structure (described in more detail in the Preventive Practices portion of the Principles and Functions of NPS Management Practices Section). Tillage breaks bonds between soil particles and aggregates. Subsequent rainfall events lead to crusting at the surface – called surface seal – that greatly reduces the ability of water to infiltrate into the soil. The long-term effect of tillage causing reduced water infiltration, coupled with the burial of residue and exposure of loose surface soil particles, leads to an increased risk of sediment erosion and NPS P contamination of water resources. Which type of P that is at most risk of loss differs by tillage regimes.

The more intense the tillage practice, the more soil structure is destroyed, resulting in a greater amount of detachment and erosion of soil particles. Therefore, losses of P attached to soil particles (particulate P) dominate so-called conventional, or intense tillage practices. Reduced or no-till soil management practices tend to cause a greater amount of P accumulation at the surface of the soil and a decreased potential for soil particle detachment compared to conventional tillage. Water infiltration then is greater in the reduced and no-till systems, leading to dissolved P losses dominating these systems. Considering the total effects of NPS P losses, conventional or intense tillage systems pose a greater risk of total P losses to water resources than reduced and no-till systems. While particulate P losses dominate in intense tillage systems, the amount of dissolved P loss with intense tillage can still be greater than those of reduced and no-till systems. As erosion increases and soil cover decreases, there is a greater interaction of water with soil particles, which increases the amount of soil-bound P becoming dissolved and carried in the soil water solution. In general, ***greater tillage induced soil disturbance results in a greater potential for soil erosion and total P losses***. Another destructive factor of tillage that can vary proportionally with tillage intensity is compaction, which also affects nutrient losses.

The negative effects of soil compaction caused by tillage and later wheel trafficking are rarely given proper consideration in soil management plans. When soil is compacted bulk density increases and water infiltration rates and water storage potential decline, which increases runoff erosion of sediments and risk of NPS P losses to surface waters. Compaction also decreases the farmable volume of the soil profile and results in economic losses for the farmer. Over time and depending upon the amount of compaction (such as whether or not there was controlled wheel-traffic), the volume of soil from which crop roots are able to extract water and nutrients can be reduced by 1/3 or more.

Research has developed several biological methods to repair soil compaction and many other conditions that can increase NPS pollution of surface waterbodies. Plants with root characteristics of penetrating deep into a soil profile and breaking through soil hardpans have been used to reduce soil compaction. A few such plants are bahia grass for the southern U.S., and alfalfa and eastern gammagrass in the Midwest. If most of the compaction is limited to near the surface, cover crops of oat, rye and various legumes are often capable of repairing the damage in a relatively short period of time. Once the compacted zones in the soil profile are broken, then water can infiltrate, which increases the productivity of a field along with its ability to store and supply water and nutrients to a crop. Other strategies to limit NPS pollution that utilize plants as biological land and water management tools have been developed over time, though as of yet have not been adopted on a large scale.

Vegetation and Water Use

Plants and their management, whether being a crop or otherwise, impact NPS pollution due to their patterns of water demand, nutrient uptake and soil stabilization by their roots, stems and leaf canopies. The risk for off-site transport of contaminants to surface waterbodies increases with greater soil moisture content just prior to a rainfall event. Uptake and transpiration of water by actively growing plants removes water and nutrients from the soil profile, which then increases the soil's ability to adsorb and store water from a succeeding rainfall event and reduces the potential for water runoff and leaching. Reduced water runoff and leaching also means that nutrients are less likely to be transported to surface waters. Although water and nutrient demand varies by time and amount among plant species, there are some common patterns by plant types.

General patterns of water and nutrient demand differ between perennial and annual plants, and cool season and warm season plants (Fig. 6). Cool season plants begin to germinate or come out of dormancy soon after the soil thaws in the spring, go back to dormancy or mature during the heat of the summer, and again become active in the fall if not previously harvested. One example is oat, an annual crop. This crop is planted and germinates in early spring, grows vigorously through spring and early summer, then is mature and is harvested by mid-summer. Oat growing season and water usage then extends over a few weeks in the first part of the year (see the cool season annual curve in Fig. 6). Another cool season example is perennial rye grass (see cool season perennial curve in Fig. 6). Once established, perennial rye becomes active soon after the soil thaws, is inactive or goes into dormancy in mid-summer, and returns to active growth in the fall and lasts until the soil freezes. The water and nutrient demand of perennial rye then has two peaks separated by a trough and extends over a wide time period. A warm season annual plant that is common to Iowa is corn (see warm season annual curve in Fig. 6). It is planted and germinates in mid-spring, reaches peak water demand in mid-summer, and matures and is harvested in the fall. The growing season and water and nutrient demand of corn then extends over the middle portion of the year and peaks during the warmest period. Switchgrass, like many native prairie grasses, is a perennial warm season plant (see warm season perennial curve in Fig. 6). Middle to late spring temperatures break dormancy of switchgrass, which reaches its greatest activity during mid-summer and returns to dormancy in the fall. Therefore, the growing season and water and nutrient demand curve of switchgrass is similar to corn. These differences in water and nutrient demand between types of plants have implications for the potential for NPS pollution.

When rainfall occurs at times of little to no plant cover and active growth, there is a greater chance for leaching and runoff losses of contaminants. The threat of NPS nutrient pollution decreases when peak plant demand for water and nutrients and plant canopy cover is more in synchrony with peak rainfall events and patterns. A relative example of the patterns of annual crop water and N uptake, precipitation and subsequent high-risk periods for nitrate leaching is shown in Fig. 7. Time periods of high-risk for nitrate leaching occurs when precipitation exceeds crop water and N demand. Conversely, nitrate is of lesser risk for leaching when crop water demand exceeds precipitation. Soil management operations interact with crop growth characteristics and can impact a field's overall risk for nutrient losses to surface waters.

Production of annual row crops in combination with fall and/or spring tillage creates a soil environment that is most vulnerable to nutrient losses during the greatest probability of peak rainfall events. In the Climate - Precipitation Section the importance of precipitation patterns is explained, where in Iowa most peak rainfall events occur in spring and early summer. Because an annual row crop and tillage system leaves the soil surface with little residue cover and no active plant growth at the time of most peak rainfall events, large amounts of nutrients can be moved off-field via erosion and leaching.

Cropping systems that include perennial plants have very different environmental conditions than systems with only annuals and are less likely to have off-field nutrient losses during the spring peak rainfall events. Tillage is usually not performed in the time period between crop establishment and rotating to a new crop, resulting in a high degree of soil surface coverage and intact root systems for long periods of time. If the perennial is a cool season crop or is a mix of cool season and warm season crops, there is active plant water and nutrient uptake already in early spring. These attributes create a soil environment that is buffered to the destructive forces of peak rainfall and snowmelt events. The intact perennial crop shoots protect the soil from raindrop impact and provide a rougher soil surface than bare soil, which slows and dissipates the energy of any runoff water flow (reducing the incidence of concentrated flow). Intact crop root systems physically hold soil particles together, making the soil more resistant to erosive forces. Also, with active plant water and nutrient uptake soon after thaw with cool season plants – or a mix a mix of cool season and warm season plants – the soil is drier prior to the rainfall event. This increases storage capacity for the following rainfall by increasing the infiltration and retention of water, further reducing the probability of runoff erosion and nutrient leaching losses of nitrate and dissolved reactive P. Inclusion of warm season perennial plants in a cropping or conservation planting system provides similar benefits in mid-summer, but extend deeper into the soil profile due to the fact that warm season plants tend to have more extensive root networks. These physical and biological attributes that improve the stability of the upper soil profile also can serve as tools for other portions of the landscape.

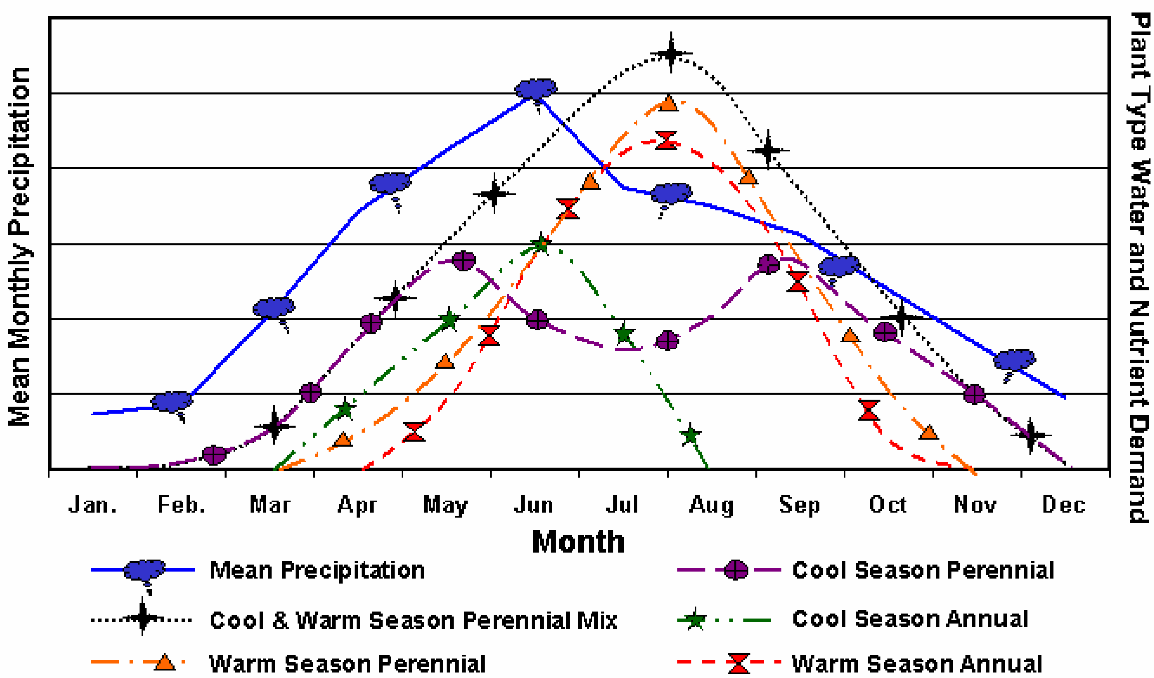

Fig. 6 General annual water and nutrient demand curves of cool and warm season annuals, cool and warm season perennials, and a cool and warm season perennial mix.

Streambank erosion can frequently contribute a majority of the sediment load transported by surface waters, so efforts to reduce sediment and P contamination must address this source. One of the primary functions of vegetative riparian buffers is to improve the stability of streambanks to the erosive forces of runoff and stream flow. Vegetative buffers perform this function by three mechanisms, two of which are biological and one physical. The presence of established vegetation on the streambank and adjacent edge physically improves bank stability by providing a frictional surface that slows runoff and stream flow just as described above, thus dissipating flow energy. Once the vegetation is established, this physical benefit exists year-round. Uptake of nutrients and water by the buffer plants is one of the biological mechanisms that can allow a buffer system to serve as a nutrient sink and improve water storage within a buffer's area. However, this mechanism only operates when the buffer plants are growing at an appreciable rate (roughly mid-spring through mid-fall). The second biological mechanism is through increased microbial populations due to accumulations of SOM, which may also serve as a nutrient sink. This mechanism too will only operate to an appreciable degree on a seasonal basis similar to plant uptake. Therefore, the two biological mechanisms do not provide NPS reduction benefits during the cool periods of the year. Also, when a buffer system matures, its N and P sink capacity may reach its upper limit. At that time, the buffer may no longer serve as a nutrient sink, and could possibly be a nutrient source to surface waters from decaying biomass. Management operations must then be performed to help maintain a vegetative buffer as a nutrient sink (i.e., schedules for vegetation harvest and removal). It must also be remembered that concentrated runoff can substantially diminish the effectiveness of a vegetative riparian buffer, then requiring other measures to manage runoff. Otherwise, a vegetative riparian buffer may not function adequately to reduce the risk for NPS nutrient and sediment contamination of surface waters.

Our current understanding of all the microscale and macroscale factors that impact NPS pollution must be integrated to the even larger regional scale to optimize use of limited resources (money and labor) by applying the best NPS management practices to the most critical source areas. To accomplish this, planning must be done at a scale beyond that of a single field or a small watershed. Tools to simulate, and later validate, different management scenarios based upon accurate knowledge of conditions within a given area can greatly improve the effectiveness of management plans to meet water quality goals.

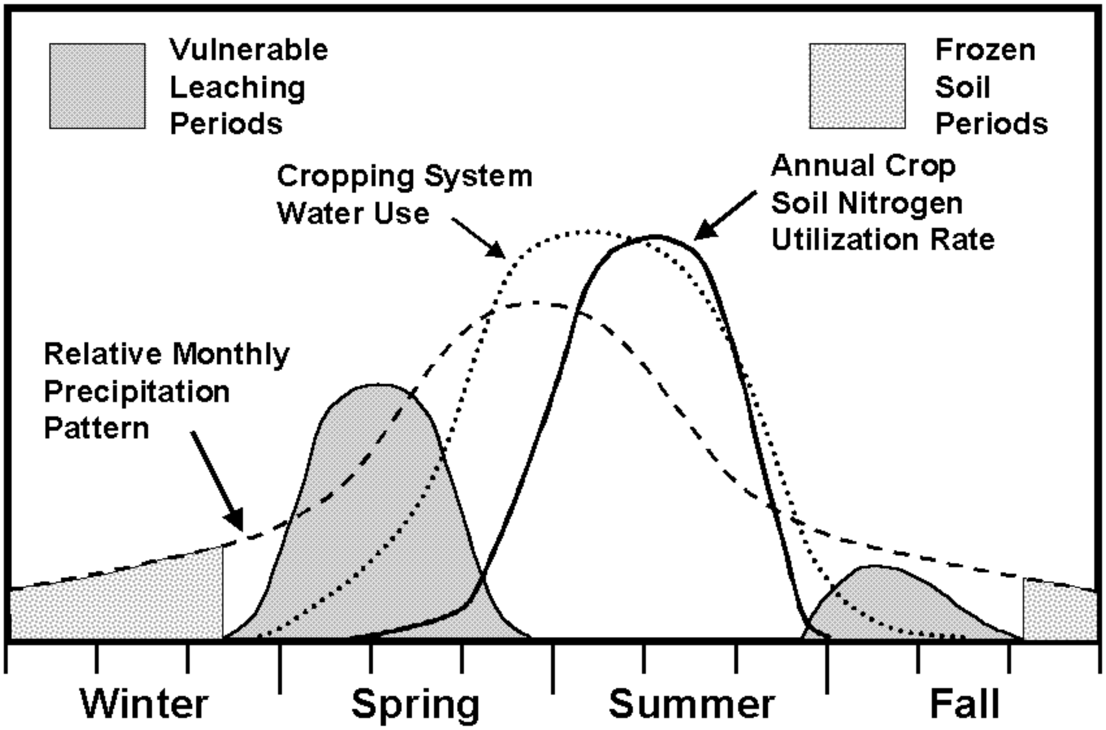

Fig. 7 General seasonal patterns for precipitation, nitrogen uptake rate by a corn crop, cropping system water use and periods potentially favorable for nitrate leaching from Midwestern corn production.

† *Reprinted from Dinnes, et al. 2002 and Adapted from Power et al., 1998. Agricultural Nitrogen Management to Protect Water Quality. IDEA No.4. Figure 2.*

Land Resource Management Planning

Several methods have been developed to define, categorize and map land areas that are unique in function and characteristics. The resulting map depends upon the topic(s) of interest and its intended use. The strict definition of a watershed itself does not take into account any biological characteristics, referring solely to the physical boundaries of a given water drainage area. However, the term "watershed approach" in reference to management of natural resources does consider both physical and biological characteristics.

Major landform resources areas (MLRAs) are geographically associated land resource units that may consist of several thousand acres and can extend beyond individual states' boundaries. Each identified MLRA is a geographically unique area that has similar patterns of soils, climate, water resources, land uses and type of agricultural practices. An information system based on these concepts was created to provide a national and regional framework for organizing and operating resource conservation programs in agricultural areas, thus not being limited to the political boundaries of a state. The relationship of MRLAs to water quality is strongly based on patterns of physical aspects (i.e., soil survey information) and human activities (i.e., agriculture practices), with minor emphasis on natural biological factors.

The ecoregion concept is the extension of the ecosystem to a regional scale. An ecosystem is an area that has unique physical and biological features, which include air, water, land and the interaction of these components resulting in habitats supporting plant and animal life. Native vegetation is an important indictor of unique ecoregions because the plants' existence, whether actual or potentially present, is the result of a combined variety of natural and human-altered features. Ecoregions have been defined as regions of relative similarity in ecological systems or in relationships between their systems. Therefore, the ecoregion classification system incorporates all components present on a landscape, being climate (air and water), biology (plants and animals), soils and topography (land).

The agroecoregion approach was developed due to limitations of the above-mentioned concepts when considering the most appropriate resource management strategies for specific areas. The agroecoregion process utilizes all of the factors accounted for by the ecoregions, and agricultural management factors of the MLRA concept. A watershed, MLRA, and ecoregion can be a complex mix of soil types, climate regimes, landscapes, land use characteristics and agricultural systems. The boundaries of each of these mapping methods are not usually similar. To produce a more refined and useful method, University of Minnesota researchers integrated both major watersheds and agroecoregions to better identify critical source areas of NPS pollution in agricultural watersheds and enable prioritized and targeted implementation of proper management practices. This method is designed with the intent to optimize the use of supportive funds for water quality improvements.

Principles and Functions of NPS Management Practices

Identifying the best-fit NPS management practices to the unique conditions of a critical source area requires an understanding of how each practice functions. Many of the principles mentioned in this section are reiterations of information presented earlier, but here it is more in the context of how the principles are utilized by the NPS management practices. Also, discussed in more detail is how the limitations of these principles affect the applicability of a practice to the environmental conditions within Iowa's landscapes. Once a person gains a comprehensive knowledge of these principles, then that knowledge can be used to help guide proper implementation plans and possibly lead to future improvements and new innovations.

As stated before, a very important, naturally occurring factor that dramatically affects NPS nutrient contamination of surface waters in Iowa is the highly variable weather. Drought, flood, high volumes of snowmelt, bitter cold, very hot, low humidity, high humidity, no wind and high winds all happen here in Iowa's continental climate. Because we cannot control the weather does not mean that there is little that can or should be done to try to reduce NPS sediment and nutrient pollution of our surface waters. This is not a hopeless situation. The fact that highly productive prairie and savannah ecosystems originally thrived here is proof that Iowa's landscapes can absorb the extremes of weather. If this were not true our landscapes would have originally been highly eroded and unproductive. But the methods used to break and drain these landscapes to allow for human housing and agricultural and industrial production exposed the lands to resource losses from the extremes of weather. All of this actually points to a great need for practices to be implemented that will make Iowa's human-altered landscapes more resilient to the effects of highly variable weather.

Implementing practices that buffer Iowa's landscapes to the extremes of weather will reduce losses of nutrients and sediments from the land to water resources. It is possible to manage an environment's physical and biological components to reduce the threat of NPS pollution from naturally occurring events. One primary role of conservation practices is to buffer a landscape to destructive forces, thus increasing the stability of the environment. A second primary role of these practices is to minimize the occurrence of a problem by limiting the existence of sources that pose a contamination threat. In the event that a contamination problem does occur, a third primary role that some conservation practices serve is to eliminate or reduce the problem to an environmentally and socially acceptable level.

There are two basic types of NPS conservation management practices: preventive and remedial. While there are plenty of exceptions, ***preventive practices generally cost less than remedial practices to meet the same water quality goal***. Unfortunately, some areas are so environmentally fragile that preventive practices alone may not provide enough protection to surface waters from NPS nutrient and sediment contamination. In those instances, remedial treatment practices will need to be employed in a coordinated manner with preventive practices to form a comprehensive conservation management plan.

Preventive Practices

Preventive refers to not creating, or at least minimizing the probability of creating, a NPS nutrient and/or sediment pollution problem. This is the basis for the philosophy that ***the solution to pollution is <u>not</u> dilution: the solution is <u>prevention</u>.*** The main reason why preventive measures cost less than remedial is that it is typically easier to prevent a problem from occurring than it is to fix the problem after it has been created. Preventive practices are designed to perform the first two primary roles mentioned above, being buffering the environment to destructive forces and limiting the existence of contamination threats.

One of the most widely applicable NPS nutrient management strategies is to use practices that are aimed at nutrient source load reduction. There are several approaches currently available and the costs of implementation are quite variable, but each work upon the principle of ***reduced nutrient load equals reduced risk***. However, balancing nutrient availability and amount with crop needs can require careful management, particularly for N. The challenge is to manipulate N availability prior to, during, and after peak crop demand so as to not cause either net economic losses from yield reductions or N losses to water resources. Being able to optimize net income and water quality then is not just a matter of better matching N fertilizer rates with crop demand, but is also a matter of timing of application. The risk of N losses increases as the time between N application and crop uptake increases. Limiting the amount of inorganic N within the soil at the end of a crop's growing season and before the next crop has established an extensive root system is a key factor for reducing N losses. In essence, ***improving the timing of nutrient application and matching the amount that is available with crop demand can improve yield and water quality***.

Changing from fall N fertilizer application to spring or split (some at planting and remainder during growing season) N application systems will better time N availability with crop demand. Use of nitrification inhibitors (i.e., nitrapyrin) with fall application has shown in some studies to improve N availability with crop demand, but the results have been inconsistent. More consistent results have been seen with managing N along with C. Cover crops and composting techniques both function to incorporate N into organic forms that will gradually release N over time by microbial decomposition of the organic N compounds. Technologies based on chlorophyll monitoring and remote sensing in concert with sidedress N application have also shown some positive results, but these systems still require more research to better define proper N rates. Nitrogen fertilizer management programs that base N rate on soil test results, such as the late-spring soil nitrate test (LSNT) and pre-sidedress nitrate test (PSNT) are tools to better identify the proper N rate for crop needs. Managing N with these programs may not always reduce overall N rates compared to conventional practices in a given year, but commonly do when assessed over a period of years. The LSNT and PSNT help to account for net gains and losses of the soil-N pool up to the time of soil testing, but cannot help to account for changes in N dynamics afterwards. The Iowa P Index is a tool that provides a field specific estimate of the risk of P loss based on soil tests of P availability, predicted erosion rates, location of the field, and other factors that affect P loss. This information from the Iowa P Index then serves to help farmers improve their P management decisions. While NPS nutrient management practices are aimed at reducing the pools of available nutrients when crops are not able to utilize them, other practices are meant to increase the pool of another resource, being soil water.

Improved in-field water storage reduces potential NPS pollution is a functional principle of many practices accomplished by an array of mechanisms. As more water is able to be stored on production fields the chance of runoff occurring with any given rainfall event decreases. Even if runoff does occur, increased water storage can reduce the amount and energy of runoff. Also, as more water is retained, there is an increased chance that cationic (positive charged ions) contaminants may be filtered out of excess water by filtration through the soil profile. Increased water infiltration rates for a given soil will slow water flow towards surface waters compared to runoff, but this may also result in greater leaching losses of nitrate and dissolved reactive P if actual water holding capacity remains the same. This too can be minimized if one of the aspects that improve water storage is increased retention by soil particles, therefore, having a greater soil water holding capacity. Practices that increase SOM improve water-holding capacity because SOM acts much like a sponge for water. A few examples of practices that can both improve water storage and soil water-holding capacities are perennial crops, cover crops, no-till and reduced till practices. All four of these practices work to increase SOM by having greater C inputs to the soil compared to conventional till row crop production of a single annual crop. The reduced soil disturbance with perennial crops, reduced till and no-till can increase SOM due to reduced decomposition rates. Also, the SOM may increase with these three practices because each leads to less erosion losses of surface sediments.

Another widely applicable function of many conservation practices is to prevent or minimize detachment and transport of soil sediments and particles. This function, as discussed previously, relates more to managing sediment, pesticide and P contamination of surface water than N contamination in many locations, though areas that have row cropped slopes of highly erodable soil can lose a large amount of N by erosion. The principle of these practices is that ***increased plant cover and decreased soil disturbance results in decreased erosion***. Again, there are a variety of practices that function in this role, some more applicable to some areas than others.

No-till row cropping systems enable the production of annual crops, but do so in a manner that minimizes disturbance of the soil. As a result, no-till fields have much greater soil surface cover than systems that use tillage, and a much reduced risk of sediment detachment and transport via runoff waters. There are three main mechanisms that lead to no-till's reduced erosion compared to tillage: the lack of surface disturbance allows soil particles to form bonds, which increases soil strength and resistance to erosive forces, being: the extensive residue cover serves as a protective shield to raindrop impact; and over time, no-till soils develop extensive networks of micro- and macropores, which increase water infiltration rates and reduces the incidence of runoff. Tillage is primarily used to increase soil aeration and prepare a smooth seedbed. However, these soil physical benefits from tillage are short-lived and a series of detrimental conditions develop later. Over time and subsequent precipitation events for soils of moderate to fine texture, fine particles created from destruction of soil aggregates by tillage will plug small pores. Settling from precipitation and other factors collapse larger pores, pore continuity is disturbed and bulk density increases. Bulk density is also increased by compaction from future wheel traffic because the tilled soil has lower load bearing strength due to its destroyed structure. The net effect of these negative aspects of tillage is that runoff erosion is greatly increased.

Cover crops, cropping systems including perennial plants and riparian buffers are other practices that serve to reduce soil erosion through not only increased surface cover, but also by the plant root systems. However, landscape areas differ as to where these practices are applied. Like no-till, cover crops are used on agricultural production fields. Besides serving to immobilize available nutrients into organic forms after harvest of the primary crop, cover crops also provide improved soil stability by increased surface coverage and binding of soil particles by root systems. Perennial crops may be established on row crop and non-row cropped fields. Since there are few soil disturbing operations required to establish, grow and harvest perennial crops, land areas typically too steep to reasonably support row cropping may be able to be utilized for production of perennials. Therefore, perennial cropping systems result in a decreased risk for erosion by providing both greater soil surface cover and less soil disturbance than row cropping systems that incorporate only annual plants (i.e., corn and soybean).

Riparian buffers, as suggested by the term, are applied to areas bordering surface waterbodies. A part of this area that is unique to the application of riparian buffers is the streambank. The roots and stems of riparian buffer plants are of even greater importance to soil stability since the major erosive force to banks is streamflow. Sediment detachment and transport is reduced for the entire period that the plants are present on the landscape since this principle is a product of the physical attributes of these practices. Riparian buffers though cannot be established on all streambanks. Deeply incised channels frequently have areas of streambank with very steep slope, sometimes nearly vertical. Buffer plants have difficulty in establishing on such steep sloped banks because these areas are unstable, having frequent sloughing and collapse of bank sediments during and after high flows. In these cases, the banks must typically be cut back to less than a 2:1 slope to allow a stable enough environment for plants to establish. The precise critical slope angle depends upon soil type and channel and bank physical characteristics (i.e., bank height and soil strength when saturated). Where bank slope reduction does not provide adequate stability, further measures may be needed, such as adding rock/concrete riprap or other materials to form specific types of protective structures.

A few of these preventive practice principles are similar to principles of remedial practices. The difference between them is where on the landscape that each respective type of practice is located. Preventive practices are basically on-field practices to prevent or reduce the transport of contaminants. Remedial practices are predominantly employed at off-field locations where contaminants have been transported, but before the contaminants have entered existing surface waters designated for public use.

Remedial Practices

Preventive practices are often the most logical and economical first-line of defense for reducing NPS contamination. However, there will likely be many instances where preventive practices alone will not be adequate to keep a problem from developing. In those instances where water quality goals still are not met, remedial practices will need to be added to the preventive measures already in place.

Once sediments have been detached and transported off-field there is a great risk of the sediments and attached nutrients entering surface waters. Therefore, measures that help to cause deposition and retention of eroded sediments and nutrients both on and off of a field, but prior to entering a surface waterbody, are important remedial practices. The guiding principle to these practices is that ***mobile sediments and nutrients deposited and retained on the land will decrease NPS pollution***. It is important to note that some of these remedial practices are to be utilized on-field, as well as, off-field. Off-field practices include riparian buffer strips and wetlands. But as mentioned earlier, wetlands can be overwhelmed by too much incoming flow and riparian buffers can be overwhelmed by concentrated flow. Therefore, on-field practices must also be used to reduce runoff volume and dissipate runoff to help maintain it as diffused sheet or rill overland flow. Waterways, terraces, vegetative buffer strips and shelterbelts are all located either within or on the edge of fields to serve this role. Each practice slows runoff, allowing sediments to fall out of suspension and deposit at the edge or within the structures. These practices help to sustain agricultural production levels by retaining sediment and nutrient resources where they can be much easier to recover and redistribute back onto the fields.

Off-field practices such as constructed wetlands and retention ponds that reduce NPS nutrient and sediment transport are also able to temporarily store runoff or artificial drainage flow for varied periods of time. The water retention time is dependent upon the incoming flow rate, amount of available storage capacity, evaporative losses and transpiration demands of plants within the structures. Storage of off-field waters prior to entering streams helps to reduce flow volume and energy during peak events, thereby reducing streambank and channel erosion. The principle is ***greater off-field water storage capacity results in less potential streambank and channel erosion***. Also, once runoff and drainage waters are collected, other practices can be utilized to remove nutrient contaminants before the waters flow into surface waterbodies designated for public use.

Related to off-field water storage is off-field nutrient storage, with the principle of ***greater off-field nutrient storage capacity improves the opportunity to prevent the nutrients from entering surface waters***. Nutrient removal by biological means is greatly influenced by the seasonal effects of temperature and soil moisture. The microbial transformation processes of nitrification and denitrification provide good examples (see the N Cycle Section for more information). Ammonium is frequently added to soils by many commercial N fertilizers and manure, and is also a product of N mineralized from SOM. At low temperatures of 32 ^{o} F to 50 ^{o} F, nitrification is slow (though given a long period of time the total amount transformed can be, and frequently is, large). At temperatures above of 50^{o} F, ammonium can be transformed to nitrate at rapidly increasing rates until reaching optimum in the range of 86^{o} F to 95^{o} F. Optimal soil moisture content for the microbes that perform nitrification is similar to the general statement in the Precipitation Section, being field capacity. Relatively dry and acidic pH soil conditions will slow the nitrification process because it does not favor the microbial groups that perform the processes. Large losses of soil moisture due to evaporation and transpiration by plants typically result in low soil moisture contents in the summer. Any microbial-based conservation practice that functions to remove nitrate by denitrification (i.e., wetlands and riparian buffers) is also affected by temperature. The denitrification process is slow at low temperatures and high at warm temperatures. Although temperature and soil moisture contents are variable in Iowa, one can still reasonably predict by historic weather patterns when these microbial nutrient transformations are most active. Fig. 8 displays the monthly average temperatures and relative soil moisture contents in Iowa. Considering these relationships with the microbial process of nitrification, one can expect that the months of October and April through June will result in active conversion of ammonium to nitrate in aerobic conditions. Also, the denitrification process that removes nitrate in anaerobic conditions will be most active in the months of June through August. The bottom line on these situations is that nitrate produced and transported to surface waters in the fall through spring will have a limited opportunity to be removed by practices that rely on denitrification as a nitrate removal mechanism. However, nitrate entering the same conservation systems during the summer will have a greater opportunity of being removed before entering streams and lakes. It must also be remembered that denitrification rates can also be limited by any situation that cannot maintain anaerobic conditions, inadequate supplies of C for microbial energy and growth, and a short water residence time that does not allow for complete nitrate removal before exiting the system. Denitrification is just one of several nutrient storage and removal mechanisms. Other biological and chemical mechanisms also exist.

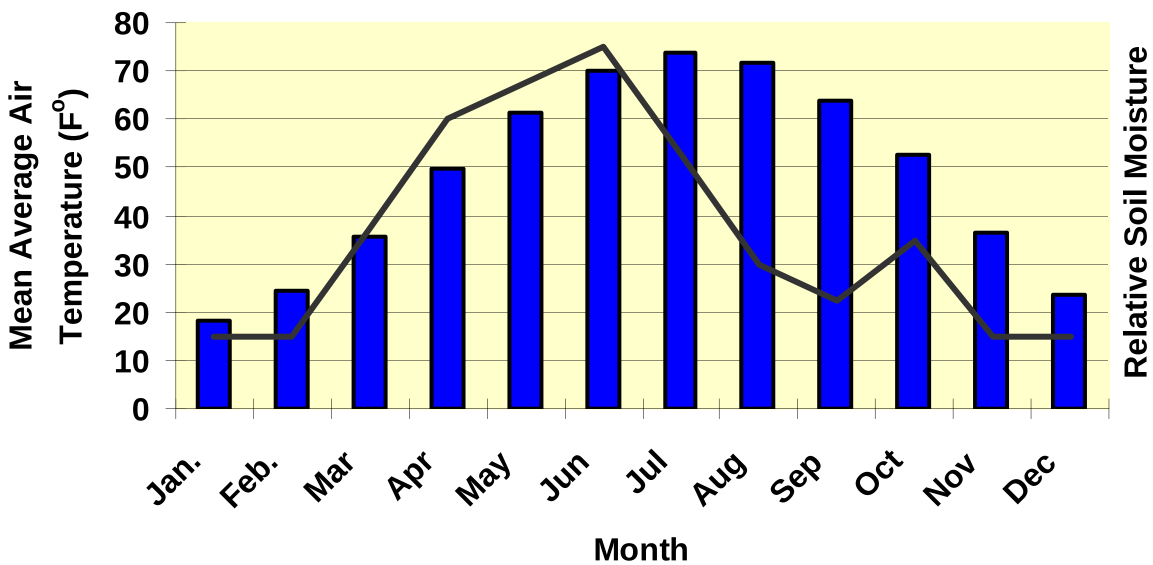

Fig. 8 Fifty-year (1951-2000) monthly average air temperatures (F^o) Ames, Iowa, and relative soil moisture content.

† *Temperature Data from Iowa State University Climatology website at:* http://mesonet.agron.iastate.edu/climodat/table.html

Both N and P can be immobilized and stored in organic forms, though this option is more applicable for N management. ***The greater the biological nutrient pool, the better synchronization of nutrient availability with crop demand and potential to capture nutrients transported off-field*** is the principle function of this reduction mechanism. Conservation practices that function to store nutrients in organic matter includes cover crops, composting, vegetative buffer strips, shelterbelts, wetlands and riparian buffers. The nutrient storage limits in terms of amount and cycling time vary considerably between each practice and depends upon the amount of plant biomass that can be supported. Due to the restricted time periods, temperatures and plant species (i.e., grasses and/or legumes) typically used for a single cover crop, the nutrient storage capacity for this practice is less than others that are comprised of plant species that are allowed more time to reach maturity and attain greater biomass. Repeated use of cover crops will, however, help to maintain greater organic nutrient pools and crop nutrient use efficiencies than conventional row cropping practices. Buffers and wetlands are maintained over a much longer time frame than cover crops, and those with large woody plants (shelterbelts and riparian buffers) can accumulate large amounts of nutrients over time that would otherwise be at risk to enter surface waters. A large biological nutrient pool also poses management issues. The goal of the off-field practices is to maintain them as nutrient sinks. But how is that to be maintained after the plants reach maturity? It is obvious that a management plan is needed to keep a buffer as a nutrient sink, instead of becoming a nutrient source. Unfortunately, such information is currently limited due to the long-term nature of these practices, the many buffer plant species that exist and the many options that may be used (such as harvest and removal schedules). Like denitrification, removal or capture of nutrients by plant uptake has seasonal limitations. Plant nutrient assimilation can only occur while the plants are actively growing, thus not being functional during the winter and possibly early spring and late fall if cool season plants are not a part of the systems.

Phosphorus pools can be managed to some extent by chemical and physical means. The availability of P is reduced when it combines with iron and aluminum in acidic soil pH conditions, and with calcium in alkaline pH conditions. The premise here is that ***reduced nutrient availability during periods of little to no crop demand results in reduced risk of NPS pollution***. And similar to the timing and rate of application principle, this must be balanced to crop P demand. Managing soil pH along with combining iron, aluminum or calcium amendments is a possible option for soils having very high P levels and are critical NPS areas, but the amendments are not similar in their stability. Calcium phosphate minerals can dissolve in even mildly acidic soil pH conditions, thus releasing P. Iron phosphate minerals may also dissolve as the iron is reduced and releases P under anaerobic conditions when the soil becomes saturated with water. Aluminum phosphate minerals are stable over a wider range of pH, aerobic and anaerobic conditions, thus holding P in a non-available pool for long periods of time. Phosphorus may be physically removed from aquatic environments simply by the deposition of sediments in the bed of a waterbody. However, the sediment must be left undisturbed to keep the P unavailable. Anything that causes turbulence, such as from motor craft and rough fish activity, can resuspend the sediments and again make this P source available for algal growth.

The information presented above applies to nearly all areas within the Upper Midwest because these are fundamental principles of our natural environment. Therefore, this information is a compilation of results gathered over many years and locations. However, when forming plans for the implementation of NPS pollution management practices, careful consideration must be given to knowledge gained from research projects conducted under conditions similar to those of Iowa.

Evaluation of Nonpoint Source Pollution Research Results

The process of assessing the most applicable conservation practices to manage NPS nutrient pollution for any given location within Iowa requires taking into account the factor of space. Where a research experiment was conducted can influence how applicable the results are to another area. It is then reasonable to give more weight to results from research projects that included similar climatic and landscape factors as to those that exist in Iowa. For example, some aspects of a riparian buffer research experiment conducted in Georgia may give some indication as to the results we may expect from implementing a riparian buffer in Iowa. But if a riparian buffer experiment conducted in Iowa properly measured the same attributes as the project in Georgia, it would be reasonable to give more consideration to the results from the Iowa experiment. This is because there would be a better chance of reproducing the results from the Iowa experiment than those of the Georgia experiment due to the inherent differences in hydrology, temperature, precipitation, soil type and possibly topography between the two states. Differences in space between states are on a rather large scale. Even smaller differences in scale must be addressed.

Some research experiments impose different treatments within the limits of small plots, others at the scale of typical farm fields (i.e., 80 acres), and on occasion, at the scale of entire watersheds. Since these water quality assessments of conservation practices are to apply to entire landscapes within Iowa, which includes many factors that will interact, results from watershed scale experiments must be given more weight than those from field and plot scales. Where watershed scale experimental results for a particular practice do not exist, then field and plot scale studies must be used for reference. Also, to better account for differences in landscapes that exist within the borders of the state, results from research experiments conducted at multiple locations within the state are given more weight than an experiment conducted at a single location. Again, this reasoning is based upon the need to take into account the many factors that may interact at the scale of interest. However, space is not the only important factor in assessing conservation management practices

Another aspect that must be considered is the factor of time. It is more probable that the results of a research experiment conducted over a relatively long period of time will be more reproducible than those of an experiment conducted over a shorter period of time. Iowa's climate is highly variable from one year to another, which greatly impacts nearly every aspect of our natural environment. If a research experiment included the climate effects from only two years and both years were dry (i.e., 1988 and 1989), then the results may not represent effects of a following year that had above average rainfall (i.e., 1993). A research experiment conducted over 4 to 10 years may not include the effects of all the climatic extremes that can occur in Iowa, but the chances are greater for a longer term research experiment to include these effects than a shorter term experiment.

Because of the varied landscape attributes across the state of Iowa, we cannot expect that implementing one conservation practice will suffice to meet water quality goals. The predominant types of limitations will differ from one location to another. Therefore, a suite of options, rather than a single solution, will need to be developed. It is also very likely that to achieve significant NPS contaminant reductions, more than one type of practice may need to be implemented on any given parcel of land. This is important to remember as one assesses the practices to determine recommendations and plans for implementation.

A multitude of publications were referred to in the preparation of the introduction and background sections. A list of these references is provided in Appendix B.

Assessments of Nutrient Management Practices for Water Quality

The USDA Natural Resource Conservation Service (USDA-NRCS) Iowa Field Office Technical Guide contains a coded list of federal government-supported conservation land management practices that provide pertinent criteria and guidelines for the applicability and implementation of these practices. So as to not create conflicts between agencies' policies and waste efforts to "reinvent the wheel," this document includes the conservation practices contained within the USDA-NRCS Iowa Field Office Technical Guide, plus other NPS nutrient management practices that been identified as having a potential to improve Iowa's surface water quality. Again, it must be remembered that the purpose of this document is not to supercede any existing federal or state policies. This document is meant to serve as a supplement to other policy manuals by providing more in-depth, scientific research-based information as to the current potential of these practices in reducing NPS N and P nutrient losses from agricultural production fields.

Each conservation practice assessment has been organized into two components: 1) an assessment summary evaluation that lists and describes the mechanisms of nutrient removal, appropriate conditions for application, conditions that can limit the practice's function and application, sources of variation and range in effectiveness of nutrient contaminant reduction, estimates of average annual and long-term nutrient contaminant reduction if appropriately applied, and the secondary benefits of applying the practice; 2) a table that lists and summarizes the information and data from scientific research studies of the NPS nutrient management practice, and identification of the studies that have been determined to be most pertinent to Iowa's landscapes and climate.

The following summary assessments include estimates of NPS N and P loss reductions in the context and scale of the nutrients being transported from a production field (off-field nutrient losses) or a relatively small watershed. Since most of the reviewed research experiments have been conducted at the field-plot to small watershed scale, it is difficult to extrapolate the results of these studies to larger scales. Future efforts through the use of computer decision aide tools (i.e., program models) may be able to transform these smaller scale research results to larger scales by accounting for the physical and climatic parameters in which the studies were conducted and applying the results to all other similar areas within the state and under varied climatic conditions. At this time, however, basing nutrient loss reduction estimates of these practices at the field scale is appropriate since it is currently the predominant scale at which land management is conducted. The estimates herein are also largely determined from the research studies deemed most pertinent to Iowa (those conducted within Iowa or neighboring states with similar soils and climate), with more weight given to results from longer term experiments conducted at field or watershed scales.

Both N and P consist of soluble and insoluble forms and the off-field transport pathways are similar for these two forms. Accordingly, there are similarities among the practices' nutrient reduction and removal mechanisms by soluble and insoluble forms, but there are some differences in these mechanisms between N and P. I have identified 17 basic reduction and removal mechanisms each for N and P soluble and insoluble (sediment- and particulate-bound) forms from the many scientific literature resources reviewed for the preparation of this document, which are listed below.

Reduction and Removal Mechanisms of Soluble Nutrients

1. Decreased artificially drained soil volume
2. Decreased exposure of nutrients to leaching by preferential flow of soil water through soil macropores or leachate diversion
3. Denitrification (nitrate-N only)
4. Dilution
5. Improved adsorption to soil matrix
6. Improved balance of nutrient application rate with crop demand
7. Improved synchronization of nutrient fertilizer availability with crop demand
8. Increased crop growing season for greater utilization of available nutrients
9. Increased crop nutrient use efficiency (crop assimilation)
10. Reduced applied nutrient load
11. Reduced in-field volume of runoff water
12. Reduced rate of nutrient mineralization (mainly for N)
13. Reduced soluble nutrient fraction within runoff water
14. Reduced volume of runoff water reaching surface waters
15. Reduced volume of shallow ground water drainage
16. Temporary nutrient sequestration in soil organic matter
17. Vegetative assimilation

Reduction and Removal Mechanisms of Insoluble Sediment- and Particulate-Bound Nutrients

1. Dilution
2. Improved balance of nutrient application rate with crop demand
3. Improved stabilization of soil surface to impede wind and water erosion detachment and transport of nutrient enriched sediment and particulates
4. Improved synchronization of nutrient fertilizer availability with crop demand
5. Improved water infiltration and nutrient adsorption to soil matrix
6. Increased crop growing season for greater utilization of available nutrients
7. Increased crop nutrient use efficiency (crop assimilation)
8. Reduced applied nutrient load
9. Reduced erosion and transport of nutrient enriched sediments and particulates
10. Reduced fine-particulate nutrient fraction in runoff water
11. Reduced in-field volume of runoff water
12. Reduced nutrient solubility to soil water and surface water
13. Reduced soil nutrient mineralization rate (mainly for N)
14. Reduced volume of runoff water reaching surface waters
15. Temporary nutrient sequestration in soil organic matter
16. Trapping and retention of transported nutrient enriched sediments and particulates

17. Vegetative assimilation

Current and future research may provide additional mechanisms for N and P nutrient reduction and removal. It is important to point out that these mechanisms do not just represent methods for reducing N and P off-field transport and contamination of surface waters, but many also represent mechanisms to improve crop nutrient use efficiency and farm profitability.

Nitrogen Management Practices

Conservation Practice Summary Assessment

Contaminant: **Total N**

Type of Strategy: **Preventive**

Strategy Name: **Conservation Tillage** (chisel plow, ridge tillage, no-till, etc.)

Pollutant reduction mechanisms
- Reduced soil-N mineralization rate
- Decreased exposure of nutrients to leaching by preferential flow of soil water through soil macropores or leachate diversion
- Reduced erosion and transport of nutrient enriched sediments and particulates
- Improved stabilization of soil surface to impede wind and water erosion detachment and transport of nutrient enriched sediment and particulates
- Reduced in-field volume of runoff water
- Reduced volume of runoff water reaching surface waters
- Temporary nutrient sequestration in soil organic matter
- Trapping and retention of transported nutrient enriched sediments and particulates

Applicable conditions
- All agricultural crop production fields within Iowa

Limiting conditions
- Slopes that are determined too steep for row crop and forage management operations due to potential for erosion and unsafe equipment operations
- Transition period from conventional and reduced tillage systems to equilibrium of subsequent soil physical properties affected by no-till
- Poor field drainage in heavy soils can pose management difficulty for no-till, though can be overcome with proper practices and becomes minimized as field reaches no-till field equilibrium soil conditions

Range of variation in effectiveness at any given point in time

Moderate Tillage vs. Intensive Tillage: -60% to +70%
No-Till vs. Moderate Tillage: -90% to +95%
No-Till vs. Intensive Tillage: -50% to +90%

Intensive tillage refers to a system of moldboard plowing with associated secondary tillage to provide an adequate seedbed for planting plus in-season cultivation. Moderate tillage refers to systems such as chisel plow with associated secondary tillage, disk tillage or disk plow, and ridge tillage. No-till refers to a system that consists only of in-row soil disturbance for seed planting.

Effectiveness depends on:

- Crop rotation and crop present at time of consideration
- Soil type
- Slope and slope length
- Climate
- Antecedent soil moisture content prior to rainfall events
- Rainfall and snowmelt duration and intensity
- Time between N applications and succeeding rainfall event(s)
- Rate of N applications
- Surface vs. knife vs. tillage incorporation of commercial N or manure fertilizer applications
- Degree of soil disturbance from tillage system
- Large rainfall event soon after application of a N fertilizer containing nitrate-N in a soil environment having a continuous network of macropores may lead to elevated nitrate-N leaching losses via preferential flow
- Greater volume of drainage from increased infiltration rates with conservation tillage systems may lead to increased nitrate-N losses, but decrease ammonium-N losses from reduced runoff and erosion
- Reduced fraction of soil water percolating through the soil matrix diminishing contact and transport of soil nitrate-N held within the matrix
- Lower soil temperatures, aeration of soil matrix and mixing of crop residues with soil in conservation tillage systems may result in slower plant residue and soil organic matter decomposition, thus causing a slower rate of N mineralization and less nitrate-N at risk for leaching losses
- Percentage of surface residue cover
- Amount of attached and detached residues
- Type of residue (i.e., corn with high C:N ratio and slow decomposition vs. soybean with low C:N ration and relatively fast decomposition)

<u>Estimated potential contaminate reduction for applicable areas within Iowa (annual basis)</u>

Moderate Tillage vs. Intensive Tillage: -40% to +45%
No-Till vs. Moderate Tillage: -55% to +60%
No-Till vs. Intensive Tillage: -25% to +60%

Major factors that influence N losses across tillage systems are crop rotation, soil type, slope, climate and N fertilizer management. Cropping system and N fertilizer management main effects on N losses are discussed elsewhere in this section of the document. In general, any management practice that reduces runoff and erosion will reduce losses of N forms that are typically sediment-bound or held with residues. A row crop system with intense to moderate tillage is more at risk for runoff-N losses than a minimal or no-till perennial crop that forms nearly complete soil cover. Practices that increase water infiltration may or may not increase losses soluble N forms. The net effect depends upon the balance between a greater fraction of precipitation infiltrating through the soil profile with actual contact of infiltrating water with soluble N in the soil matrix, a soil's water holding capacity (which can be increased with reduced tillage intensity) and water use efficiency of the crop grown. Of course, how much N is at risk for loss depends upon when and how much is supplied in relation to precipitation and crop uptake patterns.

Ammonium-N, organic-N, and total N are usually main forms of N in runoff. Losses of these N forms can be significantly reduced with progressively reduced tillage intensity. Greater residue cover and lesser soil disturbance with reduced tillage tends to increase water infiltration, thereby reducing runoff and erosion of sediments. Increased plant residues can increase losses of organic-N, but this is typically more than compensated by reduced runoff and detachment and transport of soil and fine residue particles from the sheltering effect of the larger residues.

Nitrate-N is the dominant N form associated with leaching losses. The most pertinent research projects have repeatedly determined that there are at best minor statistically significant differences between tillage systems in concentrations and load losses. The reduced soil-N mineralization and fraction of soil water that percolates through the soil matrix that reduces nitrate-N transport tends to be offset with greater drainage volumes in conservation tillage systems. Factors such as precipitation amount and intensity, N fertilizer loading rate and timing of application, and cropping system have much more impact on N losses from agricultural production fields. Thus, to achieve significant reductions in N contamination of surface waters within Iowa, changing tillage systems alone will not suffice. Other conservation practices will need to be adopted.

<u>Estimated long-term contaminant reduction for applicable areas in Iowa (multi-year basis)</u>

Moderate Tillage vs. Intensive Tillage: +3%
No-Till vs. Moderate Tillage: +5%
No-Till vs. Intensive Tillage: +10%

The most influential factors of tillage on nonpoint source N pollution are the percentage of remaining residue cover, ratio of attached residue to detached residue, water infiltration rate and storage, and N cycling dynamics within the soil. Conservation tillage systems can vary dramatically in these attributes. Attached residue is more effective at stabilizing and protecting the soil surface than detached residue, which can be transported from slope to depression areas and leave the slope areas without residue cover. Tillage systems that increase a soil's porosity, macropores and continuous macropores will increase water infiltration rates and decrease runoff. Water storage and moisture content will typically increase as residue cover increases and soil disturbance decreases. The overall impact of a tillage system on N loss depends upon how the tillage system affects partitioning of precipitation between runoff, storage, evapotranspiration and leaching (this being referred to as a water budget).

Extent of research

Moderate

While most tillage research within Iowa and neighboring states has been limited in the context of corn and soybean production systems, experiments have been conducted within most of Iowa's agroecoregions. Some of these experiments have been conducted over fairly long periods of time, then taking into account annual and seasonal variations in climate. However, there is limited information for various tillage systems applied on larger scales, such as that of a watershed. The Deep Loess Research Station near Treynor, Iowa is one of the few sites of such research. Though this site represents just one of the agroecoregions within Iowa, it is one of the most environmentally fragile agroecoregions, thus demonstrating the higher potential benefits of conservation tillage soil management. An appreciable amount of tillage research on subsurface drainage water quality has been conducted at the Iowa State University research farm near Nashua in northeast Iowa also.

One serious limitation of current tillage research is that few experiments have reported N loss data from both runoff and leaching pathways. Most experiments report tillage treatment effects on either runoff or shallow subsurface water quality, but not both. To adequately understand the risks of N loss from tillage treatments it is especially important to measure both runoff and leaching components since different forms of N dominate the two pathways and can be present in substantial amounts. Therefore, at this time it is rather difficult to make highly accurate assessments of tillage program effects on an overall surface water quality basis. It would be helpful to know how N losses are partitioned between the two pathways for each tillage system in each agroecoregion. For instance, knowing a general ratio of runoff total N loss to leaching total N loss for each tillage system for given soil types, slope and climate could improve land use management. One should not mix results from different experiments from differing sites and years. With that word of caution and the lack of better information, by compiling the data in the accompanying summary table the general ratios of runoff total N loss to leaching total N loss for each tillage system are as follows:

Intensive Tillage runoff total N: leaching total N = ~1:1
Moderate Tillage runoff total N: leaching total N = ~1:2
No-Till runoff total N: leaching total N = ~1:5

Actual runoff total N: leaching total N ratios by tillage system and location will likely differ from these broad generalizations and need to be known. Future experiments need to address this issue with a more holistic approach in the research plans.

Secondary benefits

- Significant reductions in P contamination of surface waters, depending upon the conservation tillage systems implemented (no-till being most effective)
- Significant reductions in erosion and transport of sediment to surface waters, depending upon the conservation tillage systems implemented (no-till being most effective)
- Reduced pesticide contamination of surface waters
- Soil conditions that offer a buffer for production in periods of below-average precipitation
- Reduced equipment requirements with no-till

Conservation Practice Research Summary Table

Contaminant: **Total N**

Type of Strategy: **Preventive**

Strategy Name: **Conservation Tillage** (chisel plow, ridge tillage, no-till, etc.)

References significant to Iowa identified in bold italics.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Randall and Iragava-rapu, 1995 **CT vs. NT**	Waseca, MN, US: Webster clay loam soil	11-yr	Field-plot	CC[2] w[3] 178 lb N/a spring applied.	Leaching to shallow groundwater	 CT[4] NT[5]	11-yr ave. annual NO3-N[6] mass loss NO3-N conc. 38.2 lb NO3-N/a 13.4 ppm NO3-N 36.5 lb NO3-N/a 12.0 ppm NO3-N	 – – 4.4% 10.4%	Tile flow measured at a minimum of 5 days per week. Water samples for NO3-N content taken X3/week. Years with highest precipitation yielded greatest NO3-N concentra-tions and load losses for both tillage systems.	<u>Tillage system had minimal impact on nitrate losses, growing season precipitation being larger factor.</u> Lower NO3-N losses and concentration with NT possibly due to lower N mineralization rates than with CT, and preferential flow of infiltrating water, bypassing the soil matrix, although NT had greater drainage volume.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Kanwar et al., 1997 **MP vs. CP vs. MNT vs. RT systems**	Nashua, IA, US; Floyd, Kenyon and Readlyn loam soils	3-yr	Field-plot	Multiple combin-ations of MP[7], MNT[8], RT[9] and CP[10] with Corn-Soybean (CS[11]), Soybean-Corn (SC[12]), Contin-uous Corn (CC). CC received spring applied 180 lb N/a; C in CS received spring applied 150 lb N/a	Leaching to shallow ground-water		3-yr ave. annual NO3-N mass loss and 3-yr ave. NO3-N conc.		Tile drainage flow was monitored continuously during periods of flow. Water samples for NO3-N concentration were taken X3/week.	Lower NO3-N concentrations with MNT indicating preferential flow of infiltrating water through macropores, bypassing the soil matrix. MP had consistently higher NO3-N concentrations than other tillage systems indicating intense tillage destroyed macropore networks and infiltrating water moved through soil matrix and intercepted more soil NO3-N. CP and MNT had greater drainage volume losses, but only in CC did MNT result in greater NO3-N load losses than MP and RT, CP consistently had greater NO3-N load losses. Cropping system greatly influenced N loss with tillage programs. <u>However, no significant differences between tillage systems.</u>
						<u>C</u>C MP	42 lb NO3-N/yr; 38 ppm NO3-N	_ _		
						CP	58 lb NO3-N/yr; 32 ppm NO3-N	-38%; 16%		
						RT	49 lb NO3-N/yr; 25 ppm NO3-N	-17%; 34%		
						MNT	57 lb NO3-N/yr; 23 ppm NO3-N	-36 %; 39%		
						<u>C</u>S MP	25 lb NO3-N/yr; 20 ppm NO3-N	_ _		
						CP	32 lb NO3-N/yr; 20 ppm NO3-N	-28%; 0%		
						RT	21 lb NO3-N/yr; 17 ppm NO3-N	16%; 15%		
						MNT	21 lb NO3-N/yr; 15 ppm NO3-N	16%; 25%		
						<u>S</u>C MP	29 lb NO3-N/yr; 21 ppm NO3-N	_ _		
						CP	31 lb NO3-N/yr; 20 ppm NO3-N	-7%; 5%		
						RT	23 lb NO3-N/yr; 16 ppm NO3-N	21%; 24%		
						MNT	22 lb NO3-N/yr; 14 ppm NO3-N	24%; 33%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Bakhsh et al., 2000 CP vs. NT systems	Nashua, IA, US; Floyd, Kenyon and Readlyn loam soils	6-yr	Field-plot	CP and NT CS rotation with N fertilizer applied to corn either as single spring pre-plant (SA) or late spring soil nitrate test (LSNT[13]) based sidedress N management systems. N rates varied by management system with LSNT programs (6-yr ave. 159 lb N/a for NT, 139 lb N/a for CP) having greater N rates than single spring pre-plant (98 lb N/a)	Potential leaching to shallow ground-water		6-yr ave. post-harvest residual soil NO3-N mass		Soil samples take to 4 ft depth just prior to planting and after harvest of both crops. Differences in applied N rates make comparison valid only by management system where the single spring pre-plant N application rate was lower than typical normal N application rates.	Increases in residual soil NO3-N following soybean compared to corn was attributed the release of soil-N that was temporarily immobilized while corn residues were decomposing and additions of soybean N fixation contributions. Although not significant, NT practices had lower residual soil NO3-N levels.
						CCPSA[14] at 98 lb N/a, C1[15]	24.0 lb NO3-N/a	–		
						CCPLS[16] at 139 lb N/a	29.4 lb NO3-N/a	-22.5% C1		
						CNTSA[17] at 98 lb N/a, C2[18]	18.7 lb NO3-N/a	22.1% C1		
						CNTLS[19] at 159 lb N/a	25.8 lb NO3-N/a	-7.5% C1 -38.0% C2		
						SCPSA[20] wo[21] N applied, C3[22]	31.2 lb NO3-N/a	-30.0% C1		
						SCPLS[23] wo N applied	34.7 lb NO3-N/a	-44.6% C1 -11.2% C3		
						SNTSA[24] wo N applied, C4[25]	24.9 lb NO3-N/a	-3.8% C1		
						SNTLS[26] wo N applied	25.8 lb NO3-N/a	-7.5% C1 -3.6% C4		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Bakhsh et al., 2002 CP vs. NT systems	Nashua, IA, US; Floyd, Kenyon and Readlyn loam soils	6-yr	Field-plot	CP and NT CS rotation with N fertilizer applied to corn either as single spring pre-plant (SA) or late spring soil nitrate test (LSNT) based sidedress N management systems. N rates varied by management system with LSNT programs (6-yr ave. 159 lb N/a for NT, 139 lb N/a for CP) having greater N rates than single spring pre-plant (98 lb N/a)	Leaching to shallow ground-water		6-yr ave. flow-weighted NO3-N concentration and NO3-N mass loss		Tile drainage flow was continuously recorded and water samples automatically taken when sump was operating. Tile drainage flow and NO3-N mass losses were significantly affected by annual variations in precipitation volume. Differences in applied N rates make comparison valid only by management system where the single spring pre-plant N application rate was lower than typical normal N application rates.	Single spring N application had less NO3-N mass loss in CP, but higher losses in NT due to longer period to flush NO3-N through more continuous macropore system of NT. CP systems had lower NO3-N mass losses despite higher concentrations due to reduced volume of drainage flow. NT systems had lower NO3-N concentrations possibly due to more water infiltrating through macropores than soil matrix and lower N mineralization rates than CP. Crop species and timing of N fertilizer application influenced N losses from tillage systems.
						CCPSA at 98 lb N/a, C1	12.0 ppm NO3-N; 12.5 lb NO3-N/a	– –		
						CCPLS at 139 lb N/a	11.7 ppm NO3-N; 15.1 lb NO3-N/a	2.5% C1; -20.8% C1		
						CNTSA at 98 lb N/a, C2	10.7 ppm NO3-N; 22.2 lb NO3-N/a	10.8% C1; -77.6% C1		
						CNTLS at 159 lb N/a	11.4 ppm NO3-N; 11.6 lb NO3-N/a	5.0% C1; 7.2% C1: -6.5% C2; 47.7% C2		
						SCPSA wo N applied, C3	10.4 ppm NO3-N; 11.6 lb NO3-N/a	13.3% C1; 7.2% C1		
						SCPLS wo N applied	9.2 ppm NO3-N; 14.2 lb NO3-N/a	23.3% C1; -13.6% C1: 11.5% C3; -22.4% C3		
						SNTSA wo N applied, C4	8.3 ppm NO3-N; 17.8 lb NO3-N/a	30.8% C1; -42.4% C1		
						SNTLS wo N applied	9.1 ppm NO3-N; 10.7 lb NO3-N/a	24.2% C1; 14.4% C1: -9.6% C4; 39.9% C4		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Kanwar et al., 1996 **CT vs. MNT systems**	Nashua, IA, US; Floyd, Kenyon and Readlyn loam soils	3-yr	Field-plot	Multiple combinations of MNT, CT with Corn-Soybean (CS), Soybean-Corn (SC), Continuous Corn (CC), Corn-Soybean-Oat w Berseem Clover Cover Crop (CSOBC[27]) and Alfalfa-Alfalfa-Alfalfa-Corn-Soybean Oat (AAACSO[28]) cropping rotations. Corn yrs had either no N fertilizer in AAACSO rotation or 100 lb N/a spring pre-plant, 120 lb N/a spring	Leaching to shallow ground-water	CT CC w fall manure	<u>3-yr ave values</u> 29.4 lb NO3-N/a 14.1 ppm NO3-N	_ _	First yr of experiment had much above normal rainfall (1993). Tile drainage flow and NO3-N concentration were monitored continuously during periods of flow.	<u>Slight trend of lower NO3-N concentration and load losses with MNT.</u> CS typically had lower NO3-N losses and concentrations than CC rotation. Elevated NO3-N losses in soybean likely due to carry-over of soil-N, particularly for the manured treat-ments where N rates were far above target in 2 of 3 yrs. AAACSO and CSOBC rotations led to dramatic reductions in NO3-N losses and concentration.
						CT CC w spring 120 lb N/a	21.5 lb NO3-N/a 11.3 ppm NO3-N	26.8% 19.8%		
						CT C, MNT S w fall manure	17.8 lb NO3-N/a 11.3 ppm NO3-N	39.4% 19.8%		
						CT C, MNT S w spring 100 lb N/a	12.6 lb NO3-N/a 9.6 ppm NO3-N	57.1% 31.9%		
						CT C, MNT S w LSNT N	14.6 lb NO3-N/a 10.3 ppm NO3-N	50.3% 27.0%		
						MNT CS w spring 100 lb N/a	25.0 lb NO3-N/a 9.0 ppm NO3-N	15.0% 36.2%		
						MNT CS w LSNT N	10.9 lb NO3-N/a 9.2 ppm NO3-N	62.9% 34.8%		
						MNT S, CT C w fall manure	22.8 lb NO3-N/a 7.8 ppm NO3-N	22.4% 44.7%		
						MNT S, CT C w 100 lb spring N/a	12.4 lb NO3-N/a 10.8 ppm NO3-N	57.8% 23.4%		
						MNT S, CT C w LSNT N	14.5 lb NO3-N/a 6.8 ppm NO3-N	50.7% 51.8%		
						MNT SC w spring 100 lb N/a	19.6 lb NO3-N/a 6.9 ppm NO3-N	33.3% 51.1%		
						MNT SC w LSNT N	9.2 lb NO3-N/a 6.4 ppm NO3-N	68.7% 54.6%		
						CSOBC	13.0 lb NO3-N/a 7.0 ppm NO3-N	55.8% 50.4%		
						AAACS	11.0 lb NO3-N/a 5.7 ppm NO3-N	62.6% 59.6%		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Bjorneberg et al., 1998 **CP vs. MNT systems**	Nashua, IA, US; Floyd, Kenyon and Readlyn loam soils	3-yr	Field-plot	Corn-Soybean-Corn Rotation (CSC[29]) Soybean-Corn-Soybean Rotation (SCS[30]) All spring pre-plant treatments received an ave of 98 lb N/a/yr Each MNT w LSNT treatment received an ave of 150 lb N/a/yr Each CP w LSNT treatment received an ave of 122 lb N/a	Leaching to shallow ground-water	 CP w spring pre-plant N, CSC C1 CP w spring pre-plant N, SCS C2 MNT w spring pre-plant N, CSC C3 MNT w spring pre-plant N, SCS C4 CP w LSNT, CSC C5 CP w LSNT, SCS C6 MNT w LSNT, CSC MNT w LSNT, SCS	3-yr total NO3-N mass loss and ave. flow-weighted concentration 43 lb/a NO3-N 10.2 ppm NO3-N 41 lb/a NO3-N 11.3 ppmNO3-N 70 lb/a NO3-N 9.8 ppm NO3-N 67 lb/a NO3-N 7.6 ppm NO3-N 45 lb/a NO3-N 11.3 ppm NO3-N 51 lb/a NO3-N 7.4 ppm NO3-N 35 lb/a NO3-N 9.3 ppm NO3-N 34 lb/a NO3-N 6.8 ppm NO3-N	– – – – -62.8%C1 3.9%C1 -63.4%C2 32.7%C2 -4.6%C1 -10.8%C1 -24.4%C2 34.5%C2 50.0%C3 5.1%C3 22.2%C5 17.7%C5 49.2%C4 10.5%C4 33.3%C6 8.1%C6	Flow and NO3-N concentration measured from mid-March to early December.	Mixed results in total drain flow on basis of tillage, crop sequence and N management was attributed to confounding from previous crop and tillage experiment on the same plots. Degree of NO3-N mass and concentration losses dependent upon N fertilizer application rate and timing. Significant differences of NO3-N concentrations and load losses suggest that combining MNT with the split application LSNT N fertilizer management program can have positive affect on water quality compared to the chisel plow and single pre-plant N application systems.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Karlen et al., 1998 **CT vs. RT systems**	Treynor, IA, US; Monona-Ida-Napier soil association (deep loess soils)	3-yr	Water-shed	CC RT at ave. sidedressed N at 130 lb N/a Vs. CT at ave. spring pre-plant applied 169 lb N/a	Potential leaching to shallow ground-water		Estimated 3-yr TN[31] mass losses derived from calculated N budget		Soil NO3-N samples taken prior to spring pre-plant application and in June.	Primary effect of N losses attributed to differences in N rate and application method, not tillage.
						CT, 169 lb N/a Spring pre-plant	250.1 lb/a TN	_		
						RT, 130 lb N/a sidedressed	185.6 lb/a TN	25.8%		
Kanwar and Baker, 1993 **MP vs. NT systems**	Boone, IA, US; Clarion-Nicollet-Webster soil association	8-yr	Field-plot	CC Data shown from treatment of single N application at 155 lb N/a. Tillage systems were CT and NT.	Leaching to shallow ground-water	Distance is depth in soil profile	8-yr ave. shallow groundwater NO3-N concentrations by depth in soil profile	Reduction %s for similar depth increments	Water samples taken periodically throughout each yr.	Suggested that the consistent greater NO3-N concentrations under MP due to higher N mineralization rates and less leaching of soil NO3-N than with NT. Denitrification suggested as mechanism for decreasing NO3-N concentrations by depth for both tillage systems.
						MP, 4 ft	22.3 ppm NO3-N	_		
						MP, 6 ft	14.7 ppm NO3-N	_		
						MP, 8 ft	14.4 ppm NO3-N	_		
						MP, 10 ft	12.1 ppm NO3-N	_		
						MP, 12 ft	8.8 ppm NO3-N	_		
						NT, 4 ft	15.0 ppm NO3-N	32.7%		
						NT, 6 ft	14.0 ppm NO3-N	4.8%		
						NT, 8 ft	12.4 ppm NO3-N	13.9%		
						NT, 10 ft	8.7 ppm NO3-N	28.1%		
						NT, 12 ft	5.2 ppm NO3-N	40.9%		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Katupitiya et al., 1997	Clay Center, NE, US; Hastings and Crete soil loam soils	8-yr	Field-plot	Furrow irrigated CC with single spring pre-plant application of N based on soil-test results, which averaged 174 lb N/a. Tillage systems were DP[32], RT and SP[33]	Leaching to shallow ground-water	DP RT SP	8-yr ave. residual soil NO_3-N mass 97.0 lb/a NO_3-N 66.8 lb/a NO_3-N 69.7 lb/a NO_3-N	_ 31.1% 28.1%	Soil cores samples taken annually either in the fall after harvest or following spring before planting	Greater N mineralization with DP due to crop residue being more incorporated within the soil with fall tillage than with RT and SP systems.
Eghball et al., 2000 **Grass Hedge Buffer Strips and Till vs. No-Till**	Treynor, IA, US; Monona silt loam with 12% slope	Summer	Plot, buffer ~2.5 ft wide, 12 ft X 35 ft rainfall simulation plots.	Disk tilled (DT) and no-till (NT) CC with either inorganic or manure fertilizer. Manure at rates of 336 lb N/a and 228 lb P/a. Inorganic fertilizer at rates of 134 lb N/a and 23 lb P/a.	Surface runoff	DT NT	Sum NO_3-N, NH_4-N and TN mass losses of initial + second rainfall simulations 4.495 lb/a NO_3-N 0.268 lb/a NH_4-N 13.885 lb/a TN 2.397 lb/a NO_3-N 0.193 lb/a NH_4-N 5.897 lb/a TN	_ _ _ 46.7% 28.0% 57.5%	Runoff water samples collected at 5, 10, 15, 30, and 45 minutes after initiation of runoff. Initial rainfall simulation of 1 hr at 2.5in/hr. Second rainfall simulation conducted 24 hr later at same time and rate.	Additions of inorganic and manure fertilizers increased losses all P forms, except manure PP. Although having appreciable reduction %s, no statistical significant reductions on actual data existed.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treat-ments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Laflen and Tabatabai, 1984 **MP vs. CP and RT systems**	2 sites, Ames and Castana, IA, US; Clarion sandy loam near Ames, Monona silt loam near Castana	Not reported	Plots (10X35 ft), rain simul-ations	Across 4 crop rotations (CC, SC, CS, SS) Soybean fertilized at rates of 23 lb N/a and 33 lb P/a; corn at 124 lb N/a and 33 lb P/a.	Surface runoff	Clarion Soil MP CP NT Monona Soil MP CP NT	Ave NH4-N and NO3-N concentr-ation and mass loss from sediment filtered runoff water 0.19 ppm NH4-N 0.021 lb/a NH4-N 0.18 ppm NO3-N 0.024 lb/a NO3-N 0.58 ppm NH4-N 0.068 lb/a NH4-N 0.21 ppm NO3-N 0.024 lb/a NO3-N 1.23 ppm NH4-N 0.171 lb/a NH4-N 1.59 ppm NO3-N 0.185 lb/a NO3-N 0.23 ppm NH4-N 0.069 lb/a NH4-N 0.32 ppm NO3-N 0.095 lb/a NO3-N 0.64 ppm NH4-N 0.179 lb/a NH4-N 0.86 ppm NO3-N 0.245 lb/a NO3-N 2.02 ppm NH4-N 0.615 lb/a NH4-N 1.78 ppm NO3-N 0.594 lb/a NO3-N	_ _ _ _ -205.2% -223.8% -16.7% 0.0% -547.4% -714.3% -783.3% -670.8% _ _ _ _ -178.3% -159.4% -168.8% -157.9% -778.3% -791.3% -456.3% -525.3%	Simulated rainfall rate of 2.5 in/hr for 1 hr (~25 yr. storm) 3 weeks (Monona) or 7 weeks after planting. Surface runoff water and flow rate sampled 1 minute after initiation of runoff, then at 5 minute intervals for next 5 measures, then at 10 minute intervals to end of simulation. Fertilizers surface applied either the day prior to, or day of, planting.	Although there are great differences on a relative basis, actual differences are mostly minor due to low concentrations and loads. Increased N losses from reduced incorporation of fertilizer. N concentr-ations in runoff and runoff sediment by rotation were NT>CP>MP. However, TN mass losses were MP>CP>NT because erosion and runoff volume was much greater with increased tillage. High erosion loads for a 1-hr rainfall event on Monona soil plots. Included both soils separately because of this large difference. Authors state that NT had greater runoff volume, but do not indicate how many years of no-till existed for the plots. Early years for no-till are transitional in physical properties and have less runoff and greater infiltration than tillage with time.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treat-ments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Laflen and Tabatabai, 1984 (cont.) **MP vs. CP and RT systems**	2 sites, Ames and Castana, IA, US; Clarion sandy loam near Ames, Monona silt loam near Castana	Not reported	Plots (10X35 ft), rain simul-ations	Across 4 crop rotations (CC, SC, CS, SS) Soybean fertilized at rates of 23 lb N/a and 33 lb P/a; corn at 124 lb N/a and 33 lb P/a.	Surface runoff		Ave. TN concentr-ation and mass from runoff sediment		See above	See above
						Clarion <u>Soil</u> MP	2370 ppm TN 4.64 lb/a TN	_ _		
						CP	2720 ppm TN 2.68 lb/a TN	-14.8% 42.2%		
						NT	2940 ppm TN 2.03 lb/a TN	-24.0% 56.2%		
						Monona <u>Soil</u> MP	1620 ppm TN 67.13 lb/a TN	_ _		
						CP	1770 ppm TN 49.10 lb/a TN	-9.2% 26.8%		
						NT	2020 ppm TN 20.56 lb/a TN	-24.7% 69.4%		
Johnson et al., 1979 **MP vs. DP and RT systems**	Castana, IA, US; Loess Hills, Monona-Ida-Napier soils	4-yr	Small watershed, treatment areas ranging in size from 1.4-4.3 a	CC N fertilizer applied at rate of 150 lb N/a	Surface runoff		4-yr flow-weighted average NH4-N and NO3-N concentrations		Runoff flow monitored from mid-April to mid-October each yr. Number of runoff water samples varied depending upon the duration of natural precipitation events. Typically 3-4 samples taken per event, but up to 6 for longer duration events.	No significant differences in NH4-N and NO3-N concentrations in runoff between the 3 tillage treatments. However, there was a trend towards reduced N losses with reduced tillage. N loss in runoff was associated with sediment loss to the degree of 75% for reduced tillage to 99 percent with MP.
						MP	0.19 ppm NH4-N 0.73 ppm NO3-N	_ _		
						DP	0.15 ppm NH4-N 0.82 ppm NO3-N	21.0% -12.3%		
						RT	0.15 ppm NH4-N 0.55 ppm NO3-N	21.0% 24.6%		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
McCracken et al., 1995	GA, US; sandy loam soil.	2-yr	Field-plot	CT and NT CC with spring applied 150 lb N/a. Rye cover crop fall planted following harvest.	Leaching to shallow ground-water	 CT NT	2-yr NO3-N mass loss 35.1 lb NO3-N 41.0 lb NO3-N	 _ -16.8%	Middle of study period experienced above normal precipitation, below normal precipitation at the beginning. Water sampled continuously.	Greater drainage volume with NT than CT due to greater amount of undisturbed macropores conducting more drainage from summer precipitation than with disturbed soil conditions of CT.
Angle et al., 1984	Howard Co., MD, US; Manor loam soil series	3-yr	Small water-shed, treatment areas ranging is size from 0.6-0.9a and 6-7% slopes	CC N fertilizer applied in spring at rate of 60 lb N/a	Surface runoff	 CT wo Winter Cover Crop NT w Winter Cover Crop	3-yr total sum NH4-N, NO3-N and TN mass loss in runoff 2.90 lb/a NH4-N 5.83 lb/a NO3-N 15.51 lb/a TN 0.21 lb/a NH4-N 0.73 lb/a NO3-N 1.94 lb/a TN	 _ _ _ 92.8% 87.5% 87.5%	Runoff water samples collected after each rainfall event during baseline calibration and experimental period.	CT watershed had significantly greater mass losses of all forms of N measured. CT watershed also had much greater runoff volume and transported sediment than the NT watershed. Reductions in these factors theorized as mechanisms for reduced N losses.
Seta et al., 1993 CT vs. CP vs. NT	Lexington, KY, US; Maury silt loam	2-day rainfall simulation	Plot	CC P fertilizer applied at rate of 39 lb P/a	Surface runoff	 CT CP NT	Mean concentr-ation and total mass NO3-N and NH4-N loss in runoff 9.8 ppm NO3-N 3.20 lb/a NO3-N 3.6 ppm NH4-N 1.16 lb/a NH4-N 8.7 ppm NO3-N 1.51 lb/a NO3-N 6.5 ppm NH4-N 0.62 lb/a NH4-N 13.6 ppm NO3-N 0.44 lb/a NO3-N 8.4 ppm NH4-N 0.44 lb/a NH4-N	 _ _ _ _ 11.2% 52.8% -80.6% 46.6% -38.8% 86.2% -133.3% 62.1%	Rainfall intensity was ~2.6 in/hr, 1 hr run first day, 2 30 min. runs 2nd day with 0.5 hr between runs. Runoff water samples collected at 1, 3, 6, 10, 15, 23 and 33 minutes after initiation of runoff.	Although NT had a significantly a higher NO3-N concentration, mass losses for NO3-N and NH4-N were much less with NT. Reduction mechanisms attributed to reduced volume of runoff, greater infiltration resulting from less surface soil sealing and more undisturbed macropores, and less transported sediment due to soil sheltering from increased residue cover.

1 Watershed, field, plot or laboratory.
2 CC represents continuous corn.
3 w represents with.
4 CT represents conventional tillage.
5 NT represents no-tillage.
6 NO3-N represents nitrate-nitrogen
7 MP represents moldboard plow tillage followed by disking.
8 MNT represents modified no-tillage (summer cultivation).
9 RT represents ridge tillage.
10 CP represents chisel plow followed by disking and possibly with summer cultivation.
11 CS represents corn-soybean rotation in corn year.
12 SC represents corn-soybean rotation in soybean year.
13 LSNT represents late spring soil-nitrate test.
14 CCPSA represents corn, chisel plow, single spring application of nitrogen fertilizer system.
15 C1 represents control 1 and comparison to control 1.
16 CCPLS represents corn, chisel plow, late spring soil-nitrate test N fertilizer split application system.
17 CNTSA represents corn, no-till, single spring application of nitrogen fertilizer system.
18 C2 represents control 2 and comparison to control 2.
19 CNTLS represents corn, no-till, late spring soil-nitrate test N fertilizer split application system.
20 SCPSA represents soybean, chisel plow, single spring application of nitrogen fertilizer system.
21 wo represents without.
22 C3 represents control 3 and comparison to control 3.
23 SCPLS represents soybean, chisel plow, late spring soil-nitrate test N fertilizer split application system.
24 SNTSA represents soybean, no-till, single spring application of nitrogen fertilizer system.
25 C4 represents control 4 and comparison to control 4.
26 SNTLS represents soybean, no-till, late spring soil-nitrate test N fertilizer split application system.
27 CSOBC represents corn-soybean-oat with berseem clover crop rotation.
28 AAACSO represents alfalfa-alfalfa-alfalfa-corn-soybean-oat crop rotation.
29 CSC represents corn-soybean-corn crop rotation.
30 SCS represents soybean-corn-soybean crop rotation.
31 TN represents total nitrogen.
32 DP represents disk-plant.
33 SP represents slot-plant.

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Conservation Practice Summary Assessment

Contaminant: **Total N**

Type of Strategy: **Preventive**

Strategy Name: **Cover Crops**

Pollutant Reduction Mechanisms:

- Improved stabilization of soil surface to impede wind and water erosion detachment and transport of nutrient enriched sediment and particulates
- Improved water infiltration and nutrient adsorption to soil matrix
- Increased crop growing season for greater utilization of available nutrients
- Reduced in-field volume of runoff water
- Reduced erosion and transport of nutrient enriched sediments and particulates
- Temporary nutrient sequestration in soil organic matter
- Trapping and retention of transported nutrient enriched sediments and particulates
- Vegetative assimilation

Applicable Conditions:

- Any row cropping system that has adequate time following harvest of the primary crop for the planting and establishment of the cover crop plant species prior to on-set of winter conditions.

The time period required for cover crop plant establishment varies depending upon the selected plant species. A few methods exist to plant a cover crop during the primary crop's growing season (i.e., seed spreader mounted on a cultivator, rotary or drop spreader for surface seeding under a full soybean canopy, and aerial seeding) to extend the time period for cover crop establishment and growth. Time is limited following soybean and corn harvest in Iowa for most cover crop species. Currently in Iowa, cover crops are most applicable following seed corn, sweet corn, silage corn and small grain production systems where the primary crops are harvested and removed in mid- to late-summer. Additionally, winter-hardy cover crops such as winter rye or winter wheat can be planted following early maturing soybean or corn cultivars.

Limiting Conditions:

- Limited time period from planting to on-set of winter
- Non-growing season period (winter) of cover crop plant species
- Limited runoff and shallow ground water residence time (i.e., from coarse soil texture and/or steep terrain gradient)
- Wet soil conditions following harvest of primary crop that would impede planting of the cover crop

- Inadequate precipitation following planting for cover crop plant establishment
- If using winter annual plant species, wet spring soil conditions that would impede chemical or tillage kill operations of the cover crop
- Winter annual small grain cover crops must be killed two to three weeks prior to planting of the primary crop

<u>Range of variation in effectiveness at any given point in time</u>

-20% to +90%

Effectiveness depends on:

- Temperature either detrimental or beneficial for cover crop growth
- Inadequate or excessive precipitation that is detrimental to cover crop growth and impedes planting operations
- The degree of soil-N removal by vegetative assimilation is dependent upon the type of plants species used (i.e., summer annual, winter annual, grass, brassica, or legume)
- Percentage of surface residue cover
- Crop rotation and previous primary crop
- Tillage program and associated degree and timing of soil disturbance
- Soil type
- Slope and slope length
- Antecedent soil moisture content just prior to rainfall events
- Rainfall and snowmelt duration and intensity
- Timing and rate of N fertilizer applications and succeeding rainfall event(s)
- Decomposition and mineralization of cover crop residue-N prior to established root system of subsequent primary crop may lead to increased N losses, though infrequent, is a risk with legume cover crops
- With good establishment of cover crop, adequate period (spring and/or fall) of warm temperatures, limited to no concentrated runoff flow, total-N, ammonium-N and nitrate-N removal can be substantial

<u>Estimated potential contaminate reduction for applicable areas within Iowa (annual basis)</u>

+10% to +70%

The time period required for cover crop plant establishment varies depending upon the selected plant species. A few methods exist to plant the cover crop during the primary crop's growing season (i.e., seed spreader mounted on a cultivator and aerial seeding) to extend the time period for cover crop establishment and growth. Typically in Iowa, time is limited following soybean and corn harvest for most cover crop species to establish well, though research is making some progress to solve this problem.

Temperature and precipitation greatly affects cover crop plant emergence and growth rate, and uptake and retention of N. Cover crops can establish dense surface cover given warm temperatures, plentiful rainfall, and proper planting. In cold and dry conditions few plant species are able to germinate and establish. Any cover crop plant species that is able to establish well and achieve significant biomass growth in the short period of time available from harvest of the primary crop to the onset of winter will perform much better than those that are not adapted to these conditions. Intense rainfall shortly after cover crop planting can wash the seeds to low areas and ponding can reduce cover crop stands. Nitrate uptake (assimilation) varies greatly by cover crop plant species. Grasses have shown to be much more effective at assimilating available soil-N than legumes. Brassicas (mustard, rape, turnip, etc.) tend to be intermediate in comparison to grasses and legumes. As a group, grasses and brassicas are typically 2-3 times more effective than legumes in reducing nitrate leaching. Grasses such as rye have shown to be much more effective than legumes because they can establish in cool conditions and have a denser and more fibrous root system than legumes. Legumes have shown in some studies to increase soil-nitrate concentrations and this has been attributed to their N-fixation. Alternatively, other studies have shown legumes, such as alfalfa, to decrease soil-nitrate concentrations. Thus, if reducing nitrate loss is a primary goal, grass species are a good choice for cover crops.

Differences also exist between cover plant species on how they affect N cycling dynamics. The N assimilated into grass organic matter is less available for the succeeding year's crop than that of legumes and brassicas because decomposition and release of N from grass residue occurs more slowly. Removal of a cover crop - by either chemical or mechanical means – needs to be carefully managed to time the release of the cover crop organic N with the N demands of the succeeding crop. Therefore, the N demands of the succeeding crop need to balance with the environmental goals of the cover crop. For corn following soybean, oat is one of the most suitable cover crop options. When overseeded into soybean, oat will likely have an opportunity for good establishment and a long enough period of growth before winter kill to provide substantial surface cover and uptake of residual soil nitrate. Because oat does winter kill it will not require any addition field operations in the spring to remove the cover crop. Additionally, oat will not require much additional operating expense because the seed is inexpensive.

Crop rotation and the type of crop grown prior to seeding of a cover crop, tillage program, soil type and slope can all significantly influence the water quality benefits of a cover crop. A cover crop has a greater potential to reduce ammonium and organic N losses in runoff from cropping systems and site conditions that are inherently more prone to erosion than for others that pose a lesser erosion risk. Continuous corn tends to be less erosive than a corn-soybean rotation because corn leaves greater amounts of residue cover than does soybean and corn residue persists longer than soybean because it's higher C:N ratio makes it more resistant to decomposition. Therefore, a cover crop has a greater probability for reducing ammonium and organic N losses in runoff from soybean fields than corn fields. A cover crop may or may not reduce total N losses from a field that has highly erodable soils. The net effect depends upon the balance of the amount of N at risk to erosion loss (ammonium and organic N) versus the amount at risk to leaching loss (nitrate-N). For fields with a low risk of erosion, the net effect on N loss depends more upon the balance of the amount of N at risk to leaching loss versus the amount of cover crop N uptake.

Although cover crops have shown marked reductions in runoff volume and losses of total N and nitrate mass (load), the total N concentration of any runoff and leached water that does occur may actually be higher than without a cover crop. Runoff from non-cover crop and cover crop fields may transport equal amounts of fine, clay-sized particles due to preferential transport over larger particles. Fine particles have a greater capacity to adsorb nutrients than larger soil particles. Because runoff volume would typically be less from cover crop fields than non-cover crop fields and if the two field types carry equal amounts of fine particles (due to preferential transport), then there is a potential for a cover crop field to have a higher total N nutrient concentration. In essence, there could be a runoff dilution effect from a non-cover crop field, though the total N runoff load may be higher due to a greater runoff volume.

Decreased runoff volume from cover cropped areas is primarily attributed to an increased water infiltration rate. Water infiltration is improved because cover crop residue slows runoff flow that allows more time for infiltration and then decreases runoff volume. A greater infiltration rate may intuitively suggest that the volume of water leached through the soil profile would increase, thus increasing the risk for nitrate-N loss. However, this situation usually does not occur due to water and N uptake by the cover crop. Water uptake by a cover crop also improves water infiltration because it creates a drier soil environment. This increases a soil's water storage capacity for subsequent precipitation events and can more than compensate for the greater fraction of infiltrated water compared to conditions without a cover crop. Even in instances of greater volumes of leached water with cover crops, nitrate-N leaching loss is often reduced due to its uptake of soil nitrate-N.

The timing and amount of N fertilizer applications also influence cover crop effectiveness. As mentioned elsewhere in this document, as N inputs increase so does the risk for N loss. If a high rate of N fertilizer is applied in the fall and/or a high amount of residual soil nitrate-N available following harvest of a primary crop, there will be a higher risk for N loss and a greater potential benefit from using a cover crop. If N fertilizer is spring or in-season applied, a cover crop can still provide significant N loss reduction, though likely not to the extent of fall applied N conditions.

Estimated long-term contaminant reduction for applicable areas in Iowa (multi-year basis)

+50%

The estimate above is specifically for the most applicable previous main crops or rotations for cover crops in Iowa, which are seed corn, sweet corn, silage corn and small grain production systems where the primary crops are harvested and removed in mid- to late-summer. Current cover crop technology and most cover crop plant species available would provide a substantially lesser opportunity to decrease N losses from corn and soybean row crop fields. The overall performance of cover crops in Iowa will greatly depend upon the plant type and species selected as a cover, timing of planting, and subsequent climatic conditions. However, if appropriate cover crop species or management practices are developed in the future for corn-soybean grain systems, we could expect similar benefits.

Extent of research

Moderate in eastern U.S., limited in Upper Midwest

Much of the cover crop research to date in the U.S. has been in the eastern and southeastern states. The climate in those regions is more favorable for incorporation of cover crops into cropping systems due to milder winters. The longer and colder winters in the Upper Midwest limit both the time period in the fall after primary crop harvest for planting and sufficient growth, and the number of plant species adapted to these conditions. The few research studies conducted within the Upper Midwest have shown a good potential for cover crops to reduce N contamination of surface waters, particularly from tile drained fields. Much more research is needed in evaluating plant species and cultivars that currently exist and to further develop suitable cultivars through plant breeding. A large number of cultivars of winter rye, winter wheat, other small grains, flax and brassica have not been evaluated for their use as cover crops in Upper Midwest. Searching for and screening plants that grow well in colder climates (i.e., middle to northern Canada) may also generate more good cover crop candidates. Closer to Iowa, Wisconsin studies of kura clover grown as a living mulch in corn production systems provided added surface cover without reducing corn yield. Its effects on water quality are yet unknown.

Support for further cover crop research funding is particularly important because this is one of the few conservation practices that can be applied across entire field areas, which is essential for other field-edge conservation practices that are applied in limited areas to function optimally. For example, high runoff volumes and concentrated runoff flow are two primary factors that can reduce the effectiveness of riparian and other vegetative buffers. Cover crops could reduce the volume of runoff and help to manage runoff as diffuse flow, thus reducing the load on field-edge conservation practices.

Secondary Benefits:

Potentially dramatic reductions of:

- Erosion losses of P
- Soil loss
- Sediment loads in surface waters
- Sediment-bound chemicals in surface waters

Conservation Practice Research Summary Table

Contaminant: **Total N**

Type of Strategy: **Preventive**

Strategy Name: **Cover Crops**

References significant to Iowa identified in bold italics.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Morgan et al., 1942[2]	CT, US; sandy loam soil	10-yr	Field-plot	Tobacco with 200 lb N applied before cover crop planting	Leaching to shallow groundwater		Annual ave. mass and concentration NO3-N[3]		Measures taken yr-round	N uptake dominant, also reduced drainage and SOM[4] increase
						None	74 lb/a/yr NO3-N 21 ppm NO3-N	_ _		
						Oat	32 lb/a/yr NO3-N 11 ppm NO3-N	57% 48%		
						Rye	25 lb/a/yr NO3-N 8 ppm NO3-N	66% 62%		
						Timothy	51 lb/a/yr NO3-N 14 ppm NO3-N	31% 33%		
Karraker et al., 1950[2]	KY, US; Maury silt loam soil	11-yr	Field-plot	Lespedeza that contributed net ~60 lb N/a/yr	Leaching to shallow groundwater		Annual ave. mass and concentration NO3-N		Measures taken yr-round	N uptake dominant, minor reduced drainage
						None	58 lb/a/yr NO3-N 16 ppm NO3-N	_ _		
						Rye	15 lb/a/yr NO3-N 4 ppm NO3-N	74% 72%		
Meisinger et al., 1990[2]	MD Coastal Plain, US; silt loam soil	1-yr	Field-plot	Corn with 300 lb N/a applied before cover crop planting	Leaching to shallow groundwater		Ave. NO3-N concentration		Measures taken over winter through spring months	Not quantified by mechanisms, N nutrient increased losses with legume cover crop
						None	17ppm NO3-N	_		
						Rye	12 ppm NO3-N	29%		
						Hairy Vetch	18 ppm NO3-N	-6%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Staver and Brinsfield, 1990[2]	MD, US; silt loam soil	1-yr	Field-plot	Corn with 150 lb N/a applied before cover crop planting	Leaching to shallow ground-water	 None Rye	Residual soil-NO3-N 52 lb/a soil-NO3-N 12 lb/a soil-NO3-N	 – 77%	Measures taken from Nov.-June	Not quantified by mechanisms
Nielsen and Jensen, 1985[2]	Denmark; sandy loam soil	2-yr	Field-plot	Spring barley with 80 lb N/a applied) before cover crop planting	Leaching to shallow ground-water	 None Annual Ryegrass Red Clover & Black Medic	Residual soil-NO3-N 60 lb/a NO3-N 22 lb/a NO3-N 33 lb/a NO3-N	 – 63% 45%	Measures taken for 60-d after cover crop planting	Not quantified by mechanisms
Chapman et al., 1949[2]	CA, US; loam soil	5-yr	Field-plot	Unfertilized sudangrass, 100 lb N/a applied to cover crops	Leaching to shallow ground-water	 None (straw) Mustard Sweet Clover Purple Vetch	Annual ave. mass and concentration NO3-N 46 lb/a NO3-N 75 ppm NO3-N 9 lb/a NO3-N 15 ppm NO3-N 38 lb/a NO3-N 74 ppm NO3-N 32 lb/a NO3-N 67 ppm NO3-N	 – – 80% 80% 17% 1% 30% 10%	Not identified	Not quantified by mechanisms
Volk and Bell, 1945[2]	FL, US; loamy sand soil	1-yr	Field-plot	100 lb N/a applied in fall before cover crop planting	Leaching to shallow ground-water	 None Turnips	Annual ave. mass and concentration NO3-N 113 lb/a NO3-N 32 ppm NO3-N 14 lb/a NO3-N 5 ppm NO3-N	 – – 87% 84%	Measures taken over Jan.-April	N uptake dominant, also reduced drainage
Jones, 1942[2]	AL, US; sandy loam, fine-sandy loam, clay loam	4-yr	Field-plot	Sudangrass followed by soybean residue addition (75 lb N/a) before cover crop planting	Leaching to shallow ground-water	 None Hairy Vetch Oat	Annual ave. mass NO3-N 32 lb/a NO3-N 30 lb/a NO3-N 6 lb/a NO3-N	 – 6% 81%	Measures taken yr-round	Not quantified by mechanisms

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Angle et al., 1984[5]	Howard Co., MD, US; Manor loam soil series	3-yr	Small watershed, treatment areas ranging is size from 0.6-0.9a and 6-7% slopes	CT corn with 60 lb N/a applied; NT corn with 60 lb N/a applied	Runoff	 CT[6] Corn - None NT[7] Corn - Barley	Total annual mass NO3-N and TN, annual mean concentration NO3-N 0.32 lb/a/yr NO3-N 8.78 ppm NO3-N 0.85 lb/a/yr TN 0.04 lb/a/yr NO3-N 5.88 ppm NO3-N 0.11 lb/a/yr TN	 _ _ _ 88% 33% 87%	Nitrate-N mass is total annual basis; concentration is mean annual basis; total N mass is total annual basis	Reduction in runoff volume and N uptake
Klausner et al., 1974[5]	Aurora, NY, US; Lima-Kendalia silt loam soils	1-yr	Field-plot	CT Corn, NT Corn, CT Wheat and NT Wheat all with 275 lb N/a applied	Runoff	 CT Corn – None NT Corn – Ryegrass CT Wheat - None NT Wheat – Ryegrass + Alfalfa	Total annual mass and mean concentration NO3-N 2.20 lb/a/yr NO3-N 1.41 ppm NO3-N 1.26 lb/a/yr NO3-N 3.62 ppm NO3-N 1.02 lb/a/yr NO3-N 0.66 ppm NO3-N 0.83 lb/a/yr NO3-N 1.26 ppm NO3-N	 _ _ 43% -157% _ _ 19% -91%	Nitrate-N mass is total annual basis; concentration is mean annual basis	Reduction in runoff volume and N uptake. Decreased load despite increases in concentration due to reduced runoff volume.
Pesant et al., 1987[5]	Quebec, CA	Not reported	Field-plot	CT and NT Corn with 22 lb N/a/yr applied	Runoff	 CT Corn – None NT Corn – Alfalfa + Timothy	Total annual mass NO3-N and TN, annual mean concentration NO3-N 0.36 lb/a/yr NO3-N 0.81 ppm NO3-N 0.43 lb/a/yr TN 0.52 lb/a/yr NO3-N 3.24 ppm NO3-N 0.53 lb/a/yr TN	 _ _ _ -44% -300% -23%	Nitrate-N mass is total annual basis; concentration is mean annual basis; total N mass is total annual basis	Greater N nutrient loss with legume cover crops despite reduced runoff volume attributed to N-fixation.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Yoo et al., 1988[5]	Al, US	Not reported	Field-plot	CT and NT Cotton with 90 lb N/a/yr applied	Runoff	 CT Cotton – None NT Cotton – None NT Cotton – Winter Wheat	Total annual mass NO3-N and TN, annual mean concentration NO3-N 3.07 lb/a/yr NO3-N 3.87 ppm NO3-N 3.67 lb/a/yr TN 1.25 lb/a/yr NO3-N 1.73 ppm NO3-N 2.27 lb/a/yr TN 0.50 lb/a/yr NO3-N 1.12 ppm NO3-N 0.79 lb/a/yr TN	 – – – 59% 55% 38% 84% 71% 78%	Nitrate-N mass is total annual basis; concentration is mean annual basis; total N mass is total annual basis	NT cover crop plant N uptake dominant since runoff volume was slightly higher with NT. Reduction in runoff volume and N uptake for NT with wheat cover crop.
Zhu et al., 1989[5]	Kingdom City, MO, US; Mexico silt loam soil	Not reported	Field-plot	NT Soybean with 13 lb N/a/yr applied	Runoff	 None Common Chickweed Canada Bluegrass Downy Brome	Total annual mass and mean concentration NO3-N 3.00 lb/a/yr NO3-N 4.04 ppm NO3-N 0.69 lb/a/yr NO3-N 1.86 ppm NO3-N 0.79 lb/a/yr NO3-N 1.92 ppm NO3-N 0.75 lb/a/yr NO3-N 2.06 ppm NO3-N	 – – 77% 54% 74% 52% 75% 49%	Nitrate-N mass is total annual basis; concentration is mean annual basis	Reduction in runoff volume and N uptake.
Staver and Brinsfield, 1998	MD, US	9-yr, Data from years 7 & 8	Water-shed/ Field	Ct and NT Continuous Corn with 140 lb N/a/yr applied	Leaching to shallow ground-water	 None Cereal Rye	Annual ave. mass NO3-N 19.71 lb/a/yr NO3-N 3.52 lb/a/yr NO3-N	 – 82%	Winter cover crop (Oct.-May)	N uptake dominant, also reduced drainage

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Kessavalou and Walters, 1999.	NE,US; silty clay loam soil.	3-yr	Field-plot	Varied cropping systems (see treatments column) under both CT and modified NT (one summer cultivation), w/N fertilizer rates of 0, 89 lb N/a and 267 lb N/a spring applied to corn.	Leaching to shallow ground-water		Annual ave. mass loss NO3-N		Soil sampled to depth of 4.9 ft in the spring prior to rye cover crop harvest and N fertilizer application. Data averaged across all 3 yrs, N rates and tillage practice by crop rotation.	Cover crop uptake of fall and spring residual soil nitrate caused reductions in spring just prior to soybean planting in corn-soybean with cover crop treatment. Increases in residual soil nitrate for other treatments due to mineralization of soil-nitrate from winter cover crop residues. Overall reduced risk of nitrate-N contamination of water resources with winter cover crop use.
						CC	186 lb/a/yr NO3-N	_		
						CS	202 lb/a/yr NO3-N	-8.6%		
						SC	187 lb/a/yr NO3-N	-0.5%		
						CS w/Rye winter cover crop	207 lb/a/yr NO3-N	-11.3%		
						Soybean w/Rye winter cover crop-Corn	153 lb/a/yr NO3-N	17.7%		
Logsdon et al., 2002	IA, US; Monona silt loam soil	4-yr simulation	Monolith soil profile segments	NT Corn-Soybean with 150 lb N/a applied to corn at typical sidedress timing. Cover crops planted near end of soybean growing season.	Leaching to shallow ground-water		3-yr total nitrate-N mass losses		Annual climatic cycle simulated for a 4-yr period within a controlled environment based on 30-yr normals for mid-Iowa	Cover crop plant uptake of soil-N following soybean harvest. Reduction in drainage. Rye more effective than oat due to resumed growth in spring for rye, but not for oat.
						Control (no winter cover)	112-203 lb/a NO3-N	_		
						Oat	20-95 lb/a NO3-N	15-90%		
						Rye	18-66 lb/a NO3-N	41-91%		

Reference	Location, Site Notes	Time Period of Experi -ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Ditsch et al., 1993	VA, US; silt loam soil	2-yr	Field-plot	Silage Corn-Winter Rye annual double crop rotation. N fertilizer applied to corn immediately after planting. Winter rye removed in spring either by silage harvest or chemical killing and left as mulch for corn	Leaching to shallow ground-water		2-yr ave. residual soil I-N[17] mass estimates[18]		Soil sampled to 3 ft depth in spring following winter rye removal and prior to corn planting.	Cover crop N uptake of residual fertilizer and soil derived nitrate-N. In most N rates treatments, the winter rye cover crop reduced soil inorganic-N levels similar to those found with no N fertilizer added to the corn crop with a winter rye cover. Reducing N fertilizer rate to corn with winter fallow steadily decreased the amount of residual soil inorganic-N remaining after corn production.
						WF[8], C[9] 300 lb N/a, C1[10]	138.4 lb IN/a	–		
						RM[11], C 300 lb N/a	25.8 lb IN/a	81.4% C1		
						RS[12], C 300 lb N/a	19.1 lb IN/a	86.2% C1		
						WF, C 225 lb N/a, C2[13]	112.1 lb IN/a	19.0% C1		
						RM, C 225 lb N/a	16.5 lb IN/a	88.1% C1; 5.3% C2		
						RS, C 225 lb N/a	25.4 lb IN/a	81.6% C1; 7.3% C2		
						WF, C 150 lb N/a, C3[14]	87.7 lb IN/a	36.6% C1		
						RM, C 150 lb N/a	18.7 lb IN/a	86.5% C1; 8.7% C3		
						RS, C 150 lb N/a	14.2 lb IN/a	89.7% C1; 3.8% C3		
						WF, C 75 lb N/a, C4[15]	71.2 lb IN/a	48.6% C1		
						RM, C 75 lb N/a	23.6 lb IN/a	82.9% C1; 6.9% C4		
						RS, C 75 lb N/a	17.4 lb IN/a	87.4% C1; 5.6% C4		
						WF, C 0 lb N/a, C5[16]	53.0 lb IN/a	61.7% C1		
						RM, C 0 lb N/a	15.1 lb IN/a	89.1% C1; 1.5% C5		
						RS, corn 0 lb N/a	18.7 lb IN/a	86.5% C1; 4.7% C5		

Reference	Location, Site Notes	Time Period of Experi -ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
McCracken et al., 1995	GA, US; sandy loam soil.	2-yr	Field-plot	CT and NT CC with spring applied N at 150 lb N/a. Rye cover crop fall planted following corn harvest.	Leaching to shallow ground-water	Fallow Rye cover crop	2-yr total mass loss NO3-N 39.7 lb/a NO3-N 37.4 lb/a NO3-N	– 5.8%	Middle portion of study period experienced above normal precipitation, below normal precipitation at the beginning. Water sampled continuously.	Reduction in drainage water volume and winter cover crop N uptake.
Strock et al., 2004	Lamber-ton, MN, US; Normania clay loam soil	3-yr	Plot	CS[19] with autumn seeded (after corn harvest) winter rye cover crop. Rye cover crop then succeeds corn and precedes soybean. Corn received 120 lb/a N fertilizer applied in spring.	Leaching to shallow ground-water and drainage through subsur-face tile lines	CS[20] No cover crop (C1) CS[21] No cover crop (C2) CS and rye cover crop CS and rye cover crop	3-yr ave. flow-weighted NO3-N concentration and 3-yr total NO3-N mass loss 12.0 ppm NO3-N 63.4 lb/a NO3-N 15.3 ppm NO3-N 79.3 lb/a NO3-N 9.3 ppm NO3-N 62.3 lb/a NO3-N 8.0 ppm NO3-N 63.2 lb/a NO3-N	– – -27.5% C1 -25.1% C1 22.5% C1: 39.2% C2 1.7% C1: 21.4% C2 33.3% C1: 47.7% C2 0.3% C1: 20.3% C2	Precipitation measured daily. Tile flow measured Mon.-Fri. Water chemistry grab samples taken X3/wk when flow exceeded 10 mL per minute. Winter rye cover crop planted within 5 days following fall corn harvest.	Reduction in drainage water volume and winter cover crop N uptake. Averaged across study years and cropping system, winter rye cover crop reduced subsurface drainage discharge by 11% and NO3 mass loss by 13%. Magnitude of reductions strongly varied by annual precipitation. Cover crop successful in reducing NO3 in 1 of 4 yrs in MN climate due to yrs with restricted establishment time period and low leaching potential.

1 Watershed, field, field-plot or laboratory.
2 As reported in Meisinger, J.J., W.L. Hargrove, R.L. Mikkelsen, J.R. Williams, and V.W. Benson. 1991. Effects of cover crops on groundwater quality. p. 57-68. *In* W.L. Hargrove (ed.) Cover crops for clean water. Proc. of an international conf. 9-11 April 1991. Jackson, TN. Soil Water Conserv. Soc., Ankeny, IA.
3 Soil organic matter (SOM).
4 NH4-N is ammonium-nitrogen.
5 As reported in Sharpley, A.N., and S.J. Smith. 1991. Effects of cover crops on surface water quality. p. 41-49. *In* W.L. Hargrove (ed.) Cover crops for clean water. Proc. of an international conf. 9-11 April 1991. Jackson, TN. Soil Water Conserv. Soc., Ankeny, IA.
6 CT represents conventional tillage.
7 NT represents no-tillage.
8 WF represents winter fallow.
9 C represents corn.
10 C1 represents control 1 and comparison to control 1.
11 RM represents winter rye mulch.
12 RS represents winter rye silage.
13 C2 represents control 2 and comparison to control 2.
14 C3 represents control 3 and comparison to control 3.
15 C4 represents control 4 and comparison to control 4.
16 C5 represents control 5 and comparison to control 5.
17 IN represents inorganic-N, consisting of nitrate-N and ammonium-N.
18 Data not directly reported numerically within the cited publication; data estimated from published graph figure(s).
19 CS represents corn-soybean rotation.
20 CS represents corn year in the corn-soybean rotation.
21 CS represents soybean year in the corn-soybean rotation.

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Conservation Practice Summary Assessment

Contaminant: **Total N**

Type of Strategy: **Preventive**

Strategy Name: **Diverse Cropping Systems**

Pollutant reduction mechanisms

- Improved stabilization of soil surface to impede wind and water erosion detachment and transport of nutrient enriched sediment and particulates
- Increased crop growing season for greater utilization of available soil-N
- Increased crop N nutrient use efficiency (crop assimilation)
- Reduced volume of shallow ground water drainage
- Reduced applied N nutrient load
- Reduced erosion and transport of nutrient enriched sediments and particulates
- Reduced in-field volume of runoff water
- Reduced soil-N mineralization (due to reduced tillage disturbance of soils)
- Temporary nutrient sequestration in soil organic matter
- Trapping and retention of transported nutrient enriched sediments and particulates
- Vegetative assimilation

Applicable conditions

- Any Iowa agricultural crop field that is in either continuous corn or corn-soybean rotations

Limiting conditions

- Markets for additional crops
- Storage of additional crops
- Additional equipment needs that may be not already available

Range of variation in effectiveness at any given point in time

-100% to +95%

Effectiveness depends on:

- Antecedent soil moisture content prior to rainfall events
- Climatic variability in regard to optimum growth conditions for the selected crop species
- Growing season of selected crop species
- Growth attributes of selected crop species (i.e., extent of rooting system, water and nutrient demand, cold season vs. warm season, perennial vs. annual)

- Management and removal timing of a perennial crop in regard to climatic conditions and time span until establishment of a succeeding row crop
- Percentage of surface residue cover
- Rainfall and snowmelt duration and intensity
- Slope and slope length
- Soil type
- Tillage program and associated degree of soil disturbance

<u>Estimated potential contaminate reduction for applicable areas within Iowa (annual basis)</u>

-50% to +95%

Cropping systems that are more diverse than continuous corn or corn-soybean rotations can be quite varied. Such cropping systems could include small grains, cover crops, annual and perennial forages and perennial woody crops. Some of these plants may also serve as good candidates for bioenergy as renewable energy technologies develop in the future. All of these crops, depending upon how they are managed, may extend the effective growing season for any field. Whether or not N losses are changed compared to a conventional corn-soybean rotation depends on the types of field operations associated with these additional crops. Plant water use and residue cover would typically be increased with added crops, which would probably decrease erosion and leaching. However, a few exceptions could exist. Adding a small grain without a cover crop, along with removal of residue by bailing and then followed with tillage, could leave a fallow soil surface that would be more susceptible to N losses through increased erosion and leaching. The timing of any additional field operations and alterations in field physical conditions in relation to peak rainfall and snowmelt events may impact overall N losses either positively or negatively.

Studies have shown conflicting evidence of nitrate-N leaching reductions with corn-soybean versus continuous corn production systems. Two factors are primarily involved in this situation, being fall and early spring residual soil nitrate-N following corn production and climate. If corn is either over-fertilized with N, or has reduced yield due to drought or disease, the crop will have a poor N use efficiency that leads to significant amounts of soil nitrate-N remaining after corn harvest. Since a soybean crop will typically not have an extensive root system established until July, there is a long time period (late-September to July) where the soil nitrate-N is at a high risk for leaching loss. In such instances, a corn-soybean rotation can result in greater nitrate-N leaching losses compared to a continuous corn rotation that is not over-fertilized or is under-fertilized with N.

Inclusion of a perennial into a cropping rotation may temporarily lead to increased soil nitrate-N losses. If there is a long time period after killing the perennial crop before the succeeding row crop is established along with a high amount of precipitation and warm temperatures, N mineralized from the perennial crop's residues can result in a large increase in soil nitrate-N that can leach before the row crop is established. Therefore, it is typically recommended to either kill the perennial crop in the spring as opposed to the fall before the row crop planting, or if fall-killed, to do so early enough to establish a cover crop before winter. Inclusion of an annual small grain crop has also shown to decrease nitrate-N leaching losses when added to summer annual row crops, but not as effectively as perennials. Also, since small grains are harvested by mid-summer, it should be immediately followed with a cover crop to minimize leaching of any residual soil nitrate-N and N mineralized later in the year. When properly managed, inclusion of additional crops into either a continuous corn or corn-soybean rotations have shown reductions of nitrate-N leaching losses in the general range of 10-95%.

Despite the need for additional research within Iowa on this topic, there is sufficient scientific and historical evidence to support that diversifying Iowa's currently predominant continuous corn and corn-soybean crop rotations offers the greatest opportunity of significantly reducing nitrate-N and total N contamination of surface waters of any of the agricultural best management practices for water quality. If such alternative cropping systems were widely adopted across the state and managed properly, N contaminant loads and concentrations may even be reduced to the extent of meeting proposed total maximum daily load limits.

Estimated long-term contaminant reduction for applicable areas in Iowa (multi-year basis)

+50%

Long-term expected results greatly depend upon the crop species selected and how long those species exist within a full rotation. For instance, a corn-soybean-meadow-meadow rotation will displace the annual row crops 50% of the time over the term of a full rotation. A long-term perennial crop, such as a lumber and/or nut-producing tree with meadow, will displace annual crops from the production area for many years.

Extent of research

Moderate

Most research projects investigating alternatives to continuous corn and corn-soybean rotations have focused on agronomic aspects. Several research studies have been conducted in various locations within Iowa and surrounding states within similar soils and climates that have shown marginal to dramatic reductions in nitrate leaching losses, depending upon the crops that were included and the climatic conditions of the experimental periods. Randall et al. (1997) found that row crops (corn and soybean) had 30X to 50X greater nitrate-N losses than was measured from perennial crops (CRP grass mix and alfalfa) in southern Minnesota. Huggins et al. (2001) also state that perennial crops such as alfalfa and grasses reduce soil nitrate-N concentrations and load losses to surface waters and lower drainage volumes. However, these benefits from the inclusion of perennials into a row crop system typically only last one to two years after a perennial crop is removed and followed by a row crop.

Unfortunately, research to address and overcome the listed limiting conditions is very sparse, and as of yet, has not become a major focus of governmental research funding. Scientists from both private non-profit organizations (i.e., American Society of Agronomy, The Land Institute, Leopold Center for Sustainable Agriculture, Institute for Agriculture and Trade Policy and Michael Fields Institute) and many public research institutions have repeatedly stated this need and the dramatic improvements in water quality that would result. Until federal agriculture research programs make this area a priority for funding and support, the great benefits of diverse cropping systems to farmer profitability, water quality and society will not be realized because farmers should not be required to bear the risk to their financial viability without established infrastructure and markets for these additional products.

<u>Secondary benefits</u>

- Additional wildlife habitat
- Decreased incidence of annual weeds, disease and insect pests in succeeding row crops
- Increased yield of row crops for 1-2 years following perennial crop production
- Provides some degree of flood control
- Reduce financial risk due to diversified income sources
- Reduced loss of sediment-bound chemicals
- Reduced P contamination of surface waters from reduced erosion due to greater annual vegetative cover and water uptake
- Reduced sediment contamination of surface waters from reduced erosion due to greater annual vegetative cover and water uptake
- Reduced soil loss from production fields

Conservation Practice Research Summary Table

Contaminant: **Total N**

Type of Strategy: **Preventive**

Strategy Name: **Diverse Cropping Systems**

References significant to Iowa identified in bold italics.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Randall et al., 1997	Southwest MN, US; Normania clay loam soil	6-yr	Field-plot	CT[6] Continuous Corn (CC), and Corn-Soybean (CS and SC) rotations. N fertilizer spring applied based on soil tests and yield goals. Continuous corn 6-yr ave. N rate at 122 lb N/a; Corn in CS rotation at 6-yr ave. 121 lb N/a. CRP a mix of alfalfa, bromegrass, orchardgrass and timothy. Alfalfa received 110 lb K/a annually.	Leaching to shallow ground-water		4-yr total nitrate-N mass loss; 4-yr ave. nitrate-N conc.		No tile drainage occurred for first two years of study due to drought. Last three years were above normal rainfall. Therefore, N loss data is from a 4-yr period. Tile flow measured at a minimum of 5 days per week. Water samples for nitrate-N content taken X3/week. Meadow crops had no tile drainage after June.	Longer annual crop growing season with meadow crops resulting in greater soil water and N uptake. Reduction in drainage volume with CS and meadow crops compared to CC.; meadow crops had 50-80% less drainage than row crops.
						CC[2]	194 lb nitrate-N/a; 32 ppm nitrate-N	_;_		
						CS[3]	181 lb nitrate-N/a; 23 ppm nitrate-N	6.7%; 28.1%		
						SC[4]	181 lb nitrate-N/a; 26 ppm nitrate-N	6.7%; 18.8%		
						Alfalfa	6.4 lb nitrate-N/a; 3 ppm nitrate-N	96.7%; 90.6%		
						CRP[5]	4.0 lb nitrate-N/a; 2 ppm nitrate-N	97.9%; 93.8%		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Kanwar et al., 1996	Nashua, IA, US; Floyd, Kenyon and Readlyn loam soils	3-yr	Field-plot	Multiple combinations of modified no-till (MNT), CT with Corn-Soybean (CS), Soybean-Corn (SC), Continuous Corn (CC), Corn-Soybean-Oat w Berseem Clover Cover Crop (CSOBC) and Alfalfa-Alfalfa-Alfalfa-Corn-Soybean Oat (AAACSO) cropping rotations. Corn yrs had either no N fertilizer in AAACSO rotation or 100 lb N/a spring pre-plant, 120 lb N/a spring pre-plant, fall applied manure (varied N rates) and LSNT split applied N (varied N rates). CC manured plots received 3-yr ave loading rate of 257 lb N/a, CS manured plots 212 lb N/a.	Leaching to shallow ground-water		<u>3-yr ave mass loss and concentration</u>		First yr of experiment had much above normal rainfall (1993). Tile drainage flow and nitrate-N concentration were monitored continuously during periods of flow.	CS typically had lower nitrate-N losses and concentrations than CC rotation. Elevated nitrate-N losses in soybean likely due to carry-over of soil-N, particularly for the manured treatments where N rates were far above target in 2 of 3 yrs. AAACSO and CSOBC rotations led to dramatic reductions in nitrate-N losses and concentra-tion.
						CT CC w[7] fall manure	29.4 lb nitrate-N/a 14.1 ppm nitrate-N	_ _		
						CT CC w spring 120 lb N/a	21.5 lb nitrate-N/a 11.3 ppm nitrate-N	26.8% 19.8%		
						CT C, MNT[8] S w fall manure	17.8 lb nitrate-N/a 11.3 ppm nitrate-N	39.4% 19.8%		
						CT C, MNT S w spring 100 lb N/a	12.6 lb nitrate-N/a 9.6 ppm nitrate-N	57.1% 31.9%		
						CT C, MNT S w LSNT N	14.6 lb nitrate-N/a 10.3 ppm nitrate-N	50.3% 27.0%		
						MNT CS w spring 100 lb N/a	25.0 lb nitrate-N/a 9.0 ppm nitrate-N	15.0% 36.2%		
						MNT CS w LSNT N	10.9 lb nitrate-N/a 9.2 ppm nitrate-N	62.9% 34.8%		
						MNT S, CT C w fall manure	22.8 lb nitrate-N/a 7.8 ppm nitrate-N	22.4% 44.7%		
						MNT S, CT C w 100 lb spring N/a	12.4 lb nitrate-N/a 10.8 ppm nitrate-N	57.8% 23.4%		
						MNT S, CT C w LSNT N	14.5 lb nitrate-N/a 6.8 ppm nitrate-N	50.7% 51.8%		
						MNT SC w spring 100 lb N/a	19.6 lb nitrate-N/a 6.9 ppm nitrate-N	33.3% 51.1%		
						MNT SC w LSNT N	9.2 lb nitrate-N/a 6.4 ppm nitrate-N	68.7% 54.6%		
						CSOBC[9]	13.0 lb nitrate-N/a 7.0 ppm nitrate-N	55.8% 50.4%		
						AAACSO[10]	11.0 lb nitrate-N/a 5.7 ppm nitrate-N	62.6% 59.6%		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Baker and Melvin, 1994	Pocahontas Co., IA, US; Clarion-Nicollet-Webster soil series	4-yr	Field-plot	Continuous Corn (CC) Soybean-Corn (SC) Corn-Soybean (CS) Corn-Alfalfa (CA) Alfalfa-Corn (AC) Alfalfa-Alfalfa (AA) N fertilizer applied as single spring pre-plant application to corn where N application is indicated. CT used for Corn and soybean production.	Leaching to shallow ground-water		Estimated 3-yr total nitrate-N mass loss[9]		Flow and nitrate-N concentration measured yr-round. Annual precipitation above ave 3 of 4 years of study, with first yr following a drought yr. Only reporting data from last 3 yrs of study due to AC and AA rotations had fallow in yr previous to initiation of study, where other treatments were not fallow (fallow has been shown to have dramatically greater N leaching losses than w crops).	Not directly stated, suggests better N use efficiency and greater water uptake with alfalfa. Optimum N fertilizer rate for corn in CC rotation was between 150-200 lb N/a; between 100-150 lb N/a for CS rotation. Therefore, the 200 lb N/a rate would be representative of a typical CC N rate; 150 lb N/a for CS. Considering these optimum N rates, only the CS and SC rotations had similar N leaching losses to those of CC; the CA, AC and AA rotations had substantially lower nitrate-N leaching losses than CC and CS systems
						CC w 0 lb N/a; C1[11]	32 lb nitrate-N/a	61.4% C2 74.2% C3		
						CC w 150 lb N/a; C2[12]	83 lb nitrate-N/a	-159.4% C1 33.1% C3		
						CC w 200 lb N/a; C3[13]	124 lb nitrate-N/a	-234.4% C1 -28.9% C2		
						CS w 0 lb N/a	65 lb nitrate-N/a	-103.1% C1 21.7% C2 47.6% C3		
						CS w 150 lb N/a	140 lb nitrate-N/a	-337.5% C1 -68.7% C2 -12.9% C3		
						SC w 0 lb N/a	70 lb nitrate-N/a	-118.8% C1 15.7% C2 43.5% C3		
						SC w 150 lb N/a	136 lb nitrate-N/a	-325.0% C1 -63.8% C2 -9.7% C3		
						CA[14] w 0 lb N/a	57 lb nitrate-N/a	-78.1% C1 31.3% C2 54.0% C3		
						AC[15] w 0 lb N/a	50 lb nitrate-N/a	-56.2% C1 39.8% C2 59.7% C3		
						AA[16] w 0 lb N/a	36 lb nitrate-N/a	-12.5% C1 56.6% C2 71.0% C3		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Schilling, 2002	Jasper Co., IA, US; silty clay loam, silt loam and clay loam soils	5-yr	Water-shed	Primarily CS for control watersheds, portion of total area in restored prairie for the treatment watershed. Control 1 (C1) watershed corn receiving 100 lb N/a, Control 2 (C2) watershed ave. of 150 lb N/a for corn production. C1 is upper watershed area above restored prairie treatment watershed. C2 is adjacent, differing watershed than restored prairie treatment watershed.	Baseflow and runoff nitrate-N losses to surface water		5-yr ave. nitrate-N mass loss; 5-yr ave. nitrate-N concentration		Stream flow measured continuously. Water samples for nitrate-N taken on a weekly to bimonthly basis. Years with highest precipitation and streamflow yielded greatest nitrate-N concentra-tions and load losses regardless of watershed size area.	Differences in N loading rate (none for restored prairie) partially responsible for differences in nitrate-N loss. Reduced baseflow due to greater annual plant uptake of soil water. Nitrate-N losses from restored prairie roughly 1/3-1/2 less than from conventional row crop areas, being a significant difference. Reduction in nitrate-N losses and concentration not a great as reported in other studies, likely due to not having the entire treatment area as restored prairie and was fragmented.
						CS Watershed; C1	30.3 lb nitrate-N/a 12.0 ppm nitrate-N	_ _		
						CS Watershed; C2	25.4 lb nitrate-N/a 10.4 ppm nitrate-N	_ _		
						Treatment Watershed + Upstream C1	21.3 lb nitrate-N/a 8.4 ppm nitrate-N	29.7% C1; 30.0% C1 16.1% C2; 19.2% C2		
						Estimated Restored Prairie Treatment Alone	16.7 lb nitrate-N/a 6.6 ppm nitrate-N	44.9% C1; 45.0% C1 34.2% C2; 36.5% C2		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Laflen and Tabatabai, 1984 **Combina-tions of corn and soybean crop rotations systems**	2 sites, Ames and Castana, IA, US; Clarion sandy loam near Ames, Monona silt loam near Castana	Not reported	Plots (10X35 ft), rain simul-ations	Across 4 crop rotations (CC, SC, CS, SS[17]) and three types of tillage (moldboard plow, chisel plow and no-till) Soybean fertilized at rates of 23 lb N/a and 33 lb P/a; corn at 124 lb N/a and 33 lb P/a.	Surface runoff	**Clarion Soil** SS CS SC CC **Monona Soil** SS CS SC CC	Ave TN[18] mass loss from runoff water + transported sediment 4.90 lb/a TN 1.29 lb/a TN 5.40 lb/a TN 1.56 lb/a TN 45.81 lb/a TN 53.84 lb/a TN 43.39 lb/a TN 41.79 lb/a TN	_ 73.7% -10.2% 68.2% _ -17.5% 5.3% 8.8%	Simulated rainfall rate of 2.5 in/hr for 1 hr (~25 yr. storm) 3 weeks (Monona) or 7 weeks after planting. Surface runoff water and flow rate sampled 1 minute after initiation of runoff, then at 5 minute intervals for next 5 measures, then at 10 minute intervals to end of simulation. Fertilizers surface applied either the day prior to, or day of, planting.	Rotations in the year of corn production for the Clarion soil had significantly less loss of TN than for soybean production. No significant differences by rotation for the Monona soil where TN losses were high for each crop rotation.
Kanwar et al., 1997	Nashua, IA, US; Floyd, Kenyon and Readlyn loam soils	3-yr	Field-plot	Multiple combinations of MNT, CT with Corn-Soybean (CS), Soybean-Corn (SC), Continuous Corn (CC). CC received spring applied 180 lb N/a; C in CS received spring applied 150 lb N/a.	Leaching to shallow ground-water	CC CS SC	3-yr ave. annual nitrate-N mass loss and 3-yr ave. nitrate-N conc. across all tillage systems 51.5 lb nitrate-N/yr; 29.5 ppm nitrate-N 24.8 lb nitrate-N/yr; 18.0 ppm nitrate-N 26.2 lb nitrate-N/yr; 17.8 ppm nitrate-N	_ _ 51.8%; 39.0% 49.1%; 39.7%	Tile drainage flow was monitored continuously during periods of flow. Water samples for nitrate-N concentration were taken X3/week.	Higher N fertilizer rates for CC likely accounted for higher nitrate-N losses with that rotation. Also, N fertilizer applied biannually, where N fertilizer was applied annually.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Burwell, et al., 1975	West-central MN, US; Barnes loam soil with 6% slope	10-yr data of water volume and sediment losses and 6-yr of nutrient loss data	Plot	CF[19] with 300 lb/a N applied in initial yr only CC with 100 lb/a N and 26 lb/a P applied annually in spring prior to planting COA[20] with 50 lb/a N and 26 lb/a P applied in spring prior to planting COA[21] with 16 lb/a N and 27 lb/a P applied in spring prior to planting COA[22] without N or P applied, 2 cuttings per year of forage All N and P fertilizer applications were broadcast applied and incorpor-ated with tillage.	Surface runoff	 CF (C1) CC (C2) COA COA COA COA Rotation Average	Estimates of annual ave. mass loss of TN transported in runoff solution and eroded sediment 130.7 lb/a sediment TN 3.05 lb/a solution TN 67.2 lb/a sediment TN 2.15 lb/a solution TN 30.9 lb/a sediment TN 1.05 lb/a solution TN 18.69 lb/a sediment TN 2.30 lb/a solution TN 0.08 lb/a sediment TN 3.57 lb/a solution TN 16.6 lb/a sediment TN 2.31 lb/a solution TN	 _ _ 48.6% C1 29.5% C1 76.4% C1; 54.0% C2 65.6% C1; 51.2% C2 85.7% C1; 72.2%C2 24.6% C1; -7.0% C2 99.9% C1; 99.9% C2 -17.0% C1; -66.0% C2 87.3% C1; 75.3% C2 24.3% C1; -7.4% C2	Nutrient losses were analyzed for 3 differing runoff risk periods, two at high risk (snowmelt – period 1; corn planting to 2 months afterwards – period 2) and one at low risk (remainder of year – period 3). One composite sample taken per runoff event. Nearly all runoff in alfalfa and oat was from snowmelt, attributed to the greater residue cover trapping a greater amount of snow.	Majority of sediment N losses occurred during period 2, with trends correlated to amount of residue cover (increasing residue cover decreased sediment N loss, increased soluble N loss – but generally to much lesser degree than reduction in sediment N losses). Authors emphasized that these results indicate that controlling erosion is critical to reducing N loss in surface runoff from fallow and corn production since >96% of all N loss was associated with eroded sediment transport for those systems.

1 Watershed, field, plot or laboratory.
2 CC represents continuous corn rotation.
3 CS represents corn year in corn-soybean rotation.
4 SC represents soybean year in corn-soybean rotation.
5 CRP represents conservation reserve program.
6 CT represents conventional tillage.
7 W represents with.
8 MNT represents modified no-tillage (summer cultivation).
9 CSOBC represents corn-soybean-oat with berseem clover cover crop after oat harvest.
10 AAACSO represents alfalfa-alfalfa-alfalfa-corn-soybean-oat rotation.
11 C1 represents control 1 and comparison to control 1.
12 C2 represents control 2 and comparison to control 2.
13 C3 represents control 3 and comparison to control 3.
14 CA represents corn year in corn-alfalfa rotation.
15 AC represents alfalfa year in corn-alfalfa rotation.
16 AA represents continuous alfalfa for duration of study.
17 SS represents continuous soybean.
18 TN represents total nitrogen.
19 CF represents continuous fallow.
20 COA represents corn-oat-alfalfa rotation in the year of corn production.
21 COA represents corn-oat-alfalfa rotation in the year of oat production.
22 COA represents corn-oat-alfalfa rotation in the year of alfalfa production.

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Conservation Practice Summary Assessment

Contaminant: **Total N**

Type of Strategy: **Remedial**

Strategy Name: **Drainage Management** (controlled drainage, shallow and/or wide tile placement, water table management with sub-irrigation)

Pollutant reduction mechanisms:
- Decreased artificially drained soil volume
- Denitrification
- Reduced volume of shallow ground water drainage

Applicable conditions
- For controlled drainage and water table management with sub-irrigation: any Iowa agricultural crop field that is of one percent or less slope and has tile drainage
- For shallow and/or wide tile placement: any Iowa agricultural crop field that may legally be tile drained

Limiting conditions
- For controlled drainage and water table management with sub-irrigation: only functions in the time period after plant establishment and prior to harvest when drainage may be managed without interfering with field operations
- For controlled drainage and water table management with sub-irrigation: fields with one percent or greater slope
- Brief water residence time within soil profile
- Aerobic soil conditions
- Insufficient available carbon sources to support denitrifying bacterial growth and function
- Well-drained soils having deep percolation of infiltrating water (i.e., coarse soil textures without an underlying confining layer to cause a perched water table and lateral flow of shallow groundwater)

Range of variation in effectiveness at any given point in time

Controlled drainage vs. uncontrolled drainage: 0 to +75%
Shallow and/or wide tile placement vs. standard tile placement: 0 to +75%
Water table management with sub-irrigation vs. uncontrolled drainage: 0 to +90%

Effectiveness depends on:
- Excess precipitation; may limit the shallow groundwater residence time and result in little denitrification for removal of nitrate-N

- Inadequate precipitation; water table levels below the target depth may limit denitrification due to lower carbon content with depth in soil profile (carbon is required to support growth of denitrifying bacteria) and aerobic conditions from not being water saturated to the target water table depth
- Cool temperatures; growth of denitrifying bacteria is also influenced by temperature, having greater growth and function with increasingly warmer soil temps
- With ideal conditions when controlled drainage and water table management are in operation, denitrification can remove nitrate-N at relatively high rates, well above 50%
- Shallow tile drainage line placement may be more susceptible to N losses from preferential flow than other tile drainage management practices due to having a shorter vertical transport distance from the surface to tile

Estimated potential contaminate reduction for applicable areas within Iowa (annual basis)

Controlled drainage vs. uncontrolled drainage: 0 to +50%
Shallow and/or wide tile placement vs. standard tile placement: 0 to +50%
Water table management with sub-irrigation vs. uncontrolled drainage: 0 to +70%

The time frame of optimal nitrate retention and reduction for controlled drainage and water table management can be brief in the Upper Midwest. Neither of these two practices can be implemented during times of field operations. This limitation coincides with the typical high-risk periods of nitrate-N leaching in Iowa (mid-spring to early summer and early fall). Soil temperatures also tend to be cool at these time intervals, which slows denitrification. Therefore, the only time period during the year that controlled drainage and water table management can function adequately is during late spring to early summer. Nitrate-N leaching losses may be substantial at this time in years with average to above-average precipitation. The overall impact on N loss reduction depends upon the balance of crop water and N uptake (which is at it's peak during drainage control), amount of denitrification and reduction of drainage volume compared to uncontrolled drainage.

Controlled drainage and water table management often reduces nitrate discharge and drainage volume by restricting tile flow, although on occasion conditions may exist where these practices may actually increase drainage discharge. This is possible because controlled drainage and water table management will create a higher water table and wetter soil conditions than will uncontrolled drainage. With a deeper water table than that of controlled drainage, uncontrolled drainage may have a greater water storage capacity at the time of a mid-summer peak rainfall event. However under typical Midwestern climatic conditions when controlled drainage and water table management practices would be in place, evapotranspiration (plant transpiration plus surface evaporation) typically exceeds precipitation. By restricting drainage, controlled drainage partitions more water to evapotranspiration than does uncontrolled drainage, which will continue to remove soil moisture until the water table drops below the depth of the tile lines. Controlled drainage would then in these conditions result in less subsurface drainage. Crop grain yield increases commonly documented with controlled drainage and water table management are primarily attributed to the increased availability of soil water.

Drought may also limit the effectiveness of controlled drainage in reducing N loss. Without sub-irrigation, the water table would likely drop below the depth of the control structures and even that of uncontrolled drainage tile lines. In this case, neither system would have subsurface discharge. The soil profile would also become increasingly aerobic, which inhibits denitrification. Sub-irrigation with water table management would negate this problem by maintaining the water table at or near the depth of the control structures.

Controlled drainage structures may be used on fields with flat topography (one percent or less slope), such as in flood plains and in similarly flat fields on the Des Moines Lobe (north-central Iowa) and the Iowan Surface (northeast Iowa). According to GIS analyses of soils data, there are 6,298,981 cropland acres within Iowa that is of one percent or less slope where controlled drainage and water table management can serve as a viable NPS nitrate management practice (Fig. 1). Controlled drainage and water table management have been determined to not be feasible for areas with slope above one percent because of the frequency of control structures required across a typical field length and equipment, installation and maintenance costs.

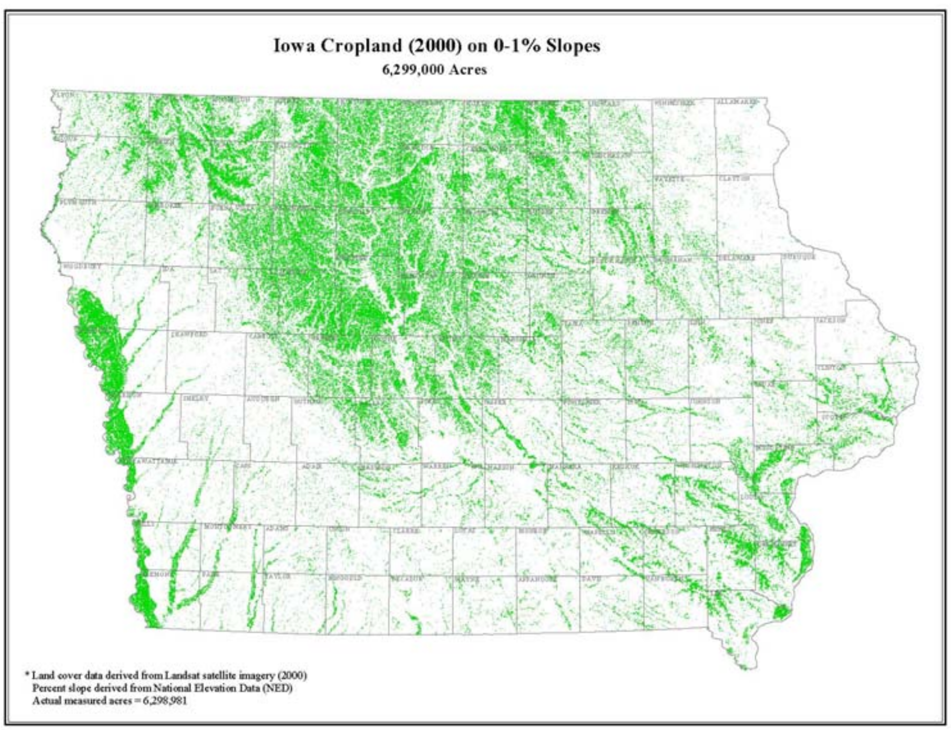

Fig. 1 Location of cropland with one percent or less slope within Iowa where controlled drainage and water table management with sub-irrigation practices would be potentially applicable.

Estimated long-term contaminant reduction for applicable areas in Iowa (multi-year basis)

Controlled drainage vs. uncontrolled drainage: +25%
Shallow and/or wide tile placement vs. standard tile placement: +20%
Water table management with sub-irrigation vs. uncontrolled drainage: +30%

When controlled drainage or water table management are installed on applicable areas with one percent or less slope and properly implemented, these practices can prevent an appreciable amount of nitrate-N in shallow groundwater from entering surface streams. Shallow an/or wide tile placement will likely have a marginally lesser impact since just changing tile location is a more passive management practice than the other alternatives. In any case, these practices alone will probably not provide adequate improvements to surface water quality. Other conservation practices (i.e. improve N fertilizer rate and timing of application, cover crops, diversified cropping systems, etc.) will also need to be used.

Extent of research

Limited

Although a few research experiments have been conducted within Iowa, there is still an inadequate amount of information to give highly reliable performance estimates. Currently there are existing experiments that will generate additional pertinent information in the near future. Most controlled drainage and water table management experiments have been conducted in Ohio, Illinois, North Carolina and Quebec, Canada. Alternative tile placement studies have also been done in Indiana. The results from those experiments are fairly applicable to conditions in Iowa due to somewhat similar climatic conditions, general soil types and the topography to which these practices are typically applied.

Secondary benefits:

- Proven to increase corn and soybean yields when managed properly
- Increased grain production may off-set portion of costs for implementation
- Reduces water deficiency for crop plants

Conservation Practice Research Summary Table

Contaminant: **Total N**

Type of Strategy: **Remedial**

Strategy Name: **Drainage Management** (controlled drainage, shallow and/or wide tile placement, water table management with sub-irrigation)

References significant to Iowa identified in bold italics.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Pathway	Applied Land-Use	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export Or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Kalita and Kanwar, 1993	Iowa, US (Ankeny and Ames); loam and silt-loam soils	3-yr	Field-plot	Leaching to shallow ground-water	CC[2] with 176 lb N/a applied	 WTM[3] at 2/3 – 3 ft from summer to harvest (Ames) WTM at 1 – 3.5 ft from summer to harvest (Ankeny)	3-yr ave. NO3-N[4] concentration by depth in soil profile Shallow WTM 7.3 ppm NO3-N Medium WTM 11.7 ppm NO3-N Deep WTM 19.0 ppm NO3-N Shallow WTM 8.8 ppm NO3-N Medium WTM 12.5 ppm NO3-N Deep WTM 16.7ppm NO3-N	No control for comparison. Same trend for both sites of nitrate concentrations decreasing with water table closer to surface.	Sampled from early summer through early fall. No sampling remainder of years.	Not identified, but denitrification is suggested.
Madra-mootoo et al., 1993	Quebec, CA; Courval sandy loam	2-yr	Soil columns, outdoor	Leaching to shallow ground-water	Soybean	 Uncontrolled Drainage WTM, 16 in. WTM, 24 in. WTM, 32 in.	2-yr ave. of soil NO3-N sampled at 28 in. depth 15.56 ppm soil NO3-N 7.49 ppm soil NO3-N 9.43 ppm soil NO3-N 9.88 ppm soil NO3-N	 – 51.9% 39.4% 36.5%	Soil samples taken May through Sept. Water table treatments imposed from June 1 through Sept. 10	Not identified, but denitrification is suggested.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Pathway	Applied Land-Use	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export Or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Fisher et al., 1999	Ohio, US; silt loam soil	2-yr	Field-plot	Leaching to shallow ground-water	NT[5] CS[6] with 132 lb N/a applied to corn		2-yr ave. NO3-N by depth in soil profile		Samples taken in March, May, June and Sept./Oct., thus includes part of annual periods of cool temperatures.	Not identified, but denitrification is suggested.
						Uncontrolled Drainage, Corn	0-6 in., 7.9 ppm NO3-N 6-12 in., 5.8 ppm NO3-N 12-30 in., 4.2 ppm NO3-N **0-30 in., 6.0 ppm NO3-N**	_ _ _ _		
						Controlled Drainage, Corn	0-6 in., 8.0 ppm NO3-N 6-12 in., 4.0 ppm NO3-N 12-30 in., 2.0 ppm NO3-N **0-30 in., 4.7 ppm NO3-N**	-1.7% 31.5% 53.3% **22.0%**		
						Uncontrolled Drainage, Soybean	0-6 in., 6.1 ppm NO3-N 6-12 in., 4.0 ppm NO3-N 12-30 in., 3.3 ppm NO3-N **0-30 in., 4.4 ppm NO3-N**	_ _ _ _		
						Controlled Drainage, Soybean	0-6 in., 6.0 ppm NO3-N 6-12 in., 3.2 ppm NO3-N 12-30 in., 2.1 ppm NO3-N **0-30 in., 3.8 ppm NO3-N**	1.1% 19.7% 36.4% **15.4%**		
Elmi, et al., 1999	Quebec, CA; fine sandy loam soil	1-yr	Field-plot	Leaching to shallow ground-water, measured at 6 in. depth	Corn with 176 lb N/a and 106 lb N/a applied		Mean soil NO3-N mass		Samples taken in May through Oct.	Denitrification main mechanism of loss.
						Uncontrolled Drainage, corn	18.5 lb/a soil NO3-N	_		
						Controlled Drainage, corn	13.2 lb/a soil NO3-N	28.6%		
Gilliam et al., 1979	NC, US; sandy loam soils	3-yr	Field	Leaching to shallow ground-water	Winter Fallow		Annual ave. NO3-N mass		Measures taken Dec. through Feb.	Primarily reduced volume of drainage waters, denitrification secondary.
						Uncontrolled Drainage	~22-26 lb N/a	_		
						Controlled Drainage	Not directly reported	Approx. 50% reported		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Pathway	Applied Land-Use	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export Or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Kladivko, et Al., 1991	Butlerville, IN, US; Clermont silt loam soil; all tiles at ave. depth of 2.5 ft	3-yr	Field-plot	Leaching to shallow groundwater	CT[7] CC with 250 lb N/a applied	 15.4 ft tile spacing 30.8 ft tile spacing 61.7 ft tile spacing	Total combined NO3-N and NH4-N[8] losses over 3-yr study 293.6 lb N/a 217.6 lb N/a 157.7 lb N/a	 _ 25.9% 46.3%	Tile drainage water monitored year-round. Flow-weighted concentration of nitrate-N varied by season; 3-yr ave. being 23.7 ppm spring/early summer, 27.3 ppm fall/mid-winter, 26.7 ppm mid-winter/mid-spring.	Drainage volume reduction with wider tile line spacing. 3-yr Totals 53.8 in. (base) 37.7 in. (30% less) 28.5 in. (47% less)
Kladivko et al., 1999	Butlerville, IN, US; Clermont silt loam soil; all tiles at ave. depth of 2.5 ft	6-yr	Field-plot	Leaching to shallow groundwater	CT CC with 250 lb N/a applied	 15.4 ft tile spacing 30.8 ft tile spacing 61.7 ft tile spacing	6-yr ave. NO3-N mass loss 52.5 lb N/a/yr 36.3 lb N/a/yr 28.1 lb N/a/yr	 _ 30.8% 46.5%	Tile drainage water monitored year-round. Most nitrate losses during fall, winter and early spring in coincidence with majority of drainage occurring. Results of last 3-yr period combined with previous 3-yr period from Kladivko et al., 1991 to derive 6-yr totals.	Drainage volume reduction with wider tile line spacing. 6-yr Drainage Volume Totals 15.4 ft spacing: 114.5 in. (base) 30.8 ft spacing: 78.0 in. (31.7% less) 61.7 ft spacing: 61.6 in. (46.0% less)

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Pathway	Applied Land-Use	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export Or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Fausey and Cooper, 1995	OH, US; silty clay soil	18 months	Field-plot	Leaching to shallow groundwater	CS		Ave. NO3-N concentration of tile drainage		Tile drainage measures taken from 7/7/92 through 11/10/93. Sub-irrigation used to raise water table at 12-16 inch depth from June 15 to Sept. 30. Soil water samples taken biweekly during growing season, and bimonthly during dormant season at 3 ft, 6 ft and 10 ft depth in soil profile.	Denitrification effective with SID at 3 ft depth, being shallow water table level. SID similar to free drainage at 6 and 10 ft depths, which were all below the level of the free drainage water table level.
						Corn, drainage only, 3 ft, C1[9]	11 ppm NO3-N	_		
						Corn w SID[10], 3 ft	8 ppm NO3-N	37.5% C1		
						Soybean, drainage only, 3 ft, C2[11]	17 ppm NO3-N	_		
						Soybean w SID, 3 ft	5 ppm NO3-N	70.6% C2		
						Corn, drainage only, 6 ft, C3[12]	3 ppm NO3-N	_		
						Corn w SID, 6 ft	5 ppm NO3-N	-66.7% C3		
						Soybean, drainage only, 6 ft, C4[13]	3 ppm NO3-N	_		
						Soybean w SID, 6 ft	2 ppm NO3-N	33.3% C4		
						Corn, drainage only, 10 ft, C5[14]	3 ppm NO3-N	_		
						Corn w SID, 10 ft	4 ppm NO3-N	-33.3% C5		
						Soybean, drainage only, 10 ft, C6[15]	5 ppm NO3-N	_		
						Soybean w SID, 10 ft	3 ppm NO3-N	40.0% C6		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Pathway	Applied Land-Use	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export Or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Doty et al., 1986[16]	NC, US; poorly drained surface soils with sandy subsoils	4-yr	Watershed	Leaching to shallow ground-water	Varied, corn being the main crop within the area	No CD[17] Period (Oct.-March)	4-yr annual ave. TN[18] concentration of stream flow		WTM-CD conducted April – Sept., No WTM-CD Oct. - March	Not directly reported, denitrification was suggested mechanism. Virtually no difference in N loss between the 2 sites during period of no drainage control (Oct.-March). Authors then accepted that the 2 sites behave similarly, thus upstream site could serve as a control for comparison.
						Upstream	4.3 ppm TN 3.8 ppm NO3-N	_ _		
						Downstream WTM-Dam Site	4.2 ppm TN 3.6 ppm NO3-N	_ _		
						CD Period (April-Sept.)				
						Upstream CD	3.9 ppm TN 3.3 ppm NO3-N	_ _		
						Downstream WTM-Dam Site, CD	2.8 ppm TN 2.2 ppm NO3-N	28.2% 33.3%		

1 Watershed, field, plot or laboratory.
2 CC represents continuous corn.
3 WTM represents water table management.
4 NO3-N represents nitrate-nitrogen.
5 NT represents no-tillage.
6 CS represents corn-soybean.
7 CT represents conventional tillage.
8 NH4-N represents ammonium-nitrogen.
9 C1 represents control 1, comparison to control 1.
10 SID represents sub-irrigation drainage.
11 C2 represents control 2, comparison to control 2.
12 C3 represents control 3, comparison to control 3.
13 C4 represents control 4, comparison to control 4.
14 C5 represents control 5, comparison to control 5.

15 C6 represents control 6, comparison to control 6.
16 As reported in Evans, R.O., J.E. Parsons, K. Stone and W. B. Wells. 1992. Water table management on a watershed scale. J. of Soil and Water Conserv. 58-64.
17 CD represents controlled drainage.
18 TN represents total-nitrogen.

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Conservation Practice Summary Assessment

Contaminant: **Total N**

Type of Strategy: **Remedial**

Strategy Name: **In-Field Vegetative Buffers** (grassed waterways, contour buffer strips, shelterbelts, hedgerow plantings, cross wind trap strips, filter strips)

Pollutant Reduction Mechanisms

- Denitrification
- Dilution
- Improved water infiltration and nutrient adsorption to soil matrix
- Reduced in-field volume of runoff water
- Reduced volume of runoff water reaching surface waters
- Temporary nutrient sequestration in soil organic matter
- Trapping and retention of transported nutrient enriched sediments and particulates
- Vegetative assimilation

Applicable Conditions

- Any Iowa agricultural crop field, particularly those in row crop production

Limiting Conditions

- Concentrated surface runoff flow (i.e., from natural gullies or narrow depressions, rills and sediment ridges that develop over time)
- Non-growing season period of buffer plant species
- Limited runoff and shallow ground water residence time (i.e., from coarse soil texture and/or steep terrain gradient)
- Cool temperatures
- Attaining upper N nutrient storage limit, may become a nutrient source to surface waters once plants reach maturity if not properly managed
- Unstable soils that are easily disturbed, making buffer plant species difficult to establish

Range of variation in effectiveness at any given point in time

-10% to +95%

Effectiveness depends on:

- Peak snowmelt and precipitation events that lead to high volumes of concentrated runoff flow that can overload a buffer

- Types of soil and crop management upslope of the in-field buffer
- Degree of slope and slope length above the in-field buffer
- Erosion risk and structure of soils above and within the in-field buffer
- Time period between any soil disturbing field operation and subsequent precipitation event
- Application timing, rate and method of commercial and manure fertilizers
- Vegetative assimilation may function efficiently for nitrate-N removal in absence of other removal mechanisms when drought occurs during the growing season
- The degree of N removal by vegetative assimilation is dependent upon the type of plants species used and the stand density (i.e., cool season vs. warm season plants, grasses vs. woody plants vs. mix of grasses and trees)
- Design and structure of the buffer (i.e., single grass strip vs. tree/shrub vs. both, width of buffer and number of buffer strips on a field landscape)
- Degree of maintenance of the buffer, particularly as it matures (i.e., harvest and removal of buffer plant biomass, preventing ridge development along upslope edges)
- With good establishment of buffer plants, warm temperatures, limited concentrated runoff flow, total-N, ammonium-N and nitrate-N removal can be substantial

Estimated potential contaminate reduction for applicable areas within Iowa (annual basis)

+10 to +50%

Landscapes and soil types within Iowa agroecoregions are amenable to placement and targeted functions of one or more types of in-field buffers. However, there can be great variability both in space and time as to the effectiveness of in-field buffers in reducing total N, ammonium-N and nitrate-N transport and contamination of surface waters.

One of the primary functions for in-field vegetative buffers is to work in concert with riparian buffers to decrease the occurrence of concentrated flow. This is critical not only for reducing erosion losses of sediment and nutrients, but also for improving the applicability of riparian buffers along the edges of surface waters (see Riparian Buffers Summary). However, in-field vegetative buffers alone have been documented to provide substantial reductions in nutrient and sediment transport, including total N and nitrate-N.

Dissolved forms of N (i.e., nitrate) are often not removed to the degree of sediment and sediment-bound N forms (also true for P). Any dissolved chemical has a lesser chance of being removed with any runoff that exits a vegetative buffer than sediment-bound chemicals because a primary function of these buffers is sediment deposition. Removal of dissolved chemicals is primarily correlated with increased infiltration rates. Partially dissolved forms of N, such as TN, are removed at an intermediate degree compared to dissolved and sediment-bound forms and both sediment deposition and infiltration are important mechanisms for reducing losses of these nutrient forms.

Relative percentage and actual nutrient load and concentration reductions are also influenced by factors relating to the contributing area. The differing types of crop and soil management methods can have a wide range of potential erosion rates. Practices that frequently and intensely disturb the soil and leave the surface barren of protective residues and plant canopy cover, such as moldboard tillage with annual row crops, lead to high erosion potentials. In contrast, a system of no-tillage with perennial crops infrequently disturbs the soil, and when disturbance does occur it is minor. A buffer strip down-slope of the former scenario would receive much more sediment and sediment-bound nutrients than the latter system. Other factors that strongly impact potential erosion are the degree of slope and slope length. Gravity will have a greater effect on the soil surface as slope percentage and the distance length of slope increases, both of which will then increase the risk of erosion. Well-structured soils have greater strength, producing greater resistance to disturbance and a lower risk of erosion. Soils that lack well-developed structure, possibly due to coarse texture and/or intense tillage, have minimal soil strength and may be more easily eroded. Buffers down-slope of intensively tilled, erosive soils will receive large loads of sediment and sediment-bound chemicals. Because soils can develop structure over time following disturbance, the longer the time period between a tillage operation and the next precipitation event the lesser the erosion risk. Similarly, the timings, rates and methods of commercial fertilizer and manure applications also impact in-field buffer effectiveness. High fertilizer rates applied to the surface of a tilled field just prior to a runoff event can transport high loads and concentrations of dissolved and sediment-bound nutrients to an in-field buffer. While the in-field buffer may reduce a large percentage of the inflowing nutrients, a significant amount may still exit this buffer, which points to the importance of designing and placing the in-field buffers in coordination with riparian buffers.

Multiple studies conducted by the Agroecology Issue Team of the Leopold Center for Sustainable Agriculture at the Bear Creek National Restoration Demonstration Watershed Project site near Roland have provided much of the most important research on buffers for Iowa. Their studies have concentrated on various aspects of riparian and vegetative buffers. From their grass buffers research they determined that reductions of N (and also P) indicate that vegetative buffer strips remove total-N mainly through deposition of sediment on the soil and litter surface within the buffer, and partly through infiltration of receiving cropland runoff waters. Vegetative assimilation of N has also been identified as an important removal mechanism in many studies from both infiltrating surface runoff and shallow ground water flow. Denitrification is not a dominant N removal mechanism for in-field vegetative buffers because these practices are typically located higher on the landscape than riparian buffers, so the soils tend to be better drained and more aerobic. Therefore, many of the in-field vegetative buffer experiments have focused on buffer effects on runoff and have not measured N reductions in shallow ground water flow within and through the buffers. The Bear Creek research projects and others have pointed out that the overall effectiveness of in-field vegetative buffers (as well as riparian buffers) is greatly dependent upon the buffer design. Buffer width and buffer plant species have significant impacts on the amount of reduction in nutrient and sediment transport from cropland runoff. Warm season grasses, such as switchgrass, have shown to be more effective than non-native cool season grasses, and sediment and nutrient retention improves with increasing width of the buffers. However, the effectiveness of the grass buffers tends to diminish with increasing rainfall intensity and repeated occurrences of runoff. This points out that conservation crop management practices such as no-till, cover crops and perennial crops would likely improve the effectiveness on in-field vegetative buffers by reducing the incidence and volume of runoff.

Maintenance is just as important with in-field vegetative buffers as it is for riparian buffers. Ridges can form at the upslope field/buffer edge due to sediment accumulation over time and any tillage operations that cut a furrow along the edge. Both the ridge and the furrow will result in excessive water ponding at the front edge and can lead to concentrated runoff flow that could cut through or bypass the buffer. Maintenance will require reforming and replanting the field/buffer edge as these conditions appear.

Estimated long-term contaminant reduction for applicable areas in Iowa (multi-year basis)

+25%

The long-term amount of contaminant reduction will greatly vary depending upon whether or not a buffer was established to NRCS guidelines, the buffer's width and its location on the landscape, buffer plant type and species selected, and whether or not the practice is used in coordination with other conservation practices (i.e., riparian buffers and no-till). The most important functions of in-field buffers are to aid in managing runoff flow, water storage and nutrient transport. These functions are critical for maintaining effective field-edge buffers by minimizing the probability that they will receive water and nutrient loads beyond their capacity to retain.

Extent of Research

Moderate in Upper Midwest.

While there has been several studies conducted within Iowa and neighboring states of some in-field buffer practices, not all types of these practices have been thoroughly evaluated in each of Iowa's agroecoregions. Most studies have utilized simulated rainfall equipment. While these studies provide good understanding of N losses during controlled rainfall events, they do not give an adequate measure of effectiveness over time. Additional research is needed that quantifies performance variability with time and differing climatic conditions over a several year period, and with both diffuse and concentrated inflow. However, enough research evidence has been compiled to prove that these practices will reduce N losses from crop fields.

Secondary Benefits

- Serve as a P sink (see Total P section)
- Sediment retention mechanism from cropland runoff
- Partial filtering and decomposition of pesticides
- Additional income source from shelterbelts (i.e., biofuel, hardwood construction, nut production) if designed, implemented and managed properly
- Additional wildlife habitat
- Provides some degree of flood control
- Reduced road maintenance and snow removal costs to local county and state governments

Conservation Practice Research Summary Table

Contaminant: Total N

Type of Strategy: Remedial

Strategy Name: **In-Field Vegetative Buffers** (filter strips, contour filter strips shelterbelts, grass hedges, etc.)

References significant to Iowa identified in bold italics.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction
Udawatta et al 2002 **Grass and Tree + Grass Contour Buffer Strips**	Knox Co, Northern Mo.; Putnam silt loam, Kilwinning silt loam, and Armstrong loam soils.	3 yr	Watershed Paired Watershed Design:	CS[2] rotation	Surface runoff		Three-yr total flow-weighted TN[3], NO3-N[4] and NH4-N[5] mass loss		Seven-yr calibration period prior to initiation of study. Runoff collected from March to December for three years. Load #'s are sum of three years. Both types of buffer strip treatments established during initial year of study. Therefore, results are only indicative of early establishment phase of the buffer systems. Second-yr had 52% of all runoff events, first-yr had 36%, third-yr had 12%.	Greater reductions in 2nd and 3rd years; poor performance in initial year reported due to not fully established buffer systems. Reductions attributed to sediment deposition within the buffer strips, vegetative assimilation and increased infiltration. Theorized that fertilizer application timing, tillage and heavy precipitation were major factors for N transport.
			Control 4.1a			Control Watershed	10.06 lb/a TN 1.69 lb/a NO3-N 0.44 lb/a NH4-N	_ _ _		
			Grass Contour Buffer Strips 7.8a			Grass Contour Buffer Strips, 15 ft wide, ~120 ft	8.63 lb/a TN 1.34 lb/a NO3-N 0.36 lb/a NH4-N	14.2% 20.7% 18.2%		
			Tree + Grass Contour Buffer Strips 11.0a			Tree + Grass Contour Buffer Strips, 15 ft wide, ~120 ft apart	8.99 lb/a TN 1.60 lb/a NO3-N 0.27 lb/a NH4-N	10.6% 5.3% 38.6%		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Schmitt et al., 1999 **Grass and Grass + Woody Plants Buffer Strips**	Mead, NE, US; Sharps-burg silty clay loam to sandy loam	Simulated 1-yr return frequency rainfall event in July	Field-plot	Contour CT sorghum with filter strips	Surface runoff		TN and N+N[10] concentration		Simul-ated 1-yr return freq-uency rainfall event in July with prior simul-ated rainfall to mimic typical field cond-itions	Particulate settling, infiltration of rainfall and runoff flow (reduction of runoff flow), and dilution. Concentr-ations of TN and N+N were significantly reduced. Masses of TN and N+N were significantly reduced, but raw data was not shown. Negative reduction %s represents increases compared to respective control. Theorized that treatment released nutrient form to runoff due to higher concentration within treatment.
						Simulated Rainfall, C1[6]	68 ppm TN 28 ppm N+N	– –		
						Contour CT[7] Sorghum, 24.37 ft width, C2[8]	50 ppm TN 23 ppm N+N	26.4%C1 17.8%C1		
						Contour CT Sorghum, 48.75 ft width, C3[9]	44 ppm TN 20 ppm N+N	35.3%C1; 12.0%C2 28.6%C1; 13.0%C2		
						25-yr-old grass, 24.37 ft width	44 ppm TN 21 ppm N+N	35.3%C1; 12.0%C2; 0%C3 25.0%C1; 8.7%C2; -5.0%C3		
						25-yr-old grass, 48.75 ft width	33 ppm TN 15 ppm N+N	51.5%C1; 44.0%C2; 25.0%C3 46.4%C1; 34.8%C2; 25.0%C3		
						2-yr-old grass, 24.37 ft width	48 ppm TN 21 ppm N+N	29.4%C1; 4.0%C2; -9.1%C3 25.0%C1; 8.7%C2; -5.0%C3		
						2-yr-old grass, 48.75 ft width	39 ppm TN 18 ppm N+N	42.6%C1; 22.0%C2; 11.4% C3 35.7%C1; 21.7%C2; 10.0%C3		
						2-yr-old grass/tree/shrub, 24.37 ft width	49 ppm TN 21 ppm N+N	27.9%C1; 2.0%C2; -11.4%C3 25.0%C1; 8.7%C2; -5.0%C3		
						2-yr-old grass/tree/shrub, 48.75 ft width	40 ppm TN 16 ppm N+N	41.2%C1; 20%C2; 9.1%C3 42.8%C1; 30.4%C2; 20%C3		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Lee et al., 1999 **Grass Riparian Buffer Strips**	Roland, IA., US; Coland silty clay loam buffers' soil, Clarion loam cropland soil	3 days (rainfall simulations)	Plot Simulated drainage to filter strip area ratio of 40:1for 9.75 ft wide strips, 20:1 ratio for 19.5 ft wide strips	Fallow period	Surface runoff	 9.75 ft wide Switchgrass Cool Season 19.5 ft wide Switchgrass Cool Season	Mass (lb/a) transport of NO3-N and TN. Only % Reductions from Runon N Content Reported NO3-N TN NO3-N TN NO3-N TN NO3-N TN	 28.1% 31.7% 22.3% 23.5% 46.9% 51.2% 37.5% 41.1%	Rainfall simulations done in August with no natural rainfall events occurring. Rainfall simulation rate was 2 in/hr intensity preceded by a 15 minute wetting period. Runon to filter strips at a rate of 10.6 gal/min. Cool season mix consisted of bromegrass, timothy and fescue. Cool season treatment derived from 7 yr ungrazed pasture prior to study, switchgrass (warm season grass) established 6 yr prior to study.	Switchgrass and the 19.5 ft strip distance were better than cool season plant mix and 9.75 ft strip width in removing N from runoff. Switchgrass produces more litter, stiffer stems, stronger root systems and spatially uniform growth than the cool season mix, which may make it more efficient at sediment and nutrient removal. TN reduction was highly correlated with sediment removal, NO3-N removal with infiltration. Although, infiltration and sediment deposition had roles in reducing both N forms. Reduced filter strip width also had lesser reductions in sediment load from runoff.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Magette et al. 1989 Grass Buffer Strips	Queens-town, MD, US; Woods-town sandy loam	Not reported.	Plot, 15 ft X 30 ft. Rainfall simul-ations	Fallow soil. Fertilizer N applied at 100 lb/a for simulations 1-6; Broiler litter applied at 224 lb N/a and 102 lb P/a for simulations 7-12.	Surface runoff	 Control 15 ft Fescue 30 ft Fescue	Sum TN mass loss from all rainfall simulations 88.3 lb/a TP 82.4 lb/a TP 48.0 lb/a TP	 _ 6.7% 45.6%	Each plot received 12 simulations @1.9 in/hr over a 2-3 month period. Numbers are sums of the 12 tests. Runoff samples taken at 1, 2 and 3 minutes after runoff initiated and every 3 minutes thereafter.	TN reductions strongly related to buffer strip length, suggesting a critical minimum length for significant TN removal.
Dillaha et al. 1989 Grass Buffer Strips	Blacks-burg, VA, US; eroded Grose-close Silt loam	1-week in spring (April)	Plot 18 ft X 60 ft, Rainfall simul-ations.	Barren, tilled corn fallow field. Applied 198 lb N/a and 100 lb P/a fertilizer several days prior to initiation of study.	Surface runoff	 Diffuse Flow, 11% Slope: No Buffer (Control) Orchard grass 15 ft buffer Orchard grass 30 ft buffer Concen-trated Flow, 5% Slope: No Buffer (Control) Orchard grass 15 ft buffer Orchard grass 30 ft buffer	Ave. sum TN, NO3-N and NH4-N, TKN[7] mass loss from all simulated rainfall events 20.87 lb/a TN 1.62 lb/a NO3-N 2.59 lb/a NH4-N 19.62 lb/a TKN 10.38 lb/a TN 1.54 lb/a NO3-N 2.02 lb/a NH4-N 8.85 lb/a TKN 6.88 lb/a TN 0.85 lb/a NO3-N 1.18 lb/a NH4-N 6.02 lb/a TKN 7.92 lb/a TN 1.08 lb/a NO3-N 0.67 lb/a NH4-N 6.84 lb/a TKN 1.40 lb/a TN 0.30 lb/a NO3-N 0.17 lb/a NH4-N 1.09 lb/a TKN 1.59 lb/a TN 0.30 lb/a NO3-N 0.11 lb/a NH4-N 1.29 lb/a TKN	 _ _ _ _ 50.3% 4.9% 22.0% 54.9% 67.0% 47.5% 54.4% 69.3% _ _ _ _ 82.3% 72.2% 74.6% 84.1% 79.9% 72.2% 83.6% 81.1%	Each plot received 6 simulations @ 2 in/hr over a ~1 week period. Water samples collected every 3 min. during runoff.	Concentrated flow plots had a 5% slope, with a 4% cross slope. Diffuse flow plots had 11% slopes with <1% cross slope. Despite having diffuse flow, the 11% slope plots had a lesser effect on N reduction than the concentrated flow plots with a 5% slope. TN, NH4-N and TKN was mainly associated with sediment, so reductions attributed to sediment deposition within the buffer strips. NO3-N not reduced to degree of other N forms.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Eghball et al., 2000 **Narrow Grass Hedge Buffer Strips**	Treynor, IA, US; Monona silt loam with 12% slope	Summer	Plot, buffer ~2.5 ft wide, 12 ft X 35 ft rainfall simul-ation plots.	Disk tilled and no-till continuous corn with either inorganic or manure fertilizer. Manure at rates of 336 lb N/a and 228 lb P/a. Inorganic fertilizer at rates of 134 lb N/a and 23 lb P/a.	Surface runoff		Sum NO3-N, NH4-N and TN mass losses of initial + second rainfall simulations		Runoff water samples collected at 5, 10, 15, 30, and 45 minutes after initiation of runoff. Initial rainfall simulation of 1 hr at 2.5in/hr. Second rainfall simulation conducted 24 hr later at same time and rate.	Additions of inorganic and manure fertilizers increased losses of all N forms, except manure TN. Grass hedge buffer strips consistently reduced losses of all N forms in main treatment comparisons, except for manure N. Removal mechanisms not reported.
						No Grass Hedge (C1)	3.39 lb/a NO3-N 0.03 lb/a NH4-N 11.43 lb/a TN	_ _ _		
						Grass Hedge (C2)	2.23 lb/a NO3-N 0.01 lb/a NH4-N 5.64 lb/a TN	34.2%C1 66.7%C1 50.6%C1		
						Inorganic Fertilizer, No Grass Hedge (C3)	5.44 lb/a NO3-N 0.69 lb/a NH4-N 16.85 lb/a TN	-60.5%C1 -2200.0%C1 -47.4%C1		
						Inorganic Fertilizer + Grass Hedge (C4[13])	3.44 lb/a NO3-N 0.25 lb/a NH4-N 11.16 lb/a TN	-54.3%C2; 36.8%C3 -2400.0%C2; 63.8%C3 -97.9%C2; 33.8%C3		
						Manure Fertilizer, No Grass Hedge (C5[14])	3.77 lb/a NO3-N 0.30 lb/a NH4-N 6.95 lb/a TN	-11.2%C1; 30.7%C3 -900.0%C1; 56.5%C3 39.2%C1; 58.8%C3		
						Manure Fertilizer + Grass Hedge	2.42 lb/a NO3-N 0.10 lb/a NH4-N 7.32 lb/a TN	-8.5%C2; 29.6%C4; 35.8%C5 -900.0%C2; 60.0%C4; 66.7%C5 -29.8%C2; 34.4%C4; -5.3%C5		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Barfield et al., 1998 Grass Buffer Strips	KY, US; Maury silt loam soil, 9% slope	2 rainfall simulation events during summer	Plot 15 ft X 72 ft erosion plots, bluegrass + fescue grass buffers of varied length	Corn – Fallow Fertilizer applied at 151 lb N/a and 39 lb P/a.	Surface runoff		Sum NO3-N and NH4-N mass losses of 2 rainfall simulations runs and both CT and NT[12] treatments		Two rainfall simulations conducted approximately 3 weeks apart during summer at 2.5in/hr intensity for 2 hr. Runoff water sampled for 10 seconds at 5-minute intervals.	Trapping efficiency increased with increasing length of brass buffers, though each length treatment trapped >90% of inflow N. Primary removal mechanism reported was infiltration, next most important mechanism was adsorption in the soil surface layer.
						<u>Inflow</u> ~15 ft Grass Buffer (C1)	340.3 lb NO3-N 413.2 lb NH4-N	_ _		
						~30 ft Grass Buffer (C2)	711.2 lb NO3-N 758.6 lb NH4-N	_ _		
						~45 ft Grass Buffer (C3)	178.0 lb NO3-N 369.4 lb NH4-N	_ _		
						<u>Outflow</u> ~15 ft Grass Buffer	7.8 lb NO3-N 20.3 lb NH4-N	97.7%C1 95.1%C1		
						~30 ft Grass Buffer	50.7 lb NO3-N 47.5 lb NH4-N	92.9%C2 93.7%C2		
						~45 ft Grass Buffer	8.0 lb NO3-N 17.9 lb NH4-N	95.5%C3 95.5%C3		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Srivastava et al., 1996 Grass Buffer Strips	Fayette-ville, AR, US; Captina silt loam soil with 3% slope	Not reported	Plot Varied source and buffer lengths (all of 5 ft width). Source lengths of ~20, 40 and 60 ft. Buffer lengths of ~0, 10, 20, 30, 40, 50 and 60 ft.	Fescue grass pasture with applied poultry litter at nutrient rates of 130 lb N/a and 54 lb P/a.	Surface runoff	Concentration by Buffer Length <u>from Source</u>	Runoff TKN and NH3-N[13] concentration[14] and mass		Rainfall simulation rate of 2 in/hr. Water sampled at 2.5 minutes, then every 10 minutes thereafter for 1 hr after initiation of runoff from plot ends.	Both N form concentrations were not significantly affected by source area length, but were by buffer strip length. No significant difference in TKN concentr-ation reductions beyond 10 ft of buffer strip length, 20 ft for NH3-N. Significantly greater runoff and mass losses of both N forms with increasing source area length. Mass reductions not significantly affected by buffer strip length, but trend did exist for greater reductions with increasing length. Lack of significance believed to be due to high degree of variation among replications. NO3-N not shown due to very low losses.
						0 ft	46 ppm TKN 24 ppm NH3-N	_ _		
						10 ft	26 ppm TKN 14 ppm NH3-N	43.5% 41.7%		
						20 ft	15 ppm TKN 9 ppm NH3-N	67.4% 62.5%		
						30 ft	9 ppm TKN 5 ppm NH3-N	80.4% 79.2%		
						40 ft	8 ppm TKN 3 ppm NH3-N	82.6% 87.5%		
						50 ft	4 ppm TKN 1 ppm NH3-N	91.3% 95.8%		
						60 ft	4 ppm TKN 0.5 ppm NH3-N	91.3% 97.9%		
						Mass by Source/Buffer Length <u>Inflow</u>				
						20 ft/60 ft	0.0196 lb TKN 0.0097 lb NH3-N	_ _		
						40 ft/40 ft	0.0410 lb TKN 0.0209 lb NH3-N	_ _		
						60 ft/20 ft	0.0476 lb TKN 0.0286 lb NH3-N	_ _		
						<u>Outflow</u>				
						20 ft/60 ft	0.0042 lb TKN 0.0013 lb NH3-N	78.6% 86.6%		
						40 ft/40 ft	0.0172 lb TKN 0.0086 lb NH3-N	58.0% 58.8%		
						60 ft/20 ft	0.0306 lb TKN 0.0211 lb NH3-N	35.7% 26.2%		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Daniels and Gilliam, 1996 Grass Buffer Strips	2 locations in NC Piedmont region, US; predominately Cecil soils (sandy loam to clay loam surface horizons) and Georgeville soils (silt loam to silty clay surface horizons)	2-yr	Field	Crops not reported, grass buffer consisted of fescue	Surface runoff	NO3-N TKN	Mass transport of PO4-P and TP. Only % Reductions from Runon P Content Reported	~50% ~50%	Water samples taken at runoff events. Runoff events among plots at the Cecil soils area ranged from 26-50 events. Georgeville soils are plots had 6-18 runoff events.	Sediment deposition, increased infiltration and sorption to soil and plant residues were primary removal mechanisms.

1 Watershed, field, plot or laboratory
2 CS represents corn-soybean
3 TN represents total nitrogen
4 NO3-N represents nitrate-nitrogen
5 NH4-N represents ammonium-nitrogen
6 C1 represents control 1, in reductions column the #% means compared to C1
7 CT represents conventional tillage
8 C2 represents control 2, in reductions column the #% means compared to C2
9 C3 represents control 3, in reductions column the #% means compared to C3
10 N+N represents nitrate plus nitrite nitrogen
11 TKN represents total Kjeldahl nitrogen, being the sum of organic-N and free ammonia-N
12 NT represents no-tillage
13 NH3-N represents ammonia-nitrogen
14 Estimates of concentration values from graph figure representations of data

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Conservation Practice Summary Assessment

Contaminant: **Total N**

Type of Strategy: **Preventive**

Strategy Name: **Landscape Management Practices** (terraces)

Pollutant reduction mechanisms

- Improved water infiltration and nutrient adsorption to soil matrix (with exception of nitrate-N form)
- Reduced erosion and transport of nutrient enriched sediments and particulates
- Reduced in-field volume of runoff water
- Reduced volume of runoff water reaching surface waters
- Trapping and retention of transported nutrient enriched sediments and particulates

Applicable conditions

- All agricultural production fields of appropriate slope ($\leq$ 18%), slope length and erosion risk to necessitate terracing or other landscape altering operations as per USDA-NRCS guidelines

Limiting conditions

- Unstable soils (i.e., low plasticity limits or coarse texture)

Range of variation in effectiveness at any given point in time

-100% to +100%

Effectiveness depends on:

- Slope and slope length
- Soil type, texture, structure, and water infiltration rate
- Intensity, quantity, duration and timing of rainfall and snowmelt events
- Crop rotation
- Tillage program and resulting degree of residue cover and soil disturbance
- Time, rate and method of N nutrient applications
- Prior land management program and associated P loss
- Existence or absence of other conservation practices
- Risk of runoff reaching surface waters either by close proximity to surface water body or presence of tile drainage and surface intakes

Estimated potential contaminate reduction for applicable areas within Iowa (annual basis)

-40% to +30%

All comparisons shown here are based upon total N data. Results differ widely by form of N, particularly for soluble forms. Total N was chosen since it is currently the N form that total maximum daily loads are to be developed for the state's surface water bodies. Estimates are also based upon the knowledge that nitrate is the dominant form of N in surface waters and that the main nitrate transport pathway is leaching.

Slope, slope length, soil texture are main factors that determine soil erodability and infiltration capacity, and with N content, affect the water quality impacts of landscape altering practices. Areas that have coarse soil texture, and steep and/or long slope are frequently classified as being highly erodable. If the soils are suitable for embankment construction, then terraces will likely reduce ammonium-N and total Kjeldahl N losses to a greater degree than for lands of low slope and erosion risk. This is accomplished by partitioning a greater amount of water to infiltration and subsurface drainage and less to runoff. However, there is a negative aspect to increased infiltration and subsurface drainage. Greater nitrate-N losses have frequently been documented with increased infiltration since this N form is soluble and anionic, not adsorbing to soil particles. Conditions may then exist that cause greater total N loss from a terraced and tile drained system compared to a similar field lacking these systems. The overall effect depends upon the difference in the amount of N retained from reduced erosion (mainly ammonium-N and total Kjeldahl N) and the amount of N lost by leaching (mainly nitrate-N). Precipitation events of that cause subsurface leaching but little runoff can then lead to greater N losses from a terraced and tile drained field than a field lacking these practices. The difference in total N loss between the two pathways may be minimal for fields of sufficient slope to require terraces.

The type of crop rotation, tillage and N nutrient management programs, and of course the former conditions being compared to, all have an impact on the degree of N loss reduction realized from adding landscape management practices (i.e., terraces). Terraces will provide a much greater benefit to reducing N loss from an annual row cropping system than from a perennial crop system. For instance, a corn or corn-soybean rotation typically receives substantial N fertilizer inputs and can commonly generate large amounts of runoff and erosion. A perennial grass/legume hay crop typically receives little to no N fertilizer inputs and provides permanent cover that inhibits runoff and erosion. Therefore, the annual row cropping system would have a much greater load of N at risk to off-field transport for terraces to retain than that from a perennial grass/legume system. Differences in N loss by tillage programs is not as significant as it is for P loss, but on balance between runoff and subsurface leaching, more intensive tillage tends to result in greater total N losses. Therefore, terraces with a moldboard plow tillage program will likely reduce N losses more than terraces with a field managed by a no-tillage program, but only to a small degree.

It is critical to properly maintain terraces due to the amount of energy and sediments that the terraces are to capture. Terraces are meant to manage both diffuse and concentrated runoff flow. The most potentially damaging of the two types is concentrated flow because as runoff water flow concentrates into smaller areas, so does the erosive force of the water. Any terrace areas that are structurally weakened by factors such as inadequate grass cover, animal burrows or gullies can collapse during a peak runoff event. Once a breach has occurred, runoff flow energy can intensify, resulting in gully erosion and failure of the terrace that may put other downslope conservation practice structures at risk. In addition to proper and regular maintenance, the presence of other conservation practices upslope and between terraces will reduce the risk of terrace failures.

The existence or absence of other conservation practices, such as vegetative buffers (in-field or riparian), wetlands and in-season N fertilizer application, can dramatically influence annual N losses from terraced fields. If other conservation practice buffers are appropriately placed in coordination with terraces to reduce runoff volume, limit concentrated flow and cause deposition of transported sediments on the landscape, then the risk of ammonium-N and total Kjeldahl N transport from the field to surface waters may be greatly reduced. Some research has identified that surface tile intakes pose a significant threat for N loss by directly routing field runoff to surface waters. This threat can be minimized if vegetative buffers surround the surface intakes and the inlet ports are far enough above the soil surface to result in minor ponding that will allow sediment to settle back onto the field and not enter tile lines that drain to surface waters.

Estimated long-term contaminant reduction for applicable areas in Iowa (multi-year basis)

-10%

This estimate of total N loss reduction applies only to row crop areas suitable for terrace construction, that have properly built and maintained terraces, and have other needed conservation practices in place to limit the probability of a terrace system being overwhelmed from peak rainfall and snowmelt events. Results may vary from this estimate depending upon the conditions described in the above section.

Extent of research

Limited

As frequently as terraces occur in the areas of considerable topographic relief in Iowa, it is surprising that more research has not been done to quantify this practice's effects on N contamination of surface waters. The literature review only found a few research articles from the Deep Loess Hills section of Iowa. Similar research should be conducted within other Iowa agroecoregions.

Secondary benefits

- Improved long-term farm profitability
- Reduced P nutrient contamination of surface waters
- Reduced sediment contamination of surface waters

Conservation Practice Research Summary Table

Contaminant: **Total N**

Type of Strategy: **Preventive**

Strategy Name: **Landscape Management Practices Conservation Tillage** (terraces)

References significant to Iowa identified in bold italics.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Burwell et al., 1974 **Level terraced vs. non-terraced, contour plant**	Macedonia and Treynor, IA (Potta-wattamie Co. deep loess hills), US: Marshall, Judson, Monona, Ida and Napier silt loam soils with slopes ranging from 2-13%.	2-yr	Watershed W1[2] = 83a W2[3] = 389a	W1: CT[4] contour plant CC[5] (100%). Fertilizers applied at rates of 150 lb/a/yr N and 35 lb/a/yr P. W2, CT level terrace CS[6] (60%) + pasture and forage crops (40%) + 2 livestock feedlots. Corn fertilized at rates of 115 lb/a/yr N and 25 lb/a/yr P.	Surface runoff and subsurface leaching (base flow)	<u>Surface runoff</u> W1, contour plant W2, level terrace <u>Subsurface leaching (base flow)</u> W1, contour plant W2, level terrace <u>Total Quantity</u> W1, contour plant W2, level terrace	Annual ave. mass loss of NO3-N[7], NH4-N[8], TKN[9] and TN[10] 0.66 lb/a NO3-N 0.80 lb/a NH4-N 29.58 lb/a TKN 0.17 lb/a NO3-N 0.56 lb/a NH4-N 3.82 lb/a TKN 1.18 lb/a NO3-N 0.12 lb/a NH4-N 0.59 lb/a NO3-N 0.30 lb/a NH4-N 32.34 lb/a TN 5.44 lb/a TN	_ _ _ 74.2% 30.0% 87.1% _ _ 50.0% -150.0% _ 83.2%	Water quality sampling began in May of yr 1 and continued through Dec. of yr 2. Surface runoff samples taken during at rise, peak and recession of each runoff event. Base flow samples taken monthly during low flow, weekly during high flow periods. W1 had 293 surface runoff samples and 46 base flow samples. W2 had 211 surface runoff samples and 39 base flow samples.	Concentration data not shown due to being reported in ranges, not flow weighted annual averages. Concentrations of N in runoff were higher from the level terraced W2. This was attributed to confounding of large NH4-N load coming from the 2 livestock feedlots near the sampling site. Mass N loads reduced by reduced runoff flow volume and sediment erosion with reduced slope from level terraces.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Burwell et al., 1977 **Level terraced vs. non-terraced, contour plant**	Deep Loess Research Station at Treynor, IA, US; Monona, Ida and Napier silt loam soils.	5-yr	Watershed W1 = 74a W2 = 81.5a W3 = 106a W4 = 148a	CC and Rotational Grazing of Bromegrass Pasture Ave. Annual P Rates W1 = 400 lb/a N W2 = 155 lb/a N W3 = 158 lb/a N W4 = 306 lb/a N W1, W2 CC with CT[8] contour planting W3 Bromegrass with Rotational Grazing yrs 1-3, CC w MT[9] contour planting yrs 4-5 W4 CC w CT and level terraces yrs 1-3, CC w MT and surface intake and outlet tiled terraces yrs 4-5	Surface runoff and subsurface leaching		Annual ave. mass loss of NO3-N, NH4-N, sediment-N, & TN		Yr 4 had 22% more precipitation than the 10-yr annual ave.	Authors stated that 94% of N and 82% of P ave. annual losses in surface runoff from the contour planted watersheds were transported with sediment. Therefore, the most practical step to reduce N and P losses is to reduce soil erosion. Deep percolation and subsurface discharge of water with level terraces increased, as did NO3-N and NH4-N via that pathway. Increased N leaching losses were attributed primarily to the greater volume of water partitioned to subsurface discharge for the level terraced area compared to the contour plant area. On balance, overall TN losses were reduced to an appreciable, but not a large, degree.
						Subsurface Leaching W1 @ 400 lb/a N	18.49 lb/a NO3-N 0.14 lb/a NH4-N	_ _		
						W4 @ 306 lb/a N	31.33 lb/a NO3-N 0.36 lb/a NH4-N	-69.4% -157.1%		
						Surface Runoff W1 @ 400 lb/a N	1.12 lb/a NO3-N 0.57 lb/a NH4-N	_ _		
						W4 @ 306 lb/a N	1.12 lb/a NO3-N 0.24 lb/a NH4-N	0.0% 57.9%		
						Runoff Sediment W1 @ 400 lb/a N	24.49 lb/a sediment-N	_		
						W4 @ 306 lb/a N	6.89 lb/a sediment-N	71.9%		
						Total Stream Discharge W1 @ 400 lb/a N	44.81 lb/a TN	_		
						W4 @ 306 lb/a N	39.94 lb/a TN	10.9%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Hanway and Laflen, 1974 **Tile-outlet terrace water quality survey**	Eldora, Guthrie Center, Creston and Charles City, IA, US: Fayette silt loam with 4% slope (Eldora), Clarion loam with 6% slope (Guthrie Center), Sharps-burg silty clay loam with 4% slope (Creston), Floyd loam with 3% slope (Charles City).	3-yr	Field	CT row crops (mainly corn) with parallel terraces, with and without tile drainage 3-yr ave. fertiliz-ation <u>rates</u> Eldora: 207 lb/a/yr N, 37 lb/a/yr P Guthrie Center: 171 lb/a/yr N, 35 lb/a/yr P Creston: 93 lb/a/yr N, 15 lb/a/yr P Charles City: 197 lb/a/yr N, 38 lb/a/yr P	Surface runoff and subsurface leaching Runoff water discharged through tile surface riser inlets to subsurface tile drainage lines at Creston and Charles City. No tile drainage at Eldora and Guthrie Center	<u>Surface runoff</u> Eldora (terraces, no tile) C1[12] Guthrie Center (terraces, no tile) C2[13] Creston (terraces with tile drainage) Charles City (terraces with tile drainage) Subsurface tile drainage (runoff intake + shallow subsurface <u>leaching)</u> Eldora (terraces, no tile) Guthrie Center (terraces, no tile) Creston (terraces with tile drainage) Charles City (terraces with tile drainage)	3-yr annual flow-weighted ave. concentr-ation and mass loss of IN[11] 2.0 ppm IN 0.36 lb/a IN 4.0 ppm IN 0.89 lb/a IN 4.0 ppm IN 1.69 lb/a IN 11.0 ppm IN 8.63 lb/a IN No measures No measures 8.0 ppm IN 1.87 lb/a IN 18.0 ppm IN 18.24 lb/a IN	_ _ _ _ -100.0%C1; 0.0%C2 -369.0%C1; -89.9%C2 -450.0%C1; -175.0%C2 -2297.2%C1; -869.7%C2	Number of runoff events varied by site for 3-yr period, being: Eldora = 22 Guthrie Center = 25 Creston = 26 Charles City = 38 Flow rate and water chemistry sampling done from April through November each of 3 yrs. Tile drainage sampled every 2 days following a runoff event. Single, continuous samples taken of runoff for each runoff event via splitters to capture $1/169^{th}$ of total runoff volume. Ave. annual precipitation across 4 sites ranged from 25.6 – 29.0 in.	IN losses were directly related to volume of runoff and subsurface drainage discharge water. Creston had approx. 3.25X greater, and Charles City 9X greater, water loss than Eldora and Guthrie Center sites. Concentra-tions of drainage water IN greater with tile drainage of terraces. No compar-ison made of subsurface leaching due to no measures at Eldora and Guthrie Center sites (leaching probably did occur, just not account-ed for).

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Schuman et al., 1973 **Level terraced vs. non-terraced, contour plant**	Deep Loess Research Station at Treynor, IA, US; Monona, Ida and Napier silt loam soils with slopes ranging from 2%-18%.	3-yr	Water-shed W1[2] = 74a W2[3] = 81.5a W3[4] = 106a W4[5] = 148a	CC and Rotational Grazing of Bromegrass Pasture <u>Ave. Annual N Rates</u> W1, W4 = 400 lb/a N W2, W3 = 150 lb/a N W1, W2 CC with contour planting W3 Bromegrass with Rotational Grazing W4 CC with level terraces	Surface runoff	W1 contour planted, no terraces W4 Level terraces	Annual ave. mass loss of NO3-N, NH4-N, TKN and TN 1.50 lb/a NO3-N 1.21 lb/a NH4-N 32.56 lb/a TKN 35.27 lb/a TN 0.16 lb/a NO3-N 0.21 lb/a NH4-N 2.33 lb/a TKN 2.70 lb/a TN	_ _ _ _ 89.3% 82.6% 92.8% 92.3%	Minimum of 4 water samples per runoff event, being: initiation of runoff, increasing runoff flow rate, at runoff flow rate peak, at decline of runoff flow rate. N losses were usually greatest during spring tillage and planting due to higher precipitation and lack of plant canopy cover and plant N and water uptake. Losses then decreased as growing season progressed.	N mass loss reduction due to reduced erosion and off-field transport of sediment. Authors reported that 92% of runoff transported N was associated with eroded sediments for all water-sheds.

1 Watershed, field, plot or laboratory.
2 W1 represents watershed 1.
3 W2 represents watershed 2.
4 CT represents conventional tillage.
5 CC represents continuous corn rotation.
6 CS represents corn-soybean rotation.
7 NO3-N represents nitrate-nitrogen.
8 NH4-N represents ammonium-nitrogen.
9 TKN represents total Kjeldahl nitrogen, being the sum of organic-N and free ammonia-N.
10 TN represents total nitrogen.
11 IN represents inorganic-nitrogen, being: nitrate-nitrogen, ammonium-nitrogen and nitrite-nitrogen.

12 C1 represents control 1 and comparison to control 1.
13 C2 represents control 2 and comparison to control 2.

References

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Conservation Practice Summary Assessment

Contaminant: **Total N**

Type of Strategy: **Preventive**

Strategy Name: **Nitrification and Urease Inhibiting Chemicals**

Pollutant Reduction Mechanisms:
- Improved synchronization of N fertilizer availability with crop demand

Applicable Conditions:
- Nitrapyrin is most beneficial to fall applied anhydrous ammonia N fertilizer
- Urease inhibitors apply to use of urea or other N fertilizers containing urea

Limiting Conditions:
- Nitrapyrin appears to be less to non-effective in neutral to slightly alkaline soil pH conditions, though other factors that interact with soil pH also have impact
- Above normal temperatures that accelerate the degradation of inhibitors to the extent that most of the added N fertilizer still transforms to nitrate and is at risk to leaching loss before the time of peak crop N demand
- Below normal temperatures that delay degradation of inhibitors to extent that most of the added N fertilizer does not become plant available until after the time of peak crop N demand
- Below normal precipitation that delays degradation of inhibitors to extent that most of the added N fertilizer does not become plant available until after the time of peak crop N demand
- Nitrapyrin less beneficial, possibly detrimental at times, with spring and split spring/in-season N fertilizer application

Range of variation in effectiveness at any given point in time

-100% to +90%

Effectiveness depends on:
- Dry soil conditions reduces leaching risk and diminishes the benefits of inhibitors
- Timing of N application: most effective for fall application, can reduce plant uptake of spring and sidedress N applications and increase the amount of residual soil-nitrate after harvest, leading to increased N leaching losses
- Rate of N fertilizer applied: applied N rate in excess of crop N demand will still lead to N leaching losses
- Neutral to slightly alkaline soil pH having greater bacteria populations and activity
- When applied with anhydrous ammonia at recommended rates, in the fall and not under listed limiting conditions, nitrification inhibitors have resulted in improved crop

N use efficiency and reduced N losses to levels typically found with spring N fertilizer applied without a nitrification inhibitor

Estimated potential contaminate reduction for applicable areas within Iowa (annual basis)

-75% to +75%

Many species of microbes produce the enzyme urease that transforms urea to ammonia. Ammonia is very volatile and subject to loss from the soil surface to the atmosphere. Urease inhibitors slow this transformation by limiting the activity of the urease enzyme, which then stabilizes urea-based N fertilizers in the soil environment. Nitrification inhibitors, such as nitrapyrin, stabilize ammonia-based N fertilizers in the soil by slowing the growth and activity of microbes that perform the first stage of nitrification, which is the transformation of ammonium to nitrite. Other species of microbes carry out the second stage of nitrification, being the transformation of nitrite to nitrate, which can occur abruptly. Nitrate is very prone to leaching losses since it is an anion, whereas ammonium is a cation and immobile within the soil. Managing N by limiting its presence in the nitrate form can increase the likelihood that the N may be utilized up by the crop and decrease the chance for the N to be lost via leaching.

While the many limiting factors vary considerably in space and time, the average impact of nitrification inhibitors when applied in fall as recommended typically result in nitrate-N leaching losses anywhere from –20% to +20%. Some years there will be little to no benefit, other years the inhibitors may improve both water quality and crop yield. It appears the issue that links all of the limiting factors together is the growth and function of soil bacteria. If soil conditions – most importantly, temperature - are favorable for the growth of bacteria that produce the inhibitor degrading enzymes, then the inhibitor’s efficacy may be reduced in a relatively brief period of time. Ammonium-N is then more subject to the transformation processes of nitrification and chemical hydrolysis. If soil and climatic conditions are not favorable for bacteria growth, then the inhibiting chemical is able to further limit nitrifying bacteria activity, thus delaying nitrification of ammonium-N. In a drier than normal year, there is an increased probability that nitrification of added N will be delayed and can result in a greater amount of residual soil-nitrate after crop harvest, increasing the risk for nitrate leaching losses.

In the absence of changing N fertilizer applications to either spring or split spring and in-season practices, use of nitrapyrin for fall N application will offer a degree of environmental benefit when averaged over a period of years. It is unknown whether or not similar results may be expected for urease inhibitors since research has yet to adequately investigate the potential water quality benefits of this class of N stabilizing chemicals.

<u>Estimated long-term contaminant reduction for applicable areas in Iowa (multi-year basis)</u>

+10%

The major assumption here is that nitrapyrin is applied at the recommended rate with fall-applied anhydrous ammonia only after the soil is at or below 10^{o}C and remains below 10^{o}C until the following spring. Over the long-term, use of N nitrification inhibitors at recommended rates with fall N application will provide some benefit in reducing N nutrient losses from production fields to surface waters despite the many limiting factors. Urease inhibitors would be more appropriate for spring application of urea-N fertilizers since such forms are not typically applied in the fall.

<u>Extent of research</u>

Moderate

In the Upper Midwest, there have been a moderate number of studies conducted on use of nitrapyrin and measured its effects on water quality, having mixed results. It seems these conflicting results are primarily due to the listed limiting conditions, which can be highly variable temporally and spatially even within a single field. Research has yet to adequately explain the reasons for the limiting effects of these factors to improve management recommendations for farmer use and environmental benefits. Also, similar research of urease inhibitors has to date been very limited.

<u>Secondary benefits</u>

- Potential for increased corn yield

Conservation Practice Research Summary Table

Contaminant: Total N

Type of Strategy: Preventive

Strategy Name: Nitrification and Urease Inhibiting Chemicals

References significant to Iowa identified in bold italics.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Ferguson et al., 1991	NE, US; silt loam	3-yr	Field-plot	Continuous corn (CT[2] and NT[3] mixed) with varied N rates and NI applied anhydrous ammonia N fertilizer at late-sidedress timing (early summer)	Leaching to shallow groundwater		Total soil NO3-N[7] content at end of 3-yr study		Soil NO3-N samples taken at varied intervals from spring through fall.	Delaying nitrification, improving crop N use efficiency *NI use NOT beneficial with early-summer N fertilizer applications due to reduced crop N use efficiency.*
						267 lb N/a wo[4] NI[5] (control 1)	~240 lb/a NO3-N[8]	–		
						267 lb N/a w[6] NI (control 2)	~231 lb/a NO3-N	–		
						134 lb N/a wo NI	~107 lb/a NO3-N	55.4% C1[9] 53.7 % C2[10]		
						134 lb N/a w NI	~76 lb/a NO3-N	68.3% C1 67.1% C2		
						67 lb N/a wo NI	~40 lb/a NO3-N	83.3% C1 82.7% C2		
						67 lb N/a w NI	~31 lb/a NO3-N	87.1% C1 86.6% C2		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Walters and Malzer, 1990	MN, US; sandy loam soil	3-yr	Field-plot	CT, irrigated Continuous corn with varied N rates, w/wo NI, and w/wo IC[11]	Leaching to shallow groundwater		3-yr total NO3-N plus ammonium-N leaching losses		Soil water samples taken throughout growing season	No significant difference in N leaching losses between w or wo use of NI, only significant difference found due to applied N rate
						160 lb N/a, wo NI, wo IC	186.7 lb N/a	_		
						160 lb N/a, wo NI, w IC	183.3 lb N/a	1.8%		
						160 lb N/a, w NI, wo IC	173.6 lb N/a	7.0%		
						160 lb N/a, w NI, w IC	184.4 lb N/a	1.2%		
						80 lb N/a, wo NI, wo IC	89.7 lb N/a	52.0%		
						80 lb N/a, wo NI, w IC	78.3 lb N/a	58.1%		
						80 lb N/a, w NI, wo IC	78.7 lb N/a	57.8%		
						80 lb N/a, w NI, w IC	75.0 lb N/a	59.8%		
McCormick et al., 1983	IN, US; silty clay loam soil	1-yr	Field-plot	Fallow with liquid swine manure applied in spring	Leaching to shallow groundwater		Total soil NO3-N		Soil samples taken 24 weeks following injection of LSM[11]	Delaying nitrification. *Implication is that it is best to use NI with fall applied LSM.*
						66.1 ton/a injected LSM[12] wo NI	36 ppm	_		
						66.1 ton/a injected LSM w NI	76 ppm	-111%		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Randall and Mulla, 2001	MN, US; Webster clay loam soil	6-yr study w only last 4-yr with tile flow	Field-plot	Continuous corn with 133.5 lb N/a of AA[13] applied at varied timings	Leaching to shallow groundwater	Fall wo NI Fall w NI Spring wo NI Split wo NI (40% pre-plant + 60% sidedress)	4-yr total NO3-N mass loss; 4-yr ave annual NO3-N concentration 235 lb/a NO3-N 20 ppm NO3-N 185 lb/a NO3-N 17 ppm NO3-N 158 lb/a NO3-N 16 ppm NO3-N 169 lb/a NO3-N 16 ppm NO3-N	_ _ 21.3% 15% 32.8% 20% 28.1% 20%	First 2-yr of study wo tile flow due to drought, which leads to greater NO3-N losses when tile flow resumes. Tile flow measured and sampled yr-round.	Delaying nitrification. In years where crop yields are low, split N application may result in greater residual soil NO3-N (NO3-N leaching potential) than with spring N application.
Goos and Johnson, 1999.	ND, US; silty clay and loam soils	1-yr	Field-plot	Winter fallow following wheat or barley w/fall applied aqua ammonia at 75 lb N/a	Leaching to shallow groundwater	Aqua Ammonia wo NI Aqua Ammonia w/0.5 lb nitrapyrin/a Aqua Ammonia w/1.5 lb nitrapyrin/a Aqua Ammonia w/15 lb ammonium thiosulfate/a	Net loss of soil-nitrate from fall to spring 36 ppm 19 ppm 13 ppm 1 ppm	_ 47.2% 63.9% 97.2%	Soil sampled 20 days after fall N fertilizer application and 1 day prior to spring planting of succeeding crop.	Delaying nitrification.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Randall et al., 2003	Waseca, MN, US; Canisteo clay loam	8-yr	Field-plot	CS[14] annual rotation, N fertilizer applied to C only	Leaching to shallow groundwater		Flow-normalized NO3-N mass losses from tile drainage (lb/a NO3-N/in drainage) over 4 CS rotation cycles (8-yr)		Three of the eight years of study had below normal precipitation, with two very dry. Five of the eight years were above normal, with two years very wet. Water sample for nitrate content on 3 day/week schedule, plus all peak precipitation events. NI applied at recommend-ed rate of 0.5 lb/a active ingredient. April, May and June accounted for 62% of total annual drainage.	Highest nitrate levels occurred when tile flow resumed after dry periods ended. Months of April, May and June accounted for 68% of annual NO3-N loss from corn, and 70% from soybean. Corn years accounted for 55% of total NO3-N losses, 45% from soybean years. Greater amounts of residual soil nitrate following corn harvest increased nitrate losses during the soybean year.
						Fall 134 lb N/a wo NI	3.75 lb/a NO3-N/in	_		
						Fall 134 lb N/a w NI	3.10 lb/a NO3-N/in	17.3%		
						Spring 134 lb N/a wo NI	3.12 lb/a NO3-N/in	16.8%		
						Split wo NI (40% pre-plant + 60% sidedress)	3.28 lb/a NO3-N/in	12.5%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Lawlor et al., 2004	Gilmore City, IA, US; Nicollet, Webster and Canisteo clay loam soils with ave. slopes of 0.5-1.5%.	4-yr	Plot	Tile-drained CS annual rotation, N fertilizer applied to C only. NI treatments received 1 lb/a nitrapyrin.	Leaching to shallow ground-water	 Fall N application @ 225 lb/a N wo NI Fall N application @ 168 lb/a N wo NI Fall N application @ 168 lb/a N w NI Spring N application @ 225 lb/a N wo NI Spring N application @ 168 lb/a N wo NI Spring N application @ 168 lb/a N w NI	4-yr ave. NO3-N concentration and mass loss 18.1 ppm NO3-N 37.9 lb/a NO3-N 14.2 ppm NO3-N 26.0 lb/a NO3-N 16.2 ppm NO3-N 31.5 lb/a NO3-N 24.4 ppm NO3-N 52.1 lb/a NO3-N 15.4 ppm NO3-N 25.3 lb/a NO3-N 17.7 ppm NO3-N 25.2 lb/a NO3-N	 _ _ 21.5% 31.4% 10.5% 16.9% -34.8% -37.5% 14.9% 33.2% 2.2% 33.5%	Continuous flow volume measurement and water chemistry sampling with analyses of sub-samples from each flow period. Spring N treatments had N applied at or shortly after corn emergence. Ave. drainage season (Mar.-Nov.) precipitation ranged from 86%-96% below normal during the 4-yr study period. Substantial early spring drainage occurred in only 1 of the 4 study years, which is the normal peak period of subsurface drainage.	For both spring and fall similar rates w and wo NI, greater losses occurred w NI. Lowest NO3-N concentrations were found in above ave. precipitation conditions following below ave. precipitation conditions. Opposite scenario led to lowest NO3-N concentrations. NO3-N losses and concentrations affected more by N rate and timing of precipitation than N application timing and NI. Though not significant, losses were lower w NI than wo in spring, but greater w NI than wo in fall.

1 Watershed, field, plot or laboratory.
2 CT represents conventional tillage.
3 NT represents no-tillage.
4 WO represents without.
5 NI represents nitrification inhibitor.
6 W represents with.
7 NO3-N represents nitrate-nitrogen.

8 Data not directly reported numerically within the cited publication; data estimated from published graph figure(s).
9 C1 represents comparison to control 1.
10 C2 represents comparison to control 2.
11 IC represents incorporation.
12 LSM represents liquid swine manure.
13 AA represents anhydrous ammonia.
14 CS represents corn-soybean annual crop rotation.

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Conservation Practice Summary Assessment

Contaminant: **Total N**

Type of Strategy: **Preventive**

Strategy Name: **N Nutrient Application Techniques** (surface broadcast, surface banding, knife injection, point liquid N injection, localized compacted dome N injection)

Pollutant reduction mechanisms

- Decreased exposure of nutrients to leaching by preferential flow of soil water through soil macropores or leachate diversion
- Improved adsorption to soil matrix
- Increased crop N use efficiency (crop assimilation)
- Reduced erosion and transport of nutrient enriched sediments and particulates

Applicable conditions

- Any agricultural crop field that receives N fertilizer applications, in Iowa, mainly corn

Limiting conditions

- Excessively dry soil conditions impede injector or knife unit penetration into the soil
- Dry soil conditions may limit some forms of N fertilizer to be adsorbed by soil particles
- Availability or cost of specialized equipment

Range of variation in effectiveness at any given point in time

All listed alternative practices vs. surface broadcast: <-100% to +90%

Effectiveness depends on:

- Practices or methods being compared
- Precipitation timing, amount and intensity
- Form of N fertilizer applied
- Soil conditions prior to application
- Soil type
- Degree of soil disturbance from application
- Rate and time of application
- Crop grown and rotation used
- Site of N fertilizer placement in relation to crop plants
- For subsurface application, existence of any furrow, slot or macropores that may lead to preferential flow in zone of application

- For surface application, exposure at the surface that may lead to erosion losses of added N nutrients

<u>Estimated potential contaminate reduction for applicable areas within Iowa (annual basis)</u>

All listed alternative practices vs. surface broadcast: -75% to +80%

The justification for listing the comparison of surface broadcast against all other practices and methods is due to the extreme ranges reported in research publications. This is also true for comparisons among the alternative practices. There are a host of possible reasons for this variability in performance among the differing practices and methods.

Climate may greatly affect the degree of N loss by practice depending the form of N fertilizer used and upon where and how it is applied in the soil profile. If a peak rainfall event occurs soon after application and mostly infiltrates into the soil, practices that apply N fertilizers high in nitrate content (i.e., UAN) can lose a portion of this N to leaching because nitrate is an anion and not readily adsorbed by soil particles. A practice that can instead apply anhydrous ammonia would likely lose less N because the ammonium cation readily adsorbs to soil particles. Also, surface broadcast or band application of UAN or ammonium nitrate could result in greater N losses than deep point injection of UAN that leaves surface residue intact if a peak runoff event occurred soon after application. Also, if knife injection created significant disturbance on sloping terrain and it was soon followed by a peak precipitation event, the injection furrow may become a zone of concentrated runoff flow. Any occurrence of concentrated flow will erode and transport sediments, which in this case could be enriched with the applied N fertilizer.

Specific site characteristics, soil properties, and other field operations also impact N retention and loss in relation to the factors mentioned above. Fields having highly erodable soils, either due to slope or soil type, will probably have less N loss with point injection than surface broadcast with tillage incorporation for the reasons. Soils of coarse texture are always at high risk for N leaching losses regardless of how the N fertilizer is applied. The risk for N leaching may also be substantial if the method of application places the N fertilizer in a soil subject to preferential flow. Soil macropores and/or furrows at an injection site frequently allow preferential flow to occur. A practice that places N fertilizer in a more accessible location to a crop's root system may lead to greater crop N use efficiency and less N loss risk than practices that place the N in zones where crop roots do not proliferate. Crops that have a high capacity to extract soil-N will likely result in less N leaching loss than crops of lesser N requirement as long as the N fertilizer rate and timing is in balance and synchronized with crop demand. The rate and timing of N application is often far more critical to N losses than any other practices. It will matter little how commercial N or manure is applied if the rate is far in excess of crop requirements. Losses related to inefficient timing of application (e. g., fall application) will in most years nullify any benefit from improvements in application practices.

Estimated long-term contaminant reduction for applicable areas in Iowa (multi-year basis)

All listed alternative practices vs. surface broadcast: +10%

The primary factors that will affect the performance of conservation N application practices will be the length of time to the next precipitation events and the amounts and intensities of those events. Also of significance is the degree of soil disturbance and remaining residue cover associated with each practice. The limited research literature documented highly variable results among the alternative practices when compared with surface broadcast methods, as evidenced by the percentages listed in the above sections. The effectiveness of any alternative practice depends heavily upon weather. In some years there may be no benefit and other years there may be a 50% decrease in N loss. In general, the probability of reduced N loss is improved to at least a marginal extent by these alternative practices.

Extent of research

Limited

While there have been studies conducted on some of the listed conservation N application techniques and practices, tests have not been conducted thoroughly by agroecoregions, nor have all been adequately tested. The review of the small amount of pertinent literature revealed a high degree of variability in performance of all alternative practices vs. surface broadcast application. Although this may suggest that the end result in terms of water quality for any N application method is greatly dependent upon climatic and a site's physical conditions, it should not be left to assumption. These variable results may also be due to inaccurate N rate application (missing the target rate). Studies of standard N applicator equipment have revealed high degrees of variation across both the toolbars and fields, particularly for anhydrous ammonia applicators. Further research to understand, account for, and/or correct the sources of error is needed to develop reliable alternative N application practices.

Secondary benefits

- Increased crop N use efficiency
- Potentially increased crop yield
- Potentially reduced P loss and delivery to surface waters if the practice reduces soil disturbance and increases residue cover
- Potentially reduced sediment loss and delivery to surface waters if the practice reduces soil disturbance and increases residue cover

Conservation Practice Research Summary Table

Contaminant: **Total N**

Type of Strategy: **Preventive**

Strategy Name: **N Nutrient Application Techniques** (surface broadcast, surface banding, knife injection, point liquid N injection, localized compacted dome N injection)

References significant to Iowa identified in bold italics.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Randall et al., 1997 **Injection vs. surface band vs. surface broadcast**	Waseca, MN, US: Webster Silt Loam	3-yr	Field-plot	RT[2] CS[3] with various N application methods, forms, timings and rates to corn. All single, pre-plant application done in spring.	Potential leaching to shallow groundwater		3-yr ave. residual soil NO3-N[11] mass		Residual soil NO3-N samples taken in early November, following corn harvest and when soil temps were below 50° F. All treatments were spring applied prior to corn emergence.	Increased crop N use efficiency and reduced ammonia volatilization attributed as reduction mechanisms. Point injection of UAN into the ridge of RT and AA injection had slightly greater residual soil NO3-N levels than banding, broadcast and point injection into the valley of RT. Only point injection in ridge vs. valley contrast was significantly different.
						100 lb N/a AA[4], INJV[5]	65 lb/a NO3-N	–		
						100 lb N/a UAN[6], BR[7]	55 lb/a NO3-N	15.4%		
						100 lb N/a UAN, BDCT[8]	51 lb/a NO3-N	21.5%		
						100 lb N/a UAN, PINJR[9]	63 lb/a NO3-N	3.1%		
						100 lb N/a UAN PINJV[10]	50 lb/a NO3-N	23.1%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Baker and Laflen, 1982 **Incorpor-ated vs. surface application**	Central IA, US; Clarion sandy loam soil with 5% slope.	1-day rainfall simula-tions	Plot	Tilled soil with varied levels of corn residue cover and fertilizer placement methods @ 127 lb/a N rate.	Surface runoff		NH4-N[12] and NO3-N Concentration and mass loss		All plots were disk tilled and 2 inches of water applied 1 week prior to rainfall simulations. P and N fertilizers and varied levels of corn residue applied 1 day prior to rainfall simulations. Rainfall simulation at 2.5 in/hr for 2 hrs and 10-11 runoff water samples and flow measures taken per plot. Rainfall simulation supply water contained 0.1 NH4-N ppm and 0.05 ppm NO3-N.	Runoff and sediment erosion increased with decreased surface corn residue levels. Point-injection of N fertilizer did not increase runoff N mass loss or concentration compared to no N fertilizer application. No significant N loss differences existed between placement of N fertilizer above or below surface corn residue.
						0 lb/a corn residue, N fertilizer surface broadcast	8.4 ppm NH4-N 3.9 lb/a NH4-N 4.2 ppm NO3-N 2.0 lb/a NO3-N	_ _ _ _		
						0 lb/a corn residue, N fertilizer point-injected 2 inch depth	0.3 ppm NH4-N 0.18 lb/a NH4-N 3.4 ppm NO3-N 2.1 lb/a NO3-N	96.4% 95.4% 19.0% -5.0%		
						0 lb/a corn residue, no N fertilizer	0.3 ppm NH4-N 0.18 lb/a NH4-N 2.4 ppm NO3-N 1.5 lb/a NO3-N	96.4% 95.4% 42.8% 25.0%		
						334 lb/a corn residue, N fertilizer broadcast above residue	7.8 ppm NH4-N 3.5 lb/a NH4-N 3.9 ppm NO3-N 1.8 lb/a NO3-N	7.1% 10.2% 7.1% 10.0%		
						334 lb/a corn residue, N fertilizer broadcast below residue	7.0 ppm NH4-N 3.3 lb/a NH4-N 4.0 ppm NO3-N 1.8 lb/a NO3-N	16.7% 15.4% 4.8% 10.0%		
						334 lb/a corn residue, no N fertilizer	0.3 ppm NH4-N 0.16 lb/a NH4-N 3.6 ppm NO3-N 1.8 lb/a NO3-N	96.4% 95.9% 14.3% 10.0%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Baker and Laflen, 1982 (cont.) **Incorpor-ated vs. surface application**	Central IA, US; Clarion sandy loam soil with 5% slope.	1-day rainfall simula-tions	Plot	Tilled soil with varied levels of corn residue cover and fertilizer placement methods @ 25 lb/a P rate.	Surface runoff		NH4-N and NO3-N Concentration and mass loss	(cont.)	- See above -	- See above -
						668 lb/a corn residue, N fertilizer broadcast above residue	7.0 ppm NH4-N 2.3 lb/a NH4-N 4.7 ppm NO3-N 1.6 lb/a NO3-N	16.7% 41.0% -11.9% 20.0%		
						668 lb/a corn residue, N fertilizer broadcast below residue	6.2 ppm NH4-N 2.5 lb/a NH4-N 4.4 ppm NO3-N 1.6 lb/a NO3-N	26.2% 35.9% -4.8% 20.0%		
						668 lb/a corn residue, no N fertilizer	0.3 ppm NH4-N 0.14 lb/a NH4-N 2.3 ppm NO3-N 1.1 lb/a NO3-N	96.4% 96.4% 45.2% 45.0%		
						1335 lb/a corn residue, N fertilizer broadcast above residue	5.3 ppm NH4-N 1.1 lb/a NH4-N 4.7 ppm NO3-N 1.1 lb/a NO3-N	36.9% 71.8% -11.9% 45.0%		
						1335 lb/a corn residue, N fertilizer broadcast below residue	4.6 ppm NH4-N 0.4 lb/a NH4-N 3.9 ppm NO3-N 0.4 lb/a NO3-N	45.2% 89.7% 7.1% 80.0%		
						1335 lb/a corn residue, no N fertilizer	0.3 ppm NH4-N 0.18 lb/a NH4-N 3.4 ppm NO3-N 2.1 lb/a NO3-N	96.4% 95.4% 19.0% -5.0%		

Reference	Location, Site Notes	Time Period of Experi -ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Baker et al., 1997 Localized dome compaction with point injections vs. point injection without compaction vs. surface broadcast	Laboratory with soil from West Lafayette, IN, US; Treaty silt loam soil.	2-days	Laboratory, simulated rainfall on soil columns	NT[13] and CP[14] Contin-uous soybean using potas-sium bromide (KBr) solution as anion to simulate NO3-N leaching potential applied at a rate of 133 lb/a Br at a depth of 3.15 in.	Subsurface leaching		Concentration and percent loss of applied KBr load		Simulated rainfall applied in two sessions; first at 1.5 in/hr for 2 hr, followed by 1 hr of no rainfall, then second 2 hr rainfall at 1 in/hr. Multiple samples taken during each of the three time periods. For CPI and PI treatments, KBr applied 18 hr prior to rainfall simulations. For SB, KBr applied 1 hr prior to rainfall simulations.	Diversion of infiltrating water away from fertilizer placement site reported as primary N loss reduction mechanism. For both NT and CP, CPI concentrations and losses were significantly less than SB and PI methods.
						<u>NT</u>				
						Surface broadcast (SB)	26.5 ppm KBr 29.9 % loss of KBr applied	_ _		
						Point injection without localized dome compaction (PI)	41.6 ppm KBr 42.8% loss of KBr applied	-57.0% -43.1%		
						Point injection with localized dome compaction (CPI)	2.9 ppm KBr 3.1% loss of KBr applied	89.1% 89.6%		
						<u>CP</u>				
						Surface broadcast (SB)	44.4 ppm KBr 46.4% loss of KBr applied	_ _		
						Point injection without localized dome compaction (PI)	42.7 ppm KBr 43.1% loss of KBr applied	3.8% 7.1%		
						Point injection with localized dome compaction (CPI)	6.6 ppm KBr 6.7% loss of KBr applied	85.1% 85.6%		

Reference	Location, Site Notes	Time Period of Experi -ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduc-tion	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Ressler et al., 1998 **Localized dome compac-tion with knife injections vs. conven-tional knife injections vs. surface broadcast**	Ames, IA, US; Nicollet silt loam soil	18 month	Small plot, lysimeters with natural and simulated rainfall	Fallow soil, anion tracer applied at rate of 56 lb/a. Anion tracer to simulate NO3-N leaching potential.	Subsurface leaching		Percent loss of anion tracer load applied		Both low intensity and high intensity rainfall simulation regimes applied, but combined here due to similar trends across treatments (and as reported in article). All lysimeters received 2 in. rainfall within 3 days after anion tracer application, then similar additional rainfall amounts throughout remaining test period. Water samples colleted immediately after each simulated and natural rainfall, then every 6 hr for 24 hr period, then 1-15 days depending upon natural rainfall events.	Diversion of infiltrating water away from fertilizer placement site and closed macropores at the bottom of injection slot were reported as primary N loss reduction mechanisms. A depressed slot from conventional knife injection resulted in preferential flow of infiltrating water through the zone of injected anion tracer. Localized compaction doming with knife significantly reduced anion leaching loss than conventional knife. Compared to surface broadcast, the localized compaction doming with knife only reduced anion loss under intense rainfall, but such conditions pose the greatest leaching risk.
						<u>6 months after tracer applied</u> Surface band	4% anion tracer applied	_		
						Conventional knife	5% anion tracer applied	-25.0%		
						Localized dome compaction with knife	1% anion tracer applied	75.0%		
						<u>18 months after tracer applied</u> Surface band	17% anion tracer applied	_		
						Conventional knife	25% anion tracer applied	-47.0%		
						Localized dome compaction with knife	13% anion tracer applied	23.5%		

Reference	Location, Site Notes	Time Period of Experi -ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Iowa Dept. of Agriculture and Land Stewardship Localized dome compaction with knife injections vs. point injection without compaction vs. conven-tional knife injection	Gilmore City, IA, US; soil type not reported	3-yr	Plot	CC[15] and CS rotations 160 lb/a N applied to CC 120 lb/a N applied to CS	Subsurface leaching		Annual Ave. NO3-N concentration and mass loss		Long-term ave. seasonal precipitation was 27.52 in. Yr-1 had 24.94 in., Yr-2 had 29.66 in., and Yr-3 had 18.02, for a 3-yr ave. of 24.2 in. (below normal).	The PINJ and LCD-Kf treatments generally had lower NO3-N concentrations, but not mass loss, compared to the conventional knife N application treatment. Mass losses across treatments were very inconsistent, lacking any clear trends. For the events where mass losses were much greater for the PINJ and LCD-Kf treatments, but concentrations were lower than the Kf treatment, the PINJ and LCD-Kf treatments must have had much greater volumes of tile drainage. However these data were not presented.
						CC; Yr-1 Kf[16]	10.50 ppm NO3-N 48.0 lb/a NO3-N	_ _		
						PINJ[17]	9.06 ppm NO3-N 6.0 lb/a NO3-N	13.7% 87.5%		
						LCD-Kf[18]	7.34 ppm NO3-N 11.0 lb/a NO3-N	30.1% 77.1%		
						CS; Yr-1 Kf	8.18 ppm NO3-N 48.0 lb/a NO3-N	_ _		
						PINJ	5.51 ppm NO3-N 7.0 lb/a NO3-N	32.6% 85.4%		
						LCD-Kf	5.29 ppm NO3-N 28.0 lb/a NO3-N	35.3% 41.7%		
						CC; Yr-2 Kf	14.80 ppm NO3-N 24.0 lb/a NO3-N	_ _		
						PINJ	11.31 ppm NO3-N 94.0 lb/a NO3-N	23.6% -291.7%		
						LCD-Kf	10.51 ppm NO3-N 87.0 lb/a NO3-N	29.0% -262.5%		
						CS; Yr-2 Kf	9.33 ppm NO3-N 25.0 lb/a NO3-N	_ _		
						PINJ	6.57 ppm NO3-N 55.0 lb/a NO3-N	29.6% -120.0%		
						LCD-Kf	8.23 ppm NO3-N 106.0 lb/a NO3-N	11.8% -324.0%		

Reference	Location, Site Notes	Time Period of Experi -ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Iowa Dept. of Agriculture and Land Stewardship (cont.) Localized dome compaction with knife injections vs. point injection without compaction vs. conven-tional knife injection	Gilmore City, IA, US; soil type not reported	3-yr	Plot	CC[15] and CS rotations 160 lb/a N applied to CC 120 lb/a N applied to CS	Subsurface leaching		Annual Ave. NO3-N concentration and mass loss	(cont.)	- See above -	- See above -
						<u>CC; Yr-3</u> Kf	11.46 ppm NO3-N 4.0 lb/a NO3-N	_ _		
						PINJ	12.05 ppm NO3-N 47.0 lb/a NO3-N	-5.1% -1075.0%		
						LCD-Kf	12.76 ppm NO3-N 23.0 lb/a NO3-N	-11.3% -475.0%		
						<u>CS; Yr-3</u> Kf	14.31 ppm NO3-N 3.0 lb/a NO3-N	_ _		
						PINJ	5.56 ppm NO3-N 3.0 lb/a NO3-N	61.1% 0.0%		
						LCD-Kf	8.93 ppm NO3-N 16.0 lb/a NO3-N	37.6% -433.3%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Al-Kaisi and Licht, 2004 **Strip-tillage vs. chisel plow vs. no-till**	Ames, IA, US; Nicollet loam and Webster silty clay loam Nashua, IA, US; Kenyon loam and Floyd loam *Only showing Ames data due to incom-plete data for the Nashua site	2-yr	Plot	CS rotation 151 lb/a N applied for C in CS rotation with varied N fertilizer manage-ment tillage and season application treatments of: FST-FF[19] FST-SF[20] SST-SF[21] FCP-FF[22] NT-FF[23]	Potential subsurface leaching	Ames Yr 1 FCP-FF NT-FF FST-FF FST-SF SST-SF Yr 2 FCP-FF NT-FF FST-FF FST-SF SST-SF	Post-harvest total residual soil NO3-N mass 25.4 lb/a NO3-N 27.0 lb/a NO3-N 12.3 lb/a NO3-N 20.2 lb/a NO3-N 28.6 lb/a NO3-N 53.8 lb/a NO3-N 24.3 lb/a NO3-N 38.8 lb/a NO3-N 33.0 lb/a NO3-N 39.2 lb/a NO3-N	 _ -6.3% 51.6% 20.5% -12.8% _ 54.8% 27.9% 38.7% 27.1%	Soil samples taken to 4.48 ft depth directly after corn harvest, being approximately Oct. 15. Annual average precipitation at Ames site is 32.03 in. Yr 1 had 30.18 in, and Yr 2 had 28.09 in precipitation.	No significant differences in residual soil NO3-N among treatments in Yr 1. In Yr 2, FCP-FF had significantly greater residual soil NO3-N than the FST-SF and NT-FF treatments. Lower residual soil NO3-N for NT compared to ST and CP suggested being due to move water percolation through the NT soil profile than other treatments. **However, no significant differences in NO3-N leaching existed among all treatments.** Below normal precipitation for Yr 2 may have led to reduced leaching and an accumulation of soil NO3-N. Suggested that CP may have had less water percolation due to tillage effects of reduced infiltration, and SP experiencing moderately reduced water infiltration, compared to NT.

1 Watershed, field, plot or laboratory.
2 RT represents ridge tillage.
3 CS represents corn-soybean rotation.
4 AA represents anhydrous ammonia.
5 INJV represents injected in valley.
6 UAN represents urea ammonium nitrate.
7 BR represents band sprayed on ridge.
8 BDCT represents surface broadcast sprayed.
9 PINJR represents point injection in ridge.
10 PINJV represents point injection point injected in valley.
11 NO3-N represents nitrate-nitrogen.
12 NH4-N represents ammonium-nitrogen.
13 NT represents no-tillage.
14 CP represents chisel plow with associated secondary tillage.
15 CC represents continuous corn rotation.
16 Kf represents conventional knife nitrogen fertilizer injection.
17 PINJ represents point injection of nitrogen fertilizer.
18 LCD-Kf represents localized dome compaction with knife injection of nitrogen fertilizer.
19 FST-FF represents fall strip tillage with fall N fertilizer application.
20 FST-SF represents fall strip tillage with spring N fertilizer application.
21 SST-SF represents spring stirp tillage with spring N fertilizer application.
22 FCP-FF represents fall chisel plow with fall N fertilizer application.
23 NT-FF represents no-tillage with fall N fertilizer application.

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Conservation Practice Summary Assessment

Contaminant: **Total N**

Type of Strategy: **Preventive**

Strategy Name: **Nitrogen Nutrient Timing and Rate Management Conservation Practices** (Spring Pre-Plant, Pre-Plant/In-Season Split, Pre-Plant/In-Season Soil-Test Based Split, Pre-Plant/In-Season Chlorophyll Monitoring Based Split, Pre-Plant/In-Season Remote Sensing Based Split)

Pollutant Reduction Mechanisms:

- Improved synchronization of N fertilizer availability with crop N demand
- Improved balance of nutrient application rate with crop demand
- Reduced applied N fertilizer nutrient load

Applicable Conditions:

- Any agricultural crop field that receives N fertilizer applications, in Iowa, mainly corn

Limiting Conditions:

- Spring, late-spring or early summer time periods may have soil conditions that are too wet for equipment trafficking
- Greater than normal precipitation may lead to N deficiencies in corn in some instances due to goal of not over-applying N
- Availability and cost of high-clearance equipment for practices that include late-season N application
- Cost of commercial N fertilizers in the spring and late-spring or early summer time periods are typically more expensive than when purchased in the fall

Range of variation in effectiveness at any given point in time

Timing: Spring Pre-Plant vs. Fall Application: -25% to +50%
Timing: Soil-Test Based Split In-Season vs. Fall Application: -25% to +70%
Timing: Soil-Test Based Split In-Season vs. Spring Pre-Plant: -50% to +70%
Rate: Yield Goal or Crop Removal Based vs. Excessive: +10% to +90%
Rate: Soil-Test Based vs. Excessive: +10% to +90%
Rate: Soil-Test Based vs. Yield Goal or Crop Removal Based: -50% to +70%

Effectiveness depends on:

- Intensity, quantity, duration and timing of rainfall
- Seasonal climatic variability of rainfall and temperature, especially following application

- N fertilization at moderate to excessive rates for one crop (i.e., corn) may cause increases in nitrate-N leaching losses in the year of the succeeding crop (i.e., soybean)
- Frequency within a rotation of a crop that receives N fertilizer application
- Soil-test based N management systems have been designed to minimize potential for yield loss due to N deficiency, therefore, these systems have shown to not always indicate soils that have little to no response to added N fertilizer that can result in over-application of N
- N losses may be temporarily greater soon after sidedress application of N fertilizer forms that have a greater proportion of nitrate (i.e., urea-ammonium-nitrate, UAN) than others (i.e., anhydrous ammonia) when a peak rainfall event occurs soon after application due to enhanced preferential flow of solutes through soil macropores
- As N rate, availability and timing of application are more accurately matched with crop N demand there is a general trend for a reduced amount of residual soil nitrate-N and decreased leaching loss of nitrate within the production field compared to off-season single point-in-time N fertilizer application methods

Estimated potential contaminate reduction for applicable areas within Iowa (annual basis)

Timing: Spring Pre-Plant vs. Fall Application: -10% to +30%
Timing: Soil-Test Based Split In-Season vs. Fall Application: -10% to +50%
Timing: Soil-Test Based Split In-Season vs. Spring Pre-Plant: -30% to +50%
Rate: Yield Goal or Crop Removal Based vs. Excessive: +20% to +70%
Rate: Soil-Test Based vs. Excessive: +30 to +80%
Rate: Soil-Test Based vs. Yield Goal or Crop Removal Based: -25% to +50%

Climate is a significant factor that influences the degree of environmental success or failure of N fertilizer management practices. Once N fertilizer has been applied, either as a single application or part of a split program, any factor that limits corn growth will reduce crop uptake of soil-N. This may occur for a variety of reasons, most commonly being drought, flood, wind or hail damage, and disease and insect infestations. Other than flooding, these yield-limiting events can lead to large pools of residual soil nitrate-N and increased N leaching losses in the future. Excess precipitation can deplete soil nitrate-N anytime other than when the soil is frozen. If a peak rainfall event occurs soon after N application, particularly for N fertilizer forms relatively high in nitrate content, preferential flow of infiltrating water through soil macropores can leach soil nitrate-N. The leached nitrate-N can enter surface waters either through baseflow (emergence of groundwater into a surface water body) or from the outlet of tile lines. Soil temperature can also affect losses and retention of applied N fertilizer since it affects ammonia nitrification and N mineralization of soil organic matter through temperature's effects on bacterial growth and function. Warm soil temperatures increase these bacterial processes, resulting in greater pools of soil nitrate-N. Cool soil temperatures do the opposite, slowing bacterial processes and accumulation of soil nitrate-N. Therefore, periods of excess rainfall with warm temperatures following drought conditions frequently result in large losses of fertilizer and soil organic matter sources of N from crop fields.

The rate of N applied and the timing of application are also very critical factors that affect crop N use efficiency and N losses. Applying any amount of N fertilizer can increase N losses from fields to surface waters compared to no added N fertilizer. However, the probability for increased N losses steadily increases as the applied N rate increases. This relationship also applies to the timing of N application and the active growth period of the crop intended to benefit from the added N. There is a steadily greater probability for increased N losses from a field as the timing between N application and peak crop N demand widens. In multiple crop rotation systems such as corn-soybean, over-applying N to one crop (corn) can cause elevated N leaching losses during the next year's crop (soybean). This is one major contributing factor as to why several studies have found similar N leaching losses from soybean and corn production years. Though N losses from soybean can be considerable, it is usually less than N losses from corn production when corn is not over-fertilized with N. In Iowa, the predominant management program of N fertilizer for corn is a yield goal based N rate applied in fall. The background section of this document describes the repeatedly documented large degrees of N losses by this practice, increasing the potential for contamination of water resources. A number of studies have investigated differences in nitrate-N leaching losses of single N fertilizer applications conducted in the spring as opposed to the fall seasons. Fall N applications have shown to result in approximately 20-35% greater nitrate-N leaching losses than spring applications. Another N fertilizer timing option is to split the N fertilizer to two in-season applications, the first application at or near planting and the second in the late spring to early summer. Selection of a N rate can be either by yield goal methods or from in-season soil test programs that determine the amount of soil-N available and estimate the amount of additional N that is needed to optimize yield while minimizing the amount of residual soil nitrate-N at the end of the growing season. Soil-test based programs, such as the late-spring soil nitrate test (LSNT) program, have shown some promise in improving the balance between production and preserving water quality.

The LSNT program has been researched to an extent not achieved by most other agricultural best management practices for water quality purposes. This N fertilizer management program has been evaluated for nitrate-N losses compared to other systems from the plot to watershed scales within Iowa. In a few instances this program has resulted in increased nitrate-N leaching losses compared to single spring N application treatments. Crop N uptake and yield limiting conditions following the soil sampling may cause soil-test based, split application programs to have elevated N leaching losses due to an accumulation of residual soil nitrate-N, as may occur with any other program. Also, because the LSNT program was developed on a basis to minimize the chances of N limited yields and normal margins of error with sampling and analysis, it has been shown to not accurately identify some soils that require little to no added N to optimize corn production. For such soils, the LSNT may recommend an N rate above crop demand. Despite these occurrences, most studies have documented reductions in nitrate-N leaching losses with the LSNT program. The most significant evidence comes from the 4-year watershed scale N management systems experiment by Jaynes et al. (2004) (see accompanying summary table). They found that the LSNT N management watershed had significantly reduced nitrate-N flow-weighted concentrations by 27-33% compared to predominantly fall N application watersheds.

<u>Estimated long-term contaminant reduction for applicable areas in Iowa (multi-year basis)</u>

Timing: Spring Pre-Plant vs. Fall Application: +15
Timing: Soil-Test Based Split In-Season vs. Fall Application: +30%
Timing: Soil-Test Based Split In-Season vs. Spring Pre-Plant: +15%
Rate: Yield Goal or Crop Removal Based vs. Excessive: +35%
Rate: Soil-Test Based vs. Excessive: +60%
Rate: Soil-Test Based vs. Yield Goal or Crop Removal Based: +25%

Since fall application is the predominant application method across Iowa, the N fertilizer application timing estimates for single fall and single spring application methods are based upon having similar N rates that are in close balance to crop requirements. The overall change in outcome of any N fertilizer management program in reducing N losses to surface waters will greatly depend upon the rate of N applied, the prior management method, climatic conditions, and the conservation practice chosen as a replacement.

<u>Extent of Research:</u>

Moderate to Extensive

There have been numerous N fertilizer rate and time of application studies conducted within Iowa and neighboring states, but most have focused on agronomic aspects. Some of these studies have measured either actual nitrate-N losses in leachate or residual soil nitrate-N, which is a good indicator of the potential for nitrate-N leaching losses. Most timing studies have investigated spring vs. fall and soil-test based in-season split vs. spring applications. However, the amount of information on the water quality effects of soil-test based in-season split vs. fall methods is somewhat lacking.

New technologies to guide in-season crop N fertilizer applications are being developed that are based upon chlorophyll monitors, aerial remote sensing, global positioning systems and geographic information systems. But these technologies still require reference strips of high-N fertilized crop for comparison, which brings into consideration issues of spatial variation and reference strips for each crop hybrid that is planted in each field. Without the high-N reference strips, none of these technologies have yet been able to distinguish N deficient plant stress from any other factor that may cause chlorosis such as disease, K or Mg deficiency, drought, and flooding. Without a high-N reference area and the presence of plant stress caused by any factor other than N deficiency, these technologies may recommend over-application of N and increased N losses. Much more research is required to refine these systems to achieve a balance between agronomic and environmental goals. A few studies have shown promising results on the agronomic aspects for these new technologies. However, experiments have not yet evaluated these technologies for their impacts on water quality.

Secondary Benefits:

- Potential for increased corn yield
- Potential for decreased input costs

Conservation Practice Research Summary Table

Contaminant: **Total N**

Type of Strategy: **Preventive**

Strategy Name: **Nitrogen Nutrient Timing and Rate Management** (Spring Pre-Plant, Pre-Plant/In-Season Split, Pre-Plant/In-Season Soil-Test Based Split, Pre-Plant/In-Season Chlorophyll Monitoring Based Split, Pre-Plant/In-Season Remote Sensing Based Split)

References significant to Iowa identified in bold italics.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Jaynes et al., 2004 **Timing & N Fertilizer Rate with Pre-plant/In-Season Soil-Test Based Split Application**	Ames, IA, US; Clarion-Nicollet-Webster soil associa-tion	4-yr	Watershed	Mainly CT[2] corn-soybean, with two field-yrs corn-corn	Leaching to shallow groundwater	 Control Sub-basin 1 w[3] mainly fall applied N Control Sub-basin 2 w mainly fall applied N fertilizer Sub-basin w LSNT[4] soil-test based N fertilizer management	Annual flow weighted ave. nitrate-N concentration at end of experiment 16.5 ppm nitrate-N 15.1 ppm nitrate-N 11.0 ppm nitrate-N	 – – 33.3% (control 1) 27.2% (control 2)	Changed from typical fall applied N fertilizer management to LSNT soil test based pre-plant/in-season split N fertilizer application for sub-basin cornfields. Tile drainage flow monitored continuously and water sampled weekly and during storm events.	Improved synchronous timing of N fertilizer application with crop N demand. On 4-yr ave., decreased N fertilizer loading rate compared to normal farmers' applied N rates. *Results statistically significant at 95% confidence level.*

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Durieux et al., 1995 Timing & N Fertilizer Rate with Pre-plant/In-Season soil-Test Based Split for Manure & Commercial N	Vermont, US; soil loam soil	4-yr	Field-plot	CT silage corn with fall rye cover crop. Manure applied 1-2 weeks pre-plant for manured treatments	Leaching to shallow ground-water		Total 4-yr soil nitrate-N mass lost from harvest to spring from 0-4 ft depth; annual ave residual soil nitrate-N after harvest		Soil samples taken just prior to spring manure applications and in fall after harvest.	Improved synchronous timing of N fertilizer application with crop N demand.
						Yield-goal Sidedress at 150 lb N/a/yr	175.3 lb nitrate-N/a; 134.7 lb nitrate-N/a	_ _		
						PSNT[5] Sidedress wo[6] manure (107 lb N/a/yr 4-yr ave)	11.0 lb nitrate-N/a; 59.0 lb nitrate-N/a	93.7% 56.2%		
						PSNT Sidedress w manure (275 lb N/a/yr 4-yr ave)	48.0 lb nitrate-N/a; 69.1 lb nitrate-N/a	72.6% 48.7%		
Randall and Mulla, 2001 **Timing & N Rate**	MN, US; Clarion-Nicollet-Webster soil associa-tion	6-yr	Field-plot	Continuous corn	Leaching to shallow ground-water		Ave annual nitrate-N mass loss from tile drainage		Tile drainage flow monitored continuously and water sampled weekly and during storm events.	Improved synchronous timing of N fertilizer application with crop N demand for spring application, and improved match of N rate to crop demand. *Fall application resulted in 36% greater nitrate-N loss compared to spring application.*
						Fall applied N at 180 lb N/a	33.8 lb nitrate-N/a (65% from applied N fertilizer)	_		
						Fall applied N at 120 lb N/a	26.7 lb nitrate-N/a	21.0%		
						Spring applied N at 180 lb N/a	25.8 lb nitrate-N/a	23.7%		
						Spring applied at 120 lb N/a	18.7 lb nitrate-N/a (15% from applied N fertilizer)	44.7%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Baker and Johnson, 1981 N Rate	Ames, IA, US; Webster silt loam soil	5-yr, 3 yr of corn production	Field-plot	Corn-Soybean-Corn-Oat-Corn with spring pre-plant applied N fertilizer	Leaching to shallow ground-water	 5-yr total of 516 lb N/a applied 5-yr total of 250 lb N/a applied	Ave annual nitrate-N concentration; ave annual nitrate-N mass loss 40.5 ppm; 42.6 lb nitrate-N/a 20.1 ppm; 23.7 lb nitrate-N/a	 _;_ 50.4%; 44.4%	Tile drainage measured daily for first 3 yr, every 3rd day for last yr.	Improved match of N rate to crop demand.
Jaynes et al., 2001 **N Rate**	Story City, IA, US; Kossuth-Ottosen soil associa-tion	4-yr	Field	CT Corn-Soybean; corn in 1996 & 1998, soybean 1997 & 1999; N fertilizer spring applied to corn	Leaching to shallow ground-water	 High N fertilizer (180 lb N/a in 1996; 153 lb N/a in 1998) Medium N fertilizer (120 lb N/a in 1996; 101 lb N/a in 1998) Low N fertilizer (60 lb N/a in 1996; 51 lb N/a in 1998)	4-yr total nitrate-N mass loss 42.7 lb N/a 31.2 lb N/a 25.8 lb N/a	 _ 26.9% 39.6%	Tile drainage flow monitored continuously and water sampled weekly. Nitrate peak losses coincided with peak discharge following N fertilizer applications.	Less nitrate available for leaching losses with lower N fertilizer rates. *However, economic optimum and amount of N fertilizer required to maintain soil-N balance was at or above high N rate.* *Significant difference at 95% confidence interval between high N rates nitrate-N losses versus medium and low N rates, no difference between medium and low.*

Reference	Location, Site Notes	Time Period of Experi -ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Bjorneberg et al., 1998 **Timing & N Fertilizer Rate with Pre-plant/In-Season Late Spring Soil Nitrate Test Based Split Application of Commercial N**	Nashua, IA, US; Floyd, Kenyon and Readlyn loam soils	3-yr	Field-plot	Corn-Soybean-Corn Rotation (CSC)	Leaching to shallow ground-water		3-yr total nitrate-N mass loss and ave flow-weighted concentration		Flow and nitrate-N concentra-tion measured from mid-March to early December.	Mixed results in total drain flow on basis of tillage, crop sequence and N management was attributed to confounding from previous crop and tillage experiment on the same plots. Instances where LSNT treatments resulted in greater nitrate leaching losses attributed to higher total N fertilizer loading rates with LSNT. Split applied N w LSNT and MNT combined systems resulted in significantly lower mass losses of nitrate-N.
				Soybean-Corn-Soybean Rotation (SCS)		CP w spring pre-plant N, CSC-control 1	43 lb N/a; 10.2 ppm	_;_		
				All spring pre-plant treatments received an ave of 98 lb N/A/yr		CP w spring pre-plant N, SCS-control 2	41 lb N/a; 11.3 ppm	_;_		
						MNT w spring pre-plant N, CSC-control 3	70 lb N/a; 9.8 ppm	_;_		
				Each MNT[7] w LSNT treatment received an ave. of 150 lb N/a/yr		MNT w spring pre-plant N, SCS-control 4	67 lb N/a; 7.6 ppm	_;_		
				Each CP[8] w LSNT treatment received an ave of 122 lb N/a		CP w LSNT, CSC	45 lb N/a; 11.3 ppm	compared to control 1 -4.6%; -10.8%		
						CP w LSNT, SCS	51 lb N/a; 7.4 ppm	compared to control 2 -24.4%; 34.5%		
						MNT[7] w LSNT, CSC	35 lb N/a; 9.3 ppm	compared to control 3 50.0%;5.1%		
						MNT w LSNT, SCS	34 lb N/a; 6.8 ppm	compared to control 4 49.2%;10.5%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Baker and Melvin, 1994 **Timing & N Fertilizer Rate. Pre-plant/In-Season Late Spring Soil Nitrate Test Based Split Application of Commercial N**	Pocahontas Co.. IA, US; Clarion-Nicollet-Webster soil series	4-yr	Field-plot	Continuous Corn (CC) Soybean-Corn (SC) Corn-Soybean (CS) Corn-Alfalfa (CA) Alfalfa-Corn (AC) Alfalfa-Alfalfa (AA) **Reporting comparable corn & soybean N fertilization treatments, all under CT**	Leaching to shallow ground-water		Estimated 4-yr total nitrate-N mass loss[9]		Flow and nitrate-N concentration measured yr-round. Annual precipitation above ave. 3 of 4 years of study, with first yr following a drought yr.	Less nitrate available for leaching losses with lower N fertilizer loading rates across most treatments. Split application increased nitrate-N losses in some treatments. This may be due to the LSNT and PSNT systems having shown in to not always identify soils that are less responsive to N additions as reported in Bundy et al., 1999. Also, the LSNT and PSNT programs may not be accurately calibrated for the soils at this site. Fall residual soil nitrate-N following corn led to similar nitrate-N losses during soybean yr. Also, the LSNT system was compared to single spring pre-plant N application, not fall N application, which is most common in IA.
						CC w 150 lb N/a spring pre-plant (control 1)	~145 lb nitrate-N/a (control 1)	_ 31.9% C2[10] 17.1% C3[11]		
						CS w 100 lb N/a spring pre-plant	~196 lb nitrate-N/a	-35.2% C1[12] 8.0% C2 12.0 % C3		
						SC w 100 lb N/a spring pre-plant	~153 lb nitrate-N/a	-5.5% C1 28.2% C2 12.6% C3		
						CC w 100 lb N/a at planting plus ave 94 lb N/a Sidedress (control 2)	~213 lb nitrate-N/a (control 2)	_ -46.9% C1 -21.7% C3		
						CS w 50 lb N/a at planting plus ave 94 lb N/a Sidedress	~150 lb nitrate-N/a	-3.4% C1 29.6% C2 14.3% C3		
						SC w 50 lb N/a at planting plus ave 94 lb N/a Sidedress	~172 lb nitrate-N/a	-18.6% C1 19.2% C2 1.7% C3		
						CC w 200 lb N/a spring pre-plant (control 3)	~175 lb nitrate-N/a (control 3)	_		
						CS w 150 lb N/a spring pre-plant	~201 lb nitrate-N/a	-38.6% C1 5.6% C2 -14.8% C3		
						SC w 150 lb N/a spring pre-plant	~196 lb nitrate-N/a	-35.2% C1 8.0% C2 12.0 % C3		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Kanwar et al., 1996 **Timing & N Fertilizer Rate with Pre-plant/In-Season Late Spring Soil Nitrate Test Based Split Application of Commercial N**	Nashua, IA, US; Floyd, Kenyon and Readlyn loam soils	3-yr	Field-plot	Multiple combinations of MNT, CT with Corn-Soybean (CS), Soybean-Corn (SC), Continuous Corn (CC), Corn-Soybean-Oat w Berseem Clover Cover Crop (CSOBC) and Alfalfa-Alfalfa-Alfalfa-Corn-Soybean Oat (AAACSO) cropping rotations. Corn yrs had either no N fertilizer in AAACSO rotation or 100 lb N/a spring pre-plant, 120 lb N/a spring pre-plant, fall applied manure (varied N rates) and LSNT split applied N (varied N rates). CC manured plots received 3-yr ave loading rate of 257 lb N/a, CS manured plots 212 lb N/a.	Leaching to shallow ground-water	CT CC w fall manure CT CC w spring 120 lb N/a CT C, MNT S w fall manure CT C, MNT S w spring 100 lb N/a CT C, MNT S w LSNT N MNT CS w spring 100 lb N/a MNT CS w LSNT N MNT S, CT C w fall manure MNT S, CT C w 100 lb spring N/a MNT S, CT C w LSNT N MNT SC w spring 100 lb N/a MNT SC w LSNT N CSOBC AAACSO	3-yr ave mass loss and concentration 29.4 lb nitrate-N/a 14.1 ppm nitrate-N 21.5 lb nitrate-N/a 11.3 ppm nitrate-N 17.8 lb nitrate-N/a 11.3 ppm nitrate-N 12.6 lb nitrate-N/a 9.6 ppm nitrate-N 14.6 lb nitrate-N/a 10.3 ppm nitrate-N 25.0 lb nitrate-N/a 9.0 ppm nitrate-N 10.9 lb nitrate-N/a 9.2 ppm nitrate-N 22.8 lb nitrate-N/a 7.8 ppm nitrate-N 12.4 lb nitrate-N/a 10.8 ppm nitrate-N 14.5 lb nitrate-N/a 6.8 ppm nitrate-N 19.6 lb nitrate-N/a 6.9 ppm nitrate-N 9.2 lb nitrate-N/a 6.4 ppm nitrate-N 13.0 lb nitrate-N/a 7.0 ppm nitrate-N 11.0 lb nitrate-N/a 5.7 ppm nitrate-N	_ _ 26.8% 19.8% 39.4% 19.8% 57.1% 31.9% 50.3% 27.0% 15.0% 36.2% 62.9% 34.8% 22.4% 44.7% 57.8% 23.4% 50.7% 51.8% 33.3% 51.1% 68.7% 54.6% 55.8% 50.4% 62.6% 59.6%	First yr of experiment had much above normal rainfall (1993). Tile drainage flow and nitrate-N concentra-tion were monitored continuously during periods of flow.	Lower N loading rates resulted in lower nitrate-N concentration. The LSNT split application system reduced nitrate-N concentrations due to better matched timing and N rate to crop needs. CS typically had lower nitrate-N losses and concentrations than CC rotation. Elevated nitrate-N losses in soybean possibily due to carry-over of soil-N, particularly for the manured treatments where N rates were far above target in 2 of 3 yrs. AAACSO and CSOBC rotations led to dramatic reductions in nitrate-N losses and concentration.

Reference	Location, Site Notes	Time Period of Experi -ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Andraski, et al., 2000 **N Fertilizer Rate**	WI, US; silt loam soil	2-yr	Plot	Multiple CT crop rotations w and wo applied manure and spring applied N fertilization rates. Rotations were: continuous corn with no manure history (CC), continuous corn with manure in past history (m-CC), second yr corn after 3 yr of alfalfa with no manure (ACC), second yr corn after 3 yr of alfalfa with manure to first yr corn (AmCC). Conducted 2 separate trials at same site: trial 1, 1993-1994; trial 2, 1994-1995.	Leaching to shallow ground-water		Total nitrate-N mass loss	By rotation	Water samples collected bi-weekly, but not during months of December through March. Drainage flow monitored continuously, however, only had tile flow in 6 months (during spring) of entire 30-month study.	Increased N availability through increased N application rates resulted in greater early season N mineralization and nitrate-N leaching losses.
						Trial 1				
						CC 182 lb N/a	18.7 lb nitrate-N/a	–		
						CC 0 lb N/a	19.6 lb nitrate-N/a	-4.8%		
						m-CC 182 lb N/a	37.4 lb nitrate-N/a	-		
						m-CC 0 lb N/a	24.9 lb nitrate-N/a	33.4%		
						ACC 182 lb N/a	31.2 lb nitrate-N/a	–		
						ACC 0 lb N/a	16.9 lb nitrate-N/a	45.8%		
						AmCC 182 lb N/a	78.3 lb nitrate-N/a	–		
						AmCC 0 lb N/a	39.2 lb nitrate-N/a	49.9%		
						Trial 2				
						CC 182 lb N/a	28.5 lb nitrate-N/a	–		
						CC 0 lb N/a	2.7 lb nitrate-N/a	90.5%		
						m-CC 182 lb N/a	74.8 lb nitrate-N/a	–		
						m-CC 0 lb N/a	8.0 lb nitrate-N/a	89.3%		
						ACC 182 lb N/a	56.1 lb nitrate-N/a	–		
						ACC 0 lb N/a	15.1 lb nitrate-N/a	73.1%		
						AmCC 182 lb N/a	65.0 lb nitrate-N/a	–		
						AmCC 0 lb N/a	17.8 lb nitrate-N/a	72.6%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Steinheimer et al., 1998 **N Fertilizer Rate**	Treynor, IA, US; Monona-Ida-Napier soil association (deep loess soils)	23-yr	Water-shed	RT[13] Continuous Corn beginning in 1972 w N fertilizer rate at 150 lb N/a. Alfalfa/brome mix for 1963-1971. No N fertilizer applied from 1963-1967. Years 1968-1971 N applied to aged alfalfa/brome stand at ave. annual rate of 140 lb N/a.	Surface runoff and leaching to shallow ground-water and stream baseflow	<u>Shallow Groundwater</u>	Ave nitrate-N concentration and nitrate-N mass loss	*Negative values indicate increase*	Grab samples of shallow seepage and stream baseflow conducted monthly. Surface runoff measured every 10 minutes during events for a maximum of 4 hr. Surface runoff losses resulted from intense precipitation and snowmelt events.	Increases in nitrate-N losses from the watershed over time were attributed to the long-term increased annual N loading rate. *Study points out the water quality impact of a sustained, long-term increase in N loading rate for corn production within lower organic matter soils in Iowa. Also shows potential nitrate reductions with changing to forage type crop rotations.*
						Initiation time point of N fertilization (1969)	0.7 ppm nitrate-N	–		
						1977	15 ppm nitrate-N	***-2042.8%***		
						1993	23 ppm nitrate-N	***-3185.7%***		
						<u>Surface Runoff</u>				
						1971	<2.7 lb N/a/yr	–		
						1983	<2.7 lb N/a/yr	***0%***		
						1993	>4.4 lb N/a/yr	***−63.0%***		
Karlen et al., 1998 Timing & N Fertilizer Rate	Treynor, IA, US; Monona-Ida-Napier soil association (deep loess soils)	3-yr	Water-shed	Continuous corn. RT at ave. sidedressed N at 130 lb N/a vs. CT at ave. spring pre-plant applied 169 lb N/a	Potential leaching to shallow ground-water		Estimated 3-yr total N mass losses derived from calculated N budget		Soil nitrate-N samples taken prior to spring pre-plant application and in June.	Reduced N loss with reduced applied N rate. Greater crop N-use efficiency and timing of N application with crop demand.
						CT, 169 lb N/a Spring pre-plant	250.1 lb N/a	–		
						RT, 130 lb N/a sidedressed	185.6 lb N/a	25.8%		

Reference	Location, Site Notes	Time Period of Experi -ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Randall et al., 1997 Timing & N Fertilizer Rate	Waseca, MN, US: Webster Silt Loam	3-yr	Field-plot	RT CS with various N application methods, forms, timings and rates to corn. All single, pre-plant application done in spring.	Potential leaching to shallow ground-water		3-yr ave. residual soil nitrate-N mass		Residual soil nitrate-N samples taken in early November, following corn harvest and when soil temps were below 50° F.	Significant reduction in residual soil nitrate-N with reduced loading rates of applied N. Although not significant, sidedressed N application resulted in a lower potential for nitrate-N leaching to shallow groundwater at the V7 timing of application. However, a greater potential for nitrate-N leaching occurred with the later timing of sidedress application (at V16). N fertilizer applications late in the growing season may then pose a greater risk for nitrate-N contamination.
						100 lb N/a AA[14], INJV[15]	65 lb nitrate-N/a	_		
						60 lb N/a UAN[16], BR[17]	49 lb nitrate-N/a	24.6%		
						100 lb N/a UAN, BR	55 lb nitrate-N/a	15.4%		
						140 lb N/a UAN, BR	55 lb nitrate-N/a	15.4%		
						100 lb N/a UAN, BDCT[18]	51 lb nitrate-N/a	21.5%		
						100 lb N/a UAN, PINJR[19]	63 lb nitrate-N/a	3.1%		
						100 lb N/a UAN PINJV[20]	50 lb nitrate-N/a	23.1%		
						30 + 70 lb N/a UAN/AA, sidedressed at V7[21], BR/INJV	55 lb nitrate-N/a	15.4%		
						30 + 70 lb N/a UAN, sidedressed at V7, BR/PINJV	55 lb nitrate-N/a	15.4%		
						30 + 70 lb N/a UAN, sidedressed at V16[22], BR/PINJV	73 lb nitrate-N/a	-12.3%		
						30 + 50 lb N/a UAN, sidedressed at V16, BR/PINJV	58 lb nitrate-N/a	10.8%		
						0 lb N/a, check	38 lb nitrate-N/a	41.5%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Ditsch et al., 1993 N Fertilizer Rate with Cover Crop	VA, US; silt loam soil	2-yr	Field-plot	Silage Corn-Winter Rye annual double crop rotation. N fertilizer applied to corn immediately after planting. Winter rye removed in spring either by silage harvest or chemical killing and left as mulch for corn.	Leaching to shallow ground-water		2-yr ave. residual soil Inorg-N[31] mass		Soil sampled to 3 ft depth in spring following winter rye removal and prior to corn planting.	Reducing N fertilizer rate to corn with winter fallow steadily decreased the amount of residual soil inorganic-N remaining after corn production. Results were mixed by N rate for treatments that included winter cover crops.
						WF[23], corn 300 lb N/a, C1[24]	138.4 lb Inorg-N/a	–		
						RM[25], corn 300 lb N/a	25.8 lb Inorg-N/a	81.4% C1		
						RS[26], corn 300 lb N/a	19.1 lb Inorg-N/a	86.2% C1		
						WF, corn 225 lb N/a, C2[27]	112.1 lb Inorg-N/a	19.0% C1		
						RM, corn 225 lb N/a	16.5 lb Inorg-N/a	88.1% C1; 85.3% C2		
						RS, corn 225 lb N/a	25.4 lb Inorg-N/a	81.6% C1; 77.3% C2		
						WF, corn 150 lb N/a, C3[28]	87.7 lb Inorg-N/a	36.6% C1		
						RM, corn 150 lb N/a	18.7 lb Inorg-N/a	86.5% C1; 78.7% C3		
						RS, corn 150 lb N/a	14.2 lb Inorg-N/a	89.7% C1; 83.8% C3		
						WF, corn 75 lb N/a, C4[29]	71.2 lb Inorg-N/a	48.6% C1		
						RM, corn 75 lb N/a	23.6 lb Inorg-N/a	82.9% C1; 66.9% C4		
						RS, corn 75 lb N/a	17.4 lb Inorg-N/a	87.4% C1; 75.6% C4		
						WF, corn 0 lb N/a, C5[30]	53.0 lb Inorg-N/a	61.7% C1		
						RM, corn 0 lb N/a	15.1 lb Inorg-N/a	89.1% C1; 71.5% C5		
						RS, corn 0 lb N/a	18.7 lb Inorg-N/a	86.5% C1; 64.7% C5		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Bakhsh et al., 2000 Timing & N Fertilizer Rate with Pre-plant/In-Season Late Spring Soil Nitrate Test Based Split Application of Commercial N, and with CP versus NT tillage systems.	Nashua, IA, US; Floyd, Kenyon and Readlyn loam soils	6-yr	Field-plot	CP and NT corn-soybean rotation with N fertilizer applied to corn either as single spring pre-plant or late spring soil nitrate test (LSNT) based sidedress N management systems. N rates varied by manage-ment system with LSNT programs (6-yr ave. 159 lb N/a for NT, 139 lb N/a for CP) having greater N rates than single spring pre-plant (98 lb N/a)	Potential leaching to shallow ground-water		6-yr ave. post-harvest residual soil nitrate-N mass		Soil samples take to 4 ft depth just prior to planting and after harvest of both crops. Differences in applied N rates make comparison valid only by management system where the single spring pre-plant N application rate was lower than typical normal N application rates.	Increases in residual soil nitrate-N following soybean compared to corn was attributed the release of soil-N that was temporarily immobilized while corn residues were decomposing and additions of soybean N fixation contributions. The LSNT system higher residual soil nitrate-N levels due to higher applied N rates and timed later during growing season.
						CSCPSA[32] at 98 lb N/a, C1	24.0 lb nitrate-N/a	–		
						CSCPLS[33] at 139 lb N/a	29.4 lb nitrate-N/a	-22.5% C1		
						CSNTSA[34] at 98 lb N/a, C2	18.7 lb nitrate-N/a	22.1% C1		
						CSNTLS[35] at 159 lb N/a	25.8 lb nitrate-N/a	-7.5% C1; -38.0% C2		
						SCCPSA[36] wo N applied, C3	31.2 lb nitrate-N/a	-30.0% C1		
						SCCPLS[37] wo N applied	34.7 lb nitrate-N/a	-44.6% C1; -11.2% C3		
						SCNTSA[38] wo N applied, C4	24.9 lb nitrate-N/a	-3.8% C1		
						SCNTLS[39] wo N applied	25.8 lb nitrate-N/a	-7.5% C1; -3.6% C4		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Bakhsh et al., 2002 **Timing & N Fertilizer Rate with Pre-plant/In-Season Late Spring Soil Nitrate Test Based Split Application of Commercial N, and with CP versus NT tillage systems.**	Nashua, IA, US; Floyd, Kenyon and Readlyn loam soils	6-yr	Field-plot	CP and NT corn-soybean rotation with N fertilizer applied to corn either as single spring pre-plant or late spring soil nitrate test (LSNT) based sidedress N manage-ment systems. N rates varied by manage-ment system with LSNT programs (6-yr ave. 159 lb N/a for NT, 139 lb N/a for CP) having greater N rates than single spring pre-plant (98 lb N/a)	Leaching to shallow ground-water		6-yr ave. flow-weighted nitrate-N concentration and nitrate-N mass loss		Tile drainage flow was continuously recorded and water samples automatically taken when sump was operating. Tile drainage flow and nitrate-N mass losses were significantly affected by annual variations in precipitation volume. Differences in applied N rates make comparison valid only by management system where the single spring pre-plant N application rate was lower than typical normal N application rates.	Single spring N application had less nitrate-N mass loss in CP, but higher losses in NT due to longer period to flush nitrate-N through better continuous macropore system of NT. CP systems had lower nitrate-N mass losses despite higher concentrations due to reduced volume of drainage flow. NT systems had lower nitrate-N concentrations possibly due to more water infiltrating through macropores than soil matrix and lower N mineralization rates than CP.
						CSCPSA at 98 lb N/a, C1	12.0 ppm nitrate-N; 12.5 lb nitrate-N/a	_ _		
						CSCPLS at 139 lb N/a	11.7 ppm nitrate-N; 15.1 lb nitrate-N/a	2.5% C1; -20.8% C1		
						CSNTSA at 98 lb N/a, C2	10.7 ppm nitrate-N; 22.2 lb nitrate-N/a	10.8% C1; -77.6% C1		
						CSNTLS at 159 lb N/a	11.4 ppm nitrate-N; 11.6 lb nitrate-N/a	5.0% C1; 7.2% C1: -6.5% C2; 47.7% C2		
						SCCPSA wo N applied, C3	10.4 ppm nitrate-N; 11.6 lb nitrate-N/a	13.3% C1; 7.2% C1		
						SCCPLS wo N applied	9.2 ppm nitrate-N; 14.2 lb nitrate-N/a	23.3% C1; -13.6% C1: 11.5% C3; -22.4% C3		
						SCNTSA wo N applied, C4	8.3 ppm nitrate-N; 17.8 lb nitrate-N/a	30.8% C1; -42.4% C1		
						SCNTLS wo N applied	9.1 ppm nitrate-N; 10.7 lb nitrate-N/a	24.2% C1; 14.4% C1: -9.6% C4; 39.9% C4		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Burwell et al., 1977 N Fertilizer Rate	Deep Loess Research Station at Treynor, IA, US; Monona, Ida and Napier silt loam soils.	5-yr	Watershed W1[40] = 74a W2[41] = 81.5a W3[42] = 106a W4[43] = 148a	Continuous corn, Rotational Grazing of Bromegrass Pasture and CT and MT[44] Ave Annual N Rates W1 = 400 lb/a N W2 = 155 lb/a N W3 = 158 lb/a N W4 = 306 lb/a N W1, W2 Continuous corn w CT contour planting W3 Bromegrass w Rotational Grazing yrs 1-3, Continuous corn w MT[9] contour planting yrs 4-5 W4 Continuous corn w CT and level terraces yrs 1-3, Continuous corn w MT and surface intake and outlet tiled terraces yrs 4-5	Surface runoff and subsurface leaching	Subsurface Leaching W1 @ 400 lb/a N W4 @ 306 lb/a N W2 @ 155 lb/a N Surface Runoff W1 @ 400 lb/a N W4 @ 306 lb/a N W2 @ 155 lb/a N Runoff Sediment W1 @ 400 lb/a N W4 @ 306 lb/a N W2 @ 155 lb/a N	Annual ave. mass loss of nitrate-N, ammonium-N and sediment-N 18.49 lb/a nitrate-N 0.14 lb/a ammonium-N 31.33 lb/a nitrate-N 0.36 lb/a ammonium-N 6.10lb/a nitrate-N 0.22 lb/a ammonium-N 1.12 lb/a nitrate-N 0.57 lb/a ammonium-N 1.12 lb/a nitrate-N 0.24 lb/a ammonium-N 0.53 lb/a nitrate-N 0.40 lb/a ammonium-N 24.49 lb/a sediment-N 6.89 lb/a sediment-N 17.79 lb/a sediment-N	_ _ -69.4% -157.1% 67.0% -57.1% _ _ 0.0% 57.9% 52.7% 29.8% _ 71.9% 27.4%	Yr 4 had 22% more precipitation than the 10-yr annual ave. Nitrate-N concentrations were highest during the early growing season.	W1 vs. W4 represents a mix of reduced N rate and terracing effects on N loss. Terracing effects are presented in the landscape management practices section. W1 vs. W2 represents reduced N rate effects only, following comments relate to this comparison. N loss was dramatically reduced with the recommended rate used for W2 compared to excessive N rate required for corn production used on W1. For W1 and W2 combined, 94% of surface runoff N loss was transported with sediment. Thus controlling erosion would significantly reduce N loss from this pathway.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Burwell et al., 1977 (cont.) N Fertilizer Rate	Deep Loess Research Station at Treynor, IA, US; Monona, Ida and Napier silt loam soils.	5-yr	Watershed W1[40] = 74a W2[41] = 81.5a W3[42] = 106a W4[43] = 148a	Continuous corn, Rotational Grazing of Bromegrass Pasture and CT and MT[44] **Ave Annual N Rates** W1 = 400 lb/a N W2 = 155 lb/a N W3 = 158 lb/a N W4 = 306 lb/a N W1, W2 Continuous corn w CT contour planting W3 Bromegrass w Rotational Grazing yrs 1-3, Continuous corn w MT contour planting yrs 4-5 W4 Continuous corn w CT and level terraces yrs 1-3, Continuous corn w MT and surface intake and outlet tiled terraces yrs 4-5	Surface runoff and subsurface leaching	Total Stream <u>Discharge</u> W1 @ 400 lb/a N W4 @ 306 lb/a N W2 @ 155 lb/a N	Annual ave. mass loss of total-N 44.81 lb/a total-N 39.94 lb/a total-N 25.04 lb/a total-N	 _ 10.9% 44.1%	See above	See above

1 Watershed, field, plot or laboratory.
2 CT represents conventional tillage.
3 W represents with.
4 LSNT represents late-spring soil nitrate test.
5 PSNT represents pre-sidedress soil nitrate test.
6 WO represents without.

7 MNT represents modified no-tillage (summer cultivation).
8 CP represents chisel plow with summer cultivation.
9 Data not directly reported numerically within the cited publication; data estimated from published graph figure(s).
10 C2 represents comparison to control 2.
11 C3 represents comparison to control 3.
12 C1 represents comparison to control 1.
13 RT represents ridge tillage.
14 AA represents anhydrous ammonia.
15 INJV represents injected in valley.
16 UAN represents urea-ammonium nitrate.
17 BR represents band sprayed on ridge.
18 BDCT represents broadcast sprayed.
19 PINJR represents point injected in ridge.
20 PINJV represents point injected in valley.
21 V7 represents corn vegetative 7growth stage.
22 V16 represents corn vegetative growth stage 16.
23 WF represents winter fallow.
24 RM represents winter rye mulch.
25 RS represents winter rye silage.
26 C1 represents control 1 and comparison to control 1.
27 C2 represents control 2 and comparison to control 2.
28 C3 represents control 3 and comparison to control 3.
29 C4 represents control 4 and comparison to control 4.
30 C5 represents control 5 and comparison to control 5.
31 Inorg-N represents inorganic-N, consisting of nitrate-N and ammonium-N.
32 CSCPSA represents corn after soybean, chisel plow, single spring pre-plant N application.
33 CSCPLS represents corn after soybean, chisel plow, late-spring soil nitrate test based N application.
34 CSNTSA represents corn after soybean, no-till, single spring pre-plant N application.
35 CSNTLS represents corn after soybean, no-till, late-spring soil nitrate test based N application.
36 SCCPSA represents soybean after corn, chisel plow, single spring pre-plant N application.
37 SCCPLS represents soybean after corn, chisel plow, late-spring soil nitrate test based N application.
38 SCNTSA represents soybean after corn, no-till, single spring pre-plant N application.
39 SCNTLS represents soybean after corn, no-till, late-spring soil nitrate test based N application.
40 W1 represents watershed 1.
41 W2 represents watershed 2.
42 W3 represents watershed 3.
43 W4 represents watershed 4.
44 MT represents mulch tillage.

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Conservation Practice Summary Assessment

Contaminant: **Total N**

Type of Strategy: **Preventive**

Strategy Name: **Pasture/Grassland Management Conservation Practices** (Livestock Exclusion from Streams/Riparian Areas, Rotational Grazing, Seasonal Grazing)

Pollutant reduction mechanisms

- Improved balance of manure nutrient application rate with crop (pasture vegetation) demand
- Improved stabilization of soil surface to impede wind and water erosion detachment and transport of nutrient enriched sediment and particulates
- Improved water infiltration and adsorption of ammonium-N and organic-N to soil matrix
- Reduced erosion and transport of nutrient enriched sediments and particulates (ammonium-N and organic-N)
- Reduced in-field volume of runoff water (ammonium-N and organic-N)
- Reduced volume of runoff water reaching surface waters (ammonium-N and organic-N)
- Vegetative assimilation

Applicable conditions

- For livestock exclusion from streams/riparian areas, any pasture/grassland used for livestock grazing that has a surface water body
- For rotational grazing, any pasture/grassland that does not have the limiting conditions listed below

Limiting conditions

- For rotational and seasonal grazing: unstable soils due to slope and/or low plastic limits
- For rotational and seasonal grazing: near proximity to surface water
- For rotational and seasonal grazing: coarse soil textures that result in low nutrient retention and fast infiltration
- For rotational and seasonal grazing: excessive animal stocking rate and residence time that leads to an accumulation of N greater than pasture vegetation demand
- For rotational and seasonal grazing: excessive rainfall or snowmelt that leads to a high potential for leaching or runoff
- For rotational and seasonal grazing: drought that causes an accrual of manure-nutrients from low plant uptake

Range of variation in effectiveness at any given point in time

Livestock exclusion from streams vs. intensive grazing: +5% to +70%
Rotational and seasonal grazing vs. constant intensive grazing: <-100% to +60%

Effectiveness depends on:

- For livestock exclusion: low stocking rates in pastures with stable streambanks and off-stream shade source may have lesser benefits
- For livestock exclusion: Losses of nitrate-N may increase due to urine deposits on land instead of in or near the stream
- For rotational and seasonal grazing: if stocking rates are greater than with continuous grazing, uneven urine deposits and areas of concentrated deposits resulting in critical source areas with high nitrate-N loads
- For rotational and seasonal grazing: conversion of a non-grazed, non-fertilized grassland (harvested for hay or idle) to grazed conditions can lead to dramatic increases in ammonium-N, organic-N and Total N loss due to hoof traffic effects on soil and localized high N nutrient inputs from animal waste deposits
- For rotational and seasonal grazing: changing from a constant intensive grazing system to rotational grazing that is less intensive (maintaining greater sward height) can lead to improved soil conditions that better cycle nutrients and reduce runoff and leaching

Estimated potential contaminate reduction for applicable areas within Iowa (annual basis)

Livestock exclusion from streams vs. intensive grazing: +10% to +50%
Rotational and seasonal grazing vs. constant intensive grazing: -100% to +50%

The elimination or reduction of defecation and urination in or near surface water with livestock exclusion will reduce surface water contamination of ammonium-N and organic-N, and Total N. However, nitrate-N losses may increase. On an overall balance, livestock exclusion practices have shown to reduce N losses.

The potential and actual effects of seasonal and rotational grazing practices are highly dependent upon several factors. First is the point of reference. If a grazing practice is compared to a non-grazed vegetative area, most commonly the grazing practice will have greater losses of N. In contrast, if a rotational or seasonal grazing practice is compared to a year-round intensive grazing practice at similar stocking rates, then the reduced presence of animals will result in less N from livestock feces and urine being deposited in the area. Reduced nutrient load frequently results in reduced nutrient loss. Variable stocking rates are another important factor. Any grazing system that has stocking rates that results in soil compaction and erosion will cause increased ammonium-N, organic-N, and Total N (as well as P) losses. Increased stocking rates have been identified as the primary reason for increased N leaching losses from grazing lands. The greater nitrate-N loss is due to leaching from localized areas of high nitrate concentrations created by animal urination. Soil nitrate-N concentrations in the urine-affected areas from cattle have been measured at approximately 620 lb N/a (Stout et al., 2004). Urea from urine can quickly react with water to form ammonia and then nitrify to nitrate (depending upon soil temperature) and be subject to leaching. Related to stocking rate is management of the pasture vegetation. As the minimum allowed vegetation density and sward height limits increase, the risk of compaction, erosion, runoff and build-up of excess manure nutrients decreases. Also, with practices limiting the presence of livestock, the timing of livestock grazing is important in regard to weather patterns. If livestock are predominantly in a pasture area during dry or cold weather, manure nutrients may build-up in excess of the plant needs. When followed by a warm and wet period, the excess manure nutrients are then at great risk to leaching and runoff losses. The type of vegetation (i.e., cool season vs. warm season plants) can influence N losses from livestock-derived nutrients depending upon when the livestock are pastured. If the animals are grazing an area dominated by cool season plants in the middle of summer when the plants are dormant, then there is a greater risk of nutrient losses. When considering the nutrient balance of a livestock pasture system, nutrients imported to the area either through added commercial fertilizers or in supplemental livestock feed (such as hay) can also increase N and P losses to surface waters.

Stout et al. (2000) stated, "…management intensive grazing systems should be regarded as a production system rather than a nutrient management system." They concluded that nutrient management techniques must be developed for management intensive grazing systems. Therefore, seasonal and rotational grazing systems cannot always be counted on to reduce N contamination of surface waters compared to conventional practices, especially if the conventional practice uses a lower stocking rate over time. Any grazing practice that puts high concentrations of animals in limited spaces has the potential to create critical source areas for N nutrient contamination.

Estimated long-term contaminant reduction for applicable areas in Iowa (multi-year basis)

Livestock exclusion from streams vs. intensive grazing: +30%

Rotational and seasonal grazing vs. constant intensive grazing: +20%

For livestock exclusion from stream and riparian areas, the above estimate is made in regard to areas that animals have unrestricted stream access on a year-round basis.

For rotational and seasonal grazing, a major assumption with all of these estimates is that the timing of the grazing period and stocking rates result in manure nutrient levels that are at or lower than pasture vegetation demand and that there are not adverse effects to soil properties that influence infiltration and runoff.

Extent of research

Limited

Livestock exclusion from stream/riparian areas has been researched to an appreciable extent across the world, but effects on water quality have rarely been measured. Here in the U.S., livestock exclusion and its impacts on water quality have not been researched adequately in many regions, particularly in the Midwest. More data and information needs to be generated from long-term field and watershed scale experiments. Despite these limitations, those projects that have examined water quality have shown reductions in N losses to surface waters due to livestock exclusion. Anecdotal evidence from demonstration projects has reported similar results. This should be a priority funding area for research due to the high potential for these practices to reduce nonpoint source N contamination of surface waters.

Rotational, management intensive and seasonal grazing systems have been researched to a greater degree than livestock exclusion, but impacts on water quality still have received limited attention. Research to date suggests that these grazing practices cannot always be regarded as a best management practice for improving water quality for the reasons mentioned above. Further research needs to be conducted at field and watershed scales to develop comprehensive nutrient management strategies for these practices.

Secondary benefits

- Reductions in soil erosion
- Reductions in sediment contamination of surface water
- Reductions in P contamination of surface waters with livestock exclusion from stream, and rotational and seasonal grazing
- Reductions in bacterial pathogen contamination of surface waters with livestock exclusion from stream (not necessarily with rotational grazing)
- Opportunity to apply streambank stabilizing practices such as re-vegetation in absence of frequent disturbance

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Conservation Practice Research Summary Table

Contaminant: **Total N**

Type of Strategy: **Preventive**

Strategy Name: **Pasture/Grassland Management Practices** (Livestock Exclusion from Streams/Riparian Areas, Rotational Grazing, Seasonal Grazing)

References significant to Iowa identified in bold italics.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Line et al., 2000 **Livestock Exclusion of Stream/ Riparian area**	Western Piedmont Region, NC, US; Tatum silt loam, and Vance sandy loam	81 week pre-treatment period for baseline establish-ment, 137 week treatment period	Small watershed	Pastured dairy cattle	Surface runoff and leaching through shallow groundwater to stream flow	Pre-treatment period Post-treatment period	Mass as lb/week 22.7 lb/wk N+N[2] 255.0 lb/wk TKN[3] 15.4 lb/wk N+N 55.0 lb/wk TKN	– – 32% 78%	Continuous discharge measures during entire study period. Weekly grab samples for chemical analyses and storm event samples via autosamplers.	Results somewhat confounded due to differences in precipitation (amount and intensities) and infiltration between pre- and post-treatment periods. Reduced incidence of livestock feces and urine deposits in and near the stream. Statistically significant reduction of TKN at 95% CI[4] level, but not for N+N.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Sheffield et al., 1997 **Off-Stream Primary Water Source vs. Stream Primary Water Source in Grazed Pasture.** **Without Stream Exclusion for Both Treatments.**	Independ-ence, VA, USA: Soil types not stated.	14 months	Field	Grazed pasture with stream	Surface runoff and subsur-face flow		Flow-weighted averages, Mass: TN[5] , NH4[6] & NO3[7] (lb/in rainfall) Conc.: TN , NH4 & NO3 (ppm)		Before-After time period comparison on same pasture area. First 7 months (Aug.-April) with the stream as the primary water source for grazing cattle vs. following 7 months (April-Oct.) with an off-stream water trough as the primary water source. Stocking rate 200 cows and 170 calves on 336 acre pasture. Bi-weekly stream samples.	Reductions in N species attributed to 51% reduc-tion of time in or near stream by cattle and amount of waste deposits to the stream. Increase in NO3 attrib-uted to treatment measurement periods, stream source occurred at fall/winter, off-stream source at spring/ summer. Warmer soil temps in latter could have led to greater soil-N mineraliz-ation. Significant reductions in TN and NH4 mass load loss at the 95% CI level. Other factors not statistically significant.
						Stream Primary Water Source	2.62 lb/in TN 1.34 ppm TN 0.45 lb/in NH4 0.32 ppm NH4 0.27 lb/in NO3 0.17 ppm NO3	_ _ _ _ _ _		
						Off-Stream Primary Water Source	1.16 lb/in TN 1.24 ppm TN 0.10 lb/in NH4 0.09 ppm NH4 0.30 lb/in NO3 0.23 ppm NO3	55.7% 7.5% 77.8% 71.9% -11.1% -35.3%		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Owens, et al., 1989 Seasonal Grazed vs. Ungrazed Pasture; Grazed Pasture vs. Woodland	Coshoc-ton, OH, USA: Silt loam soils	11 yrs total: 2 yrs ungrazed, 3 yrs summer grazing only, 6 yrs yr-round grazing with winter hay supplement	Small Water-shed	Grass Pasture	Surface runoff from storm events		Annual flow-weighted averages, Mass: NO3, Min-N[11] & Org-N[12] (lb/a) Conc.: NO3, Min-N & Org-N (ppm)		Before-After time period comparison on same watershed area of ungrazed vs. grazed treat-ments. Paired watershed comparison with untreated wooded watershed. Yrs 3-5 had greater precipitation and runoff than the other two treatment periods. Stacking rate of 17 beef cow calving herd on 70 acre pasture. Auto-sampling of storm runoff within the stream.	Minimal change in NO3 concentration with influence of cattle grazing. Mixed results for Min-N. On a percentage basis, dramatically increased losses of Org-N from yr-round grazing. Actual loss quantities of N forms are relatively low from each system. Although there were increases in Org-N, overall for this area, cattle grazing of pasture would not be expected to cause impairments to water quality from forms of N.
						Pasture No Grazing, Yrs 1-2, C1[8]	0.62 lb/a NO3 0.6 ppm NO3 0.71 lb/a Min-N 0.7 ppm Min-N 0.62 lb/a Org-N 0.6 ppm Org-N	– – – – – –		
						Wooded Watershed, Yrs 3-5, C2[9]	2.8 lb/a NO3 1.2 ppm NO3 3.03 lb/a Min-N 1.3 ppm Min-N 2.31 lb/a Org-N 1.0 ppm Org-N	– – – – – –		
						Wooded Watershed, Yrs 6-11, C3[10]	2.22 lb/a NO3 1.4 ppm NO3 2.31 lb/a Min-N 1.5 ppm Min-N 0.80 lb/a Org-N 0.4 ppm Org-N	– – – – – –		
						Pasture Summer Grazing, Yrs 3-5	1.25 lb/a NO3 0.7 ppm NO3 1.51 lb/a Min-N 0.8 ppm Min-N 2.05 lb/a Org-N 1.2 ppm Org-N	-102% C1; 55% C2 -17% C1; 42% C2 -113% C1; 50% C2 -14% C1; 38% C2 -231% C1; 11% C2 -100% C1; -20% C2		
						Pasture Yr-Round Grazing with Winter Haying, Yrs 6-11	0.89 lb/a NO3 0.8 ppm NO3 1.51 lb/a Min-N 1.6 ppm Min-N 3.20 lb/a Org-N 2.7 ppm Org-N	-44% C1; 60% C3 -33% C1; 43% C3 -113% C1; 35% C3 -128% C1; -7% C3 -416% C1; -300% C3 -350% C1; -575% C3		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Schepers and Francis, 1982 Grazed vs. Ungrazed Pasture	Clay Center, NE, US: Crete and Hastings silt loams.	3-yr	Field	Warm and cool season mixed grass pasture.	Surface Runoff		Runoff event flow-weighted averages Mass: NH4-N, NO3-N & TKN (lb/a/in) Conc.: NH4-N, NO3-N & TKN ppm		Annual precipitation below normal 2 of 3 yrs (92% and 79%). One yr above normal 168%). Average stocking rate of 40 cow-calf pairs (~2.5 a per pair). Pastures fertilized at 60 lb N/a each spring. Ungrazed pasture periodically clipped to sward height similar to grazed pasture.	Amount of contaminants within runoff directly related to stocking density and the amount of precipitation within an event. Reduced NO3 and NH4 losses via surface runoff in ungrazed pasture due to absence of livestock disturbance of soil and animal wastes. Higher TKN losses in ungrazed pasture attributed to greater amounts of transported plant organic materials and less sediment than grazed pasture.
						Grazed Pasture	0.074 lb/a/in NH4-N 0.33 ppm NH4-N 0.095 lb/a/in NO3-N 0.42 ppm NO3-N 0.752 lb/a/in TKN 3.33 ppm TKN	– – – – – –		
						Ungrazed Pasture	0.07 lb/a/in NH4-N 0.31 ppm NH4-N 0.066 lb/a/in NO3-N 0.29 ppm NO3-N 0.929 lb/a/in TKN 4.11 ppm TKN	5% 6% 29% 31% -24% -23%		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Hooda et al., 1998 Intensively Grazed Grass vs. Grass/ Clover Pasture	Dumfries, Scotland, UK: Silty clay loam topsoil over silty clay subsoil.	2- yr	Field	Grazed Grass and Grass + Clover Pasture	Sub-surface flow	Ryegrass Pasture: 222 lb/a/yr fertilizer N, 0 lb/a/yr fertilizer P, 40 lb/a/yr manure P Ryegrass + White Clover Pasture: 0 lb/a/yr fertilizer N, 22 lb/a/yr fertilizer P, 39 lb/a/yr manure P (61 lb/a/yr fertilizer + manure P)	Annual flow-weighted average and total annual NO3 loss, Mass: lb/a Conc.: ppm **Yr 1**: 26.9 lb/a NO3 3.9 ppm NO3 **Yr 2**: 39.9 lb/a NO3 10.2 ppm NO3 **Yr 1**: 21.7 lb/a NO3 3.1 ppm NO3 **Yr 2:** 33.6 lb/a NO3 8.5 ppm NO3	_ _ _ _ 19% 20% 16% 17%	Yr 1 had above normal precipitation. Yr 2 had below normal precipitation. Water samples collected every 0.02-0.08 in. drainage in winter, every 0.002 in. drainage in spring-fall. Then compiled for weekly averages. Two pastures at 89 a each for the treatments. Pastures had 2-3 silage cuts in Mar.-July, dairy cow grazing Aug.-Oct., sheep grazing Nov.-Feb.; manure applied May-July following each silage cut. Manure-N applied rates not reported.	The grass + clover treatment had significantly less mass losses of NO3 than the grass monoculture treatment in the first year, but not the second. Both NO3 mass and concentration losses were greater in the second year, which was attributed to differences in climate. The second year had periods of low precipitation; subsequent rainfall events leached NO3 that accumulated during the dry period. Climate was attributed greater significance to NO3 losses than the types of forage plant species.

1 Watershed, field, plot or laboratory.
2 N+N represents nitrate- plus nitrite- nitrogen.
3 TKN represents total Kjeldahl nitrogen, being the sum of organic-N and free ammonia-N.
4 CI represents confidence interval.
5 TN represents total nitrogen.
6 NH4 represents ammonium nitrogen.
7 NO3 represents nitrate nitrogen.
8 C1 represents control 1.
9 C2 represents control 2.
10 C3 represents control 3.
11 Min-N represents mineral nitrogen sources of ammonium + nitrate + nitrite.
12 Org-N represents organic nitrogen.

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Conservation Practice Summary Assessment

Contaminant: **Total N**

Type of Strategy: **Remedial**

Strategy Name: **Riparian Buffers** (mixed trees, shrubs and/or grasses)

Pollutant Reduction Mechanisms:

- Denitrification
- Dilution
- Improved stabilization of soil surface to impede wind and water erosion detachment and transport of nutrient enriched sediment and particulates
- Improved water infiltration
- Temporary nutrient sequestration in soil organic matter
- Trapping and Trapping and retention of transported nutrient enriched sediments and particulates
- Vegetative assimilation

Applicable Conditions:

As per USDA-NRCS guidelines, on areas adjacent to permanent or intermittent streams, lakes, ponds, wetlands, sink holes, tile inlets, agricultural drainage wells and other areas with ground water recharge.

However, special attention needs to be focused on any landscape physical conditions that may limit the ability of a riparian buffer to remove nitrate from runoff and shallow ground water as it flows towards surface water bodies (see Limiting Conditions below).

Limiting Conditions:

- Aerobic soil conditions, deep water table (i.e., below root zone)
- Attaining upper N nutrient storage limit, may become a nutrient source to surface waters once plants reach maturity if not properly managed and harvested
- Channelized (concentrated) surface runoff flow entering the buffer
- Cool temperatures
- Insufficient available carbon sources to support denitrifying bacterial growth and function
- Lack of other upslope conservation practices to maintain sheet or rill flow and to ensure as to not overloading the riparian buffer at any given location
- Limited runoff and shallow ground water residence time (i.e., from coarse soil texture and/or steep terrain gradient)
- Non-growing season (dormant period) of buffer plant species

- Steep and unstable streambanks and deeply incised channels that have not been re-formed to more stable conditions
- Steep topography that reduces time for infiltration and increases runoff volume and runoff flow rate
- Tile drainage lines passing through and around buffered areas
- Well-drained soils having deep percolation of infiltrating water to degree that groundwater flow bypasses root systems of buffer plants (i.e., coarse soil textures without an underlying confining layer to cause lateral flow of shallow groundwater)
- Overland flow of snowmelt across frozen buffer soils

Range of variation in effectiveness at any given point in time

0 to +100%

Effectiveness depends on:

- Intensity, quantity, duration and timing of rainfall and snowmelt events
- Snowmelt and precipitation events that lead to concentrated surface runoff flow and brief runoff and shallow groundwater residence time
- Vertical structure of buffer plants on and near the streambank may reduce erosion losses by stabilizing the soils during all seasons, even in the presence of concentrated runoff flow
- Cool temperatures; growth of denitrifying bacteria is influenced by temperature, with greater growth and function with increasingly warmer temps within the soil
- Drought will limit denitrification nitrate-N removal mechanism
- Water table and groundwater flow below the riparian plants' root zones will limit denitrification due to low soil carbon contents in the saturated zone and potentially reduce vegetative N assimilation
- Vegetative assimilation may function efficiently for nitrate-N removal in absence of other removal mechanisms when drought occurs during the growing season as long as shallow groundwater continues to flow through the plants' root zones (via a perched water table from a confining layer that impedes deep infiltration of water)
- The degree of soil-N removal by vegetative assimilation is dependent upon the type of plants species used and climatic conditions (i.e., cool season vs. warm season plants, grasses vs. woody plants vs. mix of grasses and trees)
- Design and structure of the buffer (i.e., single grass strip vs. tree/shrub vs. both, width of buffer and different buffer zones)
- Degree of maintenance of the buffer, particularly as it matures (i.e., harvest and removal of buffer plant biomass being critical)
- With good establishment of riparian buffer plants, warm temperatures, abundant available soil carbon, slow shallow ground water flow, water table near soil surface and no concentrated runoff flow, nitrate-N removal can be complete

<u>Estimated potential contaminate reduction for applicable areas within Iowa (annual basis)</u>

+20 to +80%

Landscapes and soil types within Iowa agroecoregions are in some areas amenable to placement and targeted functions of riparian buffers. Research in central Iowa has proven significant nitrate removal when proper siting and design conditions have been met. New methods to identify and prioritize placement and buffer width show the potential to improve siting, buffer effectiveness and economics of implementation. However, there can be great variability both in space and time as to the effectiveness of riparian buffers in reducing total N and nitrate-N contamination of surface waters.

Under the listed limiting conditions, which are common throughout Iowa's landscapes, additional strategies will need to be adopted. One example would be concentrated runoff flow entering the buffer from adjacent cropland. Concentrated flow may cut through the buffer, therefore rendering it ineffective in that location for any high volume runoff events. It is recommended by the USDA-NRCS and many scientists that riparian buffers must by used in coordination with other in-field conservation practices (i.e., grass hedges, waterways, terraces, permanent vegetative cover, no-till) to disperse and reduce the volume of runoff and maintain runoff as diffuse sheet or rill flow, and to minimize the probability of over-loading the buffer.

Another limitation that needs to be addressed and is common within Iowa is tile drainage lines that pass through a buffer and discharge directly into surface waters (including drainage ditches). Riparian buffers alone will offer no reduction of nitrate-N transported through tile drains, which is a dominant pathway of nitrate-N to surface waters. In this case, tiles will need to be rerouted to a wetland that is a part of the riparian buffer system, and/or implement other tile drainage nitrate mitigation strategies if the proper physical conditions allow (i.e., controlled drainage).

Some studies have shown low rates of N loss reduction were due to improper site or design factors that resulted in limited contact and residence time of groundwater with the buffer's root zone, particularly when it is active. Although infiltration has been identified as one of the most important sediment and nutrient removal mechanisms when assessing buffer performance, riparian buffers will not be effective for nitrate-N removal in areas with coarse textured soils (i.e., sandy and sandy loam) that lack a shallow water table. A high percentage of precipitation will infiltrate deeply and bypass most of the buffer's root zone in these areas (Hill, 1996; Schultz, et al., 2000; Simpkins et al., 2002). Vegetative assimilation and denitrification would be limited in this scenario. Denitrification requires available carbon, which would be limited below the buffer root zone.

Shallow ground water flow from upland areas may take several months to reach the riparian buffer. The buffer will have little impact on the nitrate-N concentration of shallow ground water from this source area when it reaches the buffer root zone during the non-growing (dormant) season for the buffer's plant species. Denitrification will be of little consequence during this same time period due to cool soil temperatures.

As noted above, the anaerobic bacteria driven process of denitrification is dependent upon moderate to warm soil temperatures, in addition to other factors. Denitrification is not an appreciable nitrate-N removal mechanism from late fall through mid-spring, but can be a significant removal mechanism from late spring through early fall. Since anaerobic bacteria carry out denitrification, there must be no available free oxygen, meaning that a considerable portion of the soil profile must be water saturated. Also, the water table must be near the soil surface so that sufficient organic C is available to support denitrifying bacterial growth and function. Organic carbon is commonly stratified within a soil profile, with greater amounts near or at the surface and decreasing with depth. Buffer plant species differ as to their relative C contributions to soils.

Cool season plants taking up water and nutrients primarily early and late in the growing season, warm season plants during the late-spring through early fall. Cool season plants have been shown to accumulate more organic C (supporting denitrifying bacteria growth) than native warm season grasses in the near surface soil layers. However, the native warm season grasses (i.e., switchgrass) have rooting systems that penetrate much deeper into the soil profile, which provides C for denitrifying bacteria to much greater depths than cool season grasses, fueling denitrification over a greater soil volume and longer time period due to water table fluctuations by depth in the soil profile (deeper during dry periods).

Integrated riparian buffer designs consist of differing zones of plant types and width. Therefore, mixed-species buffers may provide the greatest amount of N removal. To provide sediment trapping, grass strips are typically located at the field edge. Next, a strip of shrubs, slow-growing trees and grasses create an area designed to best retain and remove N, mainly through uptake and denitrification. In the last buffer zone along the stream edge, fast-growing, wet soil tolerant trees with deep rooting systems and grasses improve streambank stabilization. Tree and grass species differ by general groups in their growing seasons, ability to uptake soil water and nutrients, and effective sediment and runoff filtering ability. The amount of total N reduction from trapped runoff sediment is dependent upon the sediment's total N concentration, density of buffer plants, buffer width, soil texture, buffer area water infiltration rate, and slope and slope length of adjacent cropland. To function optimally, riparian buffer widths will need to be adjusted to compensate for these factors, especially steep and long slopes and gullies or non-vegetated waterways leading to the buffer. Establishment of a riparian buffer may first require efforts to stabilize streambanks that are steep and eroded.

Riparian buffers must have maintenance. After buffer plants mature, harvesting of biomass is critical to maintain the buffer as a nutrient sink. A buffer may evolve into a nutrient source to surface waters since every buffer has limits as to how much of each nutrient it can store. Once a buffer reaches its maturity it will continuously cycle nutrients and its nutrient holding capacity can diminish. Without regular harvest and removal of plant biomass (especially woody plants), decomposition of plant residues will release nutrients, some of which will then enter the nearby surface waterbody that the buffer was meant to protect. Another problem that requires maintenance is the occurrence of ridges that form at the upslope field/buffer edge due to sediment accumulation over time and any tillage operations that cut a furrow along the edge. Both the ridge and the furrow will result in excessive water ponding at the front of the edge and can lead to concentrated runoff flow, which could cut through or bypass the buffer. Maintenance will require reforming and replanting the field/buffer edge as these conditions appear. Detailed information on riparian buffers, and effective designs and maintenance can be found on the Iowa State University Agroforestry website at the following address:

http://www.buffer.forestry.iastate.edu/

If the above efforts are made to compensate for the various limitations of riparian buffers, when properly sited and designed and maintained, these buffers have been shown to be very effective in reducing N contamination of surface waters.

Estimated long-term contaminant reduction for applicable areas in Iowa (multi-year basis)

+40%

This estimate of long-term reduction in N contamination of surface waters is based upon the condition that the riparian buffer is established per NRCS guidelines and design suggested by the Agroecology Issue team of the Leopold Center for Sustainable Agriculture. The parameters of design that greatly impact the effectiveness of a riparian buffer include buffer width, and plant types and species (i.e., cool vs. warm season grasses, grass vs. grass/woody vegetation buffer). Also, this estimate assumes that the buffer is properly maintained and concentrated flow is minimal due to the presence of other properly implemented in-field conservation practices.

Extent of Research

Moderate in eastern U.S., limited in Upper Midwest.

Although there have been numerous studies of various riparian buffer aspects, most U.S. experiments have been done at just a few sites. Therefore, it is difficult to extrapolate the published results to all other areas because hydrology varies from site to site, which can significantly effect the performance of any conservation practice. Of the riparian buffer research experiments that have been published, many have limited a limited duration of measurements and do not address siting of the buffer. Few studies have provided documentation of riparian buffer performance during non-growing season periods and in areas where runoff was primarily maintained as concentrated flow. Further research needs to provide a better understanding of nutrient transport and reduction processes, optimal designs tailored for site-specific conditions (i.e., proper buffer width and plant species), and to include more comprehensive evaluations by regions within the U.S. Also, models need further development to aid proper buffer design and siting, reforming and stabilizing streambanks and channels, and identifying critical source areas within the contributing drainage area that require in-field buffers to reduce concentrated runoff flow. A few modeling tools have been developed (riparian ecosystem management model, REMM; terrain analysis with the use of elevation and soils databases, particularly the soil survey geographic georeferenced database, SSURGO) for improving proper site identification, but need to be evaluated on various landscapes.

Secondary Benefits

- Serve as a P sink
- Sediment retention mechanism from cropland runoff
- Partial filtering and decomposition of pesticides
- With proper design, streambank stabilization resulting in reduced erosion of this potential critical source area
- Increased stream dissolved oxygen levels from increased mixing of water if woody plant roots and/or structures are present within the stream
- Increased stream dissolved oxygen levels from reduced water temperature by shading if woody plants are located on and near the streambank
- Additional income source if designed, implemented and managed properly
- Additional wildlife habitat
- Provides a small degree of flood control

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Conservation Practice Research Summary Table

Contaminant: **Total N**

Type of Strategy: **Remedial**

Strategy Name: **Riparian Buffers** (mixed trees, shrubs and/or grasses)

References significant to Iowa identified in bold italics.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Lee et al., 2000 **Grass and woody plant riparian buffer strips**	Roland, IA., US; Coland silty clay loam buffers' soil, Clarion loam cropland soil	1 Month (rainfall simulations)	Plot	CS[2] rotation, study conducted in fall following soybean harvest with residue removed	Surface runoff		Mass (lb/a) transport of NO3-N[3], and TN[4] from each treatment		Water samples taken every 5 minutes from initiation of runoff to its termination. Higher intensity 1hr rainfall done 2 days after initial 2-hr less intense rainfall.	Switchgrass buffer distance was 23 ft, Woody plant & switchgrass buffer 53 ft wide (30 ft woody plants + 23 ft grass), cropland area 71.8 ft. Percentage mass reduction of N forms was strongly correlated with infiltration within the buffers. Also, percentage N mass reduction decreased with increasing rainfall intensity. Buffers were more effective at reducing sediment transport than nutrients.
						2-hr rainfall @ 1 inch/hr: No Buffer	0.38 lb/a NO3-N 0.73 lb/a TN	– –		
						Switchgrass	0.25 lb/a NO3-N 0.46 lb/a TN	34.2% 37.0%		
						Woody Plant + Switchgrass Buffer	0.07 lb/a NO3-N 0.13 lb/a TN	81.6% 82.2%		
						1-hr rainfall @ 2.7 inch/hr: No Buffer	1.02 lb/a NO3-N 2.02 lb/a TN	– –		
						Switchgrass	0.72 lb/a NO3-N 1.23 lb/a TN	29.4% 39.1%		
						Woody Plant + Switchgrass Buffer	0.44 lb/a NO3-N 0.75 lb/a TN	56.7% 62.9%		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Lee et al., 1999 **Grass Riparian Filter Strips**	Roland, IA., US; Coland silty clay loam buffers' soil, Clarion loam cropland soil	3 days (rainfall simulations)	Plot Simulated drainage to filter strip area ratio of 40:1for 9.75 ft wide strips, 20:1 ratio for 19.5 ft wide strips	Fallow period	Surface runoff		Mass (lb/a) transport of NO3-N and TN. Only % Reductions from Runon N Content Reported		Rainfall simulations done in August with no natural rainfall events occurring. Rainfall simulation rate was 2 in/hr intensity preceded by a 15 minute wetting period. Runon to filter strips at a rate of 10.6 gal/min. Cool season mix consisted of bromegrass, timothy and fescue. Cool season treatment derived from 7 yr ungrazed pasture prior to study, switchgrass (warm season grass) established 6 yr prior to study.	Switchgrass and the 19.5 ft strip distance were better than cool season plant mix and 9.75 ft strip width in removing N from runoff. Switchgrass produces more litter, stiffer stems, stronger root systems and spatially uniform growth than the cool season mix, which may make it more efficient at sediment and nutrient removal. TN reduction was highly correlated with sediment removal, NO3-N removal with infiltration. Although, infiltration and sediment deposition had roles in reducing both N forms. Reduced filter strip width also had lesser reductions in sediment load from runoff.
						<u>9.75 ft wide</u> Switchgrass	NO3-N TN	28.1% 31.7%		
						Cool Season	NO3-N TN	22.3% 23.5%		
						<u>19.5 ft wide</u> Switchgrass	NO3-N TN	46.9% 51.2%		
						Cool Season	NO3-N TN	37.5% 41.1%		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Lee et al., 2003 **Multi-Species Grass and Woody Plant Riparian Buffer**	Roland, IA, US; Coland silty clay loam buffers' soil, Clarion loam cropland soil	19 months (May Yr-1 through Nov. Yr-2)	Plot	CS rotation, soybean in yr-1, corn in yr-2	Surface runoff	 No Buffer (NB) Switchgrass Only Buffer (S) Switchgrass & Woody Plant Buffer (SWP)	Mass (lb/a) transport of NO3-N and TN. 0.08 lb/a NO3-N 0.49 lb/a TN 0.03 lb/a NO3-N 0.11 lb/a TN 0.01 lb/a NO3-N 0.04 lb/a TN	 _ _ 62.5 % 77.6 % 87.5 % 91.8 %	One composite runoff water sample per day of runoff events. Runoff events of 0.008 inch or more were 6 in yr-1, 13 in yr-2. Buffers were established 4 yrs prior to initiation of the study.	Switchgrass buffer distance was 23 ft, Woody plant & switchgrass buffer 53 ft wide (30 ft woody plants + 23 ft grass), cropland area 73 ft. Statistically significant differences in runoff volume, and NO3-N and TN removal between all treatments with trend by highest to lowest runoff amount being, NB>S>SWP. Differences in % reduction from citation due to conversion rounding error from metric to English units. Reported main removal mechanisms were infiltration of runoff for NO3-N and filtration of sediment-bound N.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Hubbard and Lowrance, 1997	Tifton, GA, US; Alapaha loamy sand soil	3-yr	Plot	Peanut-Corn-Pearl Millet N fertilizer application by order of yrs 1-4: 185, 151, 189 and 150 lb N/a.	Shallow ground water flow	 Crop Field Control Trt[5] 1 Control Trt 2 Control Trt 3 (Zone 1) Grass Buffer Trt 1 Trt 2 Trt 3 (Zone 2) Managed Forest Clear Cut Trt 1 Selective Thinning Trt 2 No Tree Removal Trt 3 (Zone 3) Permanent Mature Forest Trt 1 Trt 2 Trt 3	3-yr ave. non-flow weighted NO3-N concentration 10.4 ppm NO3-N 5.4 ppm NO3-N 11.9 ppm NO3-N 5.4 ppm NO3-N 1.7 ppm NO3-N 10.8 ppm NO3-N 1.4 ppm NO3-N 2.4 ppm NO3-N 1.1 ppm NO3-N 2.9 ppm NO3-N 4.1 ppm NO3-N 1.2 ppm NO3-N	_ _ _ 48.1% 68.5% 9.2% 86.5% 55.6% 90.8% 72.1% 24.1% 89.9%	Shallow ground water wells sampled biweekly Jan.-Sept. of each yr. Mature forest trees were approximately 45 yrs of age. Forest management trt cuttings done near end of yr-1, replacement plantings done in early yr-2.	Grass buffer was 32.5 ft, forest management trt zone was 146-162 ft, permanent mature forest was 32.5 ft. NH4-N also measured, but not shown here since most concentrations throughout the study were <0.5 ppm. Significant differences existed between trt sites and controls and zones. No significant differences between trts. Buffer vegetation assimilation of NO3-N listed as primary reduction mechanism, with dilution also contributing. Zone 3 showed marginally increased NO3-N concentrations compared to Zone 2 trts.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Vellidis, et al., 2003 Riparian Buffer and Uncontrolled Flow Restored Wetlands	Tifton, GA., US; Alapaha loamy sand wetland soil, Tifton loamy sand upland soil Water-shed to wetland area ratio of 8:1	8-yr	Small water-shed (20 acre)	Grass forage-silage corn with 534 lb N/a/yr liquid dairy manure applied, and pasture with 267 lb N/a/yr and 134 lb P/a/yr applied	Surface runoff and shallow ground water		Mean NO3-N, NH4-N[6], TKN[7] and TN concentration (ppm), and annual mean mass (lb/yr)		Wetland restored 1 yr prior to initiation of study. Shallow ground water sampled biweekly for first 6 yrs, monthly for last 2 yrs from extensive well network. Surface runoff sampled daily per runoff event. Low precipitation Sept.-Nov. and May-June. High precipitation Dec.-May and July-Aug.	Results show the overall riparian vegetation + wetland effects, not riparian area alone. NO3-N, NH4-N, TKN concentration reductions were highly significant (P<0.0001). Reductions attributed mainly to denitrification, smaller degrees for vegetative assimilation and soil storage. With the exception of increased NH4-N concentration, the first 8 yrs following wetland restoration with established riparian buffer this system removes and retains large amounts of N nutrients.
						Inflow to wetland	1.09 ppm NO3-N 0.96 ppm NH4-N 8.49 ppm TKN 8.63 ppm TN 67.3 lb/yr NO3-N 35.9 lb/yr NH4-N 238.5 lb/yr TKN 306.0 lb/yr TN	_ _ _ _ _ _ _ _		
						Outflow from wetland	0.50 ppm NO3-N 1.20 ppm NH4-N 3.78 ppm TKN 4.18 ppm TN 11.2 lb/yr NO3-N 13.2 lb/yr NH4-N 85.1 lb/yr TKN 96.4 lb/yr TN	54.1% -25.0% 55.5% 51.6% 83.4% 63.2% 64.3% 68.5%		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Peterjohn and Correll, 1984	Near Annapolis, MD; fine sandy loam soil Crop to riparian area ratio of 1.76:1	13 month	Small Watershed (40 acre)	Corn Fertilizer applications to crop of 93 lb N/a	Surface runoff and shallow ground water flow	Surface <u>Runoff</u> Exiting Corn Field (entering forest) Exiting Forest (exiting to stream) Shallow Ground <u>Water</u> Exiting Corn Field (entering forest) Exiting Forest (exiting to stream)	Ave annual mean NO3-N and NH4-N concentration 4.45 ppm NO3-N 1.89 ppm NH4-N 0.94 ppm NO3-N 0.50 ppm NH4-N 7.08 ppm NO3-N 0.07 ppm NH4-N 0.43 ppm NO3-N 0.36 ppm NH4-N	_ _ 78.9% 73.5% _ _ 93.9% -414.3%	Runoff measure at each precipitation event. Flow measured every 5 minutes. Water samples composited to weekly status. Precipitation was slightly above ave in winter, below ave for other seasons. Peaks in NO3-N concentration corresponded with precipitation and N fertilizer application events.	Vegetative assimilation and denitrification theorized as primary reduction mechanisms. Major pathway of N loss from the riparian forest buffer (75%) was from shallow ground water flow. Shallow ground water NH4-N concentration % increased dramatically due to the forest buffer, but in actual ppm the increase was nominal compared to reductions of NO3-N and surface runoff NH4-N.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Lowrance et al., 1984 Riparian Buffer and Wetlands	Little River Watershed, Tifton, GA., US;	1-yr	Large Watershed (~3900 a)	~45% Row crop (corn, soybean, peanut, tobacco, milo, winter vegetables), ~13% pasture, ~30% forest, ~12% misc.)	Surface runoff and shallow ground water flow	Subsurface Crop Field Tile Drainage Emergent Surface Flow from Riparian Buffer & Wetlands	NO3-N, NH4-N, TON[8], TN mass loss 36.0 lb/a NO3-N 0.09 lb/a NH4-N 1.9 lb/a TON 38.0 lb/a TN 0.5 lb/a NO3-N 0.09 lb/a NH4-N 2.5 lb/a TON 3.1 lb/a TN	_ _ _ _ 98.6% 0.0% -31.6% 91.8%	Streamflow samples taken on 38 dates directly after precipitation events, or no longer than 2 week intervals. Seasonality in NO3-N concentration levels with highest occurring Jan. – Mar.	Denitrification and vegetative assimilation theorized as primary reduction mechanisms. Increased loss of TON from riparian area suggested to be due to assimilation of mineral N forms to organic forms and then transported via surface and subsurface flow. Tile drainage that bypassed riparian areas was dramatically higher in NO3-N.

1 Watershed, field, plot or laboratory.
2 CS represents corn-soybean annual crop rotation.
3 NO3-N represents nitrate-nitrogen.
4 TN represents total nitrogen.
5 Trt represents treatment.
6 NH4-N represents ammonium-nitrogen.
7 TKN represents total Kjeldahl nitrogen, being the sum of organic-N and free ammonia-N.
8 TON represents total organic nitrogen.

List of References

Hubbard, R.K., and R. Lowrance. 1997. Assessment of forest management effects on nitrate removal by riparian buffer systems. Trans ASAE. 40(2): 383-391.

Lee, K.H., T.M Isenhart, R.C. Schultz, and S.K, Mickelson. 1999. Nutrient and sediment removal by switchgrass and cool-season grass filter strips in Central Iowa, USA. Agroforest. Syst. 44: 121-132.

Lee, K.H., T.M Isenhart, R.C. Schultz, and S.K, Mickelson. 2000. Multi-species riparian buffers trap sediment and nutrients during rainfall simulations. J. Environ. Qual. 29: 1200-1205.

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Lowrance, R.R., R.L. Todd, and L.E. Asmussen. 1984. Nutrient cycling in an agricultural watershed: II. Streamflow and artificial drainage. J. Environ. Qual. 13: 27-32.

Peterjohn, W.T., and D.L. Correll. 1984. Nutrient dynamics in an agricultural watershed: observations on the role of a riparian forest. Ecology 65(5): 1466-1475.

Vellidis, G., R. Lowrance, P. Gay, and R.K. Hubbard. 2003. Nutrient transport in a restored riparian wetland. J. Environ. Qual. 32: 711-726.

Conservation Practice Summary Assessment

Contaminant: **Total N**

Type of Strategy: **Remedial**

Strategy Name: **Wetlands** (restored and created wetlands)

Pollutant reduction mechanisms

- Denitrification
- Dilution
- Temporary nutrient sequestration in soil organic matter
- Trapping and retention of transported N in nutrient enriched sediments and particulates
- Vegetative assimilation

Applicable conditions

- As per NRCS guidelines for site-specific conditions and landform engineering specifications, such as: hydric soils bordered by cropland, sufficient water contribution, sufficient organic carbon content, low position within watershed landscape and sufficient water storage capacity.

Limiting conditions

- Aerobic conditions
- Attaining upper N nutrient storage limit, may become a nutrient source to surface waters once plants reach maturity if not properly managed
- Channel flow from inlet to outlet that inhibits complete mixing of inflow with retained water, decreases settling of particulates and effective retention time
- Cool temperatures
- Insufficient available carbon sources (i.e., insufficient wetland vegetation) to support denitrifying bacterial growth and function
- Limited stored water residence time (i.e., insufficient storage capacity, high volume precipitation events, coarse soil texture and/or steep terrain gradient)
- Tile drainage lines passing through and around wetland areas
- Unstable soils that are easily disturbed
- Well-drained soils having deep percolation of infiltrating water to degree that groundwater flow bypasses root systems of buffer plants (i.e., coarse soil textures without an underlying confining layer to cause lateral flow of shallow groundwater)

Range of variation in effectiveness at any given point in time

-10% to +100%

Effectiveness depends on:

- Cool temperatures; growth of denitrifying bacteria is also influenced by temperature, with greater growth and function with increasingly warmer soil temperatures
- Degree of maintenance of wetland and stabilization structures; wetland can become a nutrient source if not managed properly
- Design of wetland and stabilization structures, and land area to surface water containment ratios
- Drought can limit denitrification and nitrate-N removal, which can lead to insufficient flow contributions to a wetland structure
- Peak snowmelt and precipitation events that fill a wetland to its storage capacity, resulting in fast flow rates and limited water residence time
- The degree of N removal by vegetative assimilation is dependent upon the type of plants species used and climatic conditions
- With good establishment of plants, warm temperatures, abundant available substrate carbon, slow water flow, sufficient water storage capacity and relatively long water residence time, nitrate-N removal can be complete

Estimated potential contaminate reduction for applicable areas within Iowa (annual basis)

+20 to +40%

When attention is paid to the application and implementation requirements and specifications as identified by the USDA-NRCS, wetlands and other catchments can perform effectively in retaining sediments transported in surface runoff at any time of the year. Agricultural field drainage treatment wetlands function under very different conditions than wastewater treatment wetlands. Where inflow to wastewater treatment wetlands is relatively constant through time, agricultural drainage flow and pollutant concentrations vary with precipitation events, which is a characteristic of nonpoint source pollution (Kovacic, et al., 2000).

Nitrogen in shallow ground water has repeatedly been shown to be predominantly nitrate-N, with some soluble organic-N. Naturally occurring ammonium-N has been found in only low concentrations. Shallow ground water is the major water source to wetland catchments. High volume surface runoff events typically occur just a few times each year under average climatic conditions in Iowa (though these events can contribute the largest fraction of insoluble contaminants and water volume each year). Reductions of nitrate-N concentration and load in shallow ground water by the removal mechanisms of wetland catchments are quite variable annually. This is due to the influences of temperature and precipitation on the processes of denitrification and vegetative assimilation. Ideal temperatures for denitrifying bacteria and plant growth are similar, being the warm temps of late-spring through early-fall. So, these two removal mechanisms are not adequately functioning from mid-fall through mid-spring.

This means that wetland catchments will not be very effective for nitrate-N removal at the typically high leaching periods of mid- to late-fall and early- to mid-spring. However, significant amounts of nitrate-N can be removed during the high leaching period of late-spring through early-summer.

A wetland's storage capacity and hydrology (within the wetland and its contributing area) can significantly affect the removal of nutrient and particulate contaminants. At times of peak rainfall and snowmelt events, a wetland can quickly reach its storage capacity, especially when peak events repeatedly occur in short periods of time such those typical during spring. The residence time of water within a wetland will then be reduced, giving it less time to remove particulates and nutrients by all of the listed removal mechanisms. For particulates and chemicals/nutrients they hold, there is less settling time and the finer particles may stay in suspension, exiting the wetland and entering a surface water body. These finer particulates (plant residues and clays) typically hold greater amounts of chemicals and nutrients than the larger particles that will preferentially fall out of suspension before the finer particles. Flow may also be at fast enough rates to create turbulent conditions within a wetland that can make the water column aerobic (limiting denitrification) and resuspend sediments and nutrients that had settled to the wetland's bed. These resuspended sediments and nutrients may redeposit elsewhere in the wetland, but may also exit the wetland to enter surface waters. This is one reason why wetlands must be regularly inspected and maintained to specifications.

Another hydrologic related factor that influences a wetland's effective removal of sediment and nutrients is the extent of incoming flow dispersion over the wetland area. Complete and even dispersion of inflow across the wetland area optimizes the degree of contact of contaminants with wetland substrate, which are then available for uptake and/or removal by microbes and plants. If incoming flow is not evenly dispersed across a wetland (i.e., channel flow), then not all of the transported sediment and nutrients are available to bacterial and vegetative removal mechanisms and may exit unaltered to surface waters. Large plants within a wetland (macrophyte vegetation) can help to disperse inflow, improve settlement and reduce resuspension of sediments.

The amount and types of vegetation within a wetland and buffering its perimeter are very important for supporting both vegetative assimilation and denitrification removal mechanisms. Since denitrifying bacteria require readily available organic C for their growth and function, plant residue contributions to a wetland and its buffered perimeter are important to fuel denitrification. Criteria and guidance on wetland design, construction, wetland plant establishment and maintenance have been identified by Iowa State University scientists and this information can be obtained from the following internet address:

http://www.iawetlands.iastate.edu/

The Conservation Reserve Enhancement Program (CREP) for establishing buffered wetlands also has detailed criteria and guidance information.

When a wetland has been properly designed and constructed and has established vegetation it can be very effective at removing nitrate-N during warm periods of the year and when shallow ground water flow is slow. Several studies have documented complete removal of nitrate-N under such conditions. However, due to the highly variable climate in the Upper Midwest, these ideal conditions do not occur over a long periods of time. Because of the limiting conditions described above, research from Illinois has estimated N nutrient removal at approximately 30-40% of inputs on an annual basis. **Despite the listed limitations, N removal wetland wetlands offer one of the few currently viable options for removal of nitrate-N from tile drainage by routing effluent to a treatment wetland before entering surface water bodies.**

Estimated long-term contaminant reduction for applicable areas in Iowa (multi-year basis)

+30%

Although the effectiveness of wetland practices (especially treatment wetlands) will vary seasonally and annually due to the above listed factors, with average climatic patterns, these practices can reduce N contamination of surface waters to a considerable degree. This estimate is mainly based on treatment wetlands that are properly placed on a landscape, constructed to NRCS guidelines and at watershed to wetland area ratios between 15–20:1 as suggested by Kovacic et al. (2000). Lower watershed to wetland area ratios of similar depth will have greater water storage capacity and longer water retention time periods, which will result in greater amounts of nitrate removal. Higher watershed to wetland area ratios will be less effective than the above estimate.

Extent of research

Limited in Upper Midwest, Moderate in U.S., Extensive in Europe

Natural, restored and constructed wetlands for treatment of a wide array of contaminants have been researched in Europe and a few other countries. In the U.S., a fairly extensive amount of research has been conducted on the Eastern Coastal Plains of the Carolinas and Georgia, many of these in relation to riparian buffer research since wetlands there are frequently within riparian areas. A moderate amount of research has been conducted in the Midwest, but many aspects need to be examined further. While the removal mechanisms are the same across locations, limitations are different (see list of limiting conditions above). Wetlands have performed very well in the Eastern Coastal Plain, but since denitrification is a major removal mechanism for these wetland practices, performance here in the Upper Midwest will not be as effective because winter, spring and fall temperatures are cooler. Also, with the extensive amount of landscape alteration, artificial drainage and intensive row cropping in the Upper Midwest, restored and constructed wetlands here require careful placement and design specifications. Several very good research projects have been conducted in Iowa and Illinois, but need to be done in other agroecoregions and landscape positions.

Secondary benefits

- Serve as a P sink
- Sediment retention mechanism from cropland runoff
- Partial filtering and decomposition of pesticides
- Additional wildlife habitat
- Provides some degree of flood control
- May improve farmer profitability by removing areas that frequently have negative economic returns for crop production

References

Kovacic, D.A., M.B. David, L.E. Gentry, K.M. Starks, and R.A. Cooke. 2000. Effectiveness of constructed wetlands in reducing nitrogen and phosphorus export from agricultural tile drainage. J. Environ. Qual. 29:1262-1274.

Conservation Practice Research Summary Table

Contaminant: **Total N**

Type of Strategy: **Remedial**

Strategy Name: **Wetlands** (restored and created wetlands)

References significant to Iowa identified in bold italics.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Kovacic et al., 2000 **Uncontrolled Flow Constructed Wetlands**	Champaign Co., IL, US; Colo silty loam Watershed to wetland area ratios for the 3 replications were 17:1, 25:1 and 32:1.	3 water years (A water year is from Oct. 1 to Sept. 30 the following year).	Field-plot	Interception of tile drainage from CS[2] rotation with N fertilizer applied to C year at 120 lb N/a for 2 of 3 crop areas, and 180 lb N/a for the remaining area.	Leaching to shallow groundwater and drainage to surface water	Tile drainage w/o[3] wetland treatment Tile drainage w[4] wetland treatment	Sum 3-yr total mass removal by 3 wetlands (lb) of NO3-N[5], NH4-N[6] and TN[7] 2020 lb NO3-N 88 lb NH4-N 2109 lb TN 1250 lb NO3-N 43 lb NH4-N 1337 lb TN	– – – 38% 51% 37%	Wetlands constructed in 1994 with experiment initiated in water year 1995. Flow measured every 15 minutes yr-round. Water samples for chemical analyses taken every 15 minutes during periods of increasing flow yr-round. Water budget for the wetlands was 64% outflow, 28% seepage, 8% evapotranspiration. Winter and spring accounted for 95% of total inflow and TN load.	Denitrification and vegetative assimilation. Although 3-yr flow weighted average concentrations were not stated, reported average reductions annually ranged from 11-37% for NO3-N. Seepage passed through a riparian buffer that removed an additional 9% of NO3-N. Together with wetland removal, NO3-N was reduced 46%

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Miller et al., 2002 **Uncontrolled Flow Constructed Wetlands**	Vermilion Co., IL, US; soil type not stated	4-yr	Small Water-shed (26.9 acre)	Intercep-tion of tile drainage from CS rotation (N fertilizer loading to C year not stated)	Leaching to shallow ground-water and drainage to surface water		Median NO3-N concentration (ppm), Sum 4-yr total NO3-N mass (lb)		Continuous inflow and outflow measures. Automatic flow-proportional and manual samples at precipitation events and regular 2 week intervals. Greatest hydraulic loading during spring.	During periods of high hydrologic loading, dilution primary mechanism for concentration. Denitrification for concentration and mass reduction. Vertical seepage to groundwater for mass reduction during spring. Significant differences between seasons for NO3-N concentration. Greatest reductions during lower hydraulic loading in summer and fall, lower during high hydraulic loading during winter and spring.
						Inflow to wetland: Spring	12.50 ppm NO3-N	_		
						Summer	15.33 ppm NO3-N	_		
						Fall	No Inflow	_		
						Winter	12.05 ppm NO3-N	_		
						4-yr Total	1161.5 lb NO3-N	_		
						Outflow from wetland: Spring	11.12 ppm NO3-N	11.0%		
						Summer	1.54 ppm NO3-N	90.0%		
						Fall	0.24 ppm NO3-N	_		
						Winter	7.69 ppm NO3-N	36.2%		
						4-yr Total	779.0 lb NO3-N	32.9%		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Jordan et al., 2003 Uncontrolled Flow Constructed Wetlands	Kent Island, MD, US; Othello series and Mattapex series silt loam soils Water-shed to wetland area ratio	2-yr	Small Water-shed (34.6 acre)	CS rotation	Surface runoff	Net Flux[8] of wetland: Yr-1 Yr-2 2-yr Ave	Net Flux Yr-1, Yr-2 and Sum 2-yr total mass (lb/a/yr) removal of TN, NO3-N, NH4-N and TON[9] 40.05 lb/a/yr TN 13.35 lb/a/yr NO3-N 2.94 lb/a/yr NH4-N 28.48 lb/a/yr TON -9.79 lb/a/yr TN 8.01 lb/a/yr NO3-N 1.78 lb/a/yr NH4-N -14.24 lb/a/yr TON 15.13 lb/a/yr 10.68 lb/a/yr NO3-N 2.4 lb/a/yr NH4-N 7.03 lb/a/yr TON	Actual influx and outflux not reported, %s directly reported. 38% 48% 34% 39% -8.4% 62% 18% -15% 14% 52% 25% 8.2%	Wetland was restored 9 yrs prior to initiation of the study. Inflow and outflow measures every 15 minutes. Automatic flow-proportional samples taken every 15 minutes during periods of increasing flow and weekly manual samples whenever flow was occurring at inlet and outlet. Half of total 2-yr total inflow occurred during 24 peak inflow day events.	Suggested that NO3-N was removed via denitrification and wetland plant assimilation. Plant assimilation suggested as removal mechanism for NH4-N. Also suggested that yr-2 net export of TN and TON may have been due to greater precipitation and inflow than yr-1, causing less dispersion of inflow throughout the wetland and shorter retention period.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Kadlec and Hey, 1994 **Controlled Flow Constructed Wetlands**	Des Plaines River, Wadsworth, IL, US; soil type not stated Contributing area proportion of water-shed to wetland ratio unknown due to only partial diversion of river flow to wetlands. Wetland 1 (5.2 acre) Wetland 2 (5.6 acre) Wetland 3 (4.0 acre) Wetland 4 (7.2 acre)	2-yr	Large Water-shed (128,000 acre)	80% agricultural, 20% urban; partially tile drained	Diverted surface flow from river to wetlands	Inflow to wetlands: Wetland 1 Yr-1 Yr-2 Wetland 2 Yr-1 Yr-2 Wetland 3 Yr-1 Yr-2 Wetland 4 Yr-1 Yr-2 Outflow from wetlands: Wetland 1 Yr-1 Yr-2 Wetland 2 Yr-1 Yr-2 Wetland 3 Yr-1 Yr-2 Wetland 4 Yr-1 Yr-2	Annual ave. NO3-N concentration (ppm) 1.87 ppm NO3-N 1.22 ppm NO3-N 1.87 ppm NO3-N 1.22 ppm NO3-N 1.87 ppm NO3-N 1.22 ppm NO3-N 1.87 ppm NO3-N 1.22 ppm NO3-N 0.54 ppm NO3-N 0.23 ppm NO3-N 0.24 ppm NO3-N 0.10 ppm NO3-N 0.53 ppm NO3-N 0.18 ppm NO3-N 0.32 ppm NO3-N 0.18 ppm NO3-N	_ _ _ _ _ _ _ _ 61% 81% 87% 92% 72% 85% 83% 85%	Wetlands were constructed 1 yr prior to initiation of the study. Flow to wetlands was controlled via pump stations, removing seasonality aspect of natural flow patterns. However, NO3-N concentrations did vary seasonally, with higher concentrations in spring and fall. Flow rate and volume measured hourly. Weekly water quality samples.	Organic-N and NH4-N concentrations were negligible. Had 0.6 ppm organic-N entering and exiting the wetlands. Low 0.05 ppm NH4-N in river and wetlands. NO3-N reduction attributed to denitrification.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Vellidis, et al., 2003 Uncontrolled Flow Restored Wetlands	Tifton, GA., US; Alapaha loamy sand wetland soil, Tifton loamy sand upland soil Water-shed to wetland area ratio of 8:1	8-yr	Small water-shed (20 acre)	Grass forage-silage corn with 534 lb N/a/yr liquid dairy manure applied, and pasture with 267 lb N/a/yr and 134 lb P/a/yr applied	Surface runoff and shallow ground water		Mean NO3-N, NH4-N, TKN[10] and TN concentration (ppm), and annual mean mass (lb/yr)		Wetland restored 1 yr prior to initiation of study. Shallow ground water sampled biweekly for first 6 yrs, monthly for last 2 yrs from extensive well network. Surface runoff sampled daily per runoff event. Low precipitation Sept.-Nov. and May-June. High precipitation Dec.-May and July-Aug.	Results show the overall riparian vegetation + wetland effects, not wetland alone. NO3-N, NH4-N, TKN concentration reductions were highly significant (P<0.0001). Reductions attributed mainly to denitrification, smaller degrees for vegetative assimilation and soil storage. With the exception of increased NH4-N concentration, the first 8 yrs following wetland restoration with established riparian buffer this system removes and retains large amounts of N nutrients.
						Inflow to wetland	1.09 ppm NO3-N 0.96 ppm NH4-N 8.49 ppm TKN 8.63 ppm TN 67.3 lb/yr NO3-N 35.9 lb/yr NH4-N 238.5 lb/yr TKN 306.0 lb/yr TN	_ _ _ _ _ _ _ _		
						Outflow from wetland	0.50 ppm NO3-N 1.20 ppm NH4-N 3.78 ppm TKN 4.18 ppm TN 11.2 lb/yr NO3-N 13.2 lb/yr NH4-N 85.1 lb/yr TKN 96.4 lb/yr TN	54.1% -25.0% 55.5% 51.6% 83.4% 63.2% 64.3% 68.5%		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Baker and Crumpton, 2002	Ames, IA, US; Clarion-Nicollet-Webster soil assoc.	2-yr	Plot	CS	Shallow subsurface flow		Flow-weighted annual ave. NO3-N concentration and mass		Inflow volume and precipitation were slightly greater in yr-1 vs. yr-2. Inflow NO3-N concentration and mass were 20-25% greater in yr-1 compared to yr-2.	Denitrification listed as primary NO3-N reduction mechanism. Concentration values back calculated from percentage reductions reported from the citation. Mass NO3-N of inflow estimated from graph representation of data. Increased percentage of concentration reduction with decreasing crop to wetland area ratio. Mass and concentration reduction %s greater in yr-1 vs. yr-2 for respective treatments. In absolute terms, amounts of NO3-N mass removed were fairly consistent across the area ratio treatments. Wetland areas of 0.5-2% of drainage area (200:1 to 50:1 ratios) should result in significant NO3-N reductions.
						Inflow				
Constructed Wetlands						Yr-1ppm (all)	17 ppm NO3-N	_		
						Yr-1 mass				
	Treatment Crop to Wetland Area Ratios					1046:1	5900 lb/a NO3-N	_		
						349:1	1750 lb/a NO3-N	_		
						116:1	800 lb/a NO3-N	_		
						Yr-2 ppm (all)	13 ppm NO3-N	_		
						Yr-2 mass				
	1046:1					1046:1	4600 lb/a NO3-N	_		
						349:1	1400 lb/a NO3-N	_		
	349:1					116:1	600 lb/a NO3-N	_		
	116:1					Outflow				
						1046:1				
						Yr-1	15.5 ppm NO3-N	9%		
							885 lb/a NO3-N	15%		
						Yr-2	12.5 ppm NO3-N	4%		
							414 lb/a NO3-N	9%		
						349:1				
						Yr-1	13.3 ppm NO3-N	22%		
							770 lb/a NO3-N	44%		
						Yr-2	11.3 ppm NO3-N	13%		
							476 lb/a NO3-N	34%		
						116:1				
						Yr-1	7.1 ppm NO3-N	58%		
							592 lb/a NO3-N	74%		
						Yr-2	8.3 ppm NO3-N	36%		
							358 lb/a NO3-N	55%		

1 Watershed, field, plot or laboratory.
2 CS represents corn-soybean annual crop rotation.
3 w/o represents without.
4 w represents with
5 NO3-N represents nitrate-N.
6 NH4-N represents ammonium-N.
7 TN represents total N.
8 Net flux calculated by subtracting outflux from influx; +# means net removal (P sink), -# means net export (P source).
9 TON represents total organic nitrogen.
10 TKN represents total Kjeldahl nitrogen, being the sum of organic-N and free ammonia-N.

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Phosphorus Management Practices

Conservation Practice Summary Assessment

Contaminant: **Total P**

Type of Strategy: **Preventive**

Strategy Name: **Conservation Tillage** (chisel plow, ridge tillage, no-till, etc.)

Pollutant reduction mechanisms:
- Reduced erosion and transport of nutrient enriched sediments and particulates
- Improved water infiltration and nutrient adsorption to soil matrix
- Improved stabilization of soil surface to impede wind and water erosion detachment and transport of nutrient enriched sediment and particulates
- Reduced in-field volume of runoff water
- Reduced volume of runoff water reaching surface waters
- Temporary nutrient sequestration in soil organic matter
- Trapping and retention of transported nutrient enriched sediments and particulates

Applicable conditions
- All agricultural crop production fields within Iowa

Limiting conditions
- Slopes that are determined too steep for row crop and forage management operations due to potential for erosion and unsafe equipment operations
- Transition period from conventional and reduced tillage systems to equilibrium of improved soil physical properties with no-till
- Poor field drainage in heavy soils can pose management difficulty for no-till, though can be overcome with proper practices and becomes minimized as field reaches no-till field equilibrium soil conditions

Range of variation in effectiveness at any given point in time.

Moderate Tillage vs. Intensive Tillage: +25% to +80%
No-Till vs. Moderate Tillage: +30% to +60%
No-Till vs. Intensive Tillage: +50% to +90%

Intensive tillage refers to a system of moldboard plowing with associated secondary tillage to provide an adequate seedbed for planting plus in-season cultivation. Moderate *tillage refers to systems such as chisel plow with associated secondary tillage, disk tillage or disk plow, and ridge tillage. No-till refers to a system that only consists of in-row soil disturbance for seed planting.*

Effectiveness depends on:

- Crop rotation and crop present at time of consideration
- Soil type
- Slope and slope length
- Climate
- Antecedent soil moisture content just prior to rainfall events
- Rainfall and snowmelt duration and intensity
- Time between P applications and succeeding rainfall event(s)
- Rate of P applications
- Surface vs. knife vs. tillage incorporation of commercial P or manure fertilizer applications
- Degree of soil disturbance from tillage system
- Large rainfall event soon after commercial P fertilizer or manure application in a soil environment having a continuous network of macropores may lead to elevated soluble P leaching losses via preferential flow
- Greater volume of drainage from increased infiltration rates with conservation tillage systems may lead to increased soluble P leaching losses, but decrease sediment-bound P losses from reduced runoff and erosion
- Reduced fraction of soil water percolating through the soil matrix diminishing contact and transport of soluble P within the soil matrix
- Percentage of surface residue cover
- Amount of attached and detached residues

Estimated potential contaminate reduction for applicable areas within Iowa (annual basis)

Moderate Tillage vs. Intensive Tillage: +40% to +60%
No-Till vs. Moderate Tillage: +40% to +50%
No-Till vs. Intensive Tillage: +60% to +80%

The degree of P loss reduction depends on type of tillage systems being compared; more P loss reduction is possible when changing from a moldboard plow tillage system to no-till than from a chisel plow tillage system to no-till. On fields where there are relatively high erosion rates, reducing tillage can be more beneficial for reducing P losses as long as P fertilizers and manure are knifed or injected into the soil with minimal soil disturbance. Two main effects of tillage on runoff P loss are the degree of soil disturbance caused by the tillage system and the amount of surface residue remaining after tillage is done. The greater the degree of soil disturbance and lesser reside cover remaining, the greater the risk for runoff transport of sediment-bound P. Also, given similar residue cover percentages, surface residues attached to the plants' residue root system will be more effective at reducing runoff transport of sediment-bound P than detached residues. This is because detached residues can be moved with runoff, leaving upper slope areas barren and lower areas – which have a lesser risk for runoff - buried under the transported upslope residues.

Because P is highly reactive and readily adsorbs to cation exchange sites on soil particles, a large percentage of P contamination of surface waters is connected with eroded sediment transported in runoff that enters lakes and streams. Particulate P (P adsorbed to soil and within plant residues and soil organic matter) is commonly the dominant fraction of P in runoff waters. Therefore, any practice that either increases or decreases sediment erosion can greatly impact P losses from a landscape. Crops that are managed with soil disturbing tillage and provide little surface cover for extended periods pose a greater risk for runoff erosion and P loss than crops managed with little to no tillage and provide extensive cover for long durations of time. Soils of coarse texture and little structure are more easily eroded than fine textured and well structured soils. But runoff P load in runoff from each soil type depends upon how much P each contains and the amount of soil transported to a surface water body. A coarse textured soil is more easily eroded but holds less P than the more erosion resistant, fine textured soil. So the overall risk of P loss by soil type depends upon the balance of erodability vs. P content.

Slope, slope length, climate and soil moisture also affect soil erodability and risk for runoff P loss. Gravity, with runoff, exerts greater force on the soil surface as slope angle and length increase. Climatic factors such as precipitation and temperature and their patterns have major effects on soil and the potential for its erosion. Rainfall and snowmelt intensity/duration affects P loss by impacting runoff volume. Runoff volume is also influenced by a soil's drainage capacity and moisture content just prior to a rainfall event. An established no-till system may have a greater percentage of large soil pores (macropores), giving it better drainage that results in lesser or no runoff from a rainfall event that would produce runoff from a conventional system. Also, a soil that is at or near saturation at the beginning of a rainfall event as opposed to a dry soil, say at the wilting point, will generate more runoff P losses because the drier soil would have a greater capacity to absorb and retain water.

Increased P losses could result from surface application of fertilizer or manure followed by a runoff event. Selective erosion of finer particles in a no-till system can cause greater concentration of P in sediment (enrichment) compared to a tilled system. However, the large reduction in the sediment load and a decrease in runoff volumes typically more than compensate for P enrichment of sediment. Also, there is a progressively reduced risk with increasing time between fertilizer or manure application and the succeeding rainfall event. Inorganic fertilizer and manure P has a greater chance of adsorbing to soil particles, being retained and less apt to be directly transported in runoff, by having more time to interact with the soil. If fertilizer/manure incorporation is conducted in a manner that causes little disturbance of the soil surface and leaves a high amount of residue cover, as with knifing or injection methods, runoff transport of surface sediment-bound P is minimized.

As stated in the background as a nutrient nonpoint source pollution principle, "reduced nutrient load equals reduced risk." The converse then being true that with all other factors remaining the same, if the rate of applied P is increased there will be an increased risk for P transport to surface waters, whether it be via runoff or leaching. Although P losses are usually dominated by runoff, there have been several documented cases where leaching losses of soluble-P have been over the critical amount that can cause lake eutrophication (100 ppb P).

Estimated long-term contaminant reduction for applicable areas in Iowa (multi-year basis)

Moderate Tillage vs. Intensive Tillage: +50%
No-Till vs. Moderate Tillage: +45%
No-Till vs. Intensive Tillage: +70%

The long-term amount of P loss reduction greatly depends upon the previous type of tillage system and which conservative system is adopted. Reduction will be less when converting from a less intense tillage system to no-till. A chisel plow plus field cultivating and/or disking system may have P losses similar to moldboard plow, while mulch tillage and ridge tillage may have P losses slightly greater than no-till. The degree of reduction is greater in areas with relatively high soil erosion rates. This reduction may be variable over time with a no-till system as it evolves to new steady state soil physical conditions. For example, greater reduction of P loss may occur over time as no-till increases infiltration rates that improve soil drainage and generate less runoff.

Tillage systems that increase a soil's porosity, macropores and continuous macropores will increase water infiltration rates and decrease runoff. Water storage and moisture content will typically increase as residue cover increases and soil disturbance decreases. The overall impact of a tillage system on P loss depends upon how the tillage system affects partitioning of precipitation between runoff, storage, evapotranspiration and leaching (this being referred to as a water budget).

Extent of research

Moderate

Research has been conducted in various areas in Iowa and surrounding states. Experiments typically fall into one of the following three categories: watershed scale, plot scale with natural rainfall, and plot scale with simulated rain.

Rainfall simulations typically simulate intense single storm events, while the other two types measure losses through the growing season or multiple growing seasons. Rainfall simulation is the most commonly used approach in the lab and field, but it does not simulate the concentrated flow that may occur on a larger scale. Therefore, caution should be used when extrapolating plot results to larger scales. Despite this limitation, plot scale rainfall simulation studies are still useful to determine relative differences between treatments. Watershed scale studies are the most beneficial for assessing overall water quality impacts, but this approach is infrequently used due to difficulties in uniform application of treatments.

Although P does not have as great a risk for leaching losses as does N, in some cases it can still be a significant nonpoint source of surface water P contamination. Soils that have artificial subsurface drainage and have received large loads of P have been shown to be critical source areas for P loss. Therefore, just as mentioned in the associated N summary for tillage practices, there is a need for research information that has quantified P loss from both runoff and leaching pathways for the same experiments. Unfortunately this information is very lacking. Again, future experiments need to address this issue and use a more holistic approach in the research plans.

Secondary benefits:

- Decreased evaporation/increased moisture retention
- Reduced production costs
- Potentially reduced N loss
- Reduced soil loss
- Reduced sediment loads in surface waters
- Reduced loss of sediment-bound chemicals

Conservation Practice Research Summary Table

Contaminant: Total P

Type of Strategy: Preventive

Strategy Name: Conservation Tillage (chisel plow, ridge tillage, no-till, etc.)

References significant to Iowa identified in bold italics.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Nutrient Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction
Angle et al., 1984 CT vs. NT	Howard Co., MD, US; Manor loam soil series	3-yr	Small watershed, treatment areas ranging is size from 0.6-0.9a and 6-7% slopes	CC[2] P fertilizer applied in spring at rate of 96 lb P/a	Surface runoff	CT[3] wo[4] Winter Cover Crop NT[5] w[6] Winter Cover Crop	3-yr total sum PO4-P[7], TSP[8] and TP[9] mass loss in runoff 0.26lb/a PO4-P 0.25 lb/a TSP 2.27 lb/a TP 0.20 lb/a PO4-P 0.22 lb/a TSP 0.22 lb/a TP	– – – 30.0% 12.0% 90.3%	Runoff water samples collected after each rainfall event during baseline calibration and experimental period.	CT watershed had significantly greater mass losses of TP, but not PO4-P and TSP. CT watershed also had much greater runoff volume and transported sediment than the NT watershed. Reductions in these factors theorized as mechanisms for reduced TP losses.
Andraski et al., 1985	Arlington, WI, US; Griswold silt loam soil	Simula-tions in Sept 1980, June and July 1981, October 1982, June and July 1983	Plots, 14.5 ft^2 Rainfall simulations	Corn tillage done at 2% off-contour	Surface runoff	CT spring 1980, fall other years CP[10], spring of 1980, fall of other years NT	Sum mass loss of DRP[11] and TP from all rainfall simulations 0.70 lb/a DRP 42.87 lb/a TP 0.28 lb/a DRP 8.49 lb/a TP 0.43 lb/a DRP 5.93 lb/a TP	– – 60.0% 80.2% 38.6% 86.2%	Rainfall intensity was 3.5 in/hr for Oct 1982, 5.4 in/hr for June 1983, and rest of simulations were @ 2.9 in/hr all for 1 hr. P Fertilizer applications were made each year.	Reduced DRP and TP concentration and mass losses by reducing erosion and transport of sediments with decreasing intensity of tillage.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb P/a) and/or Nutrient Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction
Laflen and Tabatabai, 1984 **MP vs. CP vs. NT**	2 sites, Ames and Castana, IA, US; Clarion sandy loam near Ames, Monona silt loam near Castana	Not reported	Plots (10X35 ft), rain simula-tions	Data averaged across 4 crop rotations (CC, CS[12], SC[13], SS[14]) Soybean fertilized at rates of 23 lb N/a and 33 lb P/a; corn at 124 lb N/a and 33 lb P/a.	Surface runoff		Ave. PO4-P concentration and mass from sediment filtered runoff water		Simulated rainfall rate of 2.5 in/hr for 1 hr (~25 yr. storm) 3 weeks (Monona) or 7 weeks after planting. Surface runoff water and flow rate sampled 1 minute after initiation of runoff, then at 5 minute intervals for next 5 measures, then at 10 minute intervals to end of simulation. Fertilizers surface applied either the day prior to, or day of, planting.	<u>Although there are a few dramatic differences on a relative basis the associated actual differences are mostly minor due to low concentrations and loads.</u> Increased P losses from reduced incorporation of fertilizer. P concen-trations in runoff and runoff sediment by rotation were NT>CP>MP. However, TP mass losses were MP>CP>NT because erosion and runoff volume was much greater with increased tillage. High erosion loads for a 1-hr rainfall event on Monona soil plots. Included both soils separately because of this large difference. Authors state that NT had greater runoff volume, but do not indicate how many years of no-till existed for the plots. Early years for no-till are transitional in physical properties and have less runoff and greater infiltration than tillage with time.
						<u>Clarion Soil</u> MP[15]	0.08 ppm PO4-P 0.008 lb/a PO4-P	– –		
						CP	0.17 ppm PO4-P 0.018 lb/a PO4-P	-112.5% -125.0%		
						NT	0.60 ppm PO4-P 0.079 lb/a PO4-P	-650.0% -887.5%		
						Monona <u>Soil</u> MP	0.16 ppm PO4-P 0.045 lb/a PO4-P	– –		
						CP	0.32 ppm PO4-P 0.090 lb/a PO4-P	-100.0% -100.0%		
						NT	0.84 ppm PO4-P 0.257 lb/a PO4-P	-425.0% -471.1%		
							Ave. TP concentration and mass from runoff sediment			
						<u>Clarion Soil</u> MP	728 ppm TP 1.47 lb/a TP	– –		
						CP	883 ppm TP 0.91 lb/a TP	-21.3% 38.1%		
						NT	952 ppm TP 0.66 lb/a TP	-30.8% 55.1%		
						Monona <u>Soil</u> MP	771 ppm TP 31.92 lb/a TP	– –		
						CP	807 ppm TP 22.68 lb/a TP	-4.7% 28.9%		
						NT	915 ppm TP 9.38 lb/a TP	-18.7% 70.6%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Eghball et al., 2000 **DT vs. NT, also Narrow Grass Hedge Buffer Strips**	Treynor, IA, US; Monona silt loam with 12% slope	2 days during summer	Plot: buffer ~2.5 ft wide; 12 ft X 35 ft rainfall simulation plots (covering source and buffer areas).	Disk tilled (DT) and no-till (NT) CC with either inorganic or manure fertilizer. Manure at rates of 336 lb N/a and 228 lb P/a. Inorganic fertilizer at rates of 134 lb N/a and 23 lb P/a.	Surface runoff	 DT[16] NT	Sum of initial + second rainfall simulation DRP, BAP[17], PO4-P and TP mass loss 0.108 lb/a DRP 0.214 lb/a BAP 0.682 lb/a PO4-P 0.853 lb/a TP 0.108 lb/a DRP 0.166 lb/a BAP 0.280 lb/a PO4-P 0.389 lb/a TP	 _ _ _ _ 0.0% 22.4% 58.9% 54.4%	Applied water of known chemical contents for simulations. Runoff water samples collected at 5, 10, 15, 30, and 45 minutes after initiation of runoff. Initial rainfall simulation of 1 hr at 2.5in/hr. Second rainfall simulation conducted 24 hr later at same time and rate. Switchgrass hedges were established 7 yr prior to initiation of the study.	Additions of inorganic and manure fertilizers increased losses all P forms, except manure PO4-P. Although having appreciable reduction %s, no statistical significant reductions on actual data existed.
Ginting et al. 1998	Morris, MN, US; Forman-Buse loam soils, 12% slope	2-yr	Plots, 72 ft X 10 ft, natural rainfall	CC Manure-P applied at 146 lb P/a rate	Surface runoff	 MP RT[18]	TP mass loss Yr 1: 1.80 lb/a TP Yr 2: 0.60 lb/a TP Yr 1: 0.27 lb/a TP Yr 2: 0.10 lb/a TP	 _ _ Yr 1: 85.0% Yr 2: 83.3%	Runoff collected for two years. Data are annual total loss.	Increased residue cover in RT reducing erosion and transport of sediment-bound TP.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Mostaghimi et al., 1988 CT vs. NT with varied residue levels	Blacksburg, VA, US; Groseclose silt loam soil	2-day rainfall simul-ation	Plot (0.025 a), slopes ranging from 8.3-15.1%	Winter rye	Surface runoff		Average PO4-P and TP concentration and mass runoff loss		Rainfall intensity was ~2.0 in/hr, 1 hr run first day, 2 30 min. runs 2nd day with 0.5 hr between runs.	Averaged across all residue level treatments, NT reduced PO4-P losses by 91% and TP losses by 97% compared to CT. Greater PO4-P and TP concentra-tions and mass losses by increasing residue from 667 to 1335 lb/a attributed to greater P fertilizer interception, leaving it more susceptible to runoff, and greater PO4-P and TP leaching from residue. Greater PO4-P concentra-tions in NT partly attributed to less suspended runoff sediment to sorb P from runoff.
						CT 0 lb/a residue C1[19]	1.18 ppm PO4-P 9.50 ppm TP 0.45 lb/a PO4-P 4.66 lb/a TP	_ _ _ _		
						667 lb/a residue C2[20]	0.90 ppm PO4-P 3.10 ppm TP 0.24 lb/a PO4-P 0.87 lb/a TP	33.0%C1 67.4%C1 46.7%C1 81.3%C1		
						1335 lb/a residue C3[21]	4.51 ppm PO4-P 6.27 ppm TP 0.37 lb/a PO4-P 1.27 lb/a TP	-282.2%C1 34.0%C1 17.8%C1 72.7%C1		
						NT 0 lb/a residue	1.79 ppm PO4-P 11.53 ppm TP 0.06 lb/a PO4-P 0.90 lb/a TP	-51.7%C1 -21.4%C1 86.7%C1 80.7%C1		
						667 lb/a residue	1.32 ppm PO4-P 8.52 ppm TP 0.002 lb/a PO4-P 0.05 lb/a TP	-11.9%C1; -46.7%C2 10.3%C1; -174.8%C2 99.6%C1; 99.2%C2 98.9%C1; 94.2%C2		
						1335 lb/a residue	33.12 ppm PO4-P 77.85 ppm TP 0.02 lb/a PO4-P 0.09 lb/a TP	-2706.8%C1; -3580.0%C3 -719.5%C1; -2411.3%C3 95.6%C1; 91.7%C3 98.1%C1; 89.6%C3		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Seta et al., 1993 CT vs. CP vs. NT	Lexington, KY, US; Maury silt loam	2-day rainfall simulation	Plot	CC P fertilizer applied at rate of 39 lb P/a	Surface runoff	 CT CP NT	Mean concentr-ation and total mass PO4-P loss in runoff 2.3 ppm PO4-P 0.62 lb/a PO4-P 2.2 ppm PO4-P 0.36 lb/a PO4-P 5.1 ppm PO4-P 0.28 lb/a PO4-P	 – – 4.3% 41.9% -121.7% 54.8%	Rainfall intensity was ~2.6 in/hr, 1 hr run first day, 2 30 min. runs 2nd day with 0.5 hr between runs. Runoff water samples collected at 1, 3, 6, 10, 15, 23 and 33 minutes after initiation of runoff.	Although NT had a significantly higher PO4-P concentr-ation, mass losses were much less. Reduction mechanisms attributed to reduced volume of runoff, greater infiltration resulting from less surface soil sealing and more undisturbed macropores, and less transported sediment due to soil sheltering from increased residue cover.
Andraski, et al. 2003 CP vs. NT	Lancaster, WI, US; Rozetta silt loam soil with 6% slope	Rainfall simulations	Plot	CC Dairy manure fall surface applied at rates of 0 and 70 lb/a P.	Surface runoff	 CP w manure C1 CP wo manure C2 NT w manure NT wo manure	Total mass loss and of DRP and TP of spring and fall rainfall simulations combined 0.149 lb/a DRP 2.750 lb/a TP 0.082 lb/a DRP 2.298 lb/a TP 0.039 lb/a DRP 0.173 lb/a TP 0.060 lb/a DRP 0.294 lb/a TP	 – – – – 73.8% C1 93.7% C1 26.8% C2 87.2% C2	Rainfall simulations conducted in May following planting and in September following silage harvest. Rainfall intensity of ~ 3 in/hr, being a recurrence interval of 50 yr. Runoff collected for 1 hr period following onset of runoff. Tillage treatments had been in place for 7 yr prior to initiation of the study.	Lower runoff volumes and higher water infiltration rates reported as the primary P loss reduction mechanisms. DRP and TP loss significantly decreased with increasing residue cover. Authors also reported that there was no relationship between soil test P levels and runoff concentrations and loads in NT, but did in CP.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
McIsaac, et al., 1995	East-central and northwest IL, US; Catlin silt loam soil with 1.5-4% slope and Tama silt loam soil with 6-13% slope.	Two points in time for each year over a 6-yr period	Plot	CS rotation For the Catlin soil, 29 lb/a P was fall applied on soil surface after tillage, except for final yr when P fertilizer was fall applied prior to fall tillage. For the Tama soil, 45 lb/a P was applied in the spring, 3 weeks prior to any tillage and soybean planting.	Surface runoff		Mean flow-weighted TSP concentration		Rainfall simulations were done 0-10 days and 30-40 days after planning of corn and soybean. Rainfall intensity was 2.5 in/hr, a 20-25 yr recurrence. Runoff samples were taken every few minutes for 1 hr following initiation of runoff in the 1st event round. Second event round was conducted 1 hr after event round 1 ended with runoff samples taken over ½ hr time period.	Statistically greater TSP losses with NT than other tillage treatments. Tillage incorporation of surface applied P fertilizer reduced TSP losses. This situation must be considered in a comprehensive perspective since tillage – particularly in the fall – results in greater sediment and sediment-bound P loss.
						<u>Catlin Soil</u> NT	0.33 ppm TSP	–		
						RT	0.18 ppm TSP	45.4%		
						ST[22]	0.11 ppm TSP	66.7%		
						ST w RT	0.10 ppm TSP	69.7%		
						SP[23]	0.18 ppm TSP	45.4%		
						DT	0.19 ppm TSP	42.4%		
						SRT[24]	0.20 ppm TSP	39.4%		
						CP	0.15 ppm TSP	54.5%		
						MP	0.01 ppm TSP	97.0%		
						<u>Tama Soil</u> NT	0.34 ppm TSP	–		
						ST	0.23 ppm TSP	32.4%		
						CP	0.05 ppm TSP	85.3%		
						MP	0.07 ppm TSP	79.4%		

1 Watershed, field, plot or laboratory.
2 CC represents continuous corn.
3 CT represents conventional tillage. Definitions of conventional tillage can vary, but generally referred to moldboard plow with secondary tillage operations.
4 wo represents without.
5 NT represents no-tillage.
6 w represents with.
7 PO4-P represents phosphate-phosphorus (also referred to as dissolved reactive phosphorus).
8 TSP represents total soluble phosphorus (combination of phosphate-phosphorus and dissolved organic phosphorus, also referred to as biologically available phosphorus).
9 TP represents total phosphorus.
10 CP represents chisel plow followed by disking and possibly with summer cultivation.
11 DRP represents dissolved reactive phosphorus (also referred to as phosphate-phosphorus).
12 CS represents corn-soybean rotation in corn year.

13 SC represents corn-soybean rotation in soybean year.
14 SS represents continuous soybean.
15 MP represents moldboard plow tillage followed by disking.
16 DT represents disk tillage.
17 BAP represents biologically available phosphorus (also referred to as total soluble phosphorus).
18 RT represents ridge tillage.
19 C1 represents control 1 and comparison to control 1.
20 C2 represents control 2 and comparison to control 2.
21 C3 represents control 3 and comparison to control 3.
22 ST represents strip-tillage.
23 SP represents sweep plow (V-shaped sweep plow at 10 in depth followed by secondary tillage).
24 SRT represents subsoil-ridge tillage (subsoiling to 12 in depth prior to ridge tillage operations).

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Conservation Practice Summary Assessment

Contaminant: **Total P**

Type of Strategy: **Preventive**

Strategy Name: **Cover Crops**

Pollutant reduction mechanisms

- Improved stabilization of soil surface to impede wind and water erosion detachment and transport of nutrient enriched sediment and particulates
- Increased crop growing season for greater utilization of available nutrients
- Improved water infiltration and nutrient adsorption to soil matrix
- Reduced in-field volume of runoff water
- Reduced erosion and transport of nutrient enriched sediments and particulates
- Temporary nutrient sequestration in soil organic matter
- Trapping and retention of transported nutrient enriched sediments and particulates
- Vegetative assimilation

Applicable conditions

- Any row cropping system that has adequate time following harvest of the primary crop for the planting and establishment of the cover crop plant species prior to on-set of winter conditions.

The time period required for cover crop plant establishment varies depending upon the selected plant species. A few methods exist to plant a cover crop during the primary crop's growing season (i.e., seed spreader mounted on a cultivator, rotary or drop spreader for surface seeding under a full soybean canopy, and aerial seeding) to extend the time period for cover crop establishment and growth. Time is limited following soybean and corn harvest in Iowa for most cover crop species. Currently in Iowa, cover crops are most applicable following seed corn, sweet corn, silage corn and small grain production systems where the primary crops are harvested and removed in mid- to late-summer. Additionally, winter-hardy cover crops such as winter rye or winter wheat can be planted following early maturing soybean or corn cultivars.

Limiting conditions

- Limited time period from planting to on-set of winter
- Non-growing season period (winter) of cover crop plant species
- Limited runoff and shallow groundwater residence time
- Wet soil conditions following harvest of primary crop that would impede planting of the cover crop

- Inadequate precipitation following planting for cover crop plant establishment
- If using winter annual plant species, wet spring soil conditions that would impede chemical or tillage kill operations of the cover crop
- Winter annual small grain cover crops must be killed two to three weeks prior to planting of the primary crop

Range of variation in effectiveness at any given point in time

0% to 95%

Effectiveness depends on:

- Temperature either detrimental or beneficial for cover crop growth
- Inadequate or excessive precipitation that is detrimental to cover crop growth and impedes planting operations
- Type of cover crop plants species used (i.e., summer annual, winter annual, grass, brassica, or legume)
- Percentage of surface residue cover
- Crop rotation and previous primary crop
- Tillage program and associated degree and timing of soil disturbance
- Soil type
- Slope and slope length
- Antecedent soil moisture content just prior to rainfall events
- Rainfall and snowmelt duration and intensity
- Timings and rates of P applications and succeeding rainfall event(s)
- Surface vs. knife vs. tillage incorporation of commercial P or manure fertilizer applications
- Greater volume of drainage from increased infiltration rates with adoption of cover crops may lead to increased soluble P leaching losses, but decreased sediment-bound P losses from reduced runoff and erosion

Estimated potential contaminate reduction for applicable areas within Iowa (annual basis)

+10% to +70%

The time period required for cover crop plant establishment varies depending upon the selected plant species. A few methods exist to plant the cover crop during the primary crop's growing season (i.e., seed spreader mounted on a cultivator and aerial seeding) to extend the time period for cover crop establishment and growth. Typically in Iowa, time is limited following soybean and corn harvest for most cover crop species to establish well, though research is making some progress to solve this problem.

Temperature and precipitation greatly affects cover crop plant emergence and growth rate, and uptake and retention of P. Cover crops can establish dense surface coverage of the soil given warm temperatures, plentiful rainfall, and proper planting. In cold and dry conditions few plant species are able to germinate and establish. Therefore, cover crops planted in late fall usually do not provide much surface cover. Intense rainfall shortly after cover crop planting can wash the seeds to low areas and ponding can reduce cover crop stands.

Reduction of P losses varies greatly by cover crop plant species, especially in the total amount (load) and concentration of dissolved reactive (soluble) P. Any cover crop plant species that is able to establish well and achieve significant biomass growth in the short period of time available from harvest of the primary crop to the onset of winter will perform much better than those that are not adapted to these conditions. Grasses such as rye have shown to be much more effective than legumes because they can establish in cool conditions and have a denser and more fibrous root system than legumes. Brassicas (mustard, rape, turnip, etc.) tend to be intermediate in reducing P loss compared to grasses and legumes.

Crop rotation and the type of crop grown prior to seeding of a cover crop, tillage program, soil type and slope can all significantly influence the water quality benefits of a cover crop. A cover crop has a greater potential to reduce P losses from cropping systems and site conditions that are inherently more prone to erosion than for others that pose a lesser erosion risk. Continuous corn tends to be less erosive than a corn-soybean rotation because corn leaves greater amounts of residue cover than does soybean and corn residue persists longer than soybean because it's higher C:N ratio makes it more resistant to decomposition. Therefore, a cover crop has a greater probability for reducing P losses from soybean than corn fields. Given all other factors being similar, no-till has a far less risk of P loss than other tillage programs that disturb the soil. The more intense the tillage system the greater the risk for erosion and the greater the potential for a cover crop to reduce P loss. The same is true for the physical characteristics of a crop field. A cover crop will reduce P losses to a greater degree on a field that has highly erodable soils, long slope length and steep slope than a field with little to no slope).

A cover crop may provide its greatest amount of P loss reduction during peak events, such as periods of high snowmelt and intense storms, although some runoff may occur. Experiments have frequently documented higher concentrations of varied P forms in any runoff that does originate from a cover crop area compared to areas without cover crops. Any runoff from fields with cover crops preferentially transports the finer, clay-sized particles that hold greater amounts of nutrients than the larger soil particles that are transported along with fine particles from fields lacking cover crops and having greater runoff volumes. But it is important to remember that in the initial stages of runoff from non-cover cropped areas the fine particles and attached P will quickly be eroded and transported to surface waters and the larger sediment and residue particles that hold comparatively less P will be the dominant fraction later in the runoff events. Therefore, although cover crops and other conservation practices that reduce runoff may cause P enrichment of any runoff that does occur, the overall P load transported to surface waters is usually much less because of the reduced volume of runoff. Decreased runoff volume from cover cropped areas is primarily attributed to an increased water infiltration rate. Water infiltration is improved because cover crop residue slows runoff flow that allows more time for infiltration, which decreases runoff volume. Water uptake by a cover crop also improves water infiltration because it creates a drier soil environment, which then increases a soil's water storage capacity for subsequent precipitation events.

The timing and amount of P fertilizer applications also influence cover crop effectiveness in reducing P loss. The longer the time period between P fertilizer application and succeeding rainfall event, the more time P has to react with and be adsorbed to soil particles. Also, as mentioned elsewhere in this document, as P inputs increase so does the risk for P loss. There is simply more P available to be transported from the applied site. If a high rate of P fertilizer (commercial or manure) is surface applied on a previously tilled soil just prior to a runoff event, P loss from a field can be very high. A cover crop established after a tillage incorporated P fertilizer application may dramatically reduce P loss compared to a barren field with similar conditions. The potential for P loss with incorporated (full tillage or knife or slot procedures) depends upon the balance between the degree of soil disturbance and placement of P below the soil surface.

Estimated long-term contaminant reduction for applicable areas in Iowa (multi-year basis)

+50%

The estimate above is specifically for the most applicable previous main crops or rotations for cover crops in Iowa, which are seed corn, sweet corn, silage corn and small grain production systems where the primary crops are harvested and removed in mid- to late-summer. Current cover crop technology and most cover crop plant species available would provide a substantially less opportunity to decrease P losses from corn and soybean row crop fields. The overall performance of cover crops in Iowa will greatly depend upon the plant type and species selected as a cover, timing of planting, and subsequent climatic conditions. However, if appropriate cover crop species or management practices are developed in the future for corn-soybean grain systems, we could expect similar benefits.

Extent of research

Limited

Much of the cover crop research to date in the U.S. has been in the eastern and southeastern states. The climate in those regions is more favorable for incorporation of cover crops into cropping systems due to milder winters. The longer and colder winters in the Upper Midwest limit both the time period in the fall after primary crop harvest for planting and sufficient growth, and the number of plant species adapted to these conditions. Much more research is needed in evaluating plant species and cultivars that currently exist and to further develop suitable cultivars through plant breeding. A large number of cultivars of winter rye, winter wheat, other small grains, flax and brassica have not been evaluated for their use as cover crops in northern latitudes. Searching for and screening plants that grow well in colder climates (i.e., middle to northern Canada) may also generate more good cover crop candidates. Closer to Iowa, Wisconsin studies of kura clover grown as a living mulch in corn production systems provided added surface cover without reducing corn yield. Its effects on water quality are yet unknown.

Nationwide, cover crop research in relation to P has mainly focused on measuring runoff volume and transported sediment load. Nutrient retention and transport in cover crop systems have received much less attention at all spatial and temporal scales, particularly for P. Water quality research funding needs to correct this problem because cover crops are one of the few conservation practices that can be applied across entire field areas, which is essential for other field-edge conservation practices that are applied in limited areas to function optimally. High runoff volumes and concentrated runoff flow are two primary factors that reduce the effectiveness of riparian and other vegetative buffers. Cover crops could reduce the volume of runoff and help to manage runoff as diffuse flow, thereby reducing the load on field-edge conservation practices.

Secondary benefits

Potentially dramatic reductions of:

- Erosion losses of ammonium-N and organic N at or near the soil surface
- Soil loss
- Sediment loads in surface waters
- Sediment-bound chemicals in surface waters

Conservation Practice Research Summary Table

Contaminant: **Total P**

Type of Strategy: **Preventive**

Strategy Name: **Cover Crops**

References significant to Iowa identified in bold italics.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Nutrient Concentration (ppm)	Amount Nutrient Export Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction
Angle et al., 1984[2]	Howard Co., MD, US; Manor loam soil series	3-yr	Small watershed, treatment areas ranging is size from 0.6-0.9a and 6-7% slopes	CT and NT corn with 42 lb P/a applied	Runoff	 CT Corn - None NT Corn - Barley	Total annual mass SP and TP, annual mean concentration SP 0.01 lb/a/yr SP 0.40 ppm SP 0.13 lb/a/yr TP 0.01 lb/a/yr SP 1.65 ppm SP 0.01 lb/a/yr TP	 _ _ _ 0% -312% 92%	SP mass is total annual basis; concentration is mean annual basis; TP mass is total annual basis	Decreased TP losses despite increases in concentration due to reduced runoff volume and particulate P losses.
Klausner et al., 1974[2]	Aurora, NY, US; Lima-Kendalia silt loam soils	1-yr	Field-plot	CT and NT corn with 66 lb P/a applied. CT and NT wheat with 57 lb P/a/yr applied.	Runoff	 CT Corn – None NT Corn – Ryegrass CT Wheat - None NT Wheat – Ryegrass + Alfalfa	Total annual mass and annual mean concentration SP 0.44 lb/a/yr SP 0.28 ppm SP 0.12 lb/a/yr SP 0.33 ppm SP 0.29 lb/a/yr SP 0.18 ppm SP 0.15 lb/a/yr SP 0.23 ppm SP	 _ _ 73% -18% _ _ 48% -28%	SP mass is total annual basis; concentration is mean annual basis	Decreased P load losses despite increases in concentration due to reduced runoff volume.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Nutrient Concentration (ppm)	Amount Nutrient Export Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction
Langdale et al., 1985[2]	Southern Piedmont Region, GA, US; Cecil sandy loam dominant soil type	17 month	Watershed	CT Corn with 18 lb P/a/yr applied; CT Corn – Winter Rye with 45 lb P/a/yr applied	Runoff		Total annual mass SP and TP, annual mean concentration SP		SP mass is total annual basis; concentration is mean annual basis; TP mass is total annual basis	Decreased TP losses despite increases in concentration due to reduced runoff volume and particulate P losses.
						CT Corn – None	0.25 lb/a/yr SP 0.13 ppm SP 3.64 lb/a/yr TP	_ _ _		
						CT Corn – Winter Rye	0.27 lb/a/yr SP 0.20 ppm SP 1.24 lb/a/yr TP	-8% -54% 66%		
Pesant et al., 1987[2]	Quebec, CA	Not reported	Field-plot	CT and NT Corn with 40 lb P/a/yr applied	Runoff		Total annual mass SP and TP, annual mean concentration SP		SP mass is total annual basis; concentration is mean annual basis; TP mass is total annual basis	Decreased SP mass and concentration and TP mass by reduced runoff volume.
						CT Corn – None	0.24 lb/a/yr SP 0.55 ppm SP 2.70 lb/a/yr TP	_ _ _		
						NT Corn – Alfalfa + Timothy	0.21 lb/a/yr SP 0.22 ppm SP 0.17 lb/a/yr TP	12% 60% 94%		
Yoo et al., 1988[2]	Al, US	Not reported	Field-plot	CT and NT Cotton with no P applied	Runoff		Total annual mass SP and TP, annual mean concentration SP		SP mass is total annual basis; concentration is mean annual basis; TP mass is total annual basis	Decreased particulate P losses dominant since runoff volume was slightly higher with NT.
						CT Cotton – None	0.36 lb/a/yr SP 0.43 ppm SP 0.56 lb/a/yr TP	_ _ _		
						NT Cotton – None	0.28 lb/a/yr SP 0.39 ppm SP 0.39 lb/a/yr TP	22% 9% 30%		
						NT Cotton – Winter Wheat	0.14 lb/a/yr SP 0.39 ppm SP 0.18 lb/a/yr TP	61% 9% 68%		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Nutrient Concentration (ppm)	Amount Nutrient Export Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction
Zhu et al., 1989[5]	Kingdom City, MO, US; Mexico silt loam soil	Not reported	Field-plot	NT Soybean with 13 lb N/a/yr applied	Runoff	 None Common Chickweed Canada Bluegrass Downy Brome	Total annual mass and annual mean concentration SP 0.41 lb/a/yr SP 0.28 ppm SP 0.15 lb/a/yr SP 0.45 ppm SP 0.38 lb/a/yr SP 0.80 ppm SP 0.24 lb/a/yr SP 0.52 ppm SP	 _ _ 63% -61% 7% -186% 41% -86%	SP mass is total annual basis; concentration is mean annual basis	Decreased P load losses despite increases in concentration due to reduced runoff volume.
Reddy et al., 1978	Greenhouse study; Toledo silty clay, Rossmoyne silt loam and Wauseon sandy loam soils	Single day	Microplot, rainfall simula-tion	Wheat and Fallow Commercial or manure fertilizer applied at 200 lb P/a	Surface runoff and subsurface leaching flow	Runoff Solution P Fallow Wheat cover Subsurface Leachate P Fallow Wheat cover Runoff Solution P + Subsurface Leachate P + Eroded Sediment P Fallow Wheat cover	Total mass loss (mg) TP per plot for all 3 soil types combined 9.1 mg TP 6.5 mg TP 2.1 mg TP 1.1 mg TP 98.5 mg TP 36.6 mg TP	 _ 28.6% _ 47.6% _ 62.8%	Combination of rainfall durations and intensities of 12 min. and 24 min. at 2.5 in/hr, and 12 min. at 5 in/hr. Also, combinations of 1% and 4% slope. Leachate drainage collected for 23 hr period following termination of rainfall simulation. Wheat cover crop grown for 23 day period.	Wheat cover reduced erosion of sediment led to reduced TP losses.

1 Watershed, field, plot or laboratory.
2 As reported in Sharpley, A.N., and S.J. Smith. 1991. Effects of cover crops on surface water quality. P. 41-49. *In* W.L. Hargrove (ed.) Cover crops for clean water. Proc. of an international conf. 9-11 April 1991. Jackson, TN. Soil Water Conserv. Soc., Ankeny, IA.

3 CT represents conventional tillage.
4 NT represents no-tillage.
5 SP represents soluble phosphorus.
6 TP represents total phosphorus.

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Conservation Practice Summary Assessment

<u>Contaminant:</u> **Total P**

<u>Type of Strategy:</u> **Preventive**

<u>Strategy Name:</u> **Diverse Cropping Systems**

Pollutant reduction mechanisms

- Improved stabilization of soil surface to impede wind and water erosion detachment and transport of nutrient enriched sediment and particulates
- Improved water infiltration and nutrient adsorption to soil matrix
- Increased crop P nutrient use efficiency (crop assimilation)
- Increased crop growing season for greater utilization of available nutrients
- Reduced erosion and transport of nutrient enriched sediments and particulates
- Reduced in-field volume of runoff water
- Temporary nutrient sequestration in soil organic matter
- Trapping and retention of transported nutrient enriched sediments and particulates
- Vegetative assimilation

Applicable conditions

- Any Iowa agricultural crop field that is in either continuous corn or corn-soybean rotations

Limiting conditions

- Markets for additional crops
- Storage of additional crops
- Additional equipment needs that may be not already available

Range of variation in effectiveness at any given point in time

-100% to +97%

Effectiveness depends on:

- Antecedent soil moisture content prior to rainfall events
- Climatic variability in regard to optimum growth conditions for the selected crop species
- Greater volume of drainage from increased infiltration rates and greater plant residue cover may lead to increased soluble P leaching losses, but decrease sediment-bound P losses from reduced runoff and erosion
- Growing season of selected crop species

- Growth attributes of selected crop species (i.e., extent of rooting system, water and nutrient demand, cold season vs. warm season, perennial vs. annual)
- Management and removal timing of a perennial crop in regard to climatic conditions and time span until establishment of a succeeding row crop
- Percentage of surface residue cover
- Rainfall and snowmelt duration and intensity
- Slope and slope length
- Soil type
- Tillage program and associated degree of soil disturbance

Estimated potential contaminate reduction for applicable areas within Iowa (annual basis)

0% to +90%

Cropping systems that are more diverse than continuous corn or corn-soybean rotations can be quite varied. Such cropping systems could include small grains, cover crops, annual and perennial forages and perennial woody crops. Some of these plants may also serve as good candidates for bioenergy as renewable energy technologies develop in the future. All of these crops, depending upon how they are managed, may extend the effective growing season for any field. Whether or not P losses are changed compared to a conventional corn-soybean rotation depends on the types of field operations associated with these additional crops. Plant water use and residue cover would typically be increased with added crops, which would probably decrease erosion and leaching. However, a few exceptions could exist. Adding a small grain without a cover crop, along with removal of residue by bailing and then followed with tillage, could leave a fallow soil surface that would be more susceptible to P losses through increased erosion and leaching. The timing of any additional field operations and alterations in field physical conditions in relation to peak rainfall and snowmelt events may impact overall P losses either positively or negatively. Also, a longer crop rotation has a greater potential to reduce P losses from site conditions that are highly erodable than those that are of a lesser erosion risk.

Diverse cropping systems, with the potential to result in greater plant residue cover and decrease annual soil disturbance, have shown through a variety of research experiments to frequently have higher concentrations of soluble P forms in any runoff may occur compared to conventional cropping systems. This has been attributed to P enrichment of runoff from soluble P leaching from plant residues and selective transport of finer, clay-sized particles that hold greater amounts of nutrients than the larger soil particles. Therefore, although the amount of total P may be significantly reduced, the P that is lost may have a greater proportion of biologically available P. As stated in Sharpely et al. (1992):

> "… BAP is a dynamic function of physical and chemical processes controlling both soluble P and bioavailable particulate P (BPP) transport. Soluble P transport depends on desorption-dissolution reactions controlling P release from soil, fertilizer reaction products, vegetative cover, and decaying plant residues.

> Bioavailable PP is a function of physical processes controlling soil loss and particle-size enrichment and chemical properties of the eroded soil material governing P sorption and availability. Consequently, an increase in the bioavailability of P transported in runoff … may not bring about as great a reduction in the trophic status of a water body as expected from examination of total P loads only. Therefore, it will be necessary to determine the BAP transport in runoff, as both soluble P and BPP, to more reliably evaluate the biological response of a water body to agricultural inputs."

However, as pointed out with cover crops, it is important to remember that in the initial stages of runoff from conventional cropping system areas the fine particles and attached P will quickly be eroded and transported to surface waters and the larger sediment and residue particles that hold comparatively less P will be the dominant fraction later in the runoff events. Therefore, although diverse cropping systems and other conservation practices that reduce runoff may cause P enrichment of any runoff that does occur, the overall P load transported to surface waters is usually much less because of the reduced volume of runoff. Decreased runoff volume is primarily attributed to an increased water infiltration rate. Water infiltration is improved because greater plant residue cover slows runoff flow that allows more time for infiltration and then decreases runoff volume. Water uptake by additional crops also improves water infiltration since it creates a drier soil environment, which then increases a soil's water storage capacity for subsequent precipitation events. Rehm et al. (1998) stated that "… it is obvious that most of the P lost is attached to soil particles. Therefore, any cropping system which reduces soil erosion will reduce the loss of P from the landscape."

Estimated long-term contaminant reduction for applicable areas in Iowa (multi-year basis)

+50%

This judgment is based upon a comparison of a conventional tillage corn-soybean rotation to a diverse cropping system that would require no tillage for three of five years, no surface application of P fertilizer and provide at least 75% residue cover on the soil surface. A three-year perennial forage crop would typically require soil disturbing operations only at the beginning and the end of its tenure in a field, and possibly even less if managed with no-till methods. Inclusion of small grains and cover crops may further reduce P loss.

Extent of research

Limited

Similar to cover crops, diverse cropping systems are one of the few conservation practices that can be applied across entire field areas, which is essential for other field-edge conservation practices that are applied in limited areas to function optimally. Diversified cropping systems could reduce the volume of runoff and help to manage runoff as diffuse flow, then reducing the load on field-edge conservation practices.

Unfortunately, research to address and overcome the listed limiting conditions is very sparse, and as of yet, has not become a major focus of government research funding. Scientists from both private non-profit organizations (i.e., American Society of Agronomy, The Land Institute, Leopold Center for Sustainable Agriculture, Institute for Agriculture and Trade Policy and Michael Fields Institute) and many public research institutions have repeatedly stated this need and the dramatic improvements in water quality that would result. Until federal agricultural research programs make this area a priority for funding and support, the great benefits of diverse cropping systems to farmer profitability, water quality and society will not be realized because farmers should not be required to bear the risk to their financial viability without established infrastructure and markets for these additional products.

Secondary benefits

- Additional wildlife habitat
- Decreased incidence of annual weeds, disease and insect pests in succeeding row crops
- Increased yield of row crops for 1-2 years following perennial crop production
- Provides some degree of flood control
- Reduce financial risk due to diversified income sources
- Reduced loss of sediment-bound chemicals
- Reduced sediment contamination of surface waters from reduced erosion due to greater annual vegetative cover and water uptake
- Reduced soil loss from production fields
- Reduced potential for erosion losses of ammonium-N and organic N at or near the soil surface

Conservation Practice Research Summary Table

Contaminant: **Total P**

Type of Strategy: **Preventive**

Strategy Name: **Diverse Cropping Systems**

References significant to Iowa identified in bold italics.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Laflen and Tabatabai, 1984 **Combina-tions of corn and soybean crop rotations systems**	2 sites, Ames and Castana, IA, US; Clarion sandy loam near Ames, Monona silt loam near Castana	Not reported	Plots (10X35 ft), rain simul-ations	Across 4 crop rotations (CC[2], SC[3], CS[4], SS[5]) and three types of tillage (moldboard plow, chisel plow and no-till) Soybean fertilized at rates of 23 lb N/a and 33 lb P/a; corn at 124 lb N/a and 33 lb P/a.	Surface runoff	Clarion Soil SS CS SC CC Monona Soil SS CS SC CC	Ave TP[6] mass loss from runoff water + transported sediment 1.59 lb/a TP 0.37 lb/a TP 1.76 lb/a TP 0.46 lb/a TP 22.09 lb/a TP 25.56 lb/a TP 19.43 lb/a TP 18.73 lb/a TP	_ 76.7% -10.7% 71.1% _ -15.7% 12.0% 15.2%	Simulated rainfall rate of 2.5 in/hr for 1 hr (~25 yr storm) 3 weeks (Monona) or 7 weeks after planting. Surface runoff water and flow rate sampled 1 minute after initiation of runoff, then at 5 minute intervals for next 5 measures, then at 10 minute intervals to end of simulation. Fertilizers surface applied either the day prior to, or day of, planting.	Rotations in the year of corn production for the Clarion soil had significantly less loss of TP than for soybean production. No significant differences by rotation for the Monona soil where TP losses were high for each crop rotation.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Sharpley et al., 1992	Bushland, TX, El Reno, OK, ft. Cobb, OK, Woodward, OK, US; Pullman clay loam, Kirkland silt loam, Cobb fine sandy loam, Woodward loam, respective-ly	5-yr	Small watershed, 20 differing watersheds ranging in size from roughly 4a to 14 a	Crop rotations varied across the 20 watersheds. Rotations were: CT[7] peanut-sorghum, CT wheat, RdT[8] wheat-sorghum-fallow, NT[9] wheat-sorghum-fallow, NT wheat, and native grass.	Surface runoff	 CT Peanut-Sorghum, C1[11] CT Wheat, C2[12] RdT Wheat-Sorghum-Fallow, C3[13] NT Wheat-Sorghum-Fallow NT Wheat Native Grass	Mean annual mass BAP[10] and TP loss across all watersheds with listed crop rotation 9.77 lb/a BAP 34.23 lb/a TP 5.30 lb/a BAP 37.28 lb/a TP 0.77 lb/a BAP 2.88 lb/a TP 1.10 lb/a BAP 2.16 lb/a TP 7.92 lb/a BAP 12.57 lb/a TP 0.96 lb/a BAP 1.09 lb/a TP	_ _ 45.8% C1 -8.9% C1 92.1% C1 91.6% C1 88.7% C1 93.7% C1 -42.8% C3 25.0% C3 18.9% C1 63.3% C1 -49.4% C2 66.3% C2 90.2% C1 96.8% C1 81.9% C2 97.1% C2 -24.7% C3 62.2% C3	Water runoff measures taken from every runoff event at all locations over 5 yrs. Runoff events varied across the 20 watersheds, ranging for the 5-yr period from 13-60 runoff events.	Not all watersheds had similar crop rotation treatments. Other P forms also reported. SP[14] increased in systems of reduced and no-tillage that had surface application of P fertilizer. Authors stated that this situation emphasizes the need to not over apply P and to do subsurface application (i.e., injection). Although BAP loss decreased with practices that reduce runoff and erosion, the ratio of BAP to TP increased with these systems. So, BAP content is a function of physical and chemical processes that control SP and BPP[15] transport.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Karlen and Sharpley, 1994	Chickasha, OK; soils not reported	2-yr	Watershed	Alfalfa, wheat and cotton production without fertilizer applications	Surface runoff	 Cotton Wheat Alfalfa	Flow-weighted SP and TP concentration 0.36 ppm SP 2.68 ppm TP 0.26 ppm SP 1.59 ppm TP 0.81 ppm SP 1.77 ppm TP	 _ _ 27.8% 40.7% -125.0% 34.0%	None reported	Authors suggested that greater SP loss from alfalfa is due to SP leached from crop residues during months when crop was dormant.
Angle et al., 1984[16]	Howard Co., MD, US; Manor loam soil series	3-yr	Small watershed, treatment areas ranging is size from 0.6-0.9a and 6-7% slopes	CT and NT corn with 42 lb P/a applied	Runoff	 CT Corn – No Cover Crop NT Corn – Barley Cover Crop	Total annual mass SP and TP, annual mean concentration SP 0.01 lb/a/yr SP 0.40 ppm SP 0.13 lb/a/yr TP 0.01 lb/a/yr SP 1.65 ppm SP 0.01 lb/a/yr TP	 _ _ _ 0% -312.5% 92.3%	SP mass is total annual basis; concentration is mean annual basis; TP mass is total annual basis	Decreased TP losses despite increases in concentration due to reduced runoff volume and particulate P losses.
Klausner et al., 1974[16]	Aurora, NY, US; Lima-Kendalia silt loam soils	1-yr	Field-plot	CT and NT corn with 66 lb P/a applied. CT and NT wheat with 57 lb P/a/yr applied.	Runoff	 CT Corn – No Cover Crop, C1 NT Corn – Ryegrass Cover Crop CT Wheat – No Cover Crop, C2 NT Wheat – Ryegrass + Alfalfa Cover Crop	Total annual mass and annual mean concentration SP 0.44 lb/a/yr SP 0.28 ppm SP 0.12 lb/a/yr SP 0.33 ppm SP 0.29 lb/a/yr SP 0.18 ppm SP 0.15 lb/a/yr SP 0.23 ppm SP	 _ _ 72.7% C1 -17.8% C1 34.1% C1 35.7% C1 65.9% C1 17.8% C1 48.3% C2 -27.8% C2	SP mass is total annual basis; concentration is mean annual basis	Decreased P load losses despite increases in concentration due to reduced runoff volume.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Langdale et al., 1985[16]	Southern Piedmont Region, GA, US; Cecil sandy loam dominant soil type	17 month	Watershed	CT Corn with 18 lb P/a/yr applied; CT Corn – Winter Rye with 45 lb P/a/yr applied	Runoff	 CT Corn – No Cover Crop CT Corn – Winter Rye Cover Crop	Total annual mass SP and TP, annual mean concentration SP 0.25 lb/a/yr SP 0.13 ppm SP 3.64 lb/a/yr TP 0.27 lb/a/yr SP 0.20 ppm SP 1.24 lb/a/yr TP	 _ _ _ -8.0% -53.8% 65.9%	SP mass is total annual basis; concentration is mean annual basis; TP mass is total annual basis	Decreased TP losses despite increases in concentration due to reduced runoff volume and particulate P losses. Greater SP loss with added cover crop suggests that increased plant residue contributed leached SP.
Zhu et al., 1989[5]	Kingdom City, MO, US; Mexico silt loam soil	Not reported	Field-plot	NT Soybean with 13 lb N/a/yr applied	Runoff	 No cover crop Common Chickweed Cover Crop Canada Bluegrass Cover Crop Downy Brome Cover Crop	Total annual mass and annual mean concentration SP 0.41 lb/a/yr SP 0.28 ppm SP 0.15 lb/a/yr SP 0.45 ppm SP 0.38 lb/a/yr SP 0.80 ppm SP 0.24 lb/a/yr SP 0.52 ppm SP	 _ _ 63.4% -60.7% 7.3% -185.7% 41.5% -85.7%	SP mass is total annual basis; concentration is mean annual basis	Decreased P load losses despite increases in concentration due to reduced runoff volume.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Rehm et al., 1998	Various locations	Not reported	Not reported	Various cropping systems	Not specified		Mass of SP, Sediment-P and TP		None reported	Report presents data in a generalized from many locations. P losses from various landscapes are dominated by sediment-bound P. So, cropping systems that reduce sediment erosion also reduce P loss.
						CT Corn	0.27 lb/a SP 13.48 lb/a Sediment-P 13.75 lb/a TP	_ _ _		
						NT Corn	0.98 lb/a SP 1.90 lb/a Sediment-P 2.94 lb/a TP	-263.0% 85.9% 78.6%		
						Grass	0.45 lb/a SP 6.60 lb/a Sediment-P 7.05 lb/a TP	-66.7% 51.0% 48.7%		
						Wheat/Sum-mer Fallow	0.18 lb/a SP 1.25 lb/a Sediment-P 1.43 lb/a TP	33.3% 90.7% 89.6%		
Schuman et al., 1973	Deep Loess Research Station at Treynor, IA, US; Monona, Ida and Napier silt loam soils.	3-yr	Watershed W1[17] = 74a W2[18] = 81.5a W3[19] = 106a W4[20] = 148a	CC and Rotational Grazing of Brome-grass Pasture P Rates W1, W4 = 86 lb/a, P incorporated W2, W3 = 35 lb/a P surface broadcast W1, W2 CC w contour planting W3 Bromegrass w Rotational Grazing W4 CC w level terraces	Surface runoff		Annual ave. mass loss and 3-yr ave. concentration of SP and sediment-P		Minimum of 4 water samples per runoff event, being: initiation of runoff, increasing runoff flow rate, at runoff flow rate peak, at decline of runoff flow rate. P concentr-ations in snowmelt runoff were higher than runoff during other seasons.	Runoff volume reduced by 55%and sediment transport reduced 96.4% with Bromegrass pasture compared to contour planted CC. Increased SP loss with Bromegrass pasture attributed to P leaching from the grass, surface broadcast application of P fertilizer and unincorporated animal manure.
						W2 CC	0.10 lb/a SP 0.52 lb/a Sediment-P 0.17 ppm SP 29.04 ppm Sediment-P	_ _ _ _		
						W3 Bromegrass w Rotational Grazing	0.19 lb/a SP 0.06 lb/a Sediment-P 0.72 ppm SP 90.48 ppm Sediment-P	-90.0% 88.5% -323.5% -211.6%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Burwell, et al., 1975	West-central MN, US; Barnes loam soil with 6% slope	10-yr data of water volume and sediment losses and 6-yr of nutrient loss data	Plot	CF[21] with 300 lb/a N applied in initial yr only CC with 100 lb/a N and 26 lb/a P applied annually in spring prior to planting <u>C</u>OA[22] with 50 lb/a N and 26 lb/a P applied in spring prior to planting C<u>O</u>A[23] with 16 lb/a N and 27 lb/a P applied in spring prior to planting CO<u>A</u>[24] without N or P applied, 2 cuttings per year of forage All N and P fertilizer applications were broadcast applied and incorporated with tillage.	Surface runoff	CF (C1) CC (C2) <u>C</u>OA C<u>O</u>A CO<u>A</u> COA Rotation Average	Estimates of sum annual ave. mass loss of TP and IP[25] transported in runoff solution and eroded sediment 0.75 lb/a IP 29.67 lb/a TP 1.06 lb/a IP 16.55 lb/a TP 0.53 lb/a IP 7.71 lb/a TP 0.31 lb/a IP 4.67 lb/a TP 0.35 lb/a IP 0.60 lb/a TP 0.40 lb/a IP 4.33 lb/a TP	_ _ 41.3% C1 44.2% C1 29.3% C1; 50.0% C2 74.0% C1; 53.4% C2 58.7% C1; 70.8% C2 84.3% C1; 71.8% C2 53.3% C1; 67.0% C2 98.0% C1; 96.4% C2 46.7% C1; 62.3% C2 85.4% C1; 73.8% C2	Nutrient losses were analyzed for 3 differing runoff risk periods, two at high risk (snowmelt – period 1; corn planting to 2 months afterwards – period 2) and one at low risk (remainder of year – period 3). One composite sample taken per runoff event. Nearly all runoff in alfalfa and oat was from snowmelt, attributed to the greater residue cover trapping a greater amount of snow.	Majority of sediment P losses occurred during period 2, with trends correlated to amount of residue cover (increasing residue cover decreased sediment P loss, increased soluble P loss – but to much lesser degree than reduction in sediment P losses). Authors emphasized that these results indicate that controlling erosion is critical to reducing P loss from surface runoff since >95% of all P loss was associated with eroded sediment transport.

1 Watershed, field, plot or laboratory.
2 CC represents continuous corn rotation.
3 CS represents corn year in corn-soybean rotation.
4 SC represents soybean year in corn-soybean rotation.
5 SS represents continuous soybean.
6 TP represents total phosphorus.
7 CT represents conventional tillage.
8 RdT represents reduced tillage.
9 NT represents no-tillage.
10 BAP represents biologically available phosphorus.
11 C1 represents control 1 and comparison to control 1 for subsequent treatments.
12 C2 represents control 2 and comparison to control 2 for subsequent treatments.
13 C3 represents control 3 and comparison to control 3 for subsequent treatments.
14 SP represents soluble phosphorus.
15 BPP represents bioavailable particulate phosphorus.
16 As reported in Sharpley, A.N., and S.J. Smith. 1991. Effects of cover crops on surface water quality. P. 41-49. *In* W.L. Hargrove (ed.). Cover crops for clean water. Proc. of an international conf. 9-11 April 1991. Jackson, TN. Soil Water Conserv. Soc., Ankeny, IA.
17 W1 represents watershed 1.
18 W2 represents watershed 2.
19 W3 represents watershed 3.
20 W4 represents watershed 4.
21 CF represents continuous fallow.
22 COA represents corn-oat-alfalfa rotation in the year of corn production.
23 COA represents corn-oat-alfalfa rotation in the year of oat production.
24 COA represents corn-oat-alfalfa rotation in the year of alfalfa production.
25 IP represents phosphate-phosphorus in runoff solution and Bray-P1 soil test phosphorus transported with eroded sediment.

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Conservation Practice Summary Assessment

Contaminant: **Total P**

Type of Strategy: **Remedial**

Strategy Name: **Drainage Management** (controlled drainage, shallow and/or wide tile placement, water table management with sub-irrigation)

Pollutant reduction mechanisms:
- Decreased artificially drained soil volume
- Reduced volume of shallow ground water drainage

Applicable conditions
- For controlled drainage, any Iowa agricultural crop field that is of 1% or less slope and has tile drainage
- For all other drainage management practices, any field where artificial drainage is deemed necessary to improve crop production

Limiting conditions
- Controlled drainage and water table management only function in the time period after plant establishment and prior to harvest when drainage may be managed without interfering with field operations
- Controlled drainage limited to fields with 1% or less slope
- Brief water residence time within soil profile

Range of variation in effectiveness at any given point in time

All listed alternative practices vs. uncontrolled tile drainage: <-100% to +50%

Effectiveness depends on:
- Excess precipitation: may limit the shallow groundwater residence time and result in little opportunity for dissolved reactive P forms to adsorb to soil cation exchange sites or bind with aluminum, iron and calcium oxides
- For controlled drainage, inadequate precipitation: water table levels that fall below the drainage line depth will negate any benefit of controlled drainage
- For shallow tile placement, with a decreased volume of artificially drained soil there is a reduced risk for leaching of soluble P along preferential flow paths
- For controlled drainage, restricting subsurface drainage during the mid-growing season may increase soil water residence time and reduce total annual drainage volume under normal Midwestern climatic patterns, thereby reducing P off-site transport

- For controlled drainage, in the absence of peak rainfall events soon after P fertilizer or manure application, closing tile drainage lines at and after the time of application will increase soil water residence time and likelihood of the added P to adsorb to soil cation exchange sites or bind with aluminum, iron and calcium oxides
- For controlled drainage, with a wetter antecedent soil profile than uncontrolled drainage, a peak rainfall event may result in greater runoff and transport of sediment-bound and particulate P

<u>Estimated potential contaminate reduction for applicable areas within Iowa (annual basis)</u>

All listed alternative practices vs. uncontrolled tile drainage: -30% to +15%

It has been shown in previous research that tile drainage can reduce P loss from a landscape by decreasing runoff through improved subsurface drainage. However, artificial tile drainage itself is not considered a conservation practice. This is partially due to the fact that installation of tile drainage lines has caused a massive conversion of meadow and natural wetlands areas to row crop production. Additionally, tile drainage lines have repeatedly been documented to increase leaching losses of nitrate and other soluble chemicals to surface waters. Because of these mixed environmental impacts, the comparisons here are of alternative tile drainage management practices to uncontrolled tile drainage, not to the conditions of natural drainage.

One potential negative effect of controlled drainage and water table management on P loss is that they may increase the risk of runoff. The water content of the soil profile will most times be greater with controlled drainage, shallow and wide tile placement, and water table management due to the restriction of subsurface drainage, decreased drainage area and artificially perching the water table closer to the surface with these practices, respectfully, than with uncontrolled tile drainage. It is then possible that a peak rainfall event may lead to more P loss with increased runoff in these conditions created by the alternative drainage management practices. This is because the wetter the soil profile is just prior to a rainfall event, the sooner it will be saturated, which then leads to runoff.

Subsurface flow P loss may possibly increased with controlled drainage and water table management due to their effects on the oxidation status of the subsoil. Controlled drainage and water table management attempt to perch a water table shallower to the soil surface than would occur under uncontrolled artificial drainage and possibly even under natural drainage conditions. The saturated zone beneath the water table creates a situation for increased P release from the subsoil. Iron and calcium oxides that bind P are reduced under anaerobic conditions, which then become soluble and release P to the soil solution. The soluble P is then at risk to leaching losses. The same is true for aluminum oxides, but to a lesser extent than iron and calcium oxides since it is more stable under anaerobic conditions. Therefore, since controlled drainage works to retain a shallower water table than uncontrolled drainage, it may result in a greater amount of P being released from the subsoil.

Despite the potential for the above mentioned conditions to occur, controlled drainage and water table management also have the potential to reduce P loss compared to uncontrolled tile drainage under typical Midwestern climatic conditions. During the mid-summer when controlled drainage practices would be in place, evapotranspiration (plant transpiration plus surface evaporation) typically exceeds precipitation. By restricting drainage, controlled drainage partitions more water to evapotranspiration than does uncontrolled drainage, which will continue to drain the soil profile until the water table drops below the depth of the tile lines. Controlled drainage would then result in less subsurface drainage than uncontrolled drainage. The crop grain yield increases commonly documented with controlled drainage are primarily attributed to the increased availability of soil water.

Estimated long-term contaminant reduction for applicable areas in Iowa (multi-year basis)

All listed alternative practices vs. uncontrolled tile drainage: -10%

On an overall balance, these alternative tile drainage management practices increase the risk for P loss compared to free, uncontrolled tile drainage. The designs of these alternative practices are mainly aimed at reducing nonpoint source N contamination of surface waters by creating a subsoil environment more conducive for denitrification of nitrate and/or reducing the volume of drainage water.

Extent of research

Limited

Literature searches produced very little peer reviewed research publications that quantified P loss from controlled drainage or water table management practices within Iowa or its neighboring states. Future research in this area should include year-round measurement of both runoff and shallow ground water P loss pathways for soluble and insoluble P forms. The comparisons of runoff and leaching P loss from natural drainage conditions vs. controlled drainage conditions, along with uncontrolled tile drainage, should be quantified. This approach is needed to provide a comprehensive understanding of the water quality impacts of drainage management practices, particularly for systems lacking buffers surrounding surface tile intakes.

Secondary benefits:

- Proven to increase corn and soybean yields when managed properly
- Increased grain production may off-set portion of costs for implementation
- Improves crop water use efficiency

Conservation Practice Research Summary Table

<u>Contaminant:</u> **Total P**

<u>Type of Strategy:</u> **Remedial**

<u>Strategy Name:</u> **Drainage Management** (controlled drainage, shallow and/or wide tile placement, water table management with sub-irrigation)

References significant to Iowa identified in bold italics.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Pathway	Applied Land-Use	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export Or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Kladivko, et al., 1991 Tile Drain Line Spacing	Butlerville, IN, US; Clermont silt loam soil; all tiles at ave. depth of 2.5 ft	3-yr	Field-plot	Leaching to shallow groundwater, drainage through subsurface tile lines	CT[2] CC[3] with 250 lb N/a applied	 15.4 ft tile spacing 30.8 ft tile spacing 61.7 ft tile spacing	Total combined SP[4] losses over 3-yr study 0.28 lb/a SP 0.21 lb/a SP 0.16 lb/a SP	 – 25.0% 42.8%	Tile drainage water monitored year-round.	Drainage volume reduction with wider tile line spacing. <u>3-yr Drainage Volume Totals</u> 53.8 in. (base) 37.7 in. (30% less) 28.5 in. (47% less)

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Pathway	Applied Land-Use	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export Or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Stampfli and Madra-mootoo, 2004 WTM[5] plus SI[6]	Couteau-du-Lac, Quebec, CA; Soulanges very fine sandy loam, 0.5% slope	18-month	Field-plot	Leaching to shallow ground-water, drainage through subsurface tile lines	CT CC	Uncontrolled Tile Drainage WTM at 2 ft depth through mid-summer, plus SI	Total mass loss of DIP[7] and TDP[8] 0.044 lb/a DIP 0.062 lb/a TDP 0.169 lb/a DIP 0.187 lb/a TDP	_ _ -284.1% -201.6%	Continuous flow monitoring and flow-proportional composite samples. Excessively wet conditions during two non-growing seasons, very dry during mid-summers.	Significantly greater drainage volume with WTM than uncontrolled drainage, counter to many previous studies elsewhere. Authors attributed this to the water table dropping below target depth for very dry conditions and drainage system design, causing uncontrolled drainage to be able to store more soil water during non-growing seasons. Significantly greater P concentrations and load with WTM confounded by high P concentrations from well water used for SI, therefore WTM plots received higher P loads. Increased P solubility may have increased P losses with WTM due to anaerobic conditions in the upper soil profile. Although this study shows a potential for significantly greater P loss with WTM and SI, overall system effects on P loss must also consider the runoff component. Corn grain yields were increased 35% with WTM plus SI.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Pathway	Applied Land-Use	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export Or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Enright and Madra-mootoo, 2004 Surface runoff vs. subsurface tile drainage	Bedford, Quebec, CA; Rubicon sandy loam, Bedford sandy loam and St. Sebastien shaly loam soils.	2 water-yrs	Field	Surface runoff and subsurface leaching to shallow ground-water with drainage through subsurface tile lines	Not reported		Annual ave. flow-weighted TP concentration and annual total TP mass loss		Annual data are reported for water years (Oct. 1-Sept. 30). Runoff discharge volume measured every 5 seconds during runoff events, subsurface tile drainage volume measured continuously. Water chemistry samples taken at the end of each runoff event and periods of sustained subsurface tile flow, in addition to grab samples per each rainfall event.	Subsurface drainage accounted for 29% and 34% of total annual P losses for site 1, 63% and 39% for site 2. Authors stated that subsurface tile drainage can be a significant pathway for P loss from agricultural fields. Authors surmised that macropores and preferential flow contributed to the P loss from tile drainage.
						Site 1, Yr-1 Surface runoff	0.52 lb/a TP 2.15 ppm TP	_ _		
						Subsurface tile drainage	0.20 lb/a TP 0.06 ppm TP	61.5% 97.2%		
						Site 1, Yr-2 Surface runoff	0.44 lb/a TP 0.78 ppm TP	_ _		
						Subsurface tile drainage	0.23 lb/a TP 0.08 ppm TP	47.7% 89.7%		
						Site 2, Yr-1 Surface runoff	0.63 lb/a TP 1.68 ppm TP	_ _		
						Subsurface tile drainage	1.09 lb/a TP 0.37 ppm TP	-73.0% 78.0%		
						Site 2, Yr-2 Surface runoff	0.90 lb/a TP 1.90 ppm TP	_ _		
						Subsurface tile drainage	0.57 lb/a TP 0.22 ppm TP	36.7% 88.4%		

1 Watershed, field, plot or laboratory.
2 CT represents conventional tillage.
3 CC represents continuous corn.
4 SP represents soluble phosphorus.
5 WTM represents water table management.
6 SI represents sub-irrigation through tile drainage lines.
7 DIP represents dissolved inorganic phosphorus.
8 TDP represents total dissolved phosphorus (dissolved inorganic plus organic phosphorus).
9 TP represents total phosphorus.

References

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Conservation Practice Summary Assessment

Contaminant: **Total P**

Type of Strategy: **Remedial**

Strategy Name: **In-Field Vegetative Buffers** (grassed waterways, contour buffer strips, shelterbelts, hedgerow plantings, cross wind trap strips, filter strips)

Pollutant reduction mechanisms

- Dilution
- Improved water infiltration and nutrient adsorption to soil matrix
- Reduced in-field volume of runoff water
- Reduced volume of runoff water reaching surface waters
- Temporary nutrient sequestration in soil organic matter
- Trapping and retention of transported nutrient enriched sediments and particulates
- Vegetative assimilation

Applicable conditions

- Any Iowa agricultural crop field, particularly those in row crop production

Limiting conditions

- Concentrated surface runoff flow (i.e., from natural gullies or narrow depressions and sediment ridges that develop over time)
- Non-growing season period of buffer plant species
- Limited runoff and shallow ground water residence time (i.e., from coarse soil texture and/or steep terrain gradient)
- Cool temperatures
- Attaining upper N nutrient storage limit, may become a nutrient source to surface waters once plants reach maturity if not properly managed
- Unstable soils that are easily disturbed, making buffer plant species difficult to establish

Range of variation in effectiveness at any given point in time

+10% to +95%

Effectiveness depends on:

- Peak snowmelt and precipitation events that lead to high volumes of concentrated surface runoff flow that can overload a buffer
- Types of soil and crop management upslope of the in-field buffer

- Degree of slope and slope length above the in-field buffer
- Erosion risk and structure of soils above and within the in-field buffer
- Time period between any soil disturbing field operation and subsequent precipitation event
- Application timing, rate and method of commercial and/or manure fertilizers
- The degree of P removal by vegetative assimilation is dependent upon the type of plants species used and the stand density (i.e., cool season vs. warm season plants, grasses vs. woody plants vs. mix of grasses and trees)
- Design and structure of the buffer (i.e., single grass strip vs. tree/shrub vs. both, width of buffer and number of buffer strips on a field landscape)
- Degree of maintenance of the buffer, particularly as it matures (i.e., harvest and removal of buffer plant biomass, preventing ridge development along upslope edges)
- With good establishment of buffer plants, warm temperatures, limited concentrated runoff flow P removal can be substantial

Estimated potential contaminate reduction for applicable areas within Iowa (annual basis)

+20 to +70%

Landscapes and soil types within Iowa agroecoregions are amenable to placement and targeted functions of one or more types of in-field buffers. However, there can be great variability both in space and time as to the effectiveness of in-field buffers in reducing sediment-bound and soluble P transport and contamination of surface waters.

One of the primary functions for in-field vegetative buffers is to work in concert with riparian buffers to decrease the occurrence of concentrated flow. This is critical not only for reducing erosion losses of sediment and nutrients, but also for improving the applicability of riparian buffers along the edges of surface waters (see Riparian Buffers Summary). However, in-field vegetative buffers alone have been documented to provide substantial reductions in nutrient and sediment transport, including P.

Dissolved forms of P (i.e., dissolved reactive P, DRP) are often not removed to the degree of sediment and sediment-bound P forms (also true for N). Any dissolved chemical has a lesser chance of being removed with any surface runoff that exits a vegetative buffer than sediment-bound chemicals since a primary function of these buffers is sediment deposition. DRP removal is primarily correlated with increased infiltration rates, but DRP can also be removed via sorption with soil particles and plant residues. Partially dissolved forms of P, such as TP and biological available P (BAP), are removed at an intermediate degree compared to dissolved and sediment-bound forms and both sediment deposition and infiltration are important mechanisms for reducing losses of these nutrient forms.

Relative percentage and actual nutrient load and concentration reductions are also influenced by factors relating to the contributing area. The differing types of crop and soil management methods can have a wide range of potential erosion rates. Practices that frequently and intensely disturb the soil and leave the soil barren of protective residues and plant canopy cover, such as moldboard tillage with annual row crops, leads to high erosion potentials. In contrast, a system of no-tillage with perennial crops infrequently disturbs the soil, and when disturbance does occur it is minor. A buffer strip down-slope of the former scenario would receive much more sediment and sediment-bound nutrients than the latter system. Other factors that strongly impact potential erosion are the degree of slope and slope length. Gravity will have a greater effect on the soil surface as slope percentage and the length of slope increases, both of which will then increase the risk of erosion. Well-structured soils have greater strength, resulting in greater resistance to disturbance and a lower risk of erosion. Soils that lack well-developed structure, possibly due to coarse texture and/or intense tillage, have minimal soil strength and may be more easily eroded. Buffers down-slope of intensively tilled, erosive soils will receive large loads of sediment and sediment-bound chemicals. Because soils can develop structure over time following disturbance, the longer the time period between a tillage operation and the next precipitation event the lesser the erosion risk. Similarly, the timing, rate and method of commercial fertilizer and manure applications also impact in-field buffer effectiveness. High fertilizer rates applied to the surface of a tilled field just prior to a runoff event can transport high loads and concentrations of dissolved and sediment-bound nutrients to an in-field buffer. While the in-field buffer may reduce a large percentage of the inflowing nutrients, a significant amount may still exit this buffer, which points to the importance of designing and placing in-field buffers in coordination with riparian buffers.

Multiple studies conducted by the Agroecology Issue Team of the Leopold Center for Sustainable Agriculture at the Bear Creek National Restoration Demonstration Watershed Project site near Roland have provided much of the most important buffer research for Iowa. Their studies have concentrated on various aspects of riparian and vegetative buffers. From their grass buffers research they determined that reductions of P (and also N) indicate that vegetative buffer strips remove total-P mainly through deposition of sediment on the soil and litter surface within the buffer, and partly through infiltration of receiving cropland runoff waters. Vegetative assimilation of P is not as important removal mechanism as it is for N since non-leguminous plants require less P than N from the soil. The Bear Creek research projects and others have pointed out that the overall effectiveness of in-field vegetative buffers (as well as riparian buffers) is greatly dependent upon the buffer design. Buffer width and buffer plant species have significant impacts on the amount of reduction in nutrient and sediment transport from cropland runoff. Warm season grasses such as switchgrass have shown to be more effective than non-native cool season grasses, and sediment and nutrient retention improves with increasing width of the buffers. However, the effectiveness of the grass buffers tends to diminish with increasing rainfall intensity and repeated occurrences of runoff. This points out that conservation crop management practices such as no-till, cover crops and perennial crops would likely improve the effectiveness of in-field vegetative buffers by reducing the incidence and volume of runoff.

Maintenance is just as important with in-field vegetative buffers as it is for riparian buffers. As with riparian buffers, ridges can form at the upslope field/buffer edge due to sediment accumulation over time and any tillage operations that cut a furrow along the edge. Both the ridge and the furrow will result in excessive water ponding at the front edge and can lead to concentrated runoff flow that could cut through or bypass the buffer. Maintenance will require reforming and replanting the field/buffer edge as these conditions appear.

<u>Estimated long-term contaminant reduction for applicable areas in Iowa (multi-year basis)</u>

+50%

The long-term amount of contaminant reduction will greatly vary depending upon whether or not a buffer was established to NRCS guidelines, the buffer's width and its location on the landscape, buffer plant type and species selected, and whether or not the practice is used in coordination with other conservation practices (i.e., riparian buffers and no-till).

<u>Extent of research</u>

Moderate in Upper Midwest.

While there has been several studies conducted within Iowa and neighboring states of some in-field buffer practices, not all types of these practices have been thoroughly evaluated in each of Iowa's agroecoregions. Most studies have utilized simulated rainfall equipment. While these studies provide good understanding of P losses during controlled rainfall events, they do not give an adequate measure of effectiveness over time. Additional research is needed that quantifies performance variability with time and differing climatic conditions over a several year period, and with both diffuse and concentrated inflow. However, enough research evidence has been compiled to prove that these practices will reduce P losses from crop fields.

<u>Secondary benefits</u>

- Serve as a N sink
- Sediment retention mechanism from cropland runoff
- Partial filtering and decomposition of pesticides
- Additional income source from shelterbelts (i.e., biofuel, hardwood construction, nut production) if designed, implemented and managed properly
- Additional wildlife habitat
- Provides some degree of flood control
- Reduced snow removal costs to local county and state governments

Conservation Practice Research Summary Table

<u>Contaminant:</u> **Total P**

<u>Type of Strategy:</u> **Remedial**

<u>Strategy Name:</u> **In-Field Vegetative Buffers** (filter strips, contour filter strips shelterbelts, grass hedges, etc.)

References significant to Iowa identified in bold italics.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction
Udawatta et al., 2002	Knox Co, Northern Mo.; Putnam silt loam, Kilwinning silt loam, and Armstrong loam soils.	3 yr	Watershed	CS[2] rotation	Surface runoff		Three-yr total flow-weighted TP[3] mass loss		Seven-yr calibration period prior to initiation of study.	Greater reductions in 2^{nd} and 3^{rd} years; poor performance in initial year reported due to not fully established buffer systems.
Grass and Tree + Grass Contour Buffer Strips			Paired Watershed Design: Control 4.1a			Control Watershed	2.77 lb/a TP	_	Runoff collected from March to December for three years. Load #'s are sum of three years.	
			Grass Contour Buffer Strips 7.8a			Grass Contour Buffer Strips <u>Predicted Loss</u> Based on Calibration Period Data	3.14 lb/a TP	_		
			Tree + Grass Contour Buffer Strips 11.0a			Tree + Grass Contour Buffer Strips <u>Predicted Loss</u> Based on Calibration Period Data	2.57 lb/a TP	_	Both types of buffer strip treatments established during initial year of study. Therefore, results are only indicative of early establishment phase of the buffer systems.	Reductions attributed to increased infiltration, less interaction between runoff and surface soil.
						Grass Contour Buffer Strips, 15 ft wide, ~120 ft	2.90lb/a TP	<u>Reductions based on Predicted Values</u> 8% all years; 3.7% in 2^{nd} year 26% in 3^{rd} year		
						Tree + Grass Contour Buffer Strips, 15 ft wide, ~120 ft apart	2.14 lb/a TP	17% all years; 18% in 2^{nd} year 14% in 3^{rd} year	Second-yr had 52% of all runoff events, first-yr had 36%, third-yr had 12%.	

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction
Abu-Zreig et al. 2003 Grass Buffer Strips, Simulated Rainfall	Ontario, Canada; silt loam, 2.3% slope in filter strip	Not reported	Plot	Bare fallow	Surface runoff Artificial runoff was fed into buffer strips	Bare Soil (Control) 16.25 ft RFM[4] 6.5 ft RFM 16.25 ft RFM 32.5 ft RFM 48.75 ft	Due to varied applied inflow loads from varied runoff time periods among plots, loads are not presented directly. Authors standardized to P mass retention % of each individual plot's applied artificial rainfall inflow load (next column).	35% 32% 54% 67% 79%	Plots received clear water for wetting period, then applied simulated rainfall of known chemical composition upon initiation of runoff. Each strip received runoff for 54-101 minutes.	Buffer strips removed a greater % of sediment than P. Rate of sediment retention decreased with increasing buffer strip length, but P retention increased at a steadier rate. Main P removal mechanisms for 6.5-32.5 ft buffer strip lengths theorized to be sediment deposition and infiltration, beyond 32.5 ft mainly due to dilution. Longer filter strips "retain smaller particles better than short filters … provide more infiltration opportunity"

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Schmitt et al., 1999 **Grass and Grass + Woody Plants Buffer Strips**	Mead, NE, US; Sharpsburg silty clay loam to sandy loam	Simulated 1-yr return frequency rainfall event in July	Field-plot	Contour CT sorghum with filter strips	Surface runoff		TP, BAP[9], DRP[10] concentration		Simulated 1-yr return frequency rainfall event in July with prior simulated rainfall to mimic typical field conditions	Particulate settling, infiltration of rainfall and runoff flow (reduction of runoff flow), and dilution. Concentrations of all P forms were significantly reduced. Masses of P forms were significantly reduced, but raw data was not shown. Negative reduction %s represent increases compared to respective control. Theorized that treatment released nutrient form to runoff due to higher concentration within treatment.
						Simulated Rainfall, C1[5]	4.43 ppm TP 1.76 ppm BAP 0.59 ppm DRP	_ _ _		
						Contour CT[6] Sorghum, 24.38 ft width, C2[7]	2.32 ppm TP 1.08 ppm BAP 0.41 ppm DRP	47.6%C1 38.6%C1 30.5%C1		
						Contour CT Sorghum, 48.75 ft width, C3[8]	2.17 ppm TP 0.95 ppm BAP 0.30 ppm DRP	51.0%C1; 6.5%C2 46.0%C1; 12.0%C2 49.2%C1; 26.8%C2		
						25-yr-old grass, 24.38 ft width	1.30 ppm TP 0.82 ppm BAP 0.42 ppm DRP	70.6%C1; 44.0%C2; 40.1%C3 53.4%C1; 24.1%C2; 13.7%C3 28.8%C1; -2.4%C2; -40.0%C3		
						25-yr-old grass, 48.75 ft width	0.92 ppm TP 0.61 ppm BAP 0.34 ppm DRP	79.2%C1; 60.3%C2; 57.6%C3 65.3%C1; 43.5%C2; 35.8%C3 42.4%C1; 17.1%C2; -13.3%C3		
						2-yr-old grass, 24.38 ft width	1.98 ppm TP 1.07 ppm BAP 0.48 ppm DRP	55.3%C1; 14.6%C2; 8.8%C3 39.2%C1; 0.9%C2; -12.6%C3 18.6%C1; -17.1%C2; -60.0%C3		
						2-yr-old grass, 48.75 ft width	1.32 ppm TP 0.81 ppm BAP 0.41 ppm DRP	70.2%C1; 43.1%C2; 39.2%C3 54.0%C1; 25.0%C2; 14.7%C3 30.5%C1; 0.0%C2; -36.7%C3		
						2-yr-old grass/tree/shrub, 24.38 ft width	1.91 ppm TP 1.03 ppm BAP 0.48 ppm DRP	56.9%C1; 17.7%C2; 12.0%C3 41.5%C1; 4.6%C2; -8.4%C3 18.6%C1; -17.1%C2; -60.0%C3		
						2-yr-old grass/tree/shrub, 48.75 ft width	1.26 ppm TP 0.78 ppm BAP 0.38 ppm DRP	71.6%C1; 45.7%C2; 41.9%C3 55.7%C1; 27.8%C2; 17.9%C3 35.6%C1; 7.3%C2; -26.7%C3		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Lee et al., 1999 **Grass Riparian Buffer Strips**	Roland, IA, US; Coland silty clay loam buffers' soil, Clarion loam cropland soil	3 days (rainfall simulations)	Plot Simulated drainage to filter strip area ratio of 40:1for 9.75 ft wide strips, 20:1 ratio for 19.5 ft wide strips	Fallow period	Surface runoff		Mass (lb/a) transport of PO4-P[11] and TP. Only % Reductions from Runon P Content Reported		Rainfall simulations done in August with no natural rainfall events occurring. Rainfall simulation rate was 2 in/hr intensity preceded by a 15 minute wetting period. Runon to filter strips at a rate of 10.6 gal/min. Cool season mix consisted of bromegrass, timothy and fescue. Cool season treatment derived from 7 yr ungrazed pasture prior to study, switchgrass (warm season grass) established 6 yr prior to study.	Switchgrass and the 19.5 ft strip distance were better than cool season plant mix and 9.75 ft strip width in removing P from runoff. Switchgrass produces more litter, stiffer stems, stronger root systems and spatially uniform growth than the cool season mix, which may make it more efficient at sediment and nutrient removal. TP reduction was highly correlated with sediment removal, PO4-P removal with infiltration and sorption to soil particles. Although, infiltration and sediment deposition had roles in reducing both P forms. Reduced filter strip width also had lesser reductions in sediment load from runoff.
						<u>9.75 ft wide</u> Switchgrass	PO4-P TP	38.1% 39.5%		
						Cool Season	PO4-P TP	29.8% 35.2%		
						<u>19.5 ft wide</u> Switchgrass	PO4-P TP	46.0% 55.2%		
						Cool Season	PO4-P TP	39.4% 49.4%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Magette et al. 1989 Grass Buffer Strips	Queens-town, MD, US; Woods-town sandy loam	Not reported.	Plot, 15 ft X 30 ft. Rainfall simul-ations	Fallow soil. Fertilizer N applied at 100 lb/a for simulations 1-6; Broiler litter applied at 224 lb N/a and 102 lb P/a for simulations 7-12.	Surface runoff	 Control 15 ft Fescue 30 ft Fescue	Sum TP mass loss from all rainfall simulations 73.1 lb/a TP 49.3 lb/a TP 39.0 lb/a TP	 – 32.6% 46.6%	Each plot received 12 simulations @1.9 in/hr over a 2-3 month period. Numbers are sums of the 12 tests. Runoff samples taken at 1, 2 and 3 minutes after runoff initiated and every 3 minutes thereafter.	TP was mainly associated with sediment, so reductions attributed to sediment deposition within the buffer strips.
Dillaha et al. 1989 Grass Buffer Strips	Blacks-burg, VA, US; eroded Grose-close Silt loam	1-week in spring (April)	Plot, 18 ft X 60 ft, Rainfall simul-ations.	Barren, tilled corn fallow field. Applied 198 lb N/a and 100 lb P/a fertilizer several days prior to initiation of study.	Surface runoff	 Diffuse Flow, 11% Slope: No Buffer (Control) Orchard grass 15 ft buffer Orchard grass 30 ft buffer Concen-trated Flow, 5% Slope: No Buffer (Control) Orchard grass 15 ft buffer Orchard grass 30 ft buffer	Ave. sum TP, DRP[5] mass loss from all simulated rainfall events 5.68 lb/a TP 0.16 lb/a DRP 2.44 lb/a TP 0.20 lb/a DRP 1.46 lb/a TP 0.15 lb/a DRP 2.02 lb/a TP 0.09 lb/a DRP 0.31 lb/a TP 0.04 lb/a DRP 0.27 lb/a TP 0.04 lb/a DRP	 – – 57.0% -25.0% 74.3% 6.2% – – 84.6% 55.6% 86.6% 55.6%	Each plot received 6 simulations @ 2 in/hr over a ~1 week period. Water samples collected every 3 min. during runoff.	Concentrated flow plots had a 5% slope, with a 4% cross slope. Diffuse flow plots had 11% slopes with <1% cross slope. Despite having diffuse flow, the 11% slope plots had a lesser effect on P reduction than the concentrated flow plots with a 5% slope. TP was mainly associated with sediment, so reductions attributed to sediment deposition within the buffer strips. TP retained from early rainfall events theorized to be assimilated into organic forms (DRP). DRP losses increased at times as runoff exited the buffers.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Eghball et al., 2000 Narrow Grass Hedge Buffer Strips	Treynor, IA, US; Monona silt loam with 12% slope	2 days during summer	Plot, buffer ~2.5 ft wide, 12 ft X 35 ft rainfall simul-ation plots.	Disk tilled and no-till continuous corn with either inorganic or manure fertilizer. Manure at rates of 336 lb N/a and 228 lb P/a. Inorganic fertilizer at rates of 134 lb N/a and 23 lb P/a.	Surface runoff		Sum of initial + second rainfall simulation DRP, BAP, PP[12] and TP mass loss		Applied water of known chemical contents for simulations. Runoff water samples collected at 5, 10, 15, 30, and 45 minutes after initiation of runoff. Initial rainfall simulation of 1 hr at 2.5in/hr. Second rainfall simulation conducted 24 hr later at same time and rate. Switchgrass hedges were established 7 yr prior to initiation of the study.	Additions of inorganic and manure fertilizers increased losses all P forms, except manure PP. Grass hedge buffer strips consistently had statistically significant reduced losses of all P forms in main treatment comparisons. Removal mechanisms not reported.
						No Grass Hedge (C1)	0.04 lb/a DRP 0.12 lb/a BAP 0.71 lb/a PP 0.75 lb/a TP	– – – –		
						Grass Hedge (C2)	0.04 lb/a DRP 0.07 lb/a BAP 0.21 lb/a PP 0.25 lb/a TP	0.0%C1 41.7%C1 70.4%C1 66.7%C1		
						Inorganic Fertilizer, No Grass Hedge (C3)	0.11 lb/a DRP 0.21 lb/a BAP 0.76 lb/a PP 0.97 lb/a TP	-175.0%C1 -75.0%C1 -7.0%C1 -29.3%C1		
						Inorganic Fertilizer + Grass Hedge (C4[13])	0.06 lb/a DRP 0.14 lb/a BAP 0.40 lb/a PP 0.56 lb/a TP	-50.0%C2; 45.4%C3 -100.0%C2; 33.3%C3 -90.5%C2; 47.4%C3 -124.0%C2; 42.3%C3		
						Manure Fertilizer, No Grass Hedge (C5[14])	0.28 lb/a DRP 0.42 lb/a BAP 0.56 lb/a PP 0.84 lb/a TP	-600.0%C1; -154.5%C3 -250.0%C1; -100.0%C3 21.1%C1; 26.3%C3 -12.0%C1; 13.4%C3		
						Manure Fertilizer + Grass Hedge	0.12 lb/a DRP 0.17 lb/a BAP 0.23 lb/a PP 0.35 lb/a TP	-200.0%C2; -100.0%C4; 57.1%C5 -142.8%C2; -21.4%C4; 59.5%C5 -9.5%C2; 42.5%C4; 58.9%C5 -40.0%C2; 37.5%C4; 58.3%C5		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Barfield et al., 1998 Grass Buffer Strips	KY, US; Maury silt loam soil, 9% slope	2 rainfall simulation events during summer	Plot 15 ft X 72 ft erosion plots, bluegrass + fescue grass buffers of varied length	Corn – Fallow Fertilizer applied at 151 lb N/a and 39 lb P/a.	Surface runoff		Sum PO4-P mass losses of 2 rainfall simulations runs and both CT and NT[15] treatments		Two rainfall simulations conducted approximately 3 weeks apart during summer at 2.5in/hr intensity for 2 hr. Runoff water sampled for 10 seconds at 5-minute intervals.	Trapping efficiency increased with increasing length of grass buffers, though each length treatment trapped >90% of inflow N. Primary removal mechanism reported was infiltration, next most important mechanism was adsorption in the soil surface layer.
						<u>Inflow</u> ~15 ft Grass Buffer (C1)	117.4 lb PO4	–		
						~30 ft Grass Buffer (C2)	690.0 lb PO4	–		
						~45 ft Grass Buffer (C3)	99.8 lb PO4	–		
						<u>Outflow</u> ~15 ft Grass Buffer	9.6 lb PO4	91.8%C1		
						~30 ft Grass Buffer	46.5 lb PO4	93.3%C2		
						~45 ft Grass Buffer	4.3 lb PO4	95.7%C3		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Srivastava et al., 1996 Grass Buffer Strips	Fayette-ville, AR, US; Captina silt loam soil with 3% slope	Not reported	Plot Varied source and buffer lengths (all of 5 ft width). Source lengths of ~20, 40 and 60 ft. Buffer lengths of ~0, 10, 20, 30, 40, 50 and 60 ft.	Fescue grass pasture with applied poultry litter at nutrient rates of 130 lb N/a and 54 lb P/a.	Surface runoff	Concentration by Buffer Length from Source	Runoff TP and PO4-P concentration[16] and mass		Rainfall simulation rate of 2 in/hr. Water sampled at 2.5 minutes, then every 10 minutes thereafter for 1 hr after initiation of runoff from plot ends.	Both P form concentrations were not significantly affected by source area length, but were by buffer strip length. No significant difference in TP and PO4-P concentration reductions beyond 20 ft of buffer strip length. Mass transport of TP and PO4-P and runoff volume significantly affected by source area length, with greater losses with increasing length. Mass reductions not significantly affected by buffer strip length, but trend did exist for greater reductions with increasing length. Lack of significance believed to be due to high degree of variation among replications.
						0 ft	14.0 ppm TP 12 ppm PO4-P	– –		
						10 ft	8.0 ppm TP 7.5 ppm PO4-P	42.8% 37.5%		
						20 ft	5.5 ppm TP 4.5 ppm PO4-P	60.7% 62.5%		
						30 ft	3.5 ppm TP 2.5 ppm PO4-P	75.0% 79.2%		
						40 ft	2.5 ppm TP 2.0 ppm PO4-P	82.1% 83.3%		
						50 ft	1.0 ppm TP 1.0 ppm PO4-P	92.8% 91.7%		
						60 ft	1.0 ppm TP 0.5 ppm PO4-P	92.8% 95.8%		
						Mass by Source/Buffer Length Inflow				
						20 ft/60 ft	0.0051 lb TP 0.0046 lb PO4-P	– –		
						40 ft/40 ft	0.0123 lb TP 0.0108 lb PO4-P	– –		
						60 ft/20 ft	0.0165 lb TP 0.0148 lb PO4-P	– –		
						Outflow 20 ft/60 ft	0.0015 lb TP 0.0009 lb PO4-P	70.6% 80.4%		
						40 ft/40 ft	0.0064 lb TP 0.0062 lb PO4-P	48.0% 42.6%		
						60 ft/20 ft	0.0123 lb TP 0.0106 lb PO4-P	25.4% 28.4%		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Daniels and Gilliam, 1996 Grass Buffer Strips	2 locations in NC Piedmont region, US; predominately Cecil soils (sandy loam to clay loam surface horizons) and Georgeville soils (silt loam to silty clay surface horizons)	2-yr	Field	Crops not reported, grass buffer consisted of fescue	Surface runoff	TP PO4-P	Mass transport of PO4-P and TP. Only % Reductions from Runon P Content Reported	60% 50%	Water samples taken at runoff events. Runoff events among plots at the Cecil soils area ranged from 26-50 events. Georgeville soils are plots had 6-18 runoff events.	Buffer P removal not as effective as for sediment. P removal varied by erosiveness of the soils and storm intensities. Sediment deposition, increased infiltration and sorption to soil and plant residues were primary removal mechanisms.

1 Watershed, field, plot or laboratory
2 CS represents corn-soybean
3 TP represents total P
4 RFM represents red fescue mix buffer strip
5 C1 represents control 1, in reductions column the #% means compared to C1
6 CT represents conventional tillage
7 C2 represents control 2, in reductions column the #% means compared to C2
8 C3 represents control 3, in reductions column the #% means compared to C3
9 BAP represents biologically active phosphorus
10 DRP represents dissolved reactive P
11 PO4-P represents phosphate-phosphorus
12 PP represents particulate phosphorus
13 C4 represents control 4, in reductions column the #% means compared to C4
14 C5 represents control 5, in reductions column the #% means compared to C5
15 NT represents no-tillage
16 Estimates of concentration values from graph figure representations of data

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Conservation Practice Summary Assessment

Contaminant: **Total P**

Type of Strategy: **Preventive**

Strategy Name: **Landscape Management Practices** (terraces)

Pollutant reduction mechanisms

- Improved water infiltration and nutrient adsorption to soil matrix
- Reduced erosion and transport of nutrient enriched sediments and particulates
- Reduced in-field volume of runoff water
- Reduced volume of runoff water reaching surface waters
- Trapping and retention of transported nutrient enriched sediments and particulates

Applicable conditions

- All agricultural production fields of appropriate slope ($\leq$ 18%), slope length and erosion risk to necessitate terracing or other landscape altering operations as per USDA-NRCS guidelines

Limiting conditions

- Unstable soils (i.e., low plasticity limits or coarse texture)

Range of variation in effectiveness at any given point in time

-100% to +100%

Effectiveness depends on:

- Slope and slope length
- Soil type, texture, structure, and water infiltration rate
- Soil's P adsorption capacity and/or amount of extractable P
- Intensity, quantity, duration and timing of rainfall and snowmelt events
- Crop rotation
- Tillage program and resulting degree of residue cover and soil disturbance
- Time, rate and method of P nutrient applications
- Prior land management program and associated P loss
- Existence or absence of other conservation practices
- Risk of runoff reaching surface waters either by close proximity to surface water body or presence of tile drainage and surface intakes

<u>Estimated potential contaminate reduction for applicable areas within Iowa (annual basis)</u>

-20% to +90%

All comparisons shown here are based upon total P data from research conducted within Iowa. Results differ widely by form of P, particularly for soluble forms. Total P was chosen since it is currently the P form that total maximum daily loads are to be developed for the state's surface water bodies.

Slope, slope length, and soil texture are main factors that determine soil erodability, and with P content, affect the water quality impacts of landscape altering practices. Areas that have coarse soil texture, and steep and/or long slope are frequently classified as being highly erodable. If the soils are suitable for embankment construction, then terraces will likely reduce P losses to a greater degree than for lands of low slope and erosion risk. Also, soils with high clay content, cation exchange capacity (CEC) and moderate to low soil test P content (or extractable P) have a high potential to adsorb added P. But as the extractable P level increases for any soil, even with a high clay content and CEC, there is a greater risk for P loss to water resources with erosion of sediments. Terracing will likely reduce P loss to a greater degree from a high soil-test P field than one testing low for soil-P content.

In Iowa, peak rainfall and snowmelt events occur frequently enough in most years to be the dominant source of P transport to surface waters. This is particularly true if a peak rainfall or snowmelt event occurs shortly after a surface application of P fertilizer. However, greater P loss can occur if terraces are combined with tile drainage systems. A primary function of both terraces and tile drainage is to reduce runoff by portioning a greater fraction of water to infiltration and subsurface leaching. This usually reduces total P losses because most P loss is from P bound to sediments and particulates that are transported by erosion. Tile drainage lines in combination with terraces have frequently shown to increase soluble P losses (as similar to nitrate-N). When soluble P bypasses the bulk of the subsoil and enters tile lines it has no chance to react with and be adsorbed to the soil matrix. Precipitation events that increase subsurface leaching without inducing runoff can then lead to greater P losses from a terraced and tile drained field than a field lacking these practices. Tile drained terraces may still contribute significant amounts of sediment and particulate P to surface waters if the tile system includes surface intakes that allow runoff to directly enter the tile lines.

The type of crop rotation, tillage and P nutrient management programs, and of course the former conditions being compared to, all have a major impact on the degree of P loss reduction realized from adding landscape management practices (i.e., terraces). Terraces will provide a greater benefit in reducing P loss from cropping systems that typically generate significant runoff and erosion, such as annual row cropping, than from crop rotations providing permanent cover (e.g., a grass/legume hay crop). Terraces with a moldboard plow tillage program will likely reduce P losses more than terraces with a field managed with a no-tillage program. A properly managed no-till field will have much less runoff and sediment erosion than a tilled field due to tillage causing soil disturbance and burial of surface cover residues. Nutrient management is also important. The potential for P loss is influenced by method, amount and frequency of P application (see the P nutrient application techniques and timing and rate management summaries). A management program using a high P rate, applications on a tilled surface and no incorporation will cause greater P losses than a program with crop-P based rate that is injected in a narrow band. A combination of terraces with minimal or no tillage and appropriate nutrient management are needed to minimize P losses to surface waters.

It is critical to properly maintain terraces due to the amount of energy and sediments that the terraces are to capture. Terraces are meant to manage both diffuse and concentrated runoff flow. The most potentially damaging of the two types is concentrated flow because as runoff water flow concentrates into smaller areas, so does the erosive force of the water. Terrace areas that are structurally weakened by factors such as inadequate grass cover, animal burrows or gullies can collapse during a peak runoff event. Once a breach has occurred, runoff flow energy can intensify, resulting in gully erosion and failure of the terrace that may put other downslope conservation practice structures at risk. In addition to proper and regular maintenance, the presence of other conservation practices upslope and between terraces will reduce the risk of terrace failures.

The existence or absence of other conservation practices, such as vegetative buffers (in-field or riparian) and grassed waterways, can dramatically influence annual P losses from terraced fields. If other conservation practice buffers are appropriately placed in coordination with terraces to reduce runoff volume, limit concentrated flow and cause deposition of transported sediments on the landscape, then the risk of P transport from the field to surface waters may be greatly reduced. Some research has identified that surface tile intakes pose a significant threat for P loss by directly routing field runoff to surface waters. This threat can be minimized if vegetative buffers surround the surface intakes and the inlet ports are far enough above the soil surface to result in minor ponding that will allow sediment to settle back onto the field and not enter tile lines that drain to surface waters.

Estimated long-term contaminant reduction for applicable areas in Iowa (multi-year basis)

+50%

This estimate of total P loss reduction applies only to row crop areas suitable for terrace construction, that have properly built and maintained terraces, and have other needed conservation practices in place to limit the probability of a terrace system being overwhelmed from peak rainfall and snowmelt events. Results may vary from this estimate depending upon the conditions described in the above section.

Extent of research

Limited

As frequently as terraces occur in the areas of considerable topographic relief in Iowa, it is surprising that more research has not been done to quantify this practice's effects on P contamination of surface waters. The literature review only found a few research articles from the Deep Loess Hills section of Iowa. Similar research should be conducted within other agroecoregions of Iowa.

Secondary benefits

- Improved long-term farm profitability
- Reduced N nutrient contamination of surface waters
- Reduced sediment contamination of surface waters

Conservation Practice Research Summary Table

Contaminant: **Total P**

Type of Strategy: **Preventive**

Strategy Name: **Landscape Management Practices** (terraces)

References significant to Iowa identified in bold italics.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Schuman et al., 1973 **Level terraced vs. non-terraced, contour plant**	Deep Loess Research Station at Treynor, IA, US; Monona, Ida and Napier silt loam soils.	3-yr	Watershed W1[2] = 74a W2[3] = 81.5a W3[4] = 106a W4[5] = 148a	CC[6] and Rotational Grazing of Bromegrass Pasture <u>Ave. Annual P Rates</u> W1, W4 = 86 lb/a, P incorporated W2, W3 = 35 lb/a P surface broadcast W1, W2 CC with contour planting W3 Bromegrass with Rotational Grazing W4 CC with level terraces	Surface runoff	W1 CC, contour plant W4 CC, level terraces	Annual ave. mass loss and 3-yr ave. concentration of SP[7] and sediment-P 0.15 lb/a SP 0.93 lb/a Sediment-P 0.22 ppm SP 31.14 ppm Sediment-P 0.04 lb/a SP 0.08 lb/a Sediment-P 0.51 ppm SP 61.79 ppm Sediment-P	_ _ _ _ 73.3% 91.4% -131.8% -98.4%	Minimum of 4 water samples per runoff event, being: initiation of runoff, increasing runoff flow rate, at runoff flow rate peak, at decline of runoff flow rate. P concentra-tions in snowmelt runoff were higher than runoff during other seasons.	Level terraces, thus lowering slope, reduced 3-yr ave. P loss by reducing runoff volume and erosion of sediment. Authors concluded that concentrations of SP and sediment-P were variable and high due to small runoff volume and sediment losses. This situation suggests that selective erosion of fine sediments and P enrichment of sediment in W4 may have occurred, indicated by reduced mass losses, but higher P concentrations.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Burwell et al., 1977 **Level terraced vs. non-terraced, contour plant**	Deep Loess Research Station at Treynor, IA, US; Monona, Ida and Napier silt loam soils.	5-yr	Watershed W1 = 74a W2 = 81.5a W3 = 106a W4 = 148a	CC and Rotational Grazing of Bromegrass Pasture Ave. Annual P Rates W1 = 59 lb/a P W2 = 36 lb/a P W3 = 37 lb/a P W4 = 60 lb/a P W1, W2 CC w CT[8] contour planting W3 Bromegrass w Rotational Grazing yrs 1-3, CC w MT[9] contour planting yrs 4-5 W4 CC w CT and level terraces yrs 1-3, CC w MT and surface intake and outlet tiled terraces yrs 4-5	Surface runoff and subsurface leaching	Subsurface Leaching W1 @ 59 lb/a P	Annual ave. mass loss of SP, sediment-P, & TP[10] 0.04 lb/a SP	–	Yr 4 had 22% more precipitation than the 10-yr annual ave.	Authors stated that 94% of N and 82% of P ave. annual losses in surface runoff from the contour planted watersheds were transported with sediment. Therefore, the most practical step to reduce N and P losses is to reduce soil erosion. Deep percolation of water with level terraces increased SP leaching losses, but overall impact was minor compared to amount of P applied and crop P uptake.
						W4 @ 60 lb/a P	0.17 lb/a SP	-325.0%		
						Surface Runoff W1 @ 59 lb/a P	0.13 lb/a SP	–		
						W4 @ 60 lb/a P	0.09 lb/a SP	30.8%		
						Runoff Sediment W1 @ 59 lb/a P	0.68 lb/a sediment-P	–		
						W4 @ 60 lb/a P	0.18 lb/a sediment-P	73.5%		
						Total Stream Discharge W1 @ 59 lb/a P	0.85 lb/a TP	–		
						W4 @ 60 lb/a P	0.44 lb/a TP	48.2%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Burwell et al., 1974 **Level terraced vs. non-terraced, contour plant**	Macedonia and Treynor, IA (Potta-wattamie Co. deep loess hills), US: Marshall, Judson, Monona, Ida and Napier silt loam soils with slopes ranging from 2-13%.	2-yr	Watershed W1 = 83a W2 = 389a	W1: CT contour plant CC (100%). Fertilizers applied at rates of 150 lb/a/yr N and 35 lb/a/yr P. W2, CT level terrace CS[11] (60%) + pasture and forage crops (40%) + 2 livestock feedlots. Corn fertilized at rates of 115 lb/a/yr N and 25 lb/a/yr P.	Surface runoff and subsurface leaching (base flow)	Surface <u>runoff</u> W1, contour plant W2, level terrace Subsurface leaching <u>(base flow)</u> W1, contour plant W2, level terrace Total <u>Quantity</u> W1, contour plant W2, level terrace	Annual ave. mass loss of SP, sediment-P and TP 0.11 lb/a SP 0.70 lb/a sediment-P 0.17 lb/a SP 0.19 lb/a sediment-P 0.05 lb/a SP 0.04 lb/a SP 0.86 lb/a TP 0.40 lb/a TP	– – -54.5% 72.8% – 20.0% – 53.5%	Water quality sampling began in May of yr 1 and continued through Dec. of yr 2. Surface runoff samples taken during at rise, peak and recession of each runoff event. Base flow samples taken monthly during low flow, weekly during high flow periods. W1 had 293 surface runoff samples and 46 base flow samples. W2 had 211 surface runoff samples and 39 base flow samples.	Concentration data not shown due to being reported in ranges, not flow weighted annual averages. Concentrations of P and runoff SP load in runoff were higher from the level terraced W2. This was attributed to confounding of large P load coming from the 2 livestock feedlots near the sampling site. Eroded sediment was the primary source of P loss. Mass P loads reduced by reduced runoff flow volume and sediment erosion with reduced slope from level terraces.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Hanway and Laflen, 1974 **Tile-outlet terrace water quality survey**	Eldora, Guthrie Center, Creston and Charles City, IA, US: Fayette silt loam with 4% slope (Eldora), Clarion loam with 6% slope (Guthrie Center), Sharps-burg silty clay loam with 4% slope (Creston), Floyd loam with 3% slope (Charles City).	3-yr	Field	CT row crops (mainly corn) with parallel terraces, with and without tile drainage 3-yr ave. fertiliz-ation <u>rates</u> Eldora: 207 lb/a/yr N, 37 lb/a/yr P Guthrie Center: 171 lb/a/yr N, 35 lb/a/yr P Creston: 93 lb/a/yr N, 15 lb/a/yr P Charles City: 197 lb/a/yr N, 38 lb/a/yr P	Surface runoff and subsurface leaching Runoff water discharged through tile surface riser inlets to subsurface tile drainage lines at Creston and Charles City. No tile drainage at Eldora and Guthrie Center	<u>Surface runoff</u> Eldora (terraces, no tile) C1[12] Guthrie Center (terraces, no tile) C2[13] Creston (terraces with tile drainage) Charles City (terraces with tile drainage)	3-yr annual flow-weighted ave. concentration and mass loss of TP and DRP[14] 2.58 ppm TP 0.204 ppm DRP 0.49 lb/a TP 0.039 lb/a DRP 3.60 ppm TP 0.015 ppm DRP 0.75 lb/a TP 0.004 lb/a DRP 1.13 ppm TP 0.027 ppm DRP 0.39 lb/a TP 0.012 lb/a DRP 1.01 ppm TP 0.013 ppm DRP 0.94 lb/a TP 0.010 lb/a DRP	_ _ _ _ _ _ _ _ 56.2%C1; 68.6%C2 86.8%C1; -80.0%C2 20.4%C1; 48.0%C2 69.2%C1; -200.0%C2 60.8%C1; 71.9%C2 93.6%C1; 13.3%C2 -91.8%C1; -25.3%C2 74.4%C1; -150.0%C2	Number of runoff events varied by site for 3-yr period, being: Eldora = 22 Guthrie Center = 25 Creston = 26 Charles City = 38 Flow rate and water chemistry sampling done from April through November each of 3 yrs. Tile drainage sampled every 2 days following a runoff event. Single, continuous samples taken of runoff for each runoff event via splitters to capture 1/169th of total runoff volume. Ave. annual precipitation across 4 sites ranged from 25.6 – 29.0 in.	Creston had approx. 3.25X greater, and Charles City 9X greater, water loss than Eldora and Guthrie Center sites. No compar-ison made of subsurface leaching due to no measures at Eldora and Guthrie Center sites (leaching probably did occur, just not account-ed for). Concentra-tions of runoff DRP were directly related to available P levels in the surface 6 inches of soil. (cont.)

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb N/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Hanway and Laflen, 1974 (cont.) **Tile-outlet terrace water quality survey**	Eldora, Guthrie Center, Creston and Charles City, IA, US: Fayette silt loam with 4% slope (Eldora), Clarion loam with 6% slope (Guthrie Center), Sharps-burg silty clay loam with 4% slope (Creston), Floyd loam with 3% slope (Charles City).	3-yr	Field	CT row crops (mainly corn) with parallel terraces, with and without tile drainage 3-yr ave. fertiliz-ation rates Eldora: 207 lb/a/yr N, 37 lb/a/yr P Guthrie Center: 171 lb/a/yr N, 35 lb/a/yr P Creston: 93 lb/a/yr N, 15 lb/a/yr P Charles City: 197 lb/a/yr N, 38 lb/a/yr P	Surface runoff and subsurface leaching Runoff water discharged through tile surface riser inlets to subsurface tile drainage lines at Creston and Charles City. No tile drainage at Eldora and Guthrie Center	Subsurface tile drainage (runoff intake + shallow subsurface leaching) Eldora (terraces, no tile) Guthrie Center (terraces, no tile) Creston (terraces with tile drainage) Charles City (terraces with tile drainage)	3-yr annual flow-weighted ave. concentration and mass loss of TP and DRP No measures No measures 0.061 ppm TP 0.018 ppm DRP 0.02 lb/a TP 0.004 lb/a DRP 0.028 ppm TP 0.004 ppm DRP 0.04 lb/a TP 0.004 lb/a DRP	- See Above -	- See Above -	(cont.) Authors attributed reductions in P adsorbed to sediment due to reduced soil erosion losses from tile-outlet terraces, but not for soluble nutrients (DRP). TP and DRP concentra-tions were lower in tile drainage than surface runoff with tile-outlet terraces.

1 Watershed, field, plot or laboratory.
2 W1 represents watershed 1.
3 W2 represents watershed 2.
4 W3 represents watershed 3.
5 W4 represents watershed 4.
6 CC represents continuous corn rotation.
7 SP represents soluble phosphorus.
8 CT represents conventional tillage.
9 MT represents mulch tillage.
10 TP represents total phosphorus.
11 CS represents corn-soybean rotation.
12 C1 represents control 1 and comparison to control 1 for subsequent treatments.
13 C2 represents control 2 and comparison to control 2 for subsequent treatments.
14 DRP represents dissolved reactive phosphorus.

References

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Hanway, J.J., and J.M. Laflen. 1974. Plant nutrient losses from tile-outlet terraces. J. Environ. Qual. 3(4):351-356.

Schuman, G.E., R.G. Spomer, and R.F. Piest. 1973. Phosphorus losses from four agricultural watersheds on the Missouri Valley Loess. Soil Sci. Soc. Amer. Proc. 37:424-427.

Conservation Practice Summary Assessment

Contaminant: **Total P**

Type of Strategy: **Preventive**

Strategy Name: **Pasture/Grassland Management** (Livestock Exclusion from Streams/Riparian Areas, Rotational Grazing, Seasonal Grazing)

Pollutant reduction mechanisms

- Improved balance of nutrient application rate with crop (pasture vegetation) demand
- Improved stabilization of soil surface to impede wind and water erosion detachment and transport of nutrient enriched sediment and particulates
- Improved water infiltration and nutrient adsorption to soil matrix
- Reduced erosion and transport of nutrient enriched sediments and particulates
- Reduced in-field volume of runoff water
- Reduced volume of runoff water reaching surface waters
- Vegetative assimilation

Applicable conditions

- For livestock exclusion from streams/riparian areas, any pasture/grassland used for livestock grazing that has a surface water body
- For rotational grazing, any pasture/grassland that does not have the limiting conditions listed below

Limiting conditions

- For rotational and seasonal grazing: unstable soils due to slope and/or low plastic limits
- For rotational and seasonal grazing: near proximity to surface water
- For rotational and seasonal grazing: coarse soil textures that result in low nutrient retention and fast infiltration
- For rotational and seasonal grazing: excessive animal stocking rate and residence time that leads to an accumulation of P greater than pasture vegetation demand
- For rotational and seasonal grazing: excessive rainfall or snowmelt that leads to a high potential for leaching or runoff
- For rotational and seasonal grazing: drought that causes an accrual of manure-nutrients from low plant uptake

<u>Range of variation in effectiveness at any given point in time</u>

Livestock exclusion from streams vs. intensive grazing: +50% to +100%
Rotational grazing vs. constant intensive grazing: <-100% to +100%
Seasonal grazing vs. constant intensive grazing: <-100% to +100%

Effectiveness depends on:

- For livestock exclusion: previously denuded and eroded streambanks, lacking shade and an alternative water source, may have dramatic P loss reductions once these conditions are reversed
- For livestock exclusion: low stocking rates in pastures with stable streambanks and off-stream shade source may have lesser benefits
- For rotational and seasonal grazing: conversion of a non-grazed, non-fertilized grassland (harvested for hay or idle) to grazed conditions can lead to dramatic increases in P loss due to hoof traffic effects on soil and localized high P nutrient inputs from animal waste deposits
- For rotational and seasonal grazing: changing from a constant intensive grazing system to rotational grazing that is less intensive (maintaining greater sward height) can lead to improved soil conditions that better cycle nutrients, and reduce runoff and leaching

<u>Estimated potential contaminate reduction for applicable areas within Iowa (annual basis)</u>

Livestock exclusion from streams vs. intensive grazing: +65% to +90%
Rotational grazing vs. constant intensive grazing: -100% to +75%
Seasonal grazing vs. constant intensive grazing: 0% to +80%

In areas where streambanks and channels are already deeply incised and lack any practices to stabilize them, P losses may be high regardless of livestock exclusion due to pre-existing bank erosion and channel cutting. But in pasture stream areas that are stable and have extensive riparian vegetation, intensive and uncontrolled grazing frequently will increase P loss due to animal traffic that causes physical destruction of vegetative cover and soil structure. Livestock exclusion from stable stream areas will help to prevent physical degradation of the sites and minimize any potential for increases in nonpoint source P pollution of the streams. However, whether a stream area is in poor or good physical condition, eliminating or reducing livestock defecation and urination in or near the stream will reduce P contamination.

The potential and actual effects of seasonal and rotational grazing practices are highly dependent upon several factors. First is the point of reference. If a grazing practice is compared to a non-grazed vegetative area, most commonly the grazing practice will have greater P losses. In contrast, if a rotational or seasonal grazing practice is compared to a year-round intensive grazing practice at similar stocking rates, then the reduced presence of animals will result in less P from livestock waste being deposited in the area. Reduced nutrient load frequently results in reduced nutrient loss. Stocking rate is another important factor. Any grazing system that has stocking rates that result in soil compaction and erosion will cause increases in P losses. Related to stocking rate is management of the pasture vegetation. As the minimum allowed vegetation density and sward height increase, the risk of compaction, erosion, runoff and build-up of excess manure nutrients decreases. Also, with practices limiting the presence of livestock, the timing of livestock grazing is important in regard to weather patterns. If livestock are in a pasture area mainly during dry or cold weather, manure nutrients may build-up in excess of plant needs. When followed by a warm and wet period, the excess manure nutrients are then at a great risk to leaching and runoff losses. The type of vegetation (i.e., cool season vs. warm season plants) can influence P losses from livestock-derived nutrients depending upon when the livestock are pastured. If the animals are grazing an area dominated by cool season plants in the middle of summer when the plants are dormant, then there is a greater risk of nutrient losses. When considering the nutrient balance of a livestock pasture system, nutrients imported to the area either through added commercial fertilizers or in supplemental livestock feed (such as hay) can also increase P losses to surface waters.

While total P and particulate P losses are usually reduced with these conservation practices, soluble nutrient losses increased in some instances (here referring to dissolved reactive P and soluble P). Stout et al. (2000) stated, "…management intensive grazing systems should be regarded as a production system rather than a nutrient management system." They concluded that nutrient management techniques must be developed for management intensive grazing systems. Therefore, seasonal and rotational grazing systems cannot always be counted on to reduce P contamination of surface waters compared to conventional practices, especially if the conventional practice uses a lower stocking rate over time. Any grazing practice that puts high concentrations of animals in limited spaces has the potential to create critical source areas for P nutrient contamination.

<u>Estimated long-term contaminant reduction for applicable areas in Iowa (multi-year basis)</u>

Livestock exclusion from streams vs. intensive grazing: +75%
Rotational grazing vs. constant intensive grazing: +25%
Seasonal grazing vs. constant intensive grazing: +50%

For livestock exclusion from stream and riparian areas, the above estimate is made in regard to areas that animals have unrestricted access to a stream on a year-round basis and the streambank and channel are not deeply incised.

For rotational and seasonal grazing, a major assumption with these estimates is that the timing of the grazing period and stocking rates result in manure nutrient levels that are at or lower than pasture vegetation demand and that there are not adverse effects to soil properties that influence infiltration and runoff. Also, if the pasture receives P fertilizer, it is managed so as to maximize the time period from application to the next precipitation event. Phosphorus losses would increase if P fertilizer were not managed in this manner.

Extent of research

Limited

Livestock exclusion from stream/riparian areas has been researched to an appreciable extent across the world, but effects on water quality have not frequently been measured. Here in the U.S., livestock exclusion and its impacts on water quality have not been researched adequately in many regions, particularly in the Midwest. More data and information needs to be generated from long-term field and watershed scale experiments. Despite these limitations, those projects that have examined water quality have consistently shown substantial benefits to water quality. Anecdotal evidence from demonstration projects has reported similar results. This should be a priority funding area for research due to the high potential for this practice to reduce nonpoint source P contamination of surface waters. As paraphrased in Belsky et al. (1999) in their extensive review of livestock grazing impacts in the western U.S., “Elmore and Kauffman (1994) best summed up available evidence by stating that livestock exclusion has consistently resulted in the most dramatic and rapid rates of ecosystem recovery.”

Rotational, management intensive and seasonal grazing systems have been researched to a greater degree than livestock exclusion, but impacts on water quality still has received limited attention. Research to date suggests that these grazing practices cannot always be regarded as a best management practice for improving water quality due to the reasons mentioned above. Further research needs to be conducted at field and watershed scales to develop comprehensive nutrient management strategies for these practices.

Secondary benefits

- Reductions in soil erosion
- Reductions in sediment contamination of surface water
- Reductions in N contamination of surface waters with livestock exclusion from stream (not necessarily with rotational grazing)
- Reductions in bacterial pathogen contamination of surface waters with livestock exclusion from stream (not necessarily with rotational grazing)
- Opportunity to apply streambank stabilizing practices such as re-vegetation in absence of frequent disturbance

List of References

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Conservation Practice Research Summary Table

Contaminant: **Total P**

Type of Strategy: **Preventive**

Strategy Name: **Pasture/Grassland Management** (Livestock Exclusion from Streams/Riparian Areas, Rotational Grazing, etc.)

References significant to Iowa identified in bold italics.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Line et al., 2000 **Livestock Exclusion of Stream/ Riparian area**	Western Piedmont Region, NC, US; Tatum silt loam, and Vance sandy loam	81 week pre-treatment period for baseline establish-ment, 137 week treatment period	Small watershed	Pastured dairy cattle	Surface runoff and leaching through shallow ground-water to stream flow	Pre-treatment period, no livestock exclusion	Mean Mass TP[2] (lb/week) 110.4 lb/wk TP	–	Continuous discharge measures during entire study period. Weekly grab samples for chemical analyses and storm event samples via auto-samplers. Results somewhat confounded due to differences in precip-itation and infiltration between pre-treatment and treatment periods.	Reduced TP contamination due to less feces deposits in and near the stream, reduced streambank erosion and channel cutting from hoof traffic in those areas. Establish-ment of vegetation on barren areas that filtered sediments, improved infiltration and reduced runoff. Statistically significant reduction of TP at 95% CI[3] level.
						Post-treatment period, livestock excluded from stream	27.1 lb/wk TP	75.4%		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Haan et al., 2003 **Rotational Grazing**	Rhodes, IA, US; soil type not stated.	2-yr	Field-plot	Pasture	Surface runoff		Mass: TP (lb/a), SP[12] (lb/a)		Runoff measures taking from simulated rainfalls of 4 events per year (late spring, mid-summer, autumn and following early spring) at a rate of 2.8 in/hr. Stocking began in May for each summer grazed treatment at a rate of 3 cows/acre. Rotational grazing paddocks were given a 35 day regrowth period when the sward attained its minimum allowed sward height.	Rotational grazing managed for a taller sward height (here at a minimum of 4 inches) can reduce TP and SP losses compared to more intense continuous and rotational grazing. But all grazing methods led to greater losses compared to ungrazed. Mean TP losses were significantly greater (at the 95% CI level) for the 2CS and 2RS treatments than others for both years. The 2CS and 2RS treatments had a higher trend in SP losses, though results mixed statistically.
						U[4], C1[5]	**Yr 1:** 0.05 lb/a TP; 0.04 lb/a SP **Yr 2:** 0.03 lb/a TP; 0.02 lb/a SP	**Yr 1:** - TP; - SP **Yr 2:** - TP;- SP		
						HS[6], C2[7]	**Yr 1:** 0.20 lb/a TP; 0.17 lb/a SP **Yr 2:** 0.09 lb/a TP; 0.04 lb/a SP	**Yr 1:** -300% TP C1; -325% SP C1 **Yr 2:** -80% TP C1; -100% SP C1		
						2CS[8], C3[9]	**Yr 1:** 0.37 lb/a TP; 0.26 lb/a SP **Yr 2:** 0.36 lb/a TP; 0.12 lb/a SP	**Yr 1:** -640% TP C1; -85% TP C2; -550% SP C1; -53% C2 **Yr 2:** -1100% TP C1; -300% TP C2; -500% SP C1; -200% SP C2		
						2RS[10]	**Yr 1:** 0.37 lb/a TP; 0.31 lb/a SP **Yr 2:** 0.19 lb/a TP; 0.15 lb/a SP	**Yr 1:** -640% TP C1; -85% TP C2; 0% TP C3; -675% SP C1; -82% SP C2; -19% SP C3 **Yr 2:** -533% TP C1; -111% TP C2; 47% TP C3; -650% SP C1; -275% SP C2; -25% SP C3		
						4RS[11]	**Yr 1:** 0.23 lb/a TP; 0.18 lb/a SP **Yr 2:** 0.08 lb/a TP; 0.04 lb/a SP	**Yr 1:** -360% TP C1; -15% TP C2; 38% TP C3; -350% SP C1; -6% SP C2; 31% SP C3 **Yr 2:** -167% TP C1; 11% TP C2; 78% TP C3; -100% SP C1; 0% SP C2; 67% SP C3		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Owens, et al., 1989 Grazed vs. Ungrazed Pasture; Grazed Pasture vs. Woodland	Coshoc-ton, OH, USA: Silt loam soils	11 yrs total: 2 yrs ungrazed, 3 yrs summer grazing only, 6 yrs yr-round grazing with winter hay supplement	Small Watershed	Grass Pasture	Surface runoff from storm events		Annual flow-weighted averages, Mass: TP (lb/a) Conc.: TP (ppm)		Before-After time period comparison on same watershed area of ungrazed vs. grazed treatments. Paired watershed comparison with untreated wooded watershed. Stacking rate of 17 beef cow calving herd on 70 acre pasture. Autosampl-ing of storm runoff within the stream.	No reduction in TP nutrient export in comparing the controls to the grazed pasture treatments. For this area, cattle grazing of pasture would not be expected to degrade water quality from TP.
						Pasture No Grazing, Yrs 1-2, C1	0.1lb/a TP; 0.1 ppm TP	_ _		
						Wooded Watershed, Yrs 3-5, C2	0.1lb/a TP; <0.1 ppm TP	_ _		
						Wooded Watershed, Yrs 6-11, C3	0.1lb/a TP; <0.1 ppm TP	_ _		
						Pasture Summer Grazing, Yrs 3-5	0.1lb/a TP; 0.1 ppm TP	0% TP lb/a C1 & C2; 0% TP ppm C1 & C2		
						Pasture Yr-Round Grazing with Winter Haying, Yrs 6-11	0.1lb/a TP; 0.1 ppm TP	0% TP lb/a C1 & C3; 0% TP ppm C1 & C3		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Sheffield et al., 1997 **Off-Stream Primary Water Source vs. Stream Primary Water Source in Grazed Pasture.** **Without Stream Exclusion for Both Treatments.**	Independ-ence, VA, USA: Soil types not stated.	14 months	Field	Grazed pasture with stream	Surface runoff and subsur-face flow		Flow-weighted averages, Mass: TP & DRP[13] (lb/in rainfall) Conc.: TP & DRP (ppm)		Before-After time period comparison on same pasture area. First 7 months (Aug.-April) with the stream as the primary water source for grazing cattle vs. following 7 months (April-Oct.) with an off-stream water trough as the primary water source. Stocking rate 200 cows and 170 calves on 336 acre pasture. Bi-weekly stream samples.	Reductions in P contamin-ation attributed to a reduction of time spent in or near stream by 51% by the cattle, which reduced the amount of direct feces and urine deposits to the stream. Significant reduction in TP mass load loss at the 95% CI level. Other factors not statistically significant. Increased DRP concentration though load reduced.
						Stream Primary Water Source	0.203 ppm TP; 3.75 lb/in TP; 0.004 ppm DRP; 0.046 lb/in DRP	_ _ _ _		
						Off-Stream Primary Water Source	0.072 ppm TP; 0.092 lb/in TP; 0.007 ppm DRP; 0.011 lb/in DRP	64.5% 97.5% -98.5% 75.0%		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Owens, et al., 2003 Seasonal Grazing Pasture Grazing with Nutrient Inputs & Summer Grazing Only vs. Summer Grazing with Winter Feeding	Coshoc-ton, OH, USA: Silt loam soils	15 yrs total: 5 yrs with pastures managed with medium nitrogen fertility inputs, then the follow-ing 10 yrs added treatment with high nitrogen fertility inputs.	Small Watershed	Grass Pasture	Surface runoff and subsur-face flow	Surface Runoff + Subsurface <u>Flow</u> SG[14]+WF[15]/ HNF[16] C1 SG+WF/ MNF[17] C2 SG/HNF C3 SG/MNF	Annual flow-weighted averages, Mass: TP (lb/a) Conc.: TP (ppm) 3.47 lb/a TP 3.74 lb/a TP 0.54 lb/a TP 0.45 lb/a TP	_ -7.8% C1 84.4% C1 85.6% C2 87.0% C1 88.0% C2 16.7% C3	Before-After time period comparison on same watershed areas. Sampled each surface runoff event. Subsurface flow sampled weekly. Medium fertility had 50 lb N/a applied annually with P fertilizer added to maintain 25 lb P/a availability and K fertilizer added to maintain 150 lb K/a availability. High fertility had 150 lb N/a applied to SG treatment, approximately 267 lb N/a to WF/SG treatment from hay feed. Stocking rate 25 head cow/calve herd on 42 a for yrs 1-10, 30 head for yrs 11-15. Medium fertility period (yrs 1-5) had greater precipitation than high fertility period (yrs 6-15).	Subsurface flow (leaching) was the dominant pathway of TP loss for the SG treatment. Surface runoff was the dominant pathway of TP loss in the SG+WF treatment. TP losses significantly higher (at the 95% CI level) in the SG+WF vs. the SG treatment and was attributed to higher P inputs for imported hay with WF. When non-N inputs are balanced with plant requirements for N, the possibility for greater TP losses is low.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Hooda et al., 1999 Intensively Grazed Grass vs. Grass/ Clover Pasture	Dumfries, Scotland, UK: Silty clay loam topsoil over silty clay subsoil.	2- yr	Field	Grazed Grass and Grass + Clover Pasture	Sub-surface flow	Ryegrass + White Clover Pasture: 0 lb/a/yr fertilizer N, 22 lb/a/yr fertilizer P, 39 lb/a/yr manure P (61 lb/a/yr fertilizer + manure P) Ryegrass Pasture: 222 lb/a/yr fertilizer N, 0 lb/a/yr fertilizer P, 40 lb/a/yr manure P	Annual flow-weighted average and total annual, Mass: TP & DRP (lb/a) Conc.: TP & DRP (ppm) **Yr 1**: 1.81lb/a DRP 0.26 ppm DRP 4.48 lb/a TP 0.64 ppm TP **Yr 2**: 1.50 lb/a DRP 0.38 ppm DRP 3.09 lb/a TP 0.79 ppm TP **Yr 1**: 1.13 lb/a DRP 0.16 ppm DRP 3.19 lb/a TP 0.45 ppm TP **Yr 2:** 1.19 lb/a DRP 0.30 ppm DRP 2.64 lb/a TP 0.67 ppm TP	_ _ _ _ _ _ _ _ 37.6% 38.5% 28.8% 29.7% 20.7% 21.0% 14.6% 15.2%	Yr 1 had above normal precipitation. Yr 2 had below normal precipitation. Water samples collected every 0.02-0.08 in. drainage in winter, every 0.002 in. drainage in spring-fall. Then compiled for weekly averages. Two pastures at 89 a each for the treatments. Pastures had 2-3 silage cuts in Mar.-July, dairy cow grazing Aug.-Oct., sheep grazing Nov.-Feb., manure applied May-July following each silage cut. Manure-N applied rates not reported.	The grass + clover treatment had significantly greater DRP and TP losses and concentra-tions. Attrib-uted to the higher P inputs to the grass + clover treatment compared the grass only treatment, not to differences in plant species. Most P losses occurred directly after manure application to soil at or near water saturated conditions leading to preferential transport of manure through soil macropores. Both DRP and TP losses via leaching great enough to cause water quality impairment.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Schepers and Francis, 1982	Clay Center, NE, US: Crete and Hastings silt loams.	3-yr	Field	Warm and cool season mixed grass pasture.	Surface Runoff		Runoff event flow-weighted averages Mass: TP & SP (lb/a/in) Conc.: TP & SP ppm		Annual precipitation below normal 2 of 3 yrs (92% and 79%). One yr above normal 168%). Average stocking rate of 40 cow-calf pairs (~2.5 a per pair). Pastures fertilized at 60 lb N/a each spring. Ungrazed pasture periodically clipped to sward height similar to grazed pasture.	Amount of contaminants within runoff directly related to stocking density and the amount of precipitation within an event. Reduced TP and SP losses via surface runoff in ungrazed pasture due to absence of livestock disturbance of soil and animal wastes. Sources of contaminants (here TP and SP) from standing plant residues and manure.
Grazed vs. Un-grazed Pasture						Grazed Pasture	0.285 lb/a/in TP 1.26 ppm TP 0.181 lb/a/in SP 0.80 ppm SP	– – – –		
						Ungrazed Pasture	0.208 lb/a/in TP 0.92 ppm TP 0.122 lb/a/in SP 0.54 ppm SP	27.0% 27.0% 32.6% 32.5%		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Meals and Hopkins, 2002 **Mixed treatments of livestock exclusion, crossing elimination or armored crossings, and streambank stabilization**	Missisquoi River Watershed, VT, US; glacial till soils in uplands, alluvial and lacustrine soils in riparian areas Paired Watershed Design Trt watersheds: Samsonville Brook Watershed (1700 a, WS1), Godin Brook Watershed (3500 a, WS2). Control watershed: Berry Brook (2350 a, WS3)	2-yr	Large Watershed	Watersheds of nearly equal land-use, being: 60% forest, 2-3% urban, 3% corn silage, ~33% dairy and pasture/hay	Surface runoff and shallow ground water	<u>Control</u> WS3 Riparian Restoration <u>Treatments</u> WS1 WS2	2-yr mean TP mass and concentration 0.116 ppm TP 24.4 kg/wk TP 0.082 ppm TP 6.9 kg/wk TP 0.086 ppm TP 12.2 kg/wk TP	_ _ 29.3% 71.7% 25.9% 50.0%	3-yr monitored calibration period prior to initiation of treatments. 2-yr monitored treatment period. Continuous stream flow measures. Flow proportional, fixed volume water chemistry samples were composited weekly.	Riparian restoration treatments consisted of a mix of livestock exclusion, streambank stabilization, and livestock stream crossing elimination or armored crossings. Statistically significant reduced TP concentration and mass load losses from land areas to surface waters. Reduction mechanisms attributed to reduced erosion, increased sediment deposition within riparian buffers and reduced dairy fecal deposition in and near the streams.

1 Watershed, field, plot or laboratory.
1 TP represents total phosphorus.
3 CI represents confidence interval.
4 U represents ungrazed paddock.
5 C1 represents control 1.
6 HS represents summer hay harvest with winter grazing to residual sward height of 2 inches.
7 C2 represents control 2.
8 2CS represents continuous stocking to a residual sward height of 2 inches: 1213 grazing cow-days/a for 2001; 988 grazing cow-days/a for 2002.
9 C3 represents control 3.
10 2RS represents rotational grazing to a residual sward height of 2 inches: 889 grazing cow-days/a for 2001; 781 grazing cow-days/a for 2002.
11 4RS represents rotational grazing to a residual sward height of 4 inches: 677 grazing cow-days/a for 2001; 635 grazing cow-days/a for 2002.
12 SP represents soluble phosphorus.
13 DRP represents dissolved reactive phosphorus.
14 SG represents summer grazing.
15 WF represents winter feeding.
16 HNF represents high nitrogen fertility pasture management.
17 MNF represents medium nitrogen fertility pasture management.

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Conservation Practice Summary Assessment

Contaminant: **Total P**

Type of Strategy: **Preventive**

Strategy Name: **P Nutrient Application Techniques** (surface broadcast, full-field tillage incorporation, narrow band deep injection)

Pollutant reduction mechanisms

- Decreased exposure of nutrients to leaching by preferential flow of soil water through soil macropores or leachate diversion
- Improved adsorption to soil matrix
- Reduced fine-particulate nutrient fraction in runoff water
- Reduced nutrient solubility to soil water and surface water
- Reduced soluble nutrient fraction within runoff water

Applicable conditions

- All land where commercial inorganic fertilizer and/or manure P nutrients are applied

Limiting conditions

- Circumstances in which injection or incorporation will put a producer out of compliance with existing conservation plans
- Targeted application periods may have soil conditions that are too wet for equipment trafficking
- Any conditions that limit crop growth (i.e., drought, flooding, disease and insect damage) may reduce crop P uptake, which then could result in an unexpected over-application of P nutrients from applications done prior to the crop growing season
- Rainfall runoff events soon after application of P nutrients

Range of variation in effectiveness at any given point in time

All listed alternative practices vs. surface broadcast application: <-100% to +95%

Effectiveness depends on:

- Degree of surface disturbance with any of the incorporation methods
- Difference in P nutrient application methods from previous to conservation practice methods
- Difference in P nutrient seasonal timing of application
- Existence or absence of other conservation practices
- Field tillage program and resulting amount of surface residue cover
- Form of P nutrients applied, commercial inorganic fertilizer vs. manure fertilizer

- Frequency of P applications
- Intensity, quantity, duration and timing of succeeding rainfall and snowmelt events
- Risk of surface runoff reaching surface waters either by close proximity to surface water body or presence of surface tile drainage intakes
- Slope and slope length
- Soil moisture content at time of P application and the next precipitation event
- Soil type, texture, structure, cation exchange capacity and water infiltration rate
- Soil's P adsorption capacity and/or saturation state
- Time period between P application and subsequent rainfall events
- Type of crop grown (i.e., row crop vs. pasture)

Estimated potential contaminate reduction for applicable areas within Iowa (annual basis)

Deep tillage incorporation vs. surface broadcast application: -75% to +50%
Shallow tillage incorporation vs. surface broadcast application: -75% to +40%
Knifing or injection vs. surface broadcast application: -20% to +70%

All comparisons shown here are based upon total P data from multiple Midwest research experiments. Results differ widely by form of P, particularly for soluble forms. Total P was chosen since it is currently the P form that total maximum daily loads are to be developed for the state's surface water bodies.

General methods of P application or placement include surface broadcasting, full-field tillage incorporation and injection in narrow bands with knives or point-injectors, all of which interact with soil physical properties and landscape conditions that influence erosion potential. Slope, slope length, and soil texture are main factors that determine soil erodability. Areas that have coarse soil texture, and steep and/or long slope are frequently classified as being highly erodable. Also, Iowa soils with high clay content and moderate to low soil test P content (or P saturation) have a high potential to adsorb added P. But as the P saturation level increases for any soil, even with high clay content, there is a greater risk for P loss to water resources with any added P fertilizer. Phosphorus losses can be significant if the P fertilizer is left on the surface of highly erodable and runoff prone areas, or if soil has been dramatically disturbed due to aggressive tillage incorporation of P fertilizer. Injection or incorporation is particularly beneficial when the operation does little to disturb the soil residue. This results in a minimal impact on erosion while getting the P below the soil surface and out of direct contact with precipitation.

Phosphorus application method effects on P loss can greatly depend upon the form of P fertilizer applied. Many research studies have found that manure sources of P have less P loss compared to similar rates and application timing of commercial inorganic P fertilizer forms. Scientists have attributed this to the following effects: higher solubility of inorganic fertilizer P compared to manure P; a greater portion of total P tied up in organic forms; and reduced sediment erosion from manure additions due to increased soil organic matter adsorption of P, soil particle aggregation, aggregate stability and water infiltration rates.

The potential benefit of incorporation or injection in any given year often is influenced by climate. The timing of runoff events in the days and weeks following application is of particular importance. As the time period increases between P fertilizer application and succeeding rainfall event, P has more time to react with and be adsorbed to soil particles, and then a lesser chance for P loss. Research has shown that a rainfall event immediately after an application can cause extremely high P concentrations and mass losses that dominate the total annual losses, and that these high concentrations and load losses can be dramatically decreased if the manure or fertilizer is injected or incorporated. However, if there isn't a runoff event for several weeks following application, erosion may dominate the P loss from a field from the decreased crop residue coverage due to the tillage application method. The diminished soil surface residue cover and disturbed soil may lead to higher P losses than with surface banding or broadcast, particularly on erosive ground. The probability of runoff occurring is also affected by the succeeding event's intensity and quantity, and antecedent soil moisture content. If P application can be timed during a dry period, then the next rainfall has a lesser probability of generating runoff since the soil will have a greater water infiltration rate and capacity to store water than if the soil moisture content was higher. Runoff may still occur even with relatively dry soil if the rainfall event is of sufficient intensity, duration and quantity that the incoming rainfall rate exceeds the soil's water infiltration rate.

Field P levels and the presence or absence of vegetative buffers (in-field or riparian) can dramatically influence annual P losses from either surface or subsurface placement of P commercial fertilizer and manure. Experiments that evaluated crop N-based vs. crop P-based manure application rates found much higher P losses with the former method. The crop P-based method resulted in P losses at or over levels that can cause eutrophication of surface waters. If buffers of adequate width are appropriately placed to limit concentrated flow and cause deposition of transported sediments on the landscape, then the risk of P contamination may be greatly reduced. Some research has identified that surface tile intakes pose a significant threat for P loss by directly routing field runoff to surface waters. This threat can be minimized if vegetative buffers surround the surface intakes and the inlet ports are far enough above the soil surface to result in minor ponding that will allow sediment to settle back onto the field and not enter tile lines that drain to surface waters.

Estimated long-term contaminant reduction for applicable areas in Iowa (multi-year basis)

Deep tillage incorporation vs. surface broadcast application: -15%
Shallow tillage incorporation vs. surface broadcast application: -10%
Knifing or injection vs. surface broadcast application: +35%

The potential for P loss with incorporation methods vs. surface broadcast application depends upon the balance between runoff water volume, eroded soil transported to surface waters (main source of total P and particulate P), and amount of soluble P forms present at the soil surface from both added P fertilizers and plant residues. With some exceptions, incorporation of inorganic P fertilizer and manure has shown to significantly reduce losses of soluble P forms (i.e., dissolved reactive P, biologically available P and soluble organic P) that in the short-term have a greater potential to cause eutrophication of surface waters than total P. However, tillage methods to incorporate P fertilizer have also been repeatedly shown to increase soil erosion that transports adsorbed P to surface waters. Total P poses a longer-term threat for eutrophication since it may release P to water over time. Research literature shows a very wide range of results as to which application methods either decrease or increase P losses. Since total maximum daily load limits are currently to be based upon total P, full-field tillage incorporation methods tend to pose a greater risk to water quality. One tool to help a producer to resolve these management conflicts is to use a recommended P Index program along with careful consideration of P fertilizer application methods for the physical conditions of each field.

A logical compromise to the dilemma of greater total P losses with incorporation vs. greater soluble P losses with surface application to provide the least risk of P loss is injection or knife narrow banding of P fertilizers. Strip tillage and injection of starter fertilizers are two such methods. These methods may be successful if soil disturbance is minimized and P fertilizer is placed below the thin surface mixing zone of soil with runoff, then this strategy is beneficial because it greatly reduces the chance of high P losses from a runoff event immediately after application. On a multi-year basis, these application methods will decrease soil P concentrations at the soil surface relative to a field with a long-term history of broadcast applications. This should reduce P concentrations in runoff due to lower soil P at the surface.

Extent of research

Limited

Research is dramatically lacking for different P fertilizer placement method impacts on water quality. Future research should include continuous monitoring over relatively long periods of time - preferably over several years - and locations due to climatic and landscape variability. Research in this area is dominated by short-period time event samplings from rainfall simulations that typically represent worst-case scenarios that maximize the benefit of injection or incorporation. Rainfall simulations, while useful for treatment comparison, do not necessarily simulate real world conditions such as the occurrence of concentrated flow. Larger scale and longer-term studies would more accurately simulate true field-scale effects that include factors that vary both temporally and spatially.

Further study is particularly needed of injection methods in reduced tillage systems. Strip tillage is currently limited to areas of low slope due to the risk of concentrated flow at the edges of the strip from any runoff event. On sloping soils, it is not uncommon for the entire strip of disturbed soil to erode to the depth of injection or knifing, carrying with it P enriched soil. One potential solution to this problem is to apply a compound, such as a polyacrylamide, that will form a protective surface on top of the strip that sheds water and inhibits erosion. This protective shield, however, must not be so impervious as to impede later planting operations. Use of the localized dome compaction method researched in Iowa for N fertilizer application may also merit research to limit losses from knifed P applications. The benefits of such systems will not be known until research is conducted for development and evaluation.

Secondary benefits

- Improved crop P nutrient use efficiency
- Improved farm profitability
- Reduction of ammonia volatilization when applying manure
- Reduction of odor (i.e., volatile organics compounds, hydrogen sulfide, and ammonia) when applying manure
- Reduced P stratification within the soil profile with reduced tillage systems

Conservation Practice Research Summary Table

<u>Contaminant:</u> Total P

<u>Type of Strategy:</u> Preventive

<u>Strategy Name:</u> P Nutrient Application Techniques (surface broadcast, full-field tillage incorporation, narrow band deep injection)

References significant to Iowa identified in bold italics.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Bundy et al., 2001 **Manure P surface broadcast vs. incorporation at varied depths**	Arlington, WI, US; silt loam soils	One-day rainfall simulations in May and Sept.	Plot scale	CC[2] with varied tillage program methods of placement of 58 lb/a P dairy manure fertilizer applied in spring Placement <u>Methods:</u> CP[3] @ 8 in depth with secondary tillage @ 3 in depth ST[4] @ 3 in depth NT[5], surface broadcast	Surface runoff		BAP[6] concentration and BAP and TP[7] mass loss in runoff		Rainfall applied at 3.0 in/hr rate, being a 50-yr recurrence interval event. Runoff water samples collected for 1 hr after onset of runoff, and runoff volume measured.	May BAP concentration was significantly greater for NT surface broadcast application than incorporated methods. Sept. BAP load was significantly lower for NT surface broadcast application than incorporated methods. Overall BAP losses increase with increasing surface residue, but TP losses were 3-40 times greater than DRP[8] losses with intensive tillage. NT and surface manure application reduces TP load loss by reducing sediment loss; tillage incorporation lowers DRP by improving contact with soil, but increases TP loss with increased sediment erosion.
						<u>May</u> CP	0.005 lb/a BAP 0.10 ppm BAP	_ _		
						ST	0.02 lb/a BAP 0.14 ppm BAP	-300.0% -40.0%		
						NT	0.06 lb/a BAP 1.41 ppm BAP	-1100.0% -1310.0%		
						<u>Sept.</u> CP	0.20 lb/a BAP 0.31 ppm BAP	_ _		
						ST	0.17 lb/a BAP 0.27 ppm BAP	15.0% 12.9%		
						NT	0.08 lb/a BAP 0.30 ppm BAP	60.0% 3.2%		
						<u>Ave.</u> CP	1.70 lb/a TP	_		
						ST	1.73 lb/a TP	1.8%		
						NT	0.97 lb/a TP	42.9%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Tabbara, 2003 Manure and inorganic P fertilizer surface broadcast vs. disk incorpora-tion	Near Ames, IA; US; Terril sandy loam. Site was terraced and plot areas had average slopes from 6.6-7.6%.	1-day in late July	Plot, rainfall simula-tion	Tilled fallow, CS in prior years. No fertilizer in previous 4 yrs. Practices <u>Contrasted</u> Surface Broadcast vs. Disk incorporation Liquid Swine Manure vs. Inorganic Fertilizer High TP Rate vs. Lower TP Rate	Surface runoff	Surface <u>Broadcast</u> Inorganic Fertilizer, 158 lb/a TP (C1[9]) Liquid Swine Manure, 121 lb/a TP (C2[10]) Inorganic Fertilizer, 74 lb/a TP (C3[11]) Liquid Swine Manure, 62 lb/a TP (C4[12])	Flow-weighted concentration and mass loss of BAP and TP 35.18 ppm TP 21.37 lb/a TP 13.64 ppm BAP 7.37 lb/a BAP 18.77 ppm TP 9.94 lb/a TP 6.89 ppm BAP 3.65 lb/a BAP 17.76 ppm TP 11.36 lb/a TP 9.23 ppm BAP 5.90 lb/a BAP 9.18 ppm TP 5.12 lb/a TP 2.93 ppm BAP 1.64 lb/a BAP	_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _	Manure and inorganic fertilizer applied 24 hr prior to the rainfall simulation measures. Plots had weeds mowed, then disked one month prior to rainfall simulations. Rainfall simulation intensity at 2.5 in/hr for 90 minutes, being a 50-yr recurrence event. Six to eight flow rate measures and chemical samples taken for each plot rainfall simulation.	Runoff volume and P loss were reduced with disk incorporation compared to surface broadcast. *However, author did not report if a surface seal had developed in the broadcast treatment plots due to previous tillage. Results could differ for broadcast if applied to long-term no-till soil or other conditions that typically have good to high infiltration rates.* Manure and inorganic fertilizer P placed below the thin mixing zone of runoff solution with soil at the surface and increased P adsorption to the soil. The amount (from P loading rate) and availability of P were more important than tillage disturbance in P losses under the tilled, bare soil conditions of this experiment.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Tabbara, 2003 Manure and inorganic P fertilizer surface broadcast vs. disk incorpora-tion. (cont.)	Near Ames, IA, US; Terril sandy loam. Site was terraced and plot areas had average slops from 6.6-7.6%.	1-day in late July	Plot, rainfall simula-tion	Tilled fallow, CS in prior years. No fertilizer in previous 4 yrs. Practices <u>Contrasted</u> Surface Broadcast vs. Disk incorporation Liquid Swine Manure vs. Inorganic Fertilizer High TP Rate vs. Lower TP Rate	Surface runoff	<u>Disk Incorporation</u> Inorganic Fertilizer, 158 lb/a TP Liquid Swine Manure, 121 lb/a TP Inorganic Fertilizer, 74 lb/a TP Liquid Swine Manure, 62 lb/a TP	Flow-weighted concentration and mass loss of BAP and TP 18.36 ppm TP 9.46 lb/a TP 6.11 ppm BAP 3.15 lb/a BAP 12.39 ppm TP 5.76 lb/a TP 2.53 ppm BAP 1.17 lb/a BAP 12.51 ppm TP 6.29 lb/a TP 3.43 ppm BAP 1.73 lb/a BAP 9.39 ppm TP 4.70 lb/a TP 1.90 ppm BAP 0.95 lb/a BAP	47.8% C1 55.7% C1 55.2% C1 57.2% C1 34.0% C2 42.0% C2 63.3% C2 67.9% C2 29.6% C3 44.6% C3 62.8% C3 70.7% C3 -2.3% C4 8.2% C4 35.2% C4 42.1% C4	-See above-	Higher solubility of inorganic P fertilizer led to greater P loss compared to manure. The BAP:TP ratio is an indicator of long-term pollution potential, which was lower for manure compared to inorganic P fertilizer. The DRP:BAP ratio, however, was higher for manure, which is an indicator of a greater risk of short-term eutrophication potential. Sediment loss and P enrichment of sediment were lower for manure. This was attributed to soil aggregates than absorbed manure being less erodable and adsorbing greater P than from the inorganic P fertilizer source.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Andraski et al., 2003 **Manure P surface broadcast vs. incorpora-tion**	Lancaster and Madison, WI, US; Plano (Madison) and Rozetta (Lancaster) silt loam soils, 3% slope at Madison, 6% slope at Lancaster.	1-day in May, and 1-day in Sept. at Lancaster; 1-day in June at Madison	Plot, rainfall simul-ations	CP and NT CC CP only at Madison. CP and NT at Lancaster where CP consisted of fall CP plowing and disking in spring following manure application at 70 lb/a manure P rate, spring surface applied in NT.	Surface runoff		Runoff concentration and mass loss of TP, BAP and DRP		Rainfall simulations applied at rate of 3 in/hr (a 50-yr event). All runoff collected from plots for 1-hr after initiation of runoff. Sept. data displayed only, May simulation data incomplete.	Significantly reduced TP, BAP and DRP loads with NT + surface manure application due to lower sediment concentrations and/or runoff volumes compared to CP incorporation of manure. Manure application with CP did not affect runoff volume. But did decrease runoff volume 60% compared to the greater surface residue of NT, suggesting that manure increased infiltration since soil organic matter remained unchanged. Manure significantly increased TP concentration with CP, but not NT. BAP and DRP were not significantly increased with manure in NT due to reduced runoff volume from manure application. Significant linear relationships of DRP and BAP with CP, but not with NT. Manure history did not correlate with TP mass losses due to reduced sediment loss with manure. NT with manure had less P loss than CP without manure.
						<u>Lancaster</u> CP CC + 5 yrs manure application	5.18 ppm TP 10.30 lb/a TP 0.74 ppm BAP 0.60 lb/a BAP 0.22 ppm DRP 0.44 lb/a DRP	– – – – – –		
						CP CC, no manure	3.39 ppm TP 7.82 lb/a TP 0.40 ppm BAP 0.93 lb/a BAP 0.11 ppm DRP 0.26 lb/a DRP	34.6% 24.1% 45.9% -55.0% 50.0% 40.9%		
						NT CC + 5 yrs manure application	1.57 ppm TP 0.83 lb/a TP 0.50 ppm BAP 0.22 lb/a BAP 0.39 ppm DRP 0.16 lb/a DRP	69.7% 91.9% 32.4% 63.3% -77.3% 63.6%		
						NT CC, no manure	1.06 ppm TP 1.21 lb/a TP 0.27 ppm BAP 0.29 lb/a BAP 0.20 ppm DRP 0.20 lb/a DRP	79.5% 88.2% 63.5% 51.7% 9.1% 54.5%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Kimmel et al., 2001 **P broadcast vs. knife and full-field tillage incorpor-ation**	Ottawa, KS, US; Woodson silt loam soil with 1-1.5% slope	2-yr	Plot, natural runoff	Sorghum-soybean rotation Varied tillage programs with placement treatments. P applic-ation rates were 0 lb/a for the controls, 21 lb/a P for the added P treatments. All knifed P was placed at approx-imately 4 in. depth.	Surface runoff	<u>Soybean</u>	2-yr sum mass loss of TP, SP[14] and BAP from sampling periods		Runoff events were collected from June through Sept. for 2 years. P applied in spring prior to planting. For CP treatment, P was incorporated with second-ary tillage prior to planting. For RT, 1in of ridge top was moved to the furrow with planting. Sorghum for both years and soybean for the first, had 6 runoff events. Second yr soybean plots had only 3 runoff events. No significant differences in runoff volume between crop types.	Reduced P loss with knifed P application compared to broadcast. Less P available for transport in the thin surface soil-precipitation mixing zone. Significantly greater P loss by placement method for sorghum in both years. Effects of tillage systems on P loss were inconsistent. For soluble P loss, NT broadcast treatment had significantly greater losses than other treatments, RT had significantly greater losses than CP.
						CP, broadcast P	3.76 lb/a TP 0.11 lb/a SP 0.36 lb/a BAP	_ _ _		
						CP, knifed P	4.59 lb/a TP 0.08 lb/a SP 0.44 lb/a BAP	-22.1% 27.3% -22.2%		
						CP, no P	3.89 lb/a TP 0.07 lb/a SP 0.32 lb/a BAP	-3.5% 36.4% 11.1%		
						RT[13], broadcast P	2.19 lb/a TP 0.18 lb/a SP 0.34 lb/a BAP	41.8% -63.6% 5.6%		
						RT, knifed P	2.57 lb/a TP 0.15 lb/a SP 0.38 lb/a BAP	31.6% -36.4% -5.6%		
						RT, no P	2.82 lb/a TP 0.16 lb/a SP 0.43 lb/a BAP	25.0% -45.5% -19.4%		
						NT, broadcast P	3.74 lb/a TP 0.35 lb/a SP 0.78 lb/a BAP	0.5% -218.2% -116.7%		
						NT, knifed P	2.22 lb/a TP 0.18 lb/a SP 0.24 lb/a BAP	41.0% 33.3% -63.6%		
						NT, no P	1.44 lb/a TP 0.11 lb/a SP 0.28 lb/a BAP	61.7% 0.0% 22.2%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Kimmel et al., 2001 **P broadcast vs. knife and full-field tillage incorpor-ation** **(cont.)**	Ottawa, KS, US; Woodson silt loam soil with 1-1.5% slope	2-yr	Plot, natural runoff	Sorghum-soybean rotation Varied tillage programs with placement treatments. P applic-ation rates were 0 lb/a for the controls, 21 lb/a P for the added P treatments. All knifed P was placed at approx-imately 4 in. depth.	Surface runoff		2-yr sum mass loss of TP, SP and BAP from sampling periods		- See Above -	- See Above -
						<u>Sorghum</u> CP, broadcast P	6.58 lb/a TP 0.17 lb/a SP 0.54 lb/a BAP	_ _ _		
						CP, knifed P	3.85 lb/a TP 0.13 lb/a SP 0.36 lb/a BAP	41.5% 23.5% 33.3%		
						CP, no P	6.62 lb/a TP 0.35 lb/a SP 0.49 lb/a BAP	-0.6% -105.9% 9.3%		
						RT[13], broadcast P	9.06 lb/a TP 3.58 lb/a SP 4.34 lb/a BAP	-37.7% -2005.9% -703.7%		
						RT, knifed P	5.22 lb/a TP 0.80 lb/a SP 1.34 lb/a BAP	20.7% -370.6% -148.1%		
						RT, no P	3.69 lb/a TP 0.33 lb/a SP 0.73 lb/a BAP	43.9% -94.1% -35.2%		
						NT, broadcast P	12.21 lb/a TP 3.49 lb/a SP 4.64 lb/a BAP	-85.6% -1952.9% -759.3%		
						NT, knifed P	7.35 lb/a TP 0.84 lb/a SP 1.32 lb/a BAP	-11.7% -394.1% -144.4%		
						NT, no P	4.93 lb/a TP 0.18 lb/a SP 0.57 lb/a BAP	25.1% -5.9% -5.6%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Zhao et al., 2001 Moldboard plow immediate incorpor-ation vs. ridge tillage long-term surface placement	Lamberton, MN, US; Webster clay loam soil.	1-day per plot in April	Plot, rainfall simul-ation	Simulated Corn Crop, barren soil immediately following simulated corn planting operation. Urea and manure applications as subplot treatments. One-time application of inorganic P fertilizer for all plots at 108 lb/a P. Manure P applied over previous 2-yr period at total rate of 423 lb/a P for manure treatments.	Surface runoff and subsurface drainage with runoff contribution via surface tile intake		Mass loss and flow-weighted mean concentr-ations of TP and SP averaged across fertilizer source treatments		Manure and urea fertilizers were immediately incorporated in MP treatment in spring and fall. No incorpor-ation of fertilizers in RT until tillage done in late June. Rainfall simulation rate at 2.67 in/hr for 70 minutes. Water samples taken continuously during simulation period.	Significantly reduced soluble P losses with incorporation of fertilizer sources. No significant difference in overall TP losses by placement method. Authors suggest manure not well mixed with soil results in greater soluble P losses. Conversely, MP tillage program resulted in significantly greater sediment and sediment-bound P losses. Authors attributed greater P losses in subsurface drainage with RT to greater preferential flow from continuous macropores of RT system. RT system had ridges parallel to slope that drained towards the tile intakes, which could have increased runoff into the tile systems compared to perpendicular ridge orientation to slope. *Runoff entering tile surface intakes is a major conduit for transport of sediment, TP, SP and ammonium-N.*
						Surface <u>Runoff</u> MP[15]	3.11 lb/a TP 0.45 lb/a SP	_ _		
						RT	2.62 lb/a TP 1.39lb/a SP	15.7% -208.9%		
						Subsurface Tile Drainage + Intake Surface <u>Runoff</u> MP	0.02 lb/a TP 0.01 lb/a SP	_ _		
						RT	0.58 lb/a TP 0.41 lb/a SP	-2800.0% -4000.0%		
						Combined Surface Runoff and Subsurface <u>Flow</u> MP	3.13 lb/a TP 1.60 ppm TP 0.46 lb/a SP 0.24 ppm SP	_ _ _ _		
						RT	3.20 lb/a TP 1.30 ppm TP 1.81 lb/a SP 0.73 ppm SP	-2.2% 18.8% -293.5% -204.2%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Timmons et al., 1973 Plow, disk and surface placement sequence combina-tion contrasts	Morris, MN, US; Barnes loam soil, 7%slope.	Rainfall simulations over 1-day and 2-day periods	Plot	Tilled oat stubble (grain and straw removed) 35 lb/a P broadcast applied	Surface runoff		Sum of SP and BP1-STP[16] mass total loss		All tillage operations done parallel to slope. P fertilizer broadcast applied just prior to tillage incorporation treatment operations. Rainfall simulations conducted within 2-3 days after fertilization. Two storms of simulated rainfall @ 2.5 in/hr for 1-hr (30-yr return frequency), second simulated rainfall followed initial simulated rainfall by 24 hr. Runoff water samples taken at 3-minute or less intervals.	A second year rainfall simulation of only the first storm event parameters was conducted and included a plow-disk-surface broadcast P fertilizer treatment, but not a plow-surface broadcast P fertilizer-disk treatment. The plow-disk-surface broadcast P fertilizer treatment had significantly greater P loss than other treatments and suggests that surface broadcast P fertilizer on a fine tilled surface can result in high P loss and incorporation reduces P loss on initially tilled soil. However, due to this unbalanced treatment design, only the first year of results are shown. Authors attributed reductions in P loss to reduced runoff and sediment loss from a greater water infiltration rate created by tillage. However, over a greater period of time, surface sealing may reduce water infiltration rates and lead to greater P loss. This potential effect was not accounted for under the limited time period of data collection.
						First Rainfall <u>Simulation</u> Plow-surface broadcast P-disk incorporation	0.03 lb/a SP+BP1-STP	–		
						Surface broadcast P-plow-disk incorporation	0.02 lb/a SP+BP1-STP	33.3%		
						Plow-surface broadcast without incorporation	<0.01 lb/a SP+BP1-STP	> 66.7%		
						Plow-disk-no P fertilizer (control)	0.01 lb/a SP+BP1-STP	66.7%		
						Second Rainfall <u>Simulation</u> Plow-surface broadcast P-disk incorporation	0.28 lb/a SP+BP1-STP	–		
						Surface broadcast P-plow-disk incorporation	0.21 lb/a SP+BP1-STP	25.0%		
						Plow-surface broadcast without incorporation	0.10 lb/a SP+BP1-STP	64.3%		
						Plow-disk-no P fertilizer (control)	0.16 lb/a SP+BP1-STP	42.8%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Johnson et al., 1979 Incorpor-ated vs. surface application	Castana, IA, US; Loess Hills, Monona-Ida-Napier soils	4-yr	Small watershed, treatment areas ranging in size from 1.4-4.3 a	CC with rows perpen-dicular to predomin-ant slope direction.	Surface runoff		4-yr flow-weighted average DRP concentrations		Runoff flow monitored from mid-April to mid-October each yr.	Varied forms of P were measured inconsistently during the 4-yr study, not allowing for a comprehensive evaluation.
						RT, surface broadcast P	0.73 ppm DRP	–	Number of runoff water samples varied depending upon the duration of natural precipitation events. Typically 3-4 samples taken per event, but up to 6 for longer duration events.	
				P fertilizer applied in spring before any tillage operations at rate of 33 lb/a/yr P.		Disk incorporated P	0.50 ppm DRP	31.5%		Reduced DRP concentrations with increased mixing of P fertilizer with soil and placement below the thin surface mixing zone.
						Disk-Plow-Disk incorporated P	0.18 ppm DRP	75.3%		
							Yr-2 sediment-P			
						RT, surface broadcast P	2030 ppm sediment-P	–		Reduced sediment-P concentrations with increasing surface residue cover and decreased tillage disturbance of surface soil.
						Disk incorporated P	2910 ppm sediment-P	-43.3%	Each watershed was cultivated once during the mid-growing season.	
						Disk-Plow-Disk incorporated P	2090 ppm sediment-P	-3.0%	Yr 1 had 2-4 times more runoff for the watersheds compared to 4-yr averages.	

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Baker and Laflen, 1982 **Incorpor-ated vs. surface application**	Central IA, US; Clarion sandy loam soil with 5% slope.	1-day rainfall simula-tions	Plot	Tilled soil with varied levels of corn residue cover and fertilizer place-ment methods @ 25 lb/a P rate.	Surface runoff		DRP Concentration and mass loss		All plots were disk tilled and 2 in water applied 1 week prior to rainfall simulations. P and N fertilizers and varied levels of corn residue applied 1 day prior to rainfall simulations. Rainfall simulation at 2.5 in/hr for 2 hrs and 10-11 runoff water samples and flow measures taken per plot. Rainfall simulation supply water had a 0.13 ppm DRP concentration.	Authors pointed out that the 0.31ppm DRP concentration of the rainfall simulation water was adsorbed by soil and possibly residue in control plots. Less DRP adsorption may have occurred for the higher residue plots due to lower sediment erosion and mixing with dislodged sediments. Runoff and sediment erosion increased with decreased surface corn residue levels. Significantly greater DRP concentration and mass loss with added P fertilizer both above and below surface corn residue compared to no added P fertilizer.
						0 lb/a corn residue, P fertilizer surface broadcast	1.65 ppm DRP 0.76 lb/a DRP	_ _		
						0 lb/a corn residue, P fertilizer point-injected 2 in depth	0.17 ppm DRP 0.11 lb/a DRP	89.7% 85.5%		
						0 lb/a corn residue, no P fertilizer	0.18 ppm DRP 0.11 lb/a DRP	89.1% 85.5%		
						334 lb/a corn residue, P fertilizer broadcast above residue	1.69 ppm DRP 0.76 lb/a DRP	-2.4% 0.0%		
						334 lb/a corn residue, P fertilizer broadcast below residue	1.58 ppm DRP 0.72 lb/a DRP	4.2% 5.3%		
						334 lb/a corn residue, no P fertilizer	0.18 ppm DRP 0.11 lb/a DRP	89.1% 85.5%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Baker and Laflen, 1982 (cont.) **Incorpor-ated vs. surface application**	Central IA, US; Clarion sandy loam soil with 5% slope.	1-day rainfall simula-tions	Plot	Tilled soil with varied levels of corn residue cover and fertilizer place-ment methods @ 25 lb/a P rate.	Surface runoff		DRP Concentration and mass loss		- See above -	(cont.) There were no significant differences between P fertilizer placement above and below corn residue for both runoff DRP concentration and mass loss. Point-injection of P fertilizer did not increase runoff DRP mass loss nor concentration compared to no P fertilizer application.
						668 lb/a corn residue, P fertilizer broadcast above residue	1.40 ppm DRP 0.48 lb/a DRP	15.2% 36.8%		
						668 lb/a corn residue, P fertilizer broadcast below residue	1.47 ppm DRP 0.55 lb/a DRP	10.9% 27.6%		
						668 lb/a corn residue, no P fertilizer	0.26 ppm DRP 0.12 lb/a DRP	84.2% 84.2%		
						1335 lb/a corn residue, P fertilizer broadcast above residue	1.32 ppm DRP 0.28 lb/a DRP	20.0% 63.2%		
						1335 lb/a corn residue, P fertilizer broadcast below residue	1.28 ppm DRP 0.12 lb/a DRP	22.4% 84.2%		
						1335 lb/a corn residue, no P fertilizer	0.26 ppm DRP 0.04 lb/a DRP	84.2% 94.7%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Eghball and Gilley, 1999 **Incorpor-ated vs. surface application**	Lancaster Co., NE, US; Sharpsburg silty clay loam with slopes ranging from 4%-9%.	2-day rainfall simula-tions	Plot	NT and DT[17] sorghum and wheat residue spring conditions prior to planting. Varied P rate application treatments of dry beef cattle manure, composted beef cattle manure and inorganic commercial fertilizer. DT fertilizer P incorpor-ated at 3 in depth. NT fertilizer P applied to soil surface, no incorp-oration.	Surface runoff		Runoff concentration and mass loss of DRP, BAP, PP[18] and TP		Initial rainfall simulation at existing soil moisture (dry run), 2.5 in/hr for 1-hr period. Second rainfall simulation (wet run) 24-hr after initial simulation, 2.5 in/hr for 1-hr period. Runoff water samples were taken every 5 minutes for chemical analyses. Runoff flow continuously measured to determine total volume.	Significantly reduced DRP and BAP runoff concentration and mass loss with tillage incorporation of fertilizer P sources, placing P below the thin surface mixing zone. Significantly reduced PP and TP mass loss – and often concentrations - from NT surface application of fertilizer P sources during the wet simulation run, attributed to reduced sediment erosion from greater protective surface residue cover. There were significant interactions between tillage and fertilizer source and rate treatments. Crop P-based application rates of manure and compost seem to be agronomically and environmentally sound, best management practices. (cont.)
						Initial (dry run) rainfall simulation, <u>Sorghum Residue</u> NT, surface application	2.50 ppm DRP 0.31 lb/a DRP 3.39 ppm BAP 0.41 lb/a BAP 7.60 ppm PP 0.96 lb/a PP 10.10 ppm TP 1.28 lb/a TP	_ _ _ _ _ _ _ _		
						DT, incorporated application	0.28 ppm DRP 0.04 lb/a DRP 1.30 ppm BAP 0.13 lb/a BAP 10.50 ppm PP 0.99 lb/a PP 10.80 ppm TP 1.01 lb/a TP	88.8% 87.1% 61.6% 68.3% -38.2% -3.1% -6.9% 21.1%		
						Second (wet run) rainfall simulation, <u>Sorghum Residue</u> NT, surface application	1.05 ppm DRP 0.32 lb/a DRP 2.06 ppm BAP 0.61 lb/a BAP 5.50 ppm PP 1.61 lb/a PP 7.30 ppm TP 1.94 lb/a TP	_ _ _ _ _ _ _ _		
						DT, incorporated application	0.26 ppm DRP 0.08 lb/a DRP 1.15 ppm BAP 0.33 lb/a BAP 9.70 ppm PP 2.74 lb/a PP 10.00 ppm TP 2.82 lb/a TP	79.0% 75.0% 44.2% 45.9% -76.4% -70.2% -37.0% -45.4%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Eghball and Gilley, 1999 (cont.) **Incorpor-ated vs. surface application**	Lancaster Co., NE, US; Sharpsburg silty clay loam with slopes ranging from 4%-9%.	2-day rainfall simula-tions	Plot	NT and DT[17] sorghum and wheat residue spring conditions prior to planting. Varied P rate application treatments of dry beef cattle manure, composted beef cattle manure and inorganic commercial fertilizer. DT fertilizer P incorpor-ated at 3 in depth. NT fertilizer P applied to soil surface, no incorp-oration.	Surface runoff	Initial (dry run) rainfall simulation, <u>Wheat Residue</u>	Runoff concentration and mass loss of DRP, BAP, PP[18] and TP		- See above -	(cont.) Runoff DRP and BAP concentrations from crop N-based manure and compost programs were significantly greater than concentrations from crop P-based application rates for NT, but not DT. DRP and BAP concentrations tended to decrease with time after initiation of runoff. Authors stated that P losses from manure and compost will be longer and possibly larger than inorganic commercial P fertilizer due to the greater P loads applied with manure and compost. Greater sediment losses and TP runoff concentrations from sorghum compared to wheat. DRP accounted for 91% of BAP, indicating its importance in causing water impairments.
						NT, surface application	3.76 ppm DRP 0.31 lb/a DRP 4.21 ppm BAP 0.35 lb/a BAP 0.70 ppm PP 0.16 lb/a PP 4.50 ppm TP 0.35 lb/a TP	_ _ _ _ _ _ _ _		
						DT, incorporated application	0.18 ppm DRP 0.02 lb/a DRP 0.43 ppm BAP 0.04 lb/a BAP 5.60 ppm PP 0.51 lb/a PP 5.80 ppm TP 0.52 lb/a TP	95.2% 93.5% 89.8% 88.6% -700.0% -218.8% -28.9% -48.6%		
						Second (wet run) rainfall simulation, <u>Wheat Residue</u>				
						NT, surface application	1.39 ppm DRP 0.30 lb/a DRP 1.59 ppm BAP 0.35 lb/a BAP 2.30 ppm PP 0.52 lb/a PP 3.70 ppm TP 0.83 lb/a TP	_ _ _ _ _ _ _ _		
						DT, incorporated application	0.18 ppm DRP 0.06 lb/a DRP 0.48 ppm BAP 0.17 lb/a BAP 7.00 ppm PP 2.50 lb/a PP 7.20 ppm TP 2.56 lb/a TP	87.0% 80.0% 69.8% 51.4% -204.3% -380.8% -94.6% -208.4%		

1 Watershed, field, plot or laboratory.
2 CC represents continuous corn rotation.
3 CP represents chisel plow, followed by secondary tillage.
4 ST represents shallow tillage.
5 NT represents no-tillage.
6 BAP represents biologically available phosphorus.
7 TP represents total phosphorus.
8 DRP represents dissolve reactive phosphorus.
9 C1 represents control 1 and comparison to control 1 for subsequent treatments.
10 C2 represents control 2 and comparison to control 2 for subsequent treatments.
11 C3 represents control 3 and comparison to control 3 for subsequent treatments.
12 C4 represents control 4 and comparison to control 4 for subsequent treatments.
13 RT represents ridge tillage.
14 SP represents soluble phosphorus.
15 MP represents moldboard plow tillage with two secondary field cultivation operations.
16 BP1-STP represents Bray P1 soil test phosphorus.
17 DT represents disk tillage.
18 PP represents particulate phosphorus.

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Conservation Practice Summary Assessment

Contaminant: **Total P**

Type of Strategy: **Preventive**

Strategy Name: **P Nutrient Timing and Rate Management**

Pollutant reduction mechanisms

- Dilution
- Improved balance of nutrient application rate with crop demand
- Improved synchronization of nutrient fertilizer availability with crop demand
- Reduced applied nutrient load
- Reduced soluble nutrient fraction within runoff water

Applicable conditions

- All land where commercial inorganic fertilizer and/or manure P nutrients are applied

Limiting conditions

- Spring, late-spring or early summer time periods may have soil conditions that are too wet for equipment trafficking
- Any conditions that limit crop growth (i.e., drought, flooding, disease and insect damage) may reduce crop P uptake, which then could result in an unexpected over-application of P nutrients from applications done prior to the crop growing season
- Unexpected rainfall runoff events soon after application of P nutrients

Range of variation in effectiveness at any given point in time

Soil-test P rate balanced to crop use vs. high and excessive P rate: 0% to +95%
Seasonal timing of application, early/late spring vs. late fall: <-100% to +100%
Rainfall runoff event timing after application, 1-month vs. 1-day: 0% to +95%

Effectiveness depends on:

- Crops grown and P exported from harvested biomass
- Difference in P nutrient rate from previous to conservation practice methods
- Difference in P nutrient seasonal timing of application from previous to conservation practice methods
- Existence or absence of other conservation practices
- Field tillage program and resulting amount of surface residue cover
- Form of P nutrients applied, commercial inorganic fertilizer vs. manure fertilizer
- Frequency of P applications
- Intensity, quantity, duration and timing of succeeding rainfall and snowmelt events

- Method of application (surface broadcast, full-field tillage, or injection)
- Slope and slope length
- Soil moisture content at time of P application and the next precipitation event
- Soil type, texture, structure, cation exchange capacity and water infiltration rate
- Soil's P adsorption capacity and/or saturation state
- Soil's P content measured by either agronomic soil test P availability indices or environmental P availability tests

Estimated potential contaminate reduction for applicable areas within Iowa (annual basis)

Soil-test P rate balanced to crop use vs. high and excessive P rate: +35% to +50%
Seasonal timing of application, early/late spring vs. late fall: -25% to +95%
Rainfall runoff event timing after application, 1-month vs. 1-day: +25% to +40%

While P is thought to be an immobile nutrient, some studies, particularly in the eastern United States, reveal that extreme over application of P can substantially increase concentrations in subsurface drainage water in some areas. Iowa research has shown that for soils having up to four times the optimum P range, soil P levels have no effect on concentrations in subsurface drainage and that concentrations are relatively low compared to those found in runoff. Recent studies by Drs. Jim Baker and Antonio Mallarino have shown even with high P concentration additions that lateral drainage flow through a typical low P content Iowa subsoil causes much of the added P to be adsorbed to the subsoil, resulting in low P concentrated drainage being discharged from field tiles. Risk of significant P loss through subsurface drainage increases though with soils of low P sorption capacity and shallow fractured bedrock. Sand lenses close to the surface that are common in flood plains and glacial till hilltops areas and the karst topography of northeast Iowa are examples of these two situations, respectively, in Iowa.

Subsurface drainage is typically a small contributing fraction of the total nonpoint source P load entering surface waters compared to runoff. Runoff has repeatedly shown to be the greatest source of P loss to surface waters due to its transport of surface sediments enriched with P. Therefore, maintaining soil-P at optimum levels for crop production can reduce P concentrations and loads in runoff. For common sense purposes, the most practical aspect of P rate effects on P loss would be to focus on the comparison of P managed at the optimum level for crop production (which has been identified with several indices and soil tests) vs. a range of P rates and soil-P test levels above the optimum range.

The seasonal timing of P nutrient applications can also impact off-field transport of P. If commercial P fertilizer or manure is applied on frozen soils, or shortly before soils freeze, there is a high risk of P loss with later snowmelt events. This is especially true for fields of considerable slope and lacking proper conservation tillage, buffers and waterways. A change from late fall or frozen soil seasonal application to late spring improves the probability that the added P will adsorb to soil particles. If other conservation practices are in place to reduce erosion, such a change in seasonal timing of application will be even more effective. Several studies have reported that a more important aspect of P application timing is the period from application to the next rainfall event, regardless of season.

As the time period increases between P fertilizer application and a succeeding rainfall event, P has more time to react with and be adsorbed to soil particles, and then a lesser chance for P loss. If a rainfall runoff event occurs within hours or a day or two of application, high losses of P have repeatedly been documented. Managing the time of P application by weather forecasts that are favorable for dry conditions results in greater soil adsorption, then reducing P loss. The probability of runoff occurring from a rainfall event is also affected by the event's intensity and quantity, and antecedent soil moisture content. If P application can be timed during a dry period, then the next rainfall has a lesser probability of generating runoff since the soil will have a greater water infiltration rate and capacity to store water than if the soil moisture content was higher. Runoff may still occur even with relatively dry soil if the rainfall event is of sufficient intensity, duration and quantity that exceed the soil water infiltration rate.

The effects on P loss reduction from managing the P application timing and rate can greatly interact with the form of P added and method in which it is applied. Many studies have found that manures lose less P than comparable application rates and timings of commercial inorganic P fertilizer forms. Scientists have attributed this to the following effects: higher solubility of inorganic fertilizer P compared to manure P; and reduced sediment erosion from manure additions due to increased soil organic matter adsorption of P, soil particle aggregation, aggregate stability and water infiltration rates. General methods of P application or placement include surface broadcasting, full-field tillage incorporation and injection in narrow strips with knives or point-injectors (P nutrient fertilizer application techniques are addressed in their own assessment summary). As these methods relate to P timing and rate, even at a low P rate losses can be significant if the P fertilizer is left on the surface of a highly erodable and/or runoff prone environment, which can be exacerbated by aggressive tillage incorporation of P fertilizer. The potential for P loss with incorporation vs. surface broadcast application depends upon the balance between the degree of soil disturbance, placement of P below the soil surface, soil aggregate stability, and sheltering effects of surface residue.

Landscape and other soil properties and characteristics can also interact with P application timing and rate in determining the amount of nonpoint source P contamination of surface waters. Slope, slope length, and soil texture are main factors that determine soil erodability. Any highly erodable soil would have a greater risk of P loss than a soil with low erodability at the same P application rate. Also, soils with high clay content have a high potential to adsorb added P. But as the P saturation level increases for any soil, even with high clay content, there is a greater risk for P loss to water resources with any added P fertilizer. Many research studies have documented increases of P loss from soils with increasing soil test P levels.

The amount of soil-P removed by a crop of course depends on the type of crop grown and what portion of the crop is exported with harvest. Annual grain crops will remove appreciably less soil-P than a forage crop where a majority of the shoot biomass is harvested 2-4 times each year. Managing P application with a state approved P Index will account for changes in soil-P levels, along with other factors that influence potential soil erosion losses such as the existence or absence of other needed conservation practices.

Estimated long-term contaminant reduction for applicable areas in Iowa (multi-year basis)

Soil-test P rate balanced to crop use vs. high and excessive P rate: +40%
Seasonal timing of application, early/late spring vs. late fall: +30%
Rainfall runoff event timing after application, 1-month vs. 1-day: +30%

Since P is very reactive with soil particles and most Iowa soils have an appreciably high buffering capacity, lowering soil-P test levels is a long-term process. The estimates for P loss reduction by managing P loading rates are based upon a comparison of differing fields, not any given single field. For a field with soil-P levels significantly above optimum levels for crop production, it may require decades without P fertilizer application to reduce the soil-P level to the optimum crop production range. Such fields may present long-term significant nonpoint source P pollution risks to surface waters, particularly if the area has considerable erosion and/or surface runoff.

Estimates of P loss reduction by altering the season of application are very general. Changing the season of application will have little benefit to reducing P losses if attention is not paid to weather patterns that can vary greatly by season from one year to another in Iowa. Rainfall events that generate runoff soon after a P nutrient application will cause significant P loss during any season. Utilizing additional conservation practices that reduce soil erosion and sediment transport to surface waters can greatly reduce the risk of P loss following application.

Extent of research

Limited

Like many other areas of crop nutrient research, most attention to timing and rate of application has focused on crop production aspects, not environmental impacts. Some research studies have provided information on P rate and time of application effects on water quality, but more needs to be known. The recent developments of the Iowa P Index, like many other state P indices, is still being evaluated for reducing nonpoint source P pollution of water resources. It may be common sense to accept that proper use of a P Index will result in implementation of practices to reduce P loss from fields, but this remains to be documented. It is important to know the long-term nonpoint source P pollution risks from fields that have extremely high soil-P concentrations due to long term over-application, particularly for the impacts on subsurface drainage.

Potential best management practices to resolve the problem (e. g., forage crop production and aluminum-based soil amendments), other than reducing or ending P application to such fields for a period of time, also need to be evaluated.

Secondary benefits

- Improved crop P nutrient use efficiency
- Improved farm profitability
- Reduced soil loss
- Reduced sediment loads in surface waters
- Reduced loss of sediment-bound chemicals

Conservation Practice Research Summary Table

Contaminant: Total P

Type of Strategy: Preventive

Strategy Name: P Nutrient Timing and Rate Management

References significant to Iowa identified in bold italics.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Schuman et al., 1973 **P Rate**	Deep Loess Research Station at Treynor, IA, US; Monona, Ida and Napier silt loam soils.	3-yr	Watershed W1[2] = 74a W2[3] = 81.5a W3[4] = 106a W4[5] = 148a	CC[6] and Rotational Grazing of Bromegrass Pasture <u>Ave. Annual P Rates</u> W1, W4 = 86 lb/a, P incorporated W2, W3 = 35 lb/a P surface broadcast W1, W2 CC w contour planting W3 Bromegrass w Rotational Grazing W4 CC w level terraces	Surface runoff	W1 CC @ 86 lb/a P W2 CC @ 35 lb/a P	Annual ave. mass loss and 3-yr ave. concentration of SP[7] and sediment-P 0.15 lb/a SP 0.93 lb/a Sediment-P 0.22 ppm SP 31.14 ppm Sediment-P 0.10 lb/a SP 0.52 lb/a Sediment-P 0.17 ppm SP 29.04 ppm Sediment-P	_ _ _ _ 33.3% 44.1% 22.7% 6.7%	Minimum of 4 water samples per runoff event, being: initiation of runoff, increasing runoff flow rate, at runoff flow rate peak, at decline of runoff flow rate. P concentrations in snowmelt runoff were higher than runoff during other seasons.	Authors concluded that a higher P fertilization rate led to increased P loss since both mass and concentration losses increased with the applied P rate.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Burwell et al., 1977 **P Rate**	Deep Loess Research Station at Treynor, IA, US; Monona, Ida and Napier silt loam soils.	5-yr	Watershed W1 = 74a W2 = 81.5a W3 = 106a W4 = 148a	CC and Rotational Grazing of Bromegrass Pasture <u>Ave. Annual P Rates</u> W1 = 59 lb/a P W2 = 36 lb/a P W3 = 37 lb/a P W4 = 60 lb/a P W1, W2 CC w CT[8] contour planting W3 Bromegrass w Rotational Grazing yrs 1-3, CC w MT[9] contour planting yrs 4-5 W4 CC w CT and level terraces yrs 1-3, CC w MT and surface intake and outlet tiled terraces yrs 4-5	Surface runoff and subsurface leaching	Subsurface <u>Leaching</u> W1 @ 59 lb/a P W2 @ 36 lb/a P Surface <u>Runoff</u> W1 @ 59 lb/a P W2 @ 36 lb/a P Runoff <u>Sediment</u> W1 @ 59 lb/a P W2 @ 36 lb/a P Total Stream <u>Discharge</u> W1 @ 59 lb/a P W2 @ 36 lb/a P	Annual ave. mass loss of SP, sediment-P, & TP[10] 0.04 lb/a SP 0.03 lb/a SP 0.13 lb/a SP 0.11 lb/a SP 0.68 lb/a sediment-P 0.40 lb/a sediment-P 0.85 lb/a TP 0.54 lb/a TP	– 25.0% – 15.4% – 41.2% – 36.5%	Yr 4 had 22% more precipitation than the 10-yr annual ave.	P loss was reduced with the recom-mended P rate used for W2 compared to excessive P rate required for corn production used on W1. For W1 and W2 combined, 82% of surface runoff P loss was transported with sediment. Thus controlling erosion would significantly reduce P loss from this pathway.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Klatt et al., 2003 **Soil Test P Level**	Clear Lake watershed, north-central IA, US; Clarion-Nicollet-Webster soil association, loam to silty-clay-loam, 80% of area <5% slope, small areas with slopes up to 14-18%, ≤2% slope areas tile drained.	2-yr	Watershed Watershed land to lake area ratio of 2.3:1 Sub-basins (SB[11]) delineated for tributaries draining into Clear Lake and sampled separately for soil and water data.	Watershed land use: 59% agriculture (predominately CS[12] rotation), 14% small urban, 27% woodland + non-ag grassland + wetlands. Watershed field management characteristics 58% chisel plow, 24% moldboard plow, 11% ridge till, 2% no-till; 47% P fertilizer fall applied with incorporation, 25% fall applied surface broadcast without incorporation, 15% spring applied P with incorporation. Percentages vary by SB, however. Mean annual P rate for entire watershed agricultural fields at 13.4 lb P/a/yr.	Surface runoff, artificial subsurface tile drainage and base flow combined	 35 ppm M3P[13] STP[14], VH[15] 25 ppm M3P STP, H[16] 18 ppm M3P STP, O[17] 12 ppm M3P STP, L[18] 4 ppm M3P STP, VL[19]	Mean annual stream TP concentration from linear regression equations derived from this study's data (Y = 55 + 7.7X) 0.325 ppm TP 0.248 ppm TP 0.194 ppm TP 0.148 ppm TP 0.086ppm TP	 – 23.7% 40.3% 54.5% 73.5%	Soil samples to determine P levels collected during mid-portion of the study. Grab samples of surface water discharge to lake taken at 15-day intervals from April-Sept., 30-day intervals Oct.-Mar. Trained volunteers collected storm event samples. In total, 42 samplings taken during baseflow conditions, 15 samples from storm events. Water volume discharge measured continuously at 2 locations with flow meters. Yr 1 had 49% greater than annual average rainfall, yr 2 was 14% less than average.	Decreased P loss with decreased available soil-P. The derived equation suggests that the mean annual surface water discharge to the lake would be 0.178-0.331 ppm TP from soils managed in the optimum crop yield soil test P range, which is above typical eutrophication limits (0.1-0.15 ppm TP). Surface water TP concentra-tions increased linearly with increasing STP. This suggests that managing soils with a P index and practices to reduce soil erosion should improve water quality. Mean storm event TP concentrations were 0.748 ppm, snowmelt event samples averaged 1.10 ppm TP.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Klatt et al., 2002 Soil Test P Level	Central and northeast IA, US; Marshall, Nicollet, Fayette, and Tama soils. One field trial with natural rainfall, one laboratory rainfall simulation, one outdoor rainfall simulation.	1-yr	Plot and micro-plot	CS for field trials, bare soil for laboratory trial	Surface runoff		Loss concentr-ations of TP, DRP[20] BAP[21] and TDP[22] from derived regression equations		Laboratory rainfall simulations ran for 70 minutes. Field rainfall simulation at 2.5 in/hr, with runoff sampled for 30 minutes. Field study with natural rainfall had surface runoff and subsurface leaching measured, with tile flow measured every week during flow.	Decreased P loss with decreased available soil-P. Simulations suggest that if STP levels are managed to remain in the optimum range for crop production, then BAP and DRP losses may be at or below concentrations that may cause eutrophication of surface waters.
						Natural Rainfall @ 80 ppm M3P STP	1.02 ppm TDP 2.16 ppm TP	_ _		
						Natural Rainfall @ 20 ppm M3P STP	0.30 ppm TDP 0.96 ppm TP	70.6% 55.6%		
						Lab Rainfall Simulation @ 200 ppm M3P STP	0.47 ppm DRP 0.76 ppm BAP	_ _		
						Lab Rainfall Simulation @ 100 ppm M3P STP	0.27 ppm DRP 0.46 ppm BAP	42.5% 39.5%		
						Lab Rainfall Simulation @ 20 ppm M3P STP	0.11 ppm DRP 0.22 ppm BAP	76.6% 71.0%		
						Field Rainfall Simulation @ 140 ppm M3P STP	0.13 ppm DRP	_		
						Field Rainfall Simulation @ 60 ppm M3P STP	0.05 ppm DRP	61.5%		
						Field Rainfall Simulation @ 20 ppm M3P STP	0.01 ppm DRP	92.3%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Bundy et al., 2001 P Rate	Arlington and Madison, WI, US; silt loam soils	One-day rainfall simul-ations	Plot scale	CC with varied P rates from inorganic and manure fertilizers	Surface runoff	P rates are totals for the entire indicated periods <u>Arlington Site</u> 176 lb/a inorganic P applied over 4-yr period 80 lb/a inorganic P applied over 4-yr period 0 lb/a inorganic P applied <u>Madison Site</u> 739 lb/a organic biosolids P applied, annual applications over 5 yr period 295 lb/a organic biosolids P applied in 2 yr over 5 yr period 392 lb/a dairy manure P applied, annual applications over 5 yr period 0 lb/a organic P applied	BAP total mass loss and concentr-ation in runoff 0.40 lb/a BAP 0.25 ppm BAP 0.41 lb/a BAP 0.30 ppm BAP 0.19 lb/a BAP 0.10 ppm BAP 0.99 lb/a BAP 0.38 ppm BAP 0.44 lb/a BAP 0.15 ppm BAP 0.40 lb/a BAP 0.74 ppm BAP 0.19 lb/a BAP 0.06 ppm BAP	– – -2.4% -20.0% 52.5% 60.0% – – 55.6% 60.5% 59.6% -94.7% 80.8% 84.2%	Rainfall applied at 3.0 in/hr rate, being a 50-yr recurrence interval event. Runoff water samples collected for 1 hr after onset of runoff, and runoff volume measured.	Generally, decreased P loss with decreased P load applied. P applications, regardless of the fertilizer source, increase P loss, particularly when P additions exceed crop demand. Greater P losses with lower inorganic P rate were due to greater sediment erosion from that treatment's plots. Manure, having a high organic matter content, improved infiltration, which reduced runoff and sediment-P loss. BAP losses increased with increasing surface residue, but TP losses were 3-40 times greater than DRP losses with intensive tillage.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Tabbara, 2003 Manure and Inorganic P Rate	Near Ames, IA; US; Terril sandy loam. Site was terraced and plot areas had average slopes from 6.6-7.6%.	1-day in late July	Plot, rainfall simula-tion	Tilled fallow, CS in prior years. No fertilizer in previous 4 yrs. Practices <u>Contrasted</u> Surface Broadcast vs. Disk incorporation Liquid Swine Manure vs. Inorganic Fertilizer High TP Rate vs. Lower TP Rate	Surface runoff	Surface <u>Broadcast</u> Inorganic Fertilizer, 158 lb/a TP (C1[23]) Liquid Swine Manure, 121 lb/a TP (C2[24]) Inorganic Fertilizer, 74 lb/a TP Liquid Swine Manure, 62 lb/a TP	Flow-weighted concentration and mass loss of BAP and TP 35.18 ppm TP 21.37 lb/a TP 13.64 ppm BAP 7.37 lb/a BAP 18.77 ppm TP 9.94 lb/a TP 6.89 ppm BAP 3.65 lb/a BAP 17.76 ppm TP 11.36 lb/a TP 9.23 ppm BAP 5.90 lb/a BAP 9.18 ppm TP 5.12 lb/a TP 2.93 ppm BAP 1.64 lb/a BAP	_ _ _ _ 46.6% C1 53.5% C1 49.5% C1 50.5% C1 49.5% C1; 5.4% C2 46.8% C1; -14.3% C2 32.3% C1; -40.0% C2 83.2% C1; -61.6% C2 73.9% C1; 51.1% C2 76.0% C1; 48.5% C2 78.5% C1; 57.5% C2 77.7% C1; 55.1% C2	Manure and inorganic fertilizer applied 24 hr prior to the rainfall simulation measures. Plots had weeds mowed, then disked one month prior to rainfall simulations. Rainfall simulation intensity at 2.5 in/hr for 90 minutes, being a 50-yr recurrence event. Six to eight flow rate measures and chemical samples taken for each plot rainfall simulation.	Runoff volume and P loss were reduced with disk incorporation compared to surface broadcast. *However, author did not report if a surface seal had developed in the broadcast treatment plots due to previous tillage. Results could differ for broadcast if applied to long-term no-till soil or other conditions that typically have good to high infiltration rates.* Manure and inorganic fertilizer P placed below the thin mixing zone of runoff solution with soil at the surface and increased P adsorption to the soil. The amount (from P loading rate) and availability of P was more important than tillage disturbance in P losses under the tilled, bare soil conditions of this experiment.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Tabbara, 2003 (cont.)	Near Ames, IA; US; Terril sandy loam. Site was terraced and plot areas had average slopes from 6.6-7.6%.	1-day in late July	Plot, rainfall simula-tion	Tilled fallow, CS in prior years. No fertilizer in previous 4 yrs. Practices <u>Contrasted</u> Surface Broadcast vs. Disk incorporation Liquid Swine Manure vs. Inorganic Fertilizer High TP Rate vs. Lower TP Rate	Surface runoff	Disk <u>Incorporation</u> Inorganic Fertilizer, 158 lb/a TP Liquid Swine Manure, 121 lb/a TP Inorganic Fertilizer, 74 lb/a TP Liquid Swine Manure, 62 lb/a TP	Flow-weighted concentration and mass loss of BAP and TP 18.36 ppm TP 9.46 lb/a TP 6.11 ppm BAP 3.15 lb/a BAP 12.39 ppm TP 5.76 lb/a TP 2.53 ppm BAP 1.17 lb/a BAP 12.51 ppm TP 6.29 lb/a TP 3.43 ppm BAP 1.73 lb/a BAP 9.39 ppm TP 4.70 lb/a TP 1.90 ppm BAP 0.95 lb/a BAP	47.8% C1 55.7% C1 55.2% C1 57.2% C1 64.8% C1; 34.0% C2 73.0% C1; 42.0% C2 81.4% C1; 63.3% C2 84.1% C1; 67.9% C2 64.4% C1; 33.4% C2 70.6% C1; 36.7% C2 74.8% C1; 50.2% C2 76.5% C1; 52.6% C2 73.3% C1; 50.0% C2 78.0% C1; 52.7% C2 86.1% C1; 72.4% C2 87.1% C1; 74.0% C2	-See above-	Higher solubility of inorganic P fertilizer led to greater P loss compared to manure. The BAP:TP ratio is an indicator of long-term pollution potential, which was lower for manure compared to inorganic P fertilizer. The DRP:BAP ratio, however, was higher for manure, which is an indicator of a greater risk of short-term eutrophication potential. Sediment loss and P enrichment of sediment was lower for manure. This was attributed to soil aggregates than absorbed manure being less erodable and adsorbing greater P than from the inorganic P fertilizer source.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Edwards and Daniel, 1993	Fayetteville, AR, US; Captina silt loam soil	1-day	Plot, rainfall simula-tion	Fescue pasture with grass height of approximately 4 in. Two manure application rates: Low, 193 lb/a TN[25], 16.9 lb/a TP; High, 387 lb/a TN, 33.8 lb/a TP Two rainfall application rates: 2 in/hr, 4 in/hr	Surface runoff		Mean concentra-tion and mass loss of DRP and TP		Rainfall simulation applied 24 hr after swine manure slurry applications and lasted for ½ hr after initiation of runoff. Water samples taken every 5 minutes during runoff.	Decreased P losses with decreased P rate because of lesser availability of manure P constituents with lower manure rate. Higher rainfall volume from higher intensity rate decreased concentrations due to dilution effects (little difference in mass loss between the two differing manure loading rates). P losses increased linearly with increased manure loading rate.
						4 in/hr rainfall <u>intensity</u> High Manure Rate	13.9 ppm DRP 4.0 lb/a DRP 15.8 ppm TP 4.6 lb/a TP	– – – –		
						Low Manure Rate	8.0 ppm DRP 2.0 lb/a DRP 9.5 ppm TP 2.5 lb/a TP	42.4% 50.0% 39.9% 45.6%		
						No Manure	0.9 ppm DRP 0.2 lb/a DRP 1.0 ppm TP 0.2 lb/a TP	93.5% 95.0% 93.7% 95.6%		
						2 in/hr rainfall <u>intensity</u> High Manure Rate	29.4 ppm DRP 4.3 lb/a DRP 29.7 ppm TP 4.3 lb/a TP	– – – –		
						Low Manure Rate	11.9 ppm DRP 1.3 lb/a DRP 11.9 ppm TP 1.3 lb/a TP	59.5% 69.8% 59.9% 69.8%		
						No Manure	0.8 ppm DRP 0.0 lb/a DRP 1.1 ppm TP 0.0 lb/a TP	97.3% 100.0% 96.3% 100.0%		

Reference	Location, Site Notes	Time Period of Experi -ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
van Es et al., 2004 Seasonal Timing of Manure Application	Willsboro, NY, US; Muskellunge clay loam and Stafford loamy fine sand soils	3-yr	Plot	CC and Orchardgrass pasture at varied manure TP rates, and seasonal timings of applications. Small rates of P added to corn with starter fertilizer at planting and included in overall TP rate of application.	Subsurface leaching	Clay Loam Corn Early Fall, Ave. 74.5 lb/a TP Late Fall, Ave. 71.2 lb/a TP Early Spring, Ave. 64.4 lb/a TP Early + Late Spring, Ave. 68.8 lb/a TP Grass Early Fall + Late Spring, Ave. 54.3 lb/a TP Early + Late Spring, Ave. 49.2 lb/a TP	3-yr flow-weighted mean TP concentration 0.609 ppm TP 0.266 ppm TP 0.284 ppm TP 0.289 ppm TP 1.441 ppm TP 0.194 ppm TP	_ 56.3% 53.4% 52.5% _ 86.5%	Manure application were disk incorporated within 3 hr of application for corn, except for sidedressing that used cultivation instead. Manure application to grass was surface broadcast. Water chemistry samples taken 39 times, and always following manure application. (cont.)	Authors stated "the 39-fold higher leaching loss (of TP) indicates that the well-structured clay loam poses a much greater environmental concern for P leaching than the loamy sand soil". TP losses were negligible prior to the first manure application for the clay loam soil. Early fall manure application on clay loam resulted in more than X2 the losses of the other application timings for corn. TP losses increased more than X7 by applying a portion of manure to grass in the fall vs. only in the spring. Both early fall application for corn and early fall + late spring application for grass were significantly greater than other timings, with no significant differences among the other timings.

Reference	Location, Site Notes	Time Period of Experi -ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
van Es et al., 2004 (cont.) Seasonal Timing of Manure Application	Willsboro, NY, US; Muskellunge clay loam and Stafford loamy fine sand soils	3-yr	Plot	CC and Orchardgrass pasture at varied manure TP rates, and seasonal timings of applications. Small rates of P added to corn with starter fertilizer at planting and is included in overall TP rate of application.	Subsurface leaching	Loamy <u>Sand</u>	3-yr flow-weighted mean TP concentration		Overall ave. growing season precipitation was 11.4 in, but second growing season received approxim-ately 1/3 of precipitation of other 2 growing seasons. Winter period's ave. precipitation was 12.4 in., but varied by 16.8 in for first winter, 9.8 in for second winter, and 15.6 in for third winter.	Authors attributed greater TP leaching in clay loam than loamy sand due to rapid chemical transport in the clay loam through preferential flow paths of the well-structured clay loam. The loamy sand having a greater degree of matrix flow. Fall surface application of manure on clay loam grass poses a significantly greater risk of TP leaching than all other treatments, apparently due to preferential flow TP transport compared to methods of incorporation and alternative application timings. TP losses were more related to timing and intensity of precipitation following application than by influence of seasons.
						<u>Corn</u> Early Fall, Ave. 74.5 lb/a TP	0.004 ppm TP	_		
						Late Fall, Ave. 71.2 lb/a TP	0.044 ppm TP	-1000.0%		
						Early Spring, Ave. 64.4 lb/a TP	0.009 ppm TP	-125.0%		
						Early + Late Spring, Ave. 68.8 lb/a TP	0.002 ppm TP	50.0%		
						<u>Grass</u> Early Fall + Late Spring, Ave. 54.3 lb/a TP	0.005 ppm TP	_		
						Early + Late Spring, Ave. 49.2 lb/a TP	0.029 ppm TP	-480.0%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Andraski et al., 2003 **Manure P Rate and Soil Test P Level**	Lancaster and Madison, WI, US; Plano (Madison) and Rozetta (Lancaster) silt loam soils, 3% slope at Madison, 6% slope at Lancaster.	1-day in May, and 1-day in Sept. at Lancaster; 1-day in June at Madison	Plot, rainfall simul-ations	CP[26] and NT[27] CC CT only at Madison. CT and NT at Lancaster Varied manure application histories: Madison, 78 lb/a manure P applied in spring with incorpor-ation; Lancaster, 70 lb/a manure P applied in spring, incorpor-ated in CT, surface applied in NT.	Surface runoff		Runoff concentration and mass loss of TP, BAP and DRP		Rainfall simulations applied at rate of 3 in/hr (a 50-yr event). All runoff collected from plots for 1-hr after initiation of runoff.	<u>Madison</u> DRP and BAP mass loss was significantly higher with 6-yr manure application treatment compared to others at Madison due to higher concentrations. TP losses did not significantly vary due to decreased loss of sediment with manure applications. Authors attributed this to increased soil organic matter and soil aggregate stability with manure. Significant linear increases of BAP and DRP concentrations in runoff with increasing BP1 STP. Also, DRP:TP and BAP:TP ratios increased with increasing BP1 STP, suggesting that managing STP to optimum crop production levels will reduce potential DRP and BAP losses.
						<u>Madison</u> CP CC, manure in yrs 1-6 of previous 7 years, 104 BP1 STP	1.57 ppm TP 3.55 lb/a TP 0.39 ppm BAP 0.88 lb/a BAP 0.25 ppm DRP 0.57 lb/a DRP	_ _ _ _ _ _		
						CP CC, manure in yrs 3 and 5 of previous 7 yrs, 42 BP1 STP	1.80 ppm TP 4.60 lb/a TP 0.23 ppm BAP 0.57 lb/a BAP 0.12 ppm DRP 0.29 lb/a DRP	-14.6% -29.6% 41.0% 35.2% 52.0% 49.1%		
						CP CC, manure in yrs 2 and 4 of previous 7 yrs, 33 ppm BP1 STP	1.72 ppm TP 4.57 lb/a TP 0.20 ppm BAP 0.52 lb/a BAP 0.10 ppm DRP 0.25 lb/a DRP	-9.6% -28.7% 48.7% 40.9% 60.0% 56.1%		
						CP CC, no manure, 20 ppm BP1[28] STP	1.51 ppm TP 3.92 lb/a TP 0.13 ppm BAP 0.35 lb/a BAP 0.05 ppm DRP 0.13 lb/a DRP	6.0% -10.4% 66.7% 60.2% 80.0% 77.2%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Andraski et al., 2003 (cont.) **Manure P Rate and Soil Test P Level**	Lancaster and Madison, WI, US; Plano (Madison) and Rozetta (Lancaster) silt loam soils, 3% slope at Madison, 6% slope at Lancaster.	1-day in May, and 1-day in Sept. at Lancaster; 1-day in June at Madison	Plot, rainfall simul-ations	CP[26] and NT[27] CC CP only at Madison. CP and NT at Lancaster Varied manure application histories: Madison, 78 lb/a manure P applied in spring with incorpor-ation; Lancaster, 70 lb/a manure P applied in spring, incorpor-ated in CT, surface applied in NT.	Surface runoff	<u>Lancaster</u> CP CC + 5 yrs manure application	Runoff concentration and mass loss of TP, BAP and DRP 5.18 ppm TP 10.30 lb/a TP 0.74 ppm BAP 0.60 lb/a BAP 0.22 ppm DRP 0.44 lb/a DRP	_ _ _ _ _ _	Same as above for Madison, except showing Sept. data only, May simulation data incomplete.	<u>Lancaster</u> Manure application with CP did not affect runoff volume, but did decrease runoff volume 60% with the increasing surface residue of NT, suggesting that manure increased infiltration since soil organic matter remained unchanged. TP mass loss and concentration were significantly greater with CP compared to NT. Manure significantly increased TP concentration with CP, but not NT. BAP and DRP were not significantly increased with manure in NT due to reduced runoff volume from manure application. Significant linear relationships of DRP and BAP with CP as at Madison, but not with NT. Manure history did not correlate with TP mass losses due to reduced sediment loss with manure. NT with manure had less P loss than CP without manure.
						CP CC, no manure	3.39 ppm TP 7.82 lb/a TP 0.40 ppm BAP 0.93 lb/a BAP 0.11 ppm DRP 0.26 lb/a DRP	34.6% 24.1% 45.9% -55.0% 50.0% 40.9%		
						NT CC + 5 yrs manure application	1.57 ppm TP 0.83 lb/a TP 0.50 ppm BAP 0.22 lb/a BAP 0.39 ppm DRP 0.16 lb/a DRP	69.7% 91.9% 32.4% 63.3% -77.3% 63.6%		
						NT CC, no manure	1.06 ppm TP 1.21 lb/a TP 0.27 ppm BAP 0.29 lb/a BAP 0.20 ppm DRP 0.20 lb/a DRP	79.5% 88.2% 63.5% 51.7% 9.1% 54.5%		

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Sharpely, 1997 **P Application Timing**	10 differing soils from southeast OK, US; Cahaba very fine sandy loam, Captina sandy loam, Carnasaw fine sandy loam, Durant loam, Muskogee loam, Rexor silt loam, Ruston fine sandy loam, San Saba clay, Shermore fine sandy loam and Stigler silt loam soils.	1-35 days	Labor-atory, soil boxes inclined at 4% slope.	Fallow with incorporated poultry litter applied at 0.0 and 142 lb/a P, incubated from 1 – 35 days depending upon treatment.	Surface runoff	Rainfall Frequency <u>Effects</u> 142 lb/a manure P, 1st rainfall event 142 lb/a manure P, 10th rainfall event No manure P added, 1 rainfall event Rainfall Timing <u>Effects</u> 1-day following manure P application 35-days following manure P application	Average TP, DRP, BAP, and M3P STP concentrations from all 10 soils 1.50 ppm TP 0.65 ppm DRP 0.92 ppm BAP 0.64 ppm TP 0.18 ppm DRP 0.41 ppm BAP 0.22 ppm TP 0.02 ppm DRP 0.08 ppm BAP 169 ppm M3P STP 0.74 ppm DRP 121 ppm M3P STP 0.45 ppm DRP	_ _ _ 57.6% 72.4% 55.4% 85.0% 96.1% 91.6% _ _ 28.5% 38.9%	Rainfall applied at 1 in/hr intensity (a 5-yr event) for 30 minutes. Entire runoff volume collected for each simulated rainfall event. For rainfall frequency effects: soils incubated 7 days and 10 consecutive rainfall simulations ran at 1-day intervals. For rainfall timing effects: soils incubated from 1 – 35 days, then 5 consecutive rainfall simulations ran at 1-day intervals.	Potential for P runoff transport following manure application decreased with successive rainfalls. Increasing the time period between manure application and rainfall-runoff decreased P runoff concentrations and soil extractable P levels. More time for P to absorb to sediment. Time between manure application and rainfall has a greater effect on P enrichment from high P-sorbing soils than for low P-sorbing soils. DRP and BAP concentration from successive rainfall events was related to degree of P sorption saturation of soils. As P saturation increased, more P was released from soil to runoff solution, and a more rapid decrease in runoff-P occurred with successive rainfall events.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Römkens and Nelson, 1974 P Rate	IN (?), US; Russell silt loam soil	3 months, rainfall simulations	Plot	Fallow Inorganic P fertilizer added to bare soil and disk incorpor-ated prior to rainfall simulations.	Surface runoff	Runoff Solution 100 lb/a P fertilizer applied 50 lb/a P fertilizer applied Runoff Transported Sediment 100 lb/a P fertilizer applied 50 lb/a P fertilizer applied	Ave. runoff TP, BAP and PP[29] concentrations 0.44 ppm PP 0.24 ppm PP 461 ppm TP 57.6 ppm BAP 466 ppm TP 35.4 ppm BAP	_ 45.4% _ _ -1.1% 38.5%	Rainfall applied at rate of 2.5 in/hr for minimum of 1-hr for 5 simulated events over a 3 month period. Plots covered between simulations. Twelve runoff water samples taken per event. Initial sample at beginning of runoff, randomly sampled afterwards until termination.	Applied fertilizer P rate to PP and sediment extractable P was linear: P concentration in runoff increased with increasing fertilizer P rate. PP and sediment extractable P were not related to TP.
Westerman et al., 1985 P Rate	NC, US; Wagram and Norfolk loam soils.	6-yr	Plot	Coastal Bermuda-grass Surface irrigated application of manure effluent at varied rates	Surface runoff	Irrigated manure application rate of 320 lb/a/yr P Irrigated manure application rate of 160 lb/a/yr P Irrigated manure application rate of 80 lb/a/yr P	Ave. annual volume weighted concentration and mass loss of TP 5.3 ppm TP 3.4 lb/a TP 2.6 ppm TP 1.1 lb/a TP 1.9 ppm TP 0.8 lb/a TP	_ _ 50.9% 67.6% 64.2% 76.5%	Runoff measures from natural + irrigation events. Total surface water inputs were somewhat similar across years and treatments due to irrigation input management.	No significant differences by rate for TP mass loss. The high manure P rate did have significantly greater TP concentration in runoff than the lower 2 manure P rates. Reduced risk of P loss to surface water with reduced P loading rate.

Reference	Location, Site Notes	Time Period of Experi-ment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Sauer et al., 2000 P Rate	Savoy, AR, US; Nixa and Clarksville cherty silt loam soils.	1-day rainfall simulations in July	Plot	Grass Pasture Surface broadcast manure	Surface runoff		Ave. from 3 pasture sites of TP and DRP mass loss		Rainfall simulation applied 3 in/hr for a 1-hr period (a 25-yr return event). Poultry manure was surface broadcast applied approximately 1 month before rainfall simulations. During the month period 2.2 in of rainfall occurred on the plots.	Although percentage differences are relatively high, results were not significantly different for mass loss. However, concentrations (data not shown) were significantly greater for manure treated plots. This contrast due to reduced runoff from manured plots. Also, concentr-ations of DRP were similar between manured and non-manured plots that had similar STP levels. Authors indicated that this points to substantial water quality risks associated with allowing high P levels allowed to accumulate in shallow soil layers and the need to manage P so as to not apply P beyond crop and forage needs.
						Broadcast Manure at 57 lb/a P	0.34 lb/a TP 0.29 lb/a DRP	_ _		
						No Manure	0.18 lb/a TP 0.14 lb/a DRP	47.0% 51.7%		

1 Watershed, field, plot or laboratory.
2 W1 represents watershed 1.
3 W2 represents watershed 2.

4 W3 represents watershed 3.
5 W4 represents watershed 4.
6 CC represents continuous corn rotation.
7 SP represents soluble phosphorus.
8 CT represents conventional tillage.
9 MT represents mulch tillage.
10 TP represents total phosphorus.
11 SB represents sub-basin.
12 CS represents corn-soybean rotation.
13 M3P represents the Mehlich-3 soil phosphorus test procedure: Very Low = 0-8 ppm, Low = 9-15 ppm, Optimum = 16-20 ppm, High = 21-30 ppm, Very High = >30 ppm.
14 STP represents soil test phosphorus.
15 VH represents very high.
16 H represents high.
17 O represents optimum.
18 L represents low.
19 VL represents very low.
20 DRP represents dissolve reactive phosphorus.
21 BAP represents biologically available phosphorus.
22 TDP represents total dissolved phosphorus.
23 C1 represents control 1 and comparison to control 1 for subsequent treatments.
24 C2 represents control 2 and comparison to control 2 for subsequent treatments.
25 TN represents total nitrogen.
26 CP represents chisel plow.
27 NT represents no-tillage.
28 BP1 represents Bray P1-extractable soil test level.
29 PP represents phosphate-phosphorus.

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Conservation Practice Summary Assessment

Contaminant: **Total P**

Type of Strategy: **Remedial**

Strategy Name: **Riparian Buffers** (mixed trees, shrubs and/or grasses)

Pollutant reduction mechanisms:
- Dilution
- Improved stabilization of soil surface to impede wind and water erosion detachment and transport of nutrient enriched sediment and particulates
- Improved water infiltration and nutrient adsorption to soil matrix
- Reduced fine-particulate nutrient fraction in runoff water
- Reduced soluble nutrient fraction within runoff water
- Reduced volume of runoff water reaching surface waters
- Trapping and retention of transported nutrient enriched sediments and particulates
- Vegetative assimilation

Applicable conditions

As per USDA-NRCS guidelines, on areas adjacent to permanent or intermittent streams, lakes, ponds, wetlands, sink holes, tile inlets, agricultural drainage wells and other areas with ground water recharge.

However, special attention needs to be focused on any landscape physical conditions that may limit the ability of a riparian buffer to remove nitrate from runoff and shallow ground water as it flows towards surface water bodies (see Limiting Conditions below).

Limiting conditions
- Attaining upper P nutrient storage limit, may become a nutrient source to surface waters once plants reach maturity if not properly managed and harvested
- Channelized (concentrated) surface runoff flow
- Lack of other upslope conservation practices to maintain sheet or rill flow and to ensure as to not overloading the riparian buffer at any given location
- Limited runoff and shallow ground water residence time (i.e., from coarse soil texture and/or steep terrain gradient)
- Non-growing season (dormant period) of buffer plant species
- Steep and unstable streambanks and deeply incised channels that have not been re-formed to more stable conditions
- Steep topography that reduces time for infiltration and increases runoff volume and runoff flow rate
- Overland flow of snowmelt across frozen buffer soils

Range of variation in effectiveness at any given point in time

0 to +100%

Effectiveness depends on:

- Intensity, quantity, duration and timing of rainfall and snowmelt events
- Snowmelt and precipitation events that lead to concentrated surface runoff flow
- Vertical structure of buffer plants on and near the streambank may reduce erosion losses of sediment and P by stabilizing the soils during all seasons, even in the presence of concentrated runoff flow
- The degree of P uptake by vegetative assimilation and potential removal with biomass harvest is dependent upon the type of plants species used and climatic conditions (i.e., cool season vs. warm season plants, grasses vs. woody plants vs. mix of grasses and trees)
- Design and structure of the buffer (i.e., buffer width, single grass strip vs. tree/shrub vs. both, width of buffer and different buffer zones)
- Degree of maintenance of the buffer, particularly as it matures (i.e., harvest and removal of buffer plant biomass being critical)
- Water storage capacity of the contributing drainage area
- With good establishment of riparian buffer plants, adherence to proper design and siting, little to no concentrated runoff flow with presence of in-field buffers and conservation tillage (especially no-till), P removal can be substantial

Estimated potential contaminate reduction for applicable areas within Iowa (annual basis)

+25 to +65%

Landscapes and soil types within Iowa agroecoregions are in some areas amenable to placement and targeted functions of riparian buffers. Research in central Iowa has proven significant P removal when proper siting and design conditions have been met. New methods to identify and prioritize placement and buffer width show the potential to improve siting, buffer effectiveness and economics of implementation. However, there can be great variability both in space and time as to the effectiveness of riparian buffers in reducing P contamination of surface waters.

Under the listed limiting conditions, which are common throughout Iowa's landscapes, additional strategies will need to be adopted. Over a large drainage area, one conservation practice alone will likely not be able to adequately manage runoff to affect adequate reductions in P loss. Therefore, it is recommended by the USDA-NRCS and many scientists that riparian buffers must by used in coordination with other in-field conservation practices (i.e., grass hedges, waterways, terraces, permanent vegetative cover, no-till) to disperse and reduce the volume of runoff and sediment transport, maintain runoff as diffuse sheet or rill flow, and to minimize the probability of over-loading the buffer.

Concentrated runoff flow from adjacent cropland poses a major limitation to the effectiveness of riparian buffers, which can cut through the buffer and render it ineffective for treating this contamination source. Peak rainfall and snowmelt events that generate high volumes of runoff concentrated flow and can contribute the largest fraction of annual total P loss to surface waters from many landscapes. The timing of a peak runoff event greatly affects the amount of P that it may transport. A peak runoff event that occurs when a field is barren from wide spread tillage will transport much more total P than a peak event that occurs in mid-summer when the surface area is under a protective crop canopy. To reduce P loss then, conservation practices must be able to reduce the energy of cropland runoff flow from these peak events that can overwhelm a riparian buffer. This can be accomplished by methods to increase water infiltration and storage to reduce runoff volume, and other methods that disperse and slow runoff flow.

Runoff from peak rainfall and snowmelt events becomes more difficult to manage as slope steepness and length increases, which speeds and concentrates runoff flow into narrow zones, particularly from areas with low water infiltration rates. Terraces can be used to break up slope length and reduce slope angle in small areas to slow runoff flow and increase water infiltration. Inclusion of meadow crops into crop rotations have been shown to improve both water infiltration and water storage on the landscape by providing year-round physical obstacles that slow runoff flow, and having greater soil porosity and water use than row crops. Cover crops offer similar benefits, as do no-till row crop management methods, other than the water usage factor. In-field vegetative buffers help to reduce runoff volume and flow speed in areas where runoff tends to concentrate. Wetlands provide surface water storage and sediment settling areas to absorb the impact of peak rainfall and snowmelt events. Riparian buffers perform many of the same functions as those just mentioned, but the difference is that riparian buffers – along with wetlands - frequently pose the “last line of defense” to keep cropland sediment and nutrient contaminants from entering surface waters. This is why it is so important to manage the contributing drainage area in an integrated and coordinated manner to maintain the integrity of riparian buffers.

Phosphorus removal is more effective in a buffer strip than is sediment removal, but the degrees of removal depend upon a riparian buffer’s design. Buffers are typically more effective in causing deposition of the sand and silt fractions, while less effective in causing deposition of clay sized particles (as per Stokes’ Law). Therefore, buffer width and water infiltration are primary factors that influence sediment removal and P loss reduction. Wider buffers allow for increased infiltration of water and settling of finer soil particles that carry most particulate P. Iowa research does suggest that relatively small width grass filter strips (10-23 ft) reduce total P (TP) and dissolved reactive P (DRP) 35-80% and 30-60%, respectively. However, a wider (53 ft) buffer strip including switchgrass/woody vegetation is more effective, reducing TP and DRP 90% and 81%, respectively. Integrated riparian buffer designs consist of differing zones of plant types and width. In the direction of the field edge to the surface water body, the zones are as follows: grass strips are typically located at the field edge; a strip of shrubs, slow-growing trees and grasses; and fast-growing, wet soil tolerant trees with deep rooting systems and grasses for streambank stabilization. Tree and grass species differ by general groups in their growing seasons, ability to uptake soil water and nutrients, and effective sediment and runoff filtering ability. The amount of total P reduction from trapped runoff sediment is dependent upon the sediment's total P concentration, density of buffer plants, buffer width, soil texture, buffer area water infiltration rate, and slope and slope length of adjacent cropland. To function optimally, riparian buffer widths will need to be adjusted to compensate for these factors. Also, establishment of a riparian buffer may first require efforts to stabilize streambanks that are steep and eroded.

Riparian buffers must have maintenance. After buffer plants mature, harvesting of biomass is critical to maintain the buffer as a nutrient sink. A buffer may evolve into a nutrient source to surface waters since every buffer has limits as to how much of each nutrient it can store. Once a buffer reaches its maturity it will continuously cycle nutrients and its nutrient holding capacity can diminish. Without regular harvest and removal of plant biomass (especially woody plants), decomposition of plant residues will release nutrients, some of which will then enter the nearby surface waterbody that the buffer was meant to protect. Another problem that requires maintenance is the occurrence of ridges that form at the upslope field/buffer edge due to sediment accumulation over time and any tillage operations that cut a furrow along the edge. Both the ridge and the furrow will result in excessive water ponding at the front of the edge and can lead to concentrated runoff flow, which could cut through or bypass the buffer. Maintenance will require reforming and replanting the field/buffer edge as these conditions appear. Detailed information on riparian buffers, and effective designs and maintenance can be found on the Iowa State University Agroforestry website at the following address:

http://www.buffer.forestry.iastate.edu/

Estimated long-term contaminant reduction for applicable areas in Iowa (multi-year basis)

+45%

Long term effectiveness of the riparian buffers greatly depends upon design to NRCS specifications (width), plant type (grass vs. grass/woody; cool season grass vs. warm season grass), existence or absence of necessary in-field buffers to limit concentrated flow, degree of channel cutting and streambank angle, and maintenance of buffer systems. Even in the presence of unmanaged concentrated flow from drainage area, riparian buffers can provide a measure of streambank stabilization that will reduce bank erosion and head-cutting of gulleys that will reduce sediment and P loads within surface waters.

Extent of research:

Moderate in eastern U.S., limited in Upper Midwest

Although there have been numerous studies of various riparian buffer aspects, most U.S. experiments have been done at just a few sites. Therefore, it is difficult to extrapolate the published results to all other areas because hydrology varies from site to site, which can significantly effect the performance of any conservation practice. Of the riparian buffer research experiments that have been published, many have limited a limited duration of measurements and do not address siting of the buffer. Few studies have provided documentation of riparian buffer performance during non-growing seasons and in areas where runoff was primarily maintained as concentrated flow. Further research needs to provide a better understanding of nutrient transport and reduction processes, optimal designs tailored for site-specific conditions (i.e., proper buffer width and plant species), and to include more comprehensive evaluations by regions within the U.S. Also, models need further development to aid proper buffer design and siting, reforming and stabilizing streambanks and channels, and identifying critical source areas within the contributing drainage area that require in-field buffers to reduce concentrated runoff flow. A few modeling tools have been developed (riparian ecosystem management model, REMM; terrain analysis with the use of elevation and soils databases, particularly the soil survey geographic georeferenced database, SSURGO) for improving proper site identification, but need to be evaluated on various landscapes.

Secondary benefits:

- Serve as a N sink to reduce N contamination
- Sediment retention mechanism from cropland runoff
- Partial filtering and decomposition of pesticides
- With proper design, streambank stabilization resulting in reduced erosion of this potential critical source area
- Increased stream dissolved oxygen levels from increased mixing of water if woody plant roots and/or structures are present within the stream
- Increased stream dissolved oxygen levels from reduced water temperature by shading if woody plants are located on and near the streambank
- Additional income source if designed, implemented and managed properly
- Additional wildlife habitat
- Provides a small degree of flood control

Conservation Practice Research Summary Table

<u>Contaminant:</u> **Total P**

<u>Type of Strategy:</u> **Remedial**

<u>Strategy Name:</u> **Riparian Buffers** (mixed trees, shrubs and/or grasses)

References significant to Iowa identified in bold italics.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Lee et al., 2000 **Grass and woody plant riparian buffer strips**	Roland, IA., US; Coland silty clay loam buffers' soil, Clarion loam cropland soil	1 Month (rainfall simulations)	Plot	CS[2] rotation, study conducted in fall following soybean harvest with residue removed	Surface runoff	2-hr rainfall @ 1 <u>inch/hr:</u> No Buffer Switchgrass Woody Plant + Switchgrass Buffer 1-hr rainfall @ 2.7 <u>inch/hr:</u> No Buffer Switchgrass Woody Plant + Switchgrass Buffer	Mass (lb/a) transport of PO4-P[3], and TP[4] from each treatment 0.04 lb/a PO4-P 0.09 lb/a TP 0.03 lb/a PO4-P 0.04 lb/a TP 0.01 lb/a PO4-P 0.01 lb/a TP 0.10 lb/a PO4-P 0.37 lb/a TP 0.07 lb/a PO4-P 0.17 lb/a TP 0.06 lb/a PO4-P 0.09 lb/a TP	– – 25.0% 55.6% 75.0% 88.9% – – 30.0% 54.0% 40.0% 75.7%	Water samples taken every 5 minutes from initiation of runoff to its termination. Higher intensity 1hr rainfall done 2 days after initial 2-hr less intense rainfall.	Switchgrass buffer distance was 23 ft, Woody plant & switchgrass buffer 53 ft wide (30 ft woody plants + 23 ft grass), cropland area 71.8 ft. Percentage mass reduction of P forms was strongly correlated with infiltration within the buffers. Also, percentage P mass reduction decreased with increasing rainfall intensity. Buffers were more effective at reducing sediment transport than nutrients.

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Lee et al., 1999 **Grass Riparian Filter Strips**	Roland, IA., US; Coland silty clay loam buffers' soil, Clarion loam cropland soil	3 days (rainfall simulations)	Plot Simulated drainage to filter strip area ratio of 40:1for 9.75 ft wide strips, 20:1 ratio for 19.5 ft wide strips	Fallow period	Surface runoff		Mass (lb/a) transport of PO4-P and TP. Only % Reductions from Runon P Content Reported		Rainfall simulations done in August with no natural rainfall events occurring. Rainfall simulation rate was 2 in/hr intensity preceded by a 15 minute wetting period. Runon to filter strips at a rate of 10.6 gal/min. Cool season mix consisted of bromegrass, timothy and fescue. Cool season treatment derived from 7 yr ungrazed pasture prior to study, switchgrass (warm season grass) established 6 yr prior to study.	Switchgrass and the 19.5 ft strip distance were better than cool season plant mix and 9.75 ft strip width in removing P from runoff. Switchgrass produces more litter, stiffer stems, stronger root systems and spatially uniform growth than the cool season mix, which may make it more efficient at sediment and nutrient removal. TP reduction was highly correlated with sediment removal, PO4-P removal with infiltration and sorption to soil particles. Although, infiltration and sediment deposition had roles in reducing both P forms. Reduced filter strip width also had lesser reductions in sediment load from runoff.
						<u>9.75 ft wide</u> Switchgrass	PO4-P TP	38.1% 39.5%		
						Cool Season	PO4-P TP	29.8% 35.2%		
						<u>19.5 ft wide</u> Switchgrass	PO4-P TP	46.0% 55.2%		
						Cool Season	PO4-P TP	39.4% 49.4%		

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Lee et al., 2003 **Multi-Species Grass and Woody Plant Riparian Buffer**	Roland, IA., US; Coland silty clay loam buffers' soil, Clarion loam cropland soil	19 months	Plot	CS rotation,	Surface runoff		Mass (lb/a) transport of PO4-P and TP.		One composite runoff water sample per day of runoff events. Runoff events of 0.008 inch or more were 6 in yr-1, 13 in yr-2. Buffers were established 4 yrs prior to initiation of the study.	Switchgrass buffer distance was 23 ft, Woody plant & switchgrass buffer 53 ft wide (30 ft woody plants + 23 ft grass), cropland area 73 ft. Statically significant differences in volume of runoff between all treatments with trend by highest to lowest runoff amount being, NB>S>SWP. Reported main removal mechanisms were infiltration of runoff for PO4-P and filtration of sediment-bound P.
						No Buffer (NB)	0.04 lb/a PO4-P 0.18 lb/a TP	– –		
						Switchgrass Only Buffer (S)	0.02 lb/a PO4-P 0.04 lb/a TP	50.0 % 77.8 %		
						Switchgrass & Woody Plant Buffer (SWP)	0.01 lb/a PO4-P 0.02 lb/a TP	75.0 % 88.9 %		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Peterjohn and Correll, 1984	Near Annapolis, MD; fine sandy loam soil Crop to riparian area ratio of 1.76:1	13 month	Small Watershed (40 acre)	Corn Fertilizer applications to crop of 93 lb N/a	Surface runoff and shallow ground water flow	Surface Runoff Exiting Corn Field (entering forest) Exiting Forest (exiting to stream) Shallow Ground Water Exiting Corn Field (entering forest) Exiting Forest (exiting to stream)	Ave annual mean TP and DRP[5] concentration 5.03 ppm TP 0.658 ppm DRP 0.96 ppm TP 0.172 ppm DRP 0.072 ppm TP 0.154 ppm TP	_ _ 80.9% 73.9% _ -113.9%	Runoff measure at each precipitation event. Flow measured every 5 minutes. Water samples composited to weekly status. Precipitation was slightly above ave in winter, below ave for other seasons. Peaks in TP concentration corresponded with precipitation and P fertilizer application events.	Sediment deposition and sorption to soil particles primary reduction mechanisms. Nearly equal P mass loss between pathways of runoff (59%) and shallow ground water flow (41%) that exited the buffer. Shallow ground water DRP concentration % increased dramatically due to the forest buffer, but in actual ppm the increase was nominal compared to reductions of TP and DRP from surface runoff.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Vellidis, et al., 2003 Uncontrolled Flow Restored Riparian Wetland	Tifton, GA., US; Alapaha loamy sand wetland soil, Tifton loamy sand upland soil Water-shed to wetland area ratio of 8:1	8-yr	Field-plot (20 acre)	Grass forage-silage corn with 534 lb N/a/yr liquid dairy manure applied, and pasture with 267 lb N/a/yr and 134 lb P/a/yr applied	Surface runoff and shallow ground water		Mean TP and DRP concentration (ppm), and annual mean mass (lb/yr)		Wetland restored 1 yr prior to initiation of study. Shallow ground water sampled biweekly for first 6 yrs, monthly for last 2 yrs from extensive well network. Surface runoff sampled daily per runoff event. Low precipitation Sept.-Nov. and May-June. High precipitation Dec.-May and July-Aug.	Results show the overall riparian vegetation + wetland effects, not wetland alone. DRP and TP concentration reductions were highly significant (P<0.0001). Reductions attributed mainly to vegetative assimilation and soil storage. First 8 yrs following wetland restoration with established riparian buffer this system removes and retains large amounts of N nutrients.
						Inflow at field edge	1.37 ppm DRP 1.48 ppm TP 27.5 lb/yr DRP 45.8 lb/yr TP	– – – –		
						Outflow from wetland	0.31 ppm DRP 0.36 ppm TP 7.0 lb/yr DRP 11.9 lb/yr TP	77.4% 75.7% 74.5% 74.0%		

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Meals and Hopkins, 2002	Missisquoi River Watershed, VT, US; glacial till soils in uplands, alluvial and lacustrine soils in riparian areas Paired Watershed Design Trt watersheds: Samsonville Brook Watershed (1700 a, WS1), Godin Brook Watershed (3500 a, WS2). Control watershed: Berry Brook (2350 a, WS3)	2-yr	Large Watershed	Watersheds of nearly equal land-use, being: 60% forest, 2-3% urban, 3% corn silage, ~33% dairy and pasture/hay	Surface runoff and shallow ground water	<u>Control</u> WS3 Riparian Restoration <u>Treatments</u> WS1 WS2	2-yr mean TP mass and concentration 0.116 ppm TP 24.4 kg/wk TP 0.082 ppm TP 6.9 kg/wk TP 0.086 ppm TP 12.2 kg/wk TP	_ _ 29.3% 71.7% 25.9% 50.0%	3-yr monitored calibration period prior to initiation of treatments. 2-yr monitored treatment period. Continuous stream flow measures. Flow proportional, fixed volume water chemistry samples were composited weekly.	Riparian restoration treatments consisted of a mix of livestock exclusion, streambank stabilization, and livestock stream crossing elimination or armored crossings. Statistically significant reduced TP concentration and mass load losses from land areas to surface waters. Reduction mechanisms attributed to reduced erosion, increased sediment deposition within riparian buffers and reduced dairy fecal deposition in and near the streams.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Lowrance et al., 1984 Riparian Buffer and Wetlands	Little River Watershed, Tifton, GA., US;	1-yr	Large Watershed (~3900 a)	Approximately 45% Row crop (corn, soybean, peanut, tobacco, milo, winter vegetables), 13% pasture, 30% forest, 12% misc.)	Surface runoff and shallow ground water flow	Subsurface Crop Field Tile Drainage Emergent Surface Flow from Riparian Buffer & Wetlands	DRP and TP mass loss 0.09 lb/a DRP 0.6 lb/a TP 0.09 lb/a DRP 0.9 lb/a TP	– – 0.0% -50.0%	Streamflow samples taken on 38 dates directly after precipitation events, or no longer than 2 week intervals. Two largest precipitation events resulted in 19% of both the total annual flow volume and sediment load, but 27% and 22% of the total annual sediment-bound P and DRP, respectively.	Higher TP losses from riparian buffer compared to tile drainage due to runoff transport of sediment-bound P, where tile drainage had no runoff contributions.

1 Watershed, field, plot or laboratory.
2 CS represents corn-soybean annual crop rotation.
3 PO4-P represents phosphate-phosphorus, also referred to as dissolved phosphorus and soluble phosphorus (both of which include organic-phosphorus).
4 TP represents total phosphorus.
5 DRP represents dissolved reactive phosphorus.

References

Lee, K.H., T.M Isenhart, R.C. Schultz, and S.K, Mickelson. 1999. Nutrient and sediment removal by switchgrass and cool-season grass filter strips in Central Iowa, USA. Agroforest. Syst. 44: 121-132.

Lee, K.H., T.M Isenhart, R.C. Schultz, and S.K, Mickelson. 2000. Multi-species riparian buffers trap sediment and nutrients during rainfall simulations. J. Environ. Qual. 29:1200-1205.

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Lowrance, R.R., R.L. Todd, and L.E. Asmussen. 1984. Nutrient cycling in an agricultural watershed: II. Streamflow and artificial drainage. J. Environ. Qual. 13: 27-32.

Meals, D.W., and R.B. Hopkins. 2002. Phosphorus reductions following riparian restoration in two agricultural watersheds in Vermont, USA. Water Sci. Tech. 45(9): 51-60.

Peterjohn, W.T., and D.L. Correll. 1984. Nutrient dynamics in an agricultural watershed: observations on the role of a riparian forest. Ecology 65(5): 1466-1475.

Vellidis, G., R. Lowrance, P. Gay, and R.K. Hubbard. 2003. Nutrient transport in a restored riparian wetland. J. Environ. Qual. 32: 711-726.

Conservation Practice Summary Assessment

Contaminant: **Total P**

Type of Strategy: **Remedial**

Strategy Name: **Wetlands** (restored and created wetlands)

Pollutant reduction mechanisms

- Dilution
- Reduction of runoff volume reaching surface waters
- Retention of transported P nutrient enriched sediments and particulates
- Temporary nutrient sequestration in soil organic matter
- Vegetative assimilation

Applicable conditions

- As per NRCS guidelines for site-specific conditions and landform engineering specifications, such as: hydric soils bordered by cropland, sufficient water contribution, sufficient organic carbon content, low position within watershed landscape and sufficient water storage capacity.

Limiting conditions

- Attaining upper sediment, sediment-P and plant-P storage limit, may become a nutrient source to surface waters once storage limits are reached
- Channel flow from inlet to outlet that inhibits complete mixing of inflow with retained water, decreases settling of particulates and effective retention time
- Insufficient wetland emergent vegetation to slow inflow during peak events to optimize settling of particulates and sediment
- Limited stored water residence time (i.e., insufficient storage capacity, high volume precipitation events, coarse soil texture and/or steep terrain gradient)
- Potential release of P from sediments under anaerobic conditions
- Unstable soils that are easily disturbed

Range of variation in effectiveness at any given point in time

- 50% to +80%

Effectiveness depends on:

- Age and degree of maintenance of wetland and stabilization structures, may become a nutrient source if not managed to maintain P levels below its storage capacity
- Design of wetland and stabilization structures, and land area to surface water containment ratios

- Peak snowmelt and precipitation events that fill a wetland to its storage capacity, resulting in fast flow rates and limited water residence time
- The degree of P removal by vegetative assimilation is dependent upon the type of plants species used, plant densities and climatic conditions
- With good establishment of plants, inflow dominated by surface runoff (instead of tile or ground water), sufficient water storage capacity and relatively long water residence time, P removal may be substantial

Estimated potential contaminate reduction for applicable areas within Iowa (annual basis)

-20% to +50%

A wetland's design and hydrology (within the wetland and its contributing area) can significantly affect the removal of nutrient and particulate contaminants. At times of peak rainfall and snowmelt events, a wetland can quickly reach its storage capacity, especially when peak events repeatedly occur in short periods of time such as those typical during spring. If a wetland has a high watershed to wetland area ratio, is shallow and lacks vegetation, there may be limited water retention time during peak rainfall and snowmelt events. For particulates and attached chemicals/nutrients, there is less settling time and the finer particles may stay in suspension, exiting the wetland and entering a surface water body. These finer particulates (plant residues and clays) typically hold greater amounts of chemicals and nutrients than the larger particles that will preferentially fall out of suspension before the finer particles. Flow may also be at fast enough rates to create turbulent conditions within a wetland that can resuspend sediments and nutrients that had settled to the wetland's bed. Resuspended sediments and nutrients may redeposit elsewhere in the wetland, but may also exit the wetland to enter surface waters and actually increase P loading to surface water bodies. This is one reason why wetlands must be regularly inspected and maintained to specifications.

Another hydrologic related factor that influences a wetland's effective removal of sediment and nutrients is the extent of incoming flow distribution over the wetland area. Complete and even distribution of inflow across the wetland area optimizes the degree of contact of soluble P with wetland substrates (sediments and organic matter). Sorption of soluble P onto substrates may occur if chemically active sites are available and/or the soluble P concentration is greater in the incoming flow than that of the substrate materials. When inflow has lower soluble P concentrations than the wetland's substrates, the substrates will desorb the P that it holds until both are at equilibrium concentrations to each other. Large plants within a wetland (macrophyte vegetation) can help to disperse and slow inflow, improving particulate settlement and reducing resuspension of sediments. In addition to having a net uptake of P during the early stages of wetland development, wetland macrophytes may produce enough dissolved oxygen to maintain aerobic conditions that allow calcium (Ca), carbonate, and metal oxides to remove soluble P from the wetland water column (Dodds, 2003).

Calcium, iron (Fe) and aluminum (Al) are the commonly the most prevalent cations available within wetlands can impact net P retention or release. Depending on the pH of the system, Ca, Fe (ferrous Fe^{3+}) and Al oxides can complex with soluble phosphate anions and hold P in a particulate form under aerobic conditions. Under anaerobic conditions, which are common in the water saturated wetland soils, Ca and Fe oxides can become soluble through reduction (for Fe, reducing ferrous iron (Fe^{3+}) to ferric iron (Fe^{2+})) and then release the soluble phosphate anion to the water column (Sharpley, 1995). However, it has been suggested that ferric hydrous oxides may again remove some released P via sorption mechanisms (Phillips, 1998). Aluminum-phosphate oxides are more resistant to change in anaerobic conditions than Ca-phosphate and Fe-phosphate oxides, thus having a lesser potential to release soluble P to wetland waters. Due to this relationship, alum (aluminum sulfate) has recently been promoted as a P sequestering amendment.

Although a majority of the P contamination of surface waters is in the particulate-P form, shallow ground water from baseflow and tile drainage has been documented in several studies to be of high enough concentrations on their own to cause eutrophication. Shallow ground water is the major water source to wetland catchments. High volume surface runoff events typically occur just a few times each year under average climatic conditions in Iowa (though these events can contribute the largest fraction of insoluble contaminants and water volume each year).

The amount and types of vegetation within a wetland and buffering its perimeter are very important for assimilating soluble P. Criteria and guidance on wetland design, construction, wetland plant establishment and maintenance have been identified by Iowa State University scientists and this information can be obtained from the following internet address:

http://www.iawetlands.iastate.edu/

The Conservation Reserve Enhancement Program (CREP) for establishing buffered wetlands also has detailed criteria and guidance information.

When a wetland catchment has been properly designed and constructed and has established vegetation it can be effective at removing particulate-P, and to some extent soluble P, when any surface runoff and shallow ground water flow is slow.

Estimated long-term contaminant reduction for applicable areas in Iowa (multi-year basis)

+20%

This estimate is based on the following assumptions: 1) the wetland has been designed and placed appropriately to watershed characteristics and area ratios, 2) channel flow does not occur and the wetland is designed to operate under its P storage limit (predominately functioning as a P sink, not a source).

Extent of research

Limited in Upper Midwest, Moderate in U.S., Extensive in Europe

Natural, restored and constructed wetlands for treatment of a wide array of contaminants have been researched in Europe and a few other countries. In the U.S., a fairly extensive amount of research has been conducted on the Eastern Coastal Plains of the Carolinas and Georgia, many of these in relation to riparian buffer research since wetlands there are frequently within riparian areas. A moderate amount of research has been conducted in the Midwest, but many aspects yet need to be examined. While the removal mechanisms are the same across locations, limitations are different (see list of limiting conditions above). Wetlands and similar types of catchments have performed very well in the Eastern Coastal Plain and the Midwest in sediment and P removal. However, P removal is more variable since it can exist in soluble forms and desorb from sediments when in contact with solution that has lower P concentrations than those held on sediments and particulates. Also, with the extensive amount of landscape alteration, artificial drainage and intensive row cropping in the Upper Midwest, restored and constructed wetlands here require careful placement and design specifications. Several very good research projects have been conducted in Iowa and Illinois, but more intensive research needs to be done in other agroecoregions and landscape positions.

Secondary benefits

- Serve as a N sink
- Sediment retention mechanism from cropland runoff
- Partial filtering and decomposition of pesticides
- Additional wildlife habitat
- Provides some degree of flood control
- May improve farmer profitability by removing areas that frequently have negative economic returns for crop production

References

Dodds, W.K. 2003. The role of periphyton in phosphorus retention in shallow freshwater aquatic systems. J. Phycology 39(5):840-849.

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Sharpley, A. 1995. Fate and transport of nutrients: Phosphorus. USDA-NRCS Working Paper No. 8. Available on-line at: {“http://www.nrcs.usda.gov/technical/land/pubs/wp08text.html”} (Accessed and verified on 1/21/04).

Conservation Practice Research Summary Table

Contaminant: **Total P**

Type of Strategy: **Remedial**

Strategy Name: **Wetlands** (restored and created wetlands)

References significant to Iowa identified in bold italics.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Kovacic et al., 2000 **Uncontrolled Tile Drainage Flow Constructed Wetlands**	Champaign Co., IL, US; Colo silty loam Watershed to wetland area ratios for the 3 replications were 17:1, 25:1 and 32:1.	3 water years (A water year is from Oct. 1 to Sept. 30 the following year).	Field-plot	Intercep-tion of tile drainage from CS[2] rotation with N fertilizer applied to C year at 120 lb N/a for 2 of 3 crop areas, and 180 lb N/a for the remaining area.	Leaching to shallow ground-water and drainage to surface water	Tile drainage w/o[3] wetland treatment Tile drainage w[4] wetland treatment	Sum 3-yr total mass removal by 3 wetlands (lb) of DP[5] and TP[6] 28.8 lb DP 28.9 lb TP 22.3 lb DP 28.2 lb TP	– – 22% 2%	Wetlands constructed in 1994 with experiment initiated in water year 1995. Flow measured every 15 minutes yr-round. Water samples for chemical analyses taken every 15 minutes during periods of increasing flow yr-round. Water budget for the wetlands was 64% outflow, 28% seepage, 8% evapotranspir-ation. Winter and spring accounted for 95% of total inflow.	Lowest removal rates occurred in winter and spring, coinciding with greatest period of inflow. Organic P contributions offset DP and TP reductions for overall result of wetlands being neither a sink nor a source of P to surface water. However, these wetlands received primarily tile flow, not surface runoff that would carry much more particulate-P.

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Miller et al., 2002 **Uncontrolled Flow Tile Drainage Constructed Wetlands**	Vermilion Co., IL, US; soil type not stated Water-shed to wetland area ratio unknown due to wetland area not reported.	4-yr	Small Water-shed (26.9 acre)	Intercep-tion of tile drainage from CS rotation (N fertilizer loading to C year not stated)	Leaching to shallow ground-water and drainage to surface water		Median DP concentration (ppm), Sum 4-yr total DP mass (lb)		Wetland established a number of years prior to initiation of the study and reported to resemble the structure of a natural wetland. Continuous inflow and outflow measures. Automatic flow-proportional and manual samples at precipitation events and regular 2 week intervals. Greatest hydrologic loading during spring.	Increased DP in summer and winter from wetland attributed to release of DP from wetland sediments. This wetland slightly added to DP contamination of surface water. However, little DP was carried in tile drainage and amount DP increased was low. Significant difference found only in summer. Would expect lowered P contamination if inflow had runoff contributions.
						Inflow to wetland:				
						Spring	0.06 ppm DP	_		
						Summer	0.04 ppm DP	_		
						Fall	_	_		
						Winter	0.07 ppm DP	_		
						4-yr Total	10.8 lb DP	_		
						Outflow from wetland:				
						Spring	0.06 ppm DP	0%		
						Summer	0.07 ppm DP	-75.0%		
						Fall	0.26 ppm DP	_		
						Winter	0.10 ppm DP	-42.8%		
						4-yr Total	11.0 lb DP	-1.8%		

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Jordan et al., 2003 Uncontrolled Flow Constructed Wetlands	Kent Island, MD, US; Othello series and Mattapex series silt loam soils Water-shed to wetland area ratio of 11:1	2-yr	Small Water-shed (34.6 acre)	CS rotation	Surface runoff	Net Flux[7] of wetland: Yr-1 TP TDP TOP Yr-2 TP TDP TOP 2-yr Ave TP TDP TOP	Net Flux[7] Yr-1, Yr-2 and Sum 2-yr total mass (lb/a/yr) removal of TP, TDP[8] and TOP[9]. 16.02 lb/a/yr 3.65 lb/a/yr 12.46 lb/a/yr -2.50 lb/a/yr -1.25 lb/a/yr -1.25 lb/a/yr 6.76 lb/a/yr 1.25 lb/a/yr 5.52 lb/a/yr	Actual influx and outflux not reported, %s directly reported. 59% 53% 61% -11% -18% -8.3% 27% 18% 31%	Wetland was restored 9 yrs prior to initiation of the study. Inflow and outflow measures every 15 minutes. Automatic flow-proportional samples taken every 15 minutes during periods of increasing flow and weekly manual samples whenever flow was occurring at inlet and outlet. Half of total 2-yr total inflow occurred during 24 peak inflow day events.	Suggested that P removal during the first yr of study due to adsorption of P-laden sediments within the wetland and binding of DP with bed sediments of lower P concentration than that of the inflow. Also suggested that yr-2 net export of P may have been due to greater precipitation and inflow than yr-1, causing less dispersion of inflow throughout the wetland and shorter retention period. Wetlands may become net P source as they mature and fill to capacity with sediment.

Reference	Location, Site Notes	Time Period of Experiment	Applied Spatial Scale[1]	Applied Land-Use	Pathway	Treatments	Nutrient Mass (lb/a) and/or Concentration (ppm)	Amount Nutrient Export or Potential Reduction	Temporal Factors	Reported Mechanisms for Nutrient Reduction and Notes
Kadlec and Hey, 1994 **Controlled Flow Constructed Wetlands**	Des Plaines River, Wadsworth, IL, US; soil type not stated Contributing area proportion of water-shed to wetland ratio unknown due to only partial diversion of river flow to wetlands.	2-yr	Large Water-shed (128,000 acre)	80% agricultural, 20% urban; partially tile drained	Diverted surface flow from river to wetlands	Inflow to wetlands: All Wetlands Outflow from wetlands: Wetland 1 Wetland 2 Wetland 3 Wetland 4	2-yr ave. TP concentration (ppm) 0.10 ppm TP 0.031 ppm TP 0.018 ppm TP 0.026 ppm TP 0.029 ppm TP	– 69% 82% 74% 71%	Wetlands were constructed 1 yr prior to initiation of the study. Flow to wetlands was controlled via pump stations, removing seasonality aspect of natural flow patterns.	Suggested P removal mechanisms were wetland vegetation assimilation, adsorption of P-laden sediments within the wetland and binding of DP with bed sediments of lower P concentration than that of the inflow. Authors state that these mechanisms may diminish as wetlands mature and fill to capacity with sediment.

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Vellidis, et al., 2003 Uncontrolled Flow Restored Riparian Wetland	Tifton, GA., US; Alapaha loamy sand wetland soil, Tifton loamy sand upland soil Water-shed to wetland area ratio of 8:1	8-yr	Field-plot (20 acre)	Grass forage-silage corn with 534 lb N/a/yr liquid dairy manure applied, and pasture with 267 lb N/a/yr and 134 lb P/a/yr applied	Surface runoff and shallow ground water	 Inflow at field edge Outflow from wetland	Mean TP and DRP[10] concen-tration (ppm), and annual mean mass (lb/yr) 1.37 ppm DRP 1.48 ppm TP 27.5 lb/yr DRP 45.8 lb/yr TP 0.31 ppm DRP 0.36 ppm TP 7.0 lb/yr DRP 11.9 lb/yr TP	 _ _ _ _ 77.4% 75.7% 74.5% 74.0%	Wetland restored 1 yr prior to initiation of study. Shallow ground water sampled biweekly for first 6 yrs, monthly for last 2 yrs from extensive well network. Surface runoff sampled daily per runoff event. Low precipitation Sept.-Nov. and May-June. High precipitation Dec.-May and July-Aug.	Results show the overall riparian vegetation + wetland effects, not wetland alone. DRP and TP concentration reductions were highly significant (P<0.0001). Reductions attributed mainly to vegetative assimilation and soil storage. First 8 yrs following wetland restoration with established riparian buffer this system removes and retains large amounts of N nutrients.

1 Watershed, field, plot or laboratory.
2 CS represents corn-soybean annual crop rotation.
3 w/o represents without.
4 w represents with.
5 DP represents dissolved phosphorus, also termed phosphate-phosphorus.
6 TP represents total phosphorus.
7 Net flux calculated by subtracting outflux from influx; +# means net removal (P sink), -# means net export (P source)
8 TDP represents total dissolved phosphorus.
9 TOP represents total organic phosphorus.
10 DRP represents dissolved reactive phosphorus.

References

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Summary and Conclusions

It is important to keep a focus on the basic factors that influence nutrient dynamics in the natural environment while continuing to better our understanding of the smaller, more intricate factors that also play roles in NPS pollution of our surface waters. The factors that impact the cycling and N and P are numerous and very complex. If we become too focused on the intricacies and not wanting to implement change until all factors are completely understood it will paralyze society to a point of complete inaction. While there remains much to be learned, after more than 150 years of research, we do have an appreciable understanding of the fundamental principles that influence N and P losses from the landscape. Beginning with management changes based upon known fundamental principles will serve as a solid foundation from which to build upon as our knowledge increases with advances in science.

The assessments of conservation practice impacts on reducing N and P NPS contamination of Iowa's surface waters revealed generally positive long-term impacts with wide ranges of impacts in the short-term (annually to single precipitation events). A summary of the long-term estimated impacts for each assessed conservation practice is shown in Table 1. Both N and P nutrients exist in soluble and insoluble forms and it is common for any given conservation practice to decrease losses of one nutrient form while increasing losses for another. For example, conservation practices that reduce insoluble nutrient losses by increasing water infiltration to reduce runoff often increase losses of soluble forms, such as that commonly found with terraces either with or without tile drainage. Conflicting effects can also occur between N and P for a given conservation practice. Estimates of the overall impact here have been made on the basis of total N (TN) and total P (TP) to reflect the balance of all potential losses and gains in N and P transport to surface waters and because water quality standards are to be determined by the total nutrient forms.

Although nearly all of the conservation practices listed in Table 1 have been estimated to reduce TN and/or TP losses from agricultural lands, several issues must be remembered to avoid misinterpretations. First, the many differing forms of N and P that are summed to obtain TN and TP values can have disproportional impacts on aquatic environments. Some forms are more potent in causing eutrophication than others, such as dissolved reactive P (DRP) being more available for algae growth than particulate P. Secondly, as other researchers and agencies have pointed out, combining two or more conservation practices on any given field will not have an additive effect. For instance, a no-till field with a riparian buffer vs. a nearby intensively tilled field without a riparian buffer will not result in an overall 115% reduction in TP loss. One obvious reason is that a reduction in loss cannot exceed 100%. Also, the riparian buffer would only reduce the amount of TP it receives from the no-till field by 45%. If the no-till field reduces TP loss by 70%, the riparian buffer then removes 45% of the remaining 30% TP transported from the no-till field, which amounts to 13.5% of the original TP load. The combination

Table 1. Total nitrogen (TN) and total phosphorus (TP) potential nonpoint source (NPS) loss reductions estimated on a multiple year basis for conservation practices.

Conservation Practice	Percentage Impact on NPS Loss Reduction[1] TN	TP
Conservation Tillage		
Moderate vs. Intensive Tillage	+3%	+50%
No-Till vs. Intensive Tillage	+10%	+70%
No-Till vs. Moderate Tillage	+5%	+45%
Cover Crops	+50%[2]	+50%[2]
Diverse Cropping Systems	+50%	+50%
Drainage Management		
Controlled Drainage vs. Uncontrolled Drainage	+25%	-10%
Water Table Management vs. Uncontrolled Drainage	+30%	-10%
Shallow and/or Wide vs. Standard Tile Placement	+20%	-10%
In-Field Vegetative Buffers	+25%	+50%
Landscape Management	-10%	+50%
Nitrification and Urease Inhibitors	+10%	N/A[3]
Nitrogen Nutrient Application Techniques	+10%	N/A
Nitrogen Nutrient Timing and Rate Conservation Management		
Timing: Spring vs. Fall Application	+15%	N/A
Timing: Soil-Test Based Split In-Season vs. Fall	+30%	N/A
Timing: Soil-Test Based Split In-Season vs. Spring	+15%	N/A
Rate: Yield Goal or Crop Removal Based vs. Excessive	+35%	N/A
Rate: Soil-Test Based vs. Excessive	+60%	N/A
Rate: Soil-Test Based vs. Yield Goal or Crop Removal Based	+25%	N/A
Pasture/Grassland Management		
Livestock Exclusion from Streams vs. Constant Intensive Grazing	+30%	+75%
Rotational Grazing vs. Constant Intensive Grazing	+20%	+25%
Seasonal Grazing vs. Constant Intensive Grazing	+20%	+50%
Phosphorus Nutrient Application Techniques		
Deep Tillage Incorporation vs. Surface Broadcast	N/A	-15%
Shallow Tillage Incorporation vs. Surface Broadcast	N/A	-10%
Knife or Injection Incorporation vs. Surface Broadcast	N/A	+35%
Phosphorus Nutrient Timing and Rate Conservation Management		
Timing: Spring vs. Fall Application	N/A	+30%
Soil-Test P Rate Balanced to Crop Use vs. High and Excessive	N/A	+40%
Time to Runoff Event: 1-month vs. 1-day	N/A	+30%
Riparian Buffers	+40%	+45%
Wetlands	+30%	+20%

[1] Positive percentage number indicates reduced nutrient NPS pollution of surface waters; Negative percentage number indicates increased nutrient NPS pollution of surface waters.

[2] Estimate is based upon the conservation practice applied only to the most applicable systems for cover crops in Iowa, which the primary crops are harvested and removed in mid- to late-summer.

[3] N/A represents "not applicable."

of no-till and a riparian buffer therefore would provide a potential 83.5% reduction in TP loss compared to intensive tillage without a riparian buffer. Third, although this example of implementing multiple conservation practices shows there will be diminishing positive returns for each successive practice, a single practice alone may not be able to reduce

NPS N and P losses to the extent necessary to meet water quality standards. For a remedial field-edge conservation practice to function successfully it is critical to implement in-field conservation practices that are designed to increase soil water storage (thereby reducing runoff and leaching water volumes) and reduce N and P load transport. Riparian buffers and wetlands may do little to reduce nutrient and sediment losses if they receive water volumes and nutrient loads beyond their capacity to treat due to the absence of other conservation practices within a contributing drainage area. This may be particularly true if concentrated flow frequently occurs from peak precipitation events. In such instances it is not the conservation practice that failed: the failure was due to not having designed and implemented a comprehensive conservation management plan.

With the above caveats in mind, the estimated NPS nutrient loss reductions listed in Table 1 do provide general indications as to which practices have the highest probabilities to reduce TN and TP losses. Most notable among these practices are those that function to considerably reduce both TN and TP losses, which are cover crops, diverse cropping systems, in-field vegetative buffers, livestock exclusion from stream and riparian areas, and riparian buffers. Other practices that have offer appreciable reductions in NPS TN loss are N nutrient timing and rate conservation management and wetlands. For reducing NPS TP loss, moderately reduced tillage practices and no-tillage, landscape management (i.e., terraces), seasonal grazing, and P nutrient knife or injection application have been shown to perform well. These conservation practices should be prioritized for additional research funding and farmer adoption depending upon if one or both nutrients pose NPS loss risks on their lands.

Given the mostly positive effects of the conservation practices (Table 1) for reducing N and P NPS pollution, it bears asking "Why then is N and P NPS pollution still a problem within Iowa?" One answer seems to be that these conservation practices have not yet been implemented to a great enough extent and targeted to where they are most needed to meet proposed water quality standards. Another answer is that it will require more than one or two conservation practices to meet water quality standards, at times needing both preventive and remedial types. Designing successful comprehensive conservation management plans requires a number of considerations. An order of tasks is recommended here to guide the adoption, implementation and validation of conservation practices for reducing N and P NPS pollution, being:

1. Delineate Iowa's varied agroecoregions.
2. Identify the critical source areas and associated characteristics that pose high risks for N and P loss.
3. Identify the characteristics of the remaining areas and the associated degrees of N and P loss.
4. Determine water quality standards (end points that must be met) that preserve the integrity of aquatic ecosystems and meet the requirements for each waterbody's designated use.
5. Identify where each conservation practice is applicable and prioritize by highest probability to reduce nutrient losses.

6. List suites of conservation practices designed to meet water quality standards and maintain the integrity of field-edge remedial practices during peak events.
7. Apply policies, education and programs that address social and economic concerns for the adoption and implementation of conservation practices.
8. Provide assistance to farmers in designing comprehensive conservation management plans on an individual basis and in coordination with whole watershed management plans.
9. Monitor water quality to document the performance of the implemented conservation practices, determine if water quality goals are being met and guide further actions if necessary.

As pointed out in the background section of this document, N and P critical source areas often vary from each other in location. In many cases, N source areas are generally more diffused across the landscape since nitrate-N is the main N form found in surface waters, which is tends to be leached over wide areas. Since sediment- and particulate-bound P forms are dominant in surface waters, P critical source areas tend to be highly erodable areas and near stream channels, which are usually more isolated than leach prone areas. Strategies to reduce N and P NPS losses may require the application of different conservation practices for the two nutrients. McDowell et al. (2002) recommended that measures to reduce P loss should focus on treating critical source areas, while measures to reduce N loss should be more source based by concentrating on improving crop N use efficiency. Exceptions will exist, most notably on lands that have received N and P nutrient rates in excess of crop removal. Conservation practices will then need to be applied to reduce losses of both nutrients at the same locations.

Some of the above tasks suggested to guide effective implementation of conservation practices are already in use, but unfortunately not always in a coordinated manner among the various government agencies that share responsibility for preserving and improving water quality. Other aspects of the above list have not yet been adequately addressed, but are critical to the success of the entire process. Social and economic studies are greatly needed to determine existing barriers to public adoption of conservation practices and to help identify new policy options that may overcome the barriers. This point is emphasized by Shepard (2000) from a survey of farmers' nutrient management practices, "Results indicate that two out of three farmers apply excess nitrogen, while four out of five apply excess phosphorus for corn production. Few use the recommended best management practices in an appropriate fashion. These results indicate that farmers' actual behavior patterns must be brought into the design of both best management practices and implementation strategies for water quality programs."

To effect changes in behavior there must be effective education to the target audience. In terms of Iowa's surface water quality and addressing NPS pollution, this means education programs need to be developed and instituted for all residents from primary school through adult age groups. Many obstacles to adoption of conservation practices may be overcome by improving public awareness of how land management practices influence N and P cycling and NPS losses to water resources. Knowledge leads to awareness, which may then motivate changes in behavior. In this case the desired change being the adoption and implementation of comprehensive conservation management plans. Effective education is critical to achieve rural and urban support, cooperation and compliance with future water quality programs.

The basic philosophies and structures of program policies to support adoption of conservation practices and other best management practices (BMPs) are significant points of conjecture. There are advantages and drawbacks to each model. In examining the model of monetary subsidies to provide motivation for voluntary adoption, being the most popular option of landowners, the advantage is that those that adopt the supported practices generally do so without complaint and implement the practices correctly. Two major disadvantages are that it is very costly to taxpayers and that in the decades that this model has been in use it has rarely achieved adoption at scales sufficient enough to significantly improve water quality. Over 50 years ago Aldo Leopold wrote in *A Sand County Almanac* (1949): " … a system of conservation based solely on economic self-interest is hopelessly lopsided. It tends to ignore, and thus eventually to eliminate, many elements in the land community that lack commercial value, but that are (as far as we know) essential to its healthy functioning. It assumes, falsely, I think, that the economic parts of the biotic clock will function without the uneconomic parts. It tends to relegate government to too many functions eventually too large, too complex, or too widely dispersed to be performed by government.

An ethical obligation on the part of the private owner is the only remedy for these situations."

An option that has been proposed that includes an aspect of landowner obligation is the performance-based model. The basic premise of a performance-based model is for government to require that water quality standards be met, but allow the landowner and/or operator the flexibility to choose and implement their choice among a suite of conservation practices that are appropriate to the characteristics and N and P NPS pollution risks that exist on their lands. There are merits to this approach. Allowing the landowner and/or operator such flexibility would result in more willing cooperation and proper implementation of adopted practices than by a purely mandatory approach. The drawbacks are that it may still be costly to taxpayers depending upon if and how program subsidies are structured and that it may take much longer to meet water quality standards because time frames for adoption would likely be longer than with compliance demands from mandatory programs. Fortunately, an example of a program very similar to the performance-based model, with an added component of local regulation, exists in a neighboring state for Iowa to consider.

Over 30 years ago, shortly after the passage of the 1972 Clean Water Act, the state of Nebraska formed a local, self-governing system for managing water quality called the Nebraska Association of Resource Districts (NARD). The districts are organized by watersheds (23 total) and are governed by locally elected boards of directors. There are 12 areas of responsibilities for each district related to the management of their natural resources. One such responsibility is in regard to water quality, where the districts must maintain water quality to state and federal standards. If water quality standards are not being met, then the Board of Directors have the power to assess fines to landowners that do not manage theirs lands with approved conservation practices. The NARD system of a performance-based water quality program with local responsibility and regulatory control is a viable option for the state of Iowa to consider adopting. It is a working model that will likely limit public defiance and discord since penalties for non-compliance are assessed by local residents, not state or federal agencies that are frequently viewed as being removed from the affected area and people.

Since the purpose of this document is to help guide management of Iowa's agricultural lands to meet water quality standards it should be periodically updated to keep its information current with advances in science. Recommendations for subsequent updates are as follows:

- Inclusion of results from mathematical and georeferenced models after being verified and validated for uncertainty. This is necessary due to limited information from local long-term watershed scale research.
- Evaluate applicable practices from other regions of the world that have been proved to function efficiently both in terms of water quality and economics. Most notably, European research and development of treatment wetlands and New Zealand and Australian research and development of grazing land management are very advanced compared to efforts to date in the U.S. Doing so may save tax monies and speed the improvement of our surface water quality.
- Address streambank erosion and channel cutting processes and corrective practices since these are frequently NPS pollution critical source areas to water quality too.

Gaps and weaknesses in available information regarding water quality impacts of the reviewed conservation practices were determined and proved to be substantial. Recommendations to guide research in providing the information needed for more reliable water quality assessments in the future are listed below.

- More long-term watershed scale studies are needed of all conservation practices to enable highly reliable assessments to be done. State nutrient management strategies must be applied at these spatial and temporal scales, but comprehensive studies at these scales are rare.
- Research projects of all conservation practices should determine nutrient losses from both runoff and leaching pathways to provide more complete information of impacts on surface waters. This is a significant shortcoming for conservation tillage research that needs to be corrected.
- Further evaluation and development of plant species and varieties needs to be conducted to identify more suitable candidates to serve as cover crops in the Upper Midwest. Source areas to target future investigations for suitable cover crops would be from plants that grow well in colder climates (i.e., middle to northern Canada) such as wheat and other small grains, flax and brassica varieties. Some winter annual plant species and kura clover may be good cover crop candidates.

- Development of markets, storage technologies and low cost equipment options are required to support adoption of diverse cropping systems.
- Further development of low cost methods and technologies for controlled drainage, sub-irrigation, alternative tile placement designs, and methods to increase denitrification and plant assimilation nitrate-N drainage waters prior to exiting the tile systems. Control comparisons should include natural drainage conditions in addition to uncontrolled tile drainage where possible.
- Additional in-field buffers research is needed to quantify variability in performance with time and differing climatic conditions over a several year period, and with both diffuse and concentrated flow.
- Investigations of landscape management practices such as terraces need to be conducted in all of Iowa's agroecosystems that have cropped areas of sufficient slope.
- Strip tillage nutrient application, minimal disturbance manure injection and other nutrient placement method effects on water quality have yet to be sufficiently quantified. Future research should include continuous monitoring over relatively long periods of time - preferably over several years - and locations due to climatic and landscape variability.
- Some applications of precision farming technologies have proven to be reliable for improving crop production. However, to date no evaluations of these technologies as to their impacts on water quality have been conducted, which needs to be done since one of the primary goals of precision farming methods is to improve crop nutrient use efficiencies.
- The recent developments of the Iowa P Index, like many other state P indices, need to be evaluated for reducing nonpoint source P pollution of water resources. It may be common sense to accept that proper use of a P Index will result in implementation of practices to reduce P loss from fields, but this remains to be documented. It is important to know the long-term nonpoint source P pollution risks from fields that have extremely high soil-P concentrations due to long term over-application, particularly for the impacts on subsurface drainage. Potential best management practices to resolve the problem (i.e., forage crop production and aluminum-based soil amendments), other than reducing or ending P application to such fields for a period of time, also need to be researched within the state.
- Research has yet to adequately explain the variable performance of nitrification inhibitors across the Midwest, which needs to be done to improve management recommendations for farmer use and meet water quality goals.
- The water quality benefits of rotational, management intensive and seasonal grazing systems and livestock exclusion from stream riparian areas have not been researched adequately in many regions, particularly in the Midwest. This should be a priority funding area due to the high potential for these practices to reduce NPS nutrient contamination of surface waters.
- Many riparian buffer research experiments have limited measures to the time of the buffer's plant growing seasons and more-or-less ideal siting of the buffer. Few studies have provided documentation of riparian buffer performance during non-growing season periods and in areas where runoff was primarily maintained

as concentrated flow. Further research needs to provide a better understanding of nutrient transport and reduction processes, optimal designs tailored for site-specific conditions (i.e., proper buffer width and plant species), and to include more comprehensive evaluations by regions within the U.S. Also, models need further development to aid proper buffer design and siting, reforming and stabilizing streambanks and channels, and identifying critical source areas within the contributing drainage area that require in-field buffers to reduce concentrated runoff flow.

- While the nutrient removal mechanisms of wetlands are similar across locations, limitations differ. With the extensive amount of landscape alteration, artificial drainage and intensive row cropping in the Upper Midwest, restored and constructed wetlands here require careful placement and design specifications. Several very good research projects have been conducted in Iowa and Illinois, but need to be done in other agroecoregions and landscape positions.

Another recommendation is for policy makers and administrators to support changes in how environmental research is funded and structured. Environmental research could be more efficient in terms of funding and time if projects were designed in a holistic manner. Currently, most environmental research is conducted in a disjointed, reductionist manner with individual research projects focusing on only portions of nutrient cycles, and many times for only one nutrient. One primary reason for this is that research funding mainly supports the non-integrated approach. This document has mainly concentrated on the soil and water components of the N and P cycles. However, the atmospheric component is of great significance (particularly for N) as evidenced by the emerging issues of air quality. There are many important questions about how nutrient flow and transformations within the soil-water-plant-animal-microbe systems affect the atmosphere (and vice-versa), such as: Are nitrous oxide greenhouse gasses increased within the atmosphere from conservation practices that use denitrification as a main nitrate-N removal mechanism? Or, is dinitrogen gas the main end product of denitrification? If so, how much? How much does the quality of C sources (i.e., easily assimilated amino-sugars vs. the difficult to assimilate ligin in plant residues) impact denitrification N gas end product emissions? Are N greenhouse gas emissions an important factor to consider with each of the conservation practices in each agroecoregion? What factors interact with denitrification? To answer these and other similar questions the air component needs to be a part of environmental research projects, otherwise earlier research has to be repeated. Only holistically designed research projects can uncover and quantify all of the interacting factors that influence nutrient cycling within and between soil, water and air. Therefore, a new paradigm for funding and conducting research programs will need to be adopted. Holistic research will require much more cooperation and coordination across agencies, institutions and disciplines. Teams of scientists and graduate students will need to work together on common projects with each contributing their expertise for all to understand how entire systems function. This has been accomplished to some extent with some watershed scale studies and the Bear Creek riparian buffer project, but this needs to be greatly expanded upon.

An important question facing the people of Iowa is, “Do we have the courage and determination to work together as a functional society to confront and correct the causes of NPS pollution within our state?” To do so means that each person that owns or operates any land must look at their activities and change practices that cause off-site losses of sediment and N and P nutrients. It also means that we need to assist and support others in implementing change on their Iowa lands when the magnitude and cost of change threatens their livelihoods. This will require new and innovative approaches in financial support, but also offers the potential to strengthen healthy and productive ties between individuals and groups that will improve communities. Cooperation and coordination among local, state and federal agencies, state universities, and agricultural and non-profit organizations in this endeavor can greatly accelerate progress. The first step will be for all to agree on the need for improved water quality, and then work toward this common goal through active participation.

It must be remembered that one cannot expect change without first performing change. When determining what and where to enact changes, one must choose the applicable technologies and practices that have shown the greatest potential for achieving success. All Iowans will share in the benefits of improved water quality, and all Iowans must share the responsibility to make it a reality.

Appendices

Appendix A
Glossary of Terms

Absorption - the incorporation of an ion or compound into the structure of another compound.

Adsorption - the adherence of an ion or compound onto the surface of a solid particle.

Aerobic - above-ground or soil atmospheric conditions that contains enough free oxygen to support unhindered respiration of aerobic organisms.

Agroecoregion – a unique area characterized by all of the factors accounted for by the ecoregion concept, plus the agricultural factors of the major landform resource area concept.

Anaerobic - above-ground or soil atmospheric conditions that are absent of free oxygen and supports unhindered respiration of other gaseous compounds by anaerobic organisms.

Anion - an ion or compound with a negative surface charge.

Assimilation - the uptake and incorporation of a nutrient or compound into a living organism's tissues.

Baseflow – ground water flow to a surface waterbody, usually occurring in low volumes over sustained periods of time.

Biogeochemical processes - nutrient and ion transformations that occur either biologically, physically or chemically.

Biomass - the amount of living tissue of an organism.

Brownian movement - the vibration of ions, which increases with rising temperature.

Cation - an ion or compound with a positive surface charge.

Cation exchange capacity (CEC) - a measure of soil fertility that refers to a soil's ability or potential to supply nutrients to support plant growth, being the amount of negative charge sites on the surface of soil particles for a given volume of soil.

Concentrated flow/runoff - runoff water that collects from a diffuse flow into a smaller, limited area such as a channel or gully before entering a surface waterbody, having more energy than diffuse flow.

Confining layer - a solid subsurface barrier to vertical water movement, which causes water to perch above the barrier and flow laterally.

Conservation practice - a method or structure that utilizes physical, chemical and/or biological mechanisms to retain a natural resource at its origin or site of application and/or to remove or reduce contaminants from degrading another natural resource.

Cool season plant - a plant that is most active in growth during spring and fall, and less active during summer.

Critical source area - an area or location on a landscape that poses a much greater contamination risk to water resources than surrounding areas within the same drainage basin.

Denitrification - a process mediated by bacterial, physical and chemical means that transforms nitrate to nitrite, then to gaseous N forms of nitrous oxide (N_2O) and dinitrogen (N_2). The bacterial processes only occur under anaerobic (no free oxygen present) soil and water conditions.

Diffuse flow/runoff - runoff water that is spread over a wide area, having less energy than concentrated flow.

Drainage basin/area - The area of a landscape that contributes runoff and baseflow waters to a surface waterbody. Same as a watershed.

Ecoregion - a unique set of physical and biological features that include air, water, land and the interactions of these components that result in the unique habitats that support plant and animal life. An extension of the ecosystem concept to a regional scale.

Ecosystem - a biological community of plants, animals, microbes that interacts with its physical, non-living environment. Actions that affect the living component will also affect the physical, non-living component, and vice-versa.

Field capacity soil moisture content - the maximum amount of water held within a soil without the occurrence of gravitational water drainage.

Hydrology - patterns of surface and subsurface water flow within a given area over space and time, which determines the boundaries of a watershed or drainage basin.

Hypoxia - a condition of limited available free oxygen (< 2 ppm) for either terrestrial or aquatic organisms that can harm or kill the organisms by limiting respiration.

Major landform resource area (MLRA) - a geographically unique area that has similar patterns of soils, climate, water resources, land uses and types of agricultural practices.

Nitrification - the bacterial transformations of ammoniac forms of N first to nitrite, and then to nitrate.

Nitrogen fixation - a symbiotic biological relationship between specific species of plants and bacteria whereby the plants harbor the bacteria within root nodules with the plant providing energy derived from photosynthesis and oxygen to the bacteria and the bacteria providing N to the plant from their ability to mineralize N from atmospheric dinitrogen gas. Also is a process of where N is adsorbed by 2:1 clay particles and held tightly in-between layers of the clays.

Nonpoint source pollution - any source of water pollution that does not meet the definition of point source, being diffuse across a landscape and occurs at intermittent intervals, due mostly to weather-related events. Examples of NPS pollution are contaminated urban and agricultural runoff and leachate waters, flow from abandoned mines and atmospheric deposition of contaminants directly to waterbodies.

Nutrient enrichment - the process of high nutrient content surface materials being preferentially eroded and transported before heavier particles or aggregates in runoff water.

Nutrient immobilization - the assimilation of a nutrient by an organism, making the nutrient unavailable to other organisms.

Nutrient mineralization - the transformation and release of a nutrient from an unavailable to an available form for plant, microbe or animal assimilation.

Nutrient use efficiency - a measure of the amount of a nutrient that a plant assimilates into its biomass compared to the amount of the nutrient that was available within the plant's root zone during the its growing season. This can be expressed either as a ratio or on a percentage basis.

pH - a measure (negative logarithm) of the hydrogen ion concentration of water or cellular and soil solutions. The pH number is Scale varies from 1 to 14 with 1 being the most acidic, 7 being neutral and 14 the most alkaline.

Point source pollution - contamination that is generated by an internal process or activity (not from effects of weather) and is from an identifiable location. Examples of point source pollution may be municipal and industrial wastewater facilities, ground coal storage areas, hazardous waste spill areas, and runoff or leachate from solid waste disposal and concentrated animal feeding confinement sites.

Pothole - a small enclosed depression on a landscape.

Preventive conservation practice - a conservation practice that does not allow the creation of, or at least minimizes the probability of creating, a pollution problem by buffering the environment to destructive forces and limiting the existence of contamination threats.

Remedial conservation practice - a conservation practice that removes or reduces the existence of a pollution problem after the threat of contamination has been created. Such practices are predominantly employed at off-field locations where contaminants have been transported, but before the contaminants have entered existing surface waters designated for public use.

Sequestration - the binding, assimilation or transformation of a nutrient or compound in a form that is stable and resistant to mineralization.

Soil organic matter - both living and dead tissues and decomposed derivative compounds that exists with soil.

Soil surface seal - a thin solid crust of small soil particles bound together that covers a large portion of the soil surface and inhibits water infiltration. This condition occurs after the first precipitation event following a tillage operation and is a major cause of runoff and erosion.

Split fertilizer application - a method of fertilizer management where a nominal amount of N fertilizer is applied at or near the time of planting, then followed by the later in the growing season with a second N fertilizer application. The method by which N fertilizer rates are selected can vary.

Total Kjeldahl-Nitrogen – the sum of organic-N and free ammonia-N.

Total maximum daily load (TMDL) - the maximum allowable mass of a contaminant to pass a measurement point within a 24 hour period without being considered as exceeding an established water quality standard.

Total nitrogen (TN) - the total amount and/or concentration of all N compounds within a given sample of water or soil.

Total phosphorus (TP) - the total amount and/or concentration of all P compounds within a given sample of water or soil.

Vegetative buffer - an area where plants of one or more species exist to remove or reduce the amount of contaminants transported within or off of an agricultural production field in runoff and/or shallow ground water flow before these waters enter a surface waterbody.

Warm season plant - a plant that is most active in growth during summer, and less active during spring and fall.

Water infiltration - water entering and passing through a soil profile in both vertical and lateral directions.

Water percolation - vertical water movement within a soil profile and/or bedrock.

Water residence time - the amount of time for a given volume of water exists within a waterbody, from the point in time of entrance to that of exit.

Watershed - Same as drainage basin/area (see above), the size of which depends upon the surface waterbody of reference.

Appendix B
Background Section References

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Appendix C
Assessments and Summary and Conclusions Section References

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