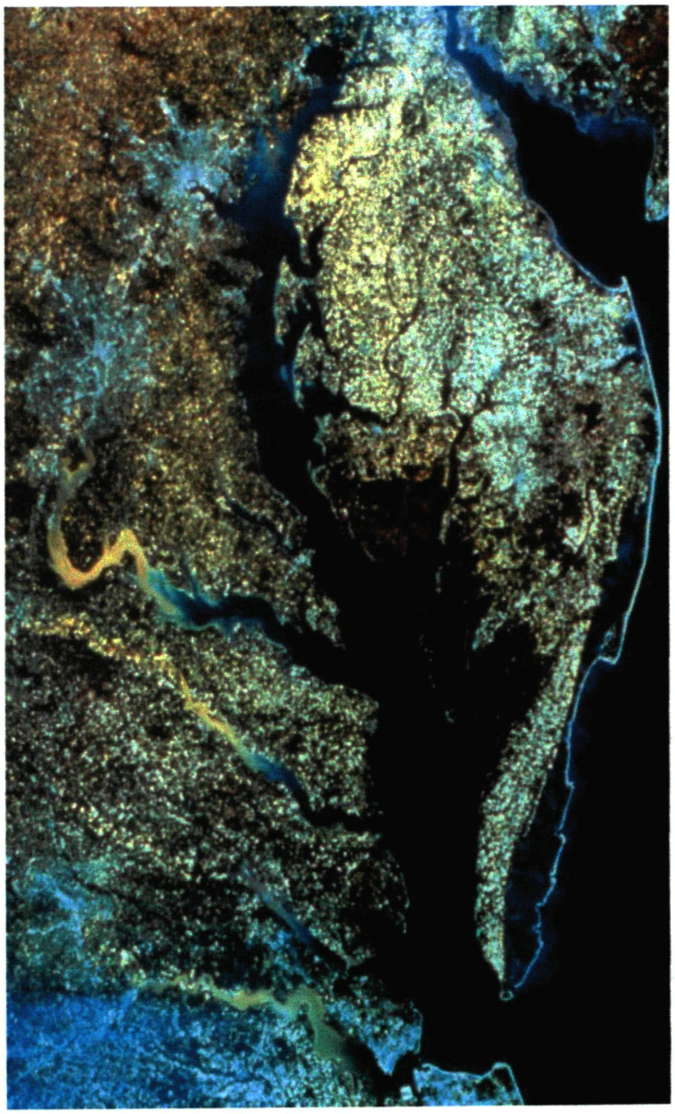
Innovative Cropping Systems Incentive Program Professional Development Training

May 21-22, 2002



Sponsored by a grant from SARE

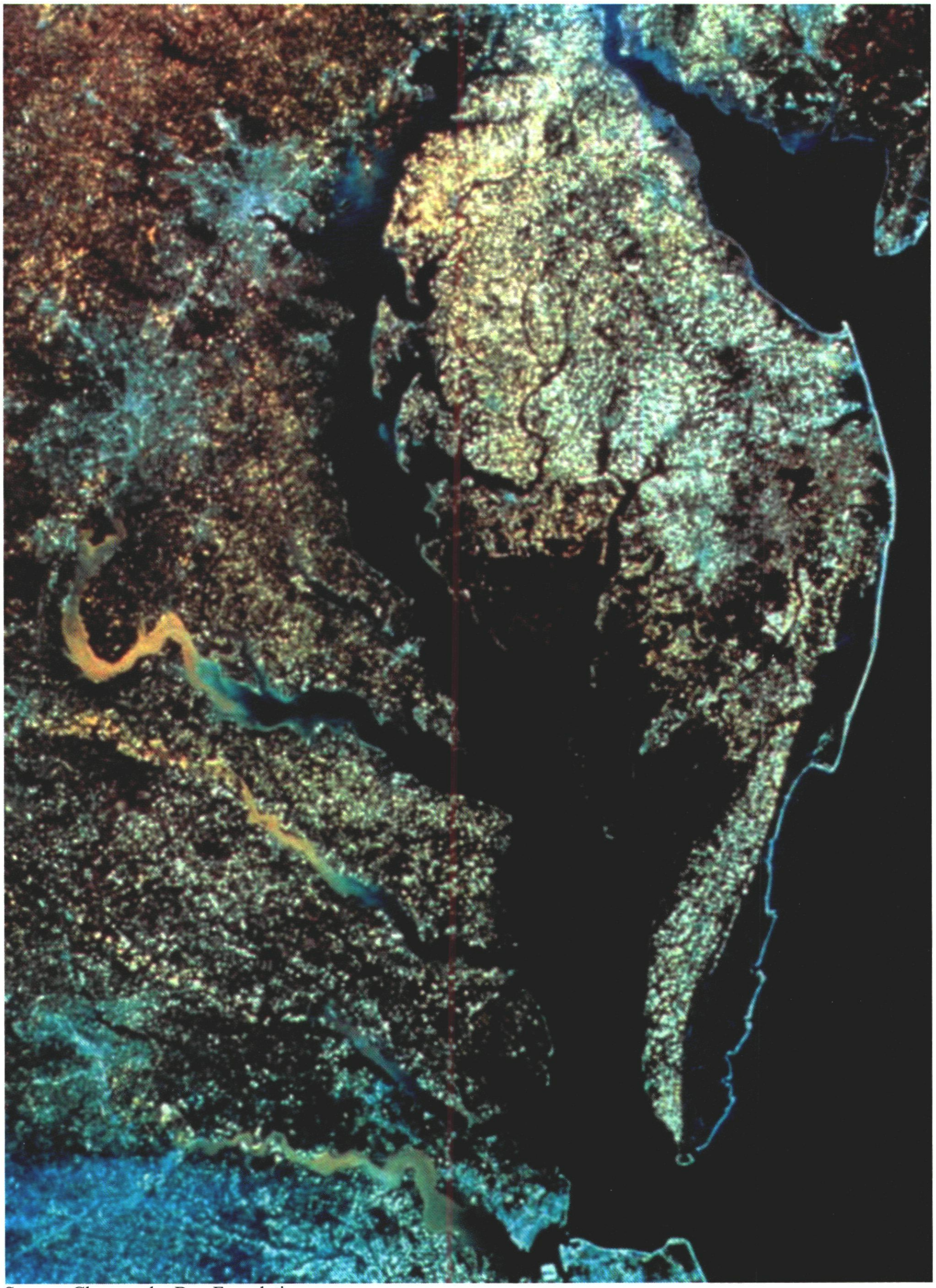
Introduction

Thank you for attending the Innovative Cropping Systems (ICS) & Soil Quality Professional Training. The subject matter and program participants represent a milestone for the ICS cooperators. The long - term commitment to efficient management and resource conservation by local producers can not be overstated. The potential of their efforts indicates a revolution in crop production and environmental protection. It is the goal of this Grassroots initiative for you to better understand the dynamics of ICS and utilize the potential in your own capacity as a professional. Please take advantage of this opportunity to ask questions of the many individuals that have made themselves available for the two-day program. The quality of individuals available on the program represent, are on the forefront, and are some of the most active and knowledgeable authorities on a national, regional and local scale. The sponsors of ICS are the pioneering farmers, the Colonial Soil & Water Conservation District, New Kent & Charles City Cooperative Extension & Virginia Tech. A USDA/ Sustainable Agriculture Research & Education (SARE) Professional Development Program Grant provided the primary financial support for this training. The training material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, under Agreement No. RE675-107/1789847. Any opinions, findings, conclusions, or recommendations expressed are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture or other program participants and sponsors. Partial support has been provided by grants from the Virginia Department of Conservation & Recreation, Va. Agricultural BMP Cost Share Program Innovative BMP Demonstration Grant, James & York Tributary Strategies Implementation Grants and DCR Mini Grant Programs. The social on the 21st is sponsored by Monsanto (Sandston, Va. Branch). The field tour refreshments are sponsored by Colonial Farm Credit. Gustafson sponsors the field tour dinner. Thanks to all of our partners and sponsors that have made this event possible. All programs and services of the Colonial Soil & Water Conservation District, Virginia Tech & Virginia Cooperative Extension are offered on a nondiscriminatory basis without regard to race, color, national origin, religion, sex, age, marital status, or handicap.

ICS

INNOVATIVE CROPPING Systems

The Chesapeake Bay and its major tributaries depicted by satellite imagery.



Source: Chesapeake Bay Foundation

Acknowledgements

Primary ICS Partners

Colonial Soil and Water Conservation District

Board Members
Archer Ruffin
Steve Lueke
Eric Randolph

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Jim Wallace
Kelley Bartell

Virginia Cooperative Extension

Dr. Mark Alley
Dr. Blake Ross
Paul Davis
Vernon Heath

Pioneering ICS Farmers

David Black
Jon Black
David Hula
Frank Hula

Special thanks goes to Paul Davis, New Kent Cooperative Extension Agent, for his superior technical support and outreach efforts. Without his commitment and dedication, the ICS project would not have been possible.

ICS THE FUTURE

The ICS partnership has evolved from a grassroots commitment that relies on sound science and incentive-based initiatives to support agricultural efficiency and resource conservation.

There is a proven track record in Virginia that continuous no-till management can be productive and advantageous, not only to agricultural producers but also the general public.

By reducing erosion, increasing the potential for groundwater recharge, regulating stream flow, and potentially mitigating global climate change, the achievements of the ICS project appeal to more than the agricultural community.

Although the ICS project began in the coastal plain of Virginia, with its goal being improved water quality in the Chesapeake Bay, this agricultural management system offers a model that can easily be adapted to other impaired watersheds nationwide.

The ICS partnership has realized the potential for improved soil quality. Part of this realization inlcudes the understanding that we still have much to discover about the dynamics of the soil ecosystem.

The next step of the program lies in scientific research needed to quantify the beneficial impact of and define the agronomic variables associated with the system that will make continuous no-till a standard practice on a national scale.

"Agricultural intensification through the adoption of scientifically proven BMPs can solve, rather than cause, numerous environmental problems..."

This scientific base will expand producer confidence and provide support in securing competitive grant funds. Initiatives for voluntary implementation such as technical exchange, financial assistance, and management system refinement are all needed to experience large-scale adoption of ICS.

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Chesapeake Bay Foundation

Colonial Soil and Water Conservation District

Hampton Roads Planning District Commission (HRPDC)

USDA/NRCS Soil Quality Institute

Disclaimer

ICS INNOVATIVE CROPPING SYSTEMS

Foreword

Since the mid 1990s, farmers and staff of the Colonial Soil and Water Conservation District have cooperatively planned and implemented conservation practices that accomplish water quality goals as part of the Tributary Strategies Initiative in Virginia. This initiative is a voluntary approach that promotes the development of goals to reach a projected improvement in water quality in each of the tidal estuaries of the Chesapeake Bay's major tributaries.

The Colonial SWCD has sponsored competitive grant proposals to support the Innovative Cropping Systems (ICS) partnership. District representatives and cooperative stakeholders have worked to evaluate and promote methods to achieve water quality goals. Funds made available by the Virginia General Assembly for Soil and Water Conservation Districts to promote Virginia's Tributary Strategies Initiative represent the primary financial support for the project.

This publication was funded by the York Watershed Council, through the Virginia Department of Conservation and Recreation, to promote ICS methodology across Tidewater Virginia and beyond. ICS is a product of grassroots efforts fulfilling the intended mission and vision of the Virginia General Assembly in dedicating funds to organizations such as the York Watershed Council.

A 1993 study measured the amount of carbon dioxide released from soil nineteen days after wheat stubble had been plowed. The moldboard plow caused as much carbon to be oxidized as had been photosynthesized in the roots and residue during the whole growing season. This rate was five times greater than in comparable, untilled plots. Traditionally, it has been thought that forested lands hold the largest potential for the sequestration of carbon. Recent information has indicated, however, that combining intensive agricultural rotations including cover crops with continuous no-till management could possibly sink more carbon than native forests.

The potential of U.S. cropland to sequester carbon over the next 50 years is in the range of 5000 million metric tons (MMT) through the adoption of BMPs. BMPs can improve soil organic carbon (SOC) content, enhance soil quality, restore degraded ecosystems, increase biomass productions, improve crop yield, and encourage reinvestment in soil resources for soil restoration.

ICS MANAGING THE DETAILS OF TECHNOLOGY

Adopting conservation tillage systems, such as continuous no-till, can result in equivalent or higher yields and improvements in soil quality. However, as with any new technology, there are management challenges to overcome, like reduced soil temperature, disease, and compaction.

SOIL TEMPERATURE

Maintaining residue on the soil surface, as with continuous no-till, contributes to a slower warming of the soil in the early spring compared to a plow-tilled seedbed. Lower soil temperature tends to have adverse effects, such as decreased germination rates and delayed maturity on crops such as corn and cotton more so than soybeans.

The type, distribution, and amount of residue on the soil surface influence the rate of warming. Wheat, rye, and corn crops produce dense, slowly decomposing residues that, compared to soybeans, result in delayed soil warming.

To overcome lower soil temperatures during spring planting, local farmers are finding success by clearing residue from the row area with flat disks, sweeps and fluted coulters. The use of raised beds also tends to positively affect soil warming in no-till systems.

In an Iowa study, removing approximately four inches of residue in the corn row resulted in:

- Increased corn height
- Decreased days to emergence by 50%
- Decreased days to tassel by 50%
- Increased yield by 5 bu/ac

DISEASE

The wetter, cooler soil environment created by the use of no-till management systems also produces conditions that encourage disease. In order for disease to become a problem, there must be a host, a pathogen and favorable environmental conditions present. However, maintaining conditions favorable for plant growth alters the potential of diseases such as stem and stalk rot and foliar diseases.

Some agronomic management practices that eliminate or reduce disease conditions (i.e. favorable for plant growth) are:

- Selection of resistant varieties
- Crop rotation
- Use of recommended fungicides and seed treatments
- Timing of planting
- Control of insects and weeds
- Maintenance of adequate soil fertility

BULK DENSITY AND COMPACTION

A soil's bulk density refers to its dry weight per given volume. This value indicates how much pore space is contained in the soil column that is sampled. For example, the higher the bulk density, the lower the amount of pore space.

Pore spaces found in the soil profile are necessary for air and gas exchange, as well as surface water infiltration. Pore spaces are actually voids in the soil that are created by decayed plant roots and earthworm burrows.

By implementing continuous no-till management systems, the soil profile is rarely disturbed and never inverted as with conventional tillage, thereby

Source: Soil Quality Institute

preserving pore space, maintaining a lower bulk density, and increasing water infiltration.

Local observations indicate that, over time, continuous no-till management can correct poorly drained and compacted soils. Even though conservation tillage will reverse some of the degradation of soil properties caused by tillage, yields may be reduced too substantially to proceed with conservation tillage prior to alleviating the compacted soil.In an effort to speed up the process of alleviating compacted soils (consequently, making the land more productive), in-row subsoiling or ripping has been incorporated as a management tool.

The process of ripping consists of pulling a steel shank, usually between 12"-20" deep, through the soil profile, shattering the compacted or restrictive layer. The shanks are typically less than 1" in width and 30" apart, thereby minimizing surface disturbance.

In areas where continuous no-till has been implemented on a long-term basis (7+ years), the use of ripping has shown no agronomic benefit indicating that soil quality has improved to the point where ripping has become unnecessary.

PERENNIAL WEED CONTROL

Farmers who utilize the ICS management system have acknowledged that overall weed pressure has decreased in their fields. However, some perennial broadleaf weeds such as milkweed, pokeweed, and trumpet creeper continue to be a nuisance. The use of technological advancements in genetically modified crops, specifically corn and soybeans, in conjunction with non-selective herbicides has contributed to the success of continuous no-till systems.

Cover crops (such as small grains) help reduce erosion, compaction, and nutrient loss while increasing the amount of crop residue returned to the soil surface.

COVER CROPS

The use of cover crops with continuous no-till rotations is an excellent way to avoid and resolve compacted soil problems. Cover crops such as wheat, barley, rye, or clover, enhance the soil ecosystem by increasing vegetative cover and residue. This management alternative is especially beneficial during periods when erosion energy is high and cash crops are not in the rotation. Above ground, this vegetative cover serves to break the impact of raindrops, thereby reducing surface compaction. Underground, actively growing roots trap nutrients, stabilize soil, and eventually lead to more pore space.

SMALL GRAINS: THE LAST GREAT HURDLE

Although many crops have been successfully managed using no-till planting methods, small grains, including wheat and barley, have not. Farmers who have incorporated no-till small grain into the rotation have identified several key ingredients in their success.

Planting speed and depth

With heavy corn residue present, it is especially important to slow planting speed to ensure proper seed depth and seed to soil contact. Today's technology has adapted to the need for heavy-duty, no-till seed drills to overcome heavy crop residue.

Elimination of all green matter

It is very important to eliminate all living plants in the field with the use of a non-selective herbicide. Without the burn down of volunteer plant material, a "green bridge" can occur, causing pest infestation.

Use of Soil and Tissue Tests

Due to increased nutrient cycling and nutrient availability, the traditional wisdom that accompanied conventional tillage must be revised. The only way to determine specific plant needs is through the use of soil and tissue tests.

ICS THE EVOLUTION

A small group of central Virginia farmers have been credited over the years with many technical achievements that protect water quality. In addition, these farmers have shown a great deal of willingness to share ideas through partnerships.

These early efforts evolved into the project known as the Innovative Cropping Systems Incentive Program (ICS).

ICS emerged in the form of intensive biomass cropping rotations that incorporate continuous no-till and nutrient management. These techniques became the cornerstones of an innovation that is now receiving national attention.

Research, demonstration and financial incentives have been utilized to address technical and financial risk associated with ICS practices. Farmers helped develop the program and sponsor adoption for the Virginia Cost-Share Program.

These efforts have been combined and coordinated with many long-term and existing efforts that have been critical to the current ICS milestone.

Documented success and farmer outreach have led to greater producer confidence in ICS management.

Jim Wallace, Colonial SWCD; Dan Towery, Conservation Technology Information Center; Paul Davis, New Kent Cooperative Extension; Dr. John Kimble, USDA-NRCS National Soil Laboratory; and Dr. Ron Follet, USDA Agricultural Research Service, observe ICS first-hand.

CHALLENGING ESTABLISHED METHODS

Citing a multitude of obstacles, in the beginning many farmers and technical authorities cautioned the ICS partners against continuous no-till. Impediments such as disease risk in wheat, substantial equipment cost, nutrient/lime incorporation, reduced soil temperature, and initial yield reductions seemed too extreme to justify the controversial methods of ICS.

However, individual farmers have blazed trails to overcome these obstacles and assisted technical partners in identifying a multitude of variables as the management system has evolved.

ATTRACTING NATIONAL ATTENTION

Recently, news of the phenomenal potential of these accomplishments has attracted nationwide attention. National authorities have inquired about and visited Colonial SWCD to better understand ICS. The national perspective has shown that the ICS farmers are leading the nation in this technology, and the soil quality improvement potential is real. The ICS story has been a featured agenda item of many major agricultural and watershed conferences. Articles in two national agricultural publications (CTIC Partners June 2001 & No-Till Farmer, May 2001), along with a multitude of local publications and newsletters, have highlighted the success of ICS.

In addition, a video entitled "Continuous No-till Grain Production Systems", detailing the performance of ICS, was funded through the Department of Conservation and Recreation. The video primarily utilizes interviews with participating farmers who have first-hand experience with and knowledge of ICS practices.

In February 2002, the video received the District Outreach Award in Broadcast Media at the 2002 National Association of Conservation Districts (NACD) annual meeting.

PROPONENTS OF CHANGE

The Colonial Soil & Water Conservation District, Virginia Tech, Virginia Cooperative Extension-New Kent County and Charles City County Offices, and the York Watershed Council would like to recognize the ICS farmers for their achievement, outreach, and partnership commitments.

The success of this program can be attributed to a cooperating partnership built on trust and careful planning. The partnership worked to acquire grant funds to provide technical and financial based incentives to encourage participation. In addition, long-term research and demonstration have been a large part of the evolution of ICS.

While the activities of all the cooperators have been critical, it must be recognized that the farmers have made ICS a reality.

ICS A VOLUNTARY, COST-EFFECTIVE ALTERNATIVE TO REGULATIONS

In planning future actions toward improving water quality, federal, state, and local governments commonly use computer modeling to compare the efficiency of various ideas to determine the most appropriate course of action. This strategy has been used for the Chesapeake Bay Watershed including each of its major tributaries.

The tributary models predict ecological responses associated with several strategy scenarios. The most ambitious scenario, known as Limit of Technology (LOT), promotes one hundred percent compliance with regulations and implementation of stringent restrictions and Best Management Practices (BMPs).

In the James Watershed, LOT predicts a reduction of 341,700 tons of sediment per year. According to EPA projections, the cost of achieving this goal by the year 2010 has been estimated at $464.67 million.

The ICS pilot cost-share program shows much promise as an alternative strategy to reach goals at a fraction of the projected cost.

ICS has the potential to replace many other BMPs by preventing erosion at the site of raindrop impact before accumulation and acceleration of runoff. Additionally, the efficient nature of no-till guarantees a perpetual lifespan; other conventional BMPs have relatively short life spans and intensive maintenance requirements.

LOCAL WATER QUALITY AND AVAILABILITY

Local aquatic ecosystems have continued to suffer from the conversion of forests to impervious surfaces and decreased soil quality in suburban and urban areas across Virginia. Nutrient and sediment pollution has resulted in decreased dissolved oxygen levels and poor water clarity, which impact the habitats and health of the vital aquatic ecology.

Submerged aquatic vegetation (SAV) historically supported the aquatic life that created the valued ecology and economy of the Chesapeake Bay and local rivers. With increased human activities in the watershed, poor water quality has devastated local SAV populations, and drastically impacted numerous other species.

It is estimated that approximately 1.1 million acres in Virginia could implement ICS practices.

Bulk density is an indirect measure of soil pore space that helps quantify soil compaction.

An undisturbed soil profile increases soil aggregation, promotes root and earthworm channels, and enhances surface water infiltration. These factors promote plant growth, which lead to more crop residue and organic matter.

Organic Matter

The amount of organic matter in soil is the result of the combined influences of climate, inherent soil characteristics, land cover, land use, and management practices.

Generally, organic matter increases with higher rainfall or irrigation and moderate temperatures, because these conditions are favorable for plant growth (biomass production).

Conversely, soils formed under arid climates are usually low in organic matter, generally due to decreased biomass. Organic matter stores water and nutrients, feeds soil organisms that decompose organic material, and returns basic nutrients to the soil. Carbon, oxygen, nitrogen and other nutrients must be available to soil microorganisms for the development of organic matter.

Biological Activity

A healthy soil has a diverse set of macro and microorganisms that assure a well-functioning soil food web.

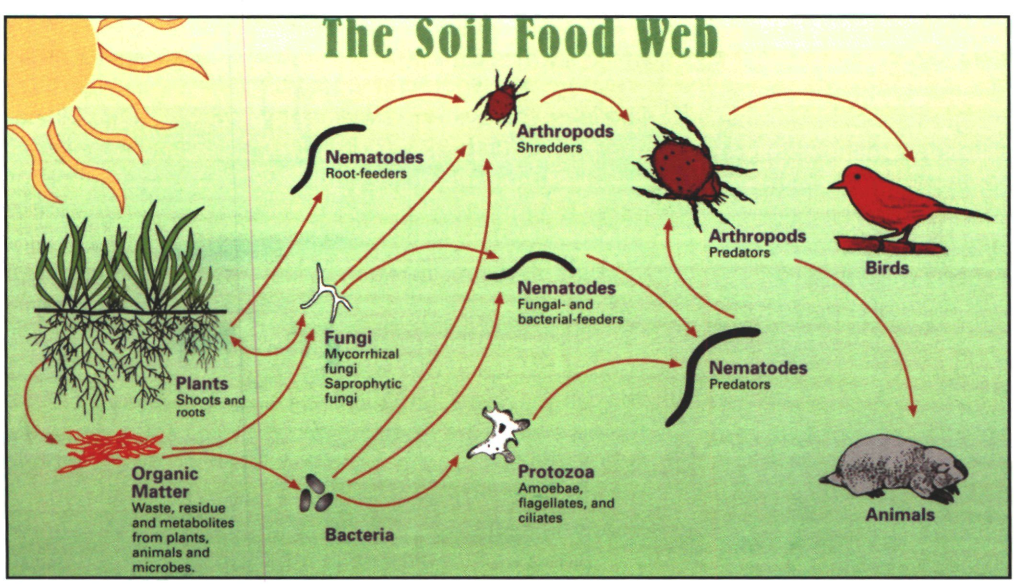
Earthworms play a major role in improving soil quality.

Microorganisms decompose organic material, store nutrients in their bodies, and release nutrients as they decay or become food for other organisms.

Macroorganisms such as earthworms have significant impacts on soil properties by creating channels in the soil. These channels increase the flow of water and air through the soil, promoting root development.

Earthworms also improve soil structure and tilth by digesting organic material and other soil particles. The resulting casts help bind the soil with their stability.

> "Earthworms may, in effect, partially replace the work of tillage implements by mixing materials and making them available for subsequent crops."



Source: Soil Quality Institute

Diversity of organisms within an ecosystem is a primary indicator of soil health.

WATER QUALITY

Improving soil quality has significant effects on additional natural resources including water and air. Differences in soil organic matter, microbial activity, pore space, and aggregate stability lead to improved surface water infiltration resulting in reduced surface runoff. Runoff carries sediment, nutrients and trace amounts of heavy metals, which can contaminate surface water sources.

As water moves through the soil profile, it has the potential to be held in soil pore space and organic matter or stored by living plant roots. As soil becomes saturated, water moves down toward groundwater reservoirs. The soil acts as a filter to retain impurities and nutrients that are either used by plants or consumed by microorganisms. This process reduces, and in some instances eliminates, groundwater contamination.

The fact that continuous no-till promotes this type of water filtration and groundwater recharge is important because potable water resources are predicted to be in short supply due to changes in hydrologic regimes, increased water usage, and population growth. The Newport News Water Works projects a need of approximately 75 million gallons per day to satisfy future requirements for the Lower Peninsula. Current surface and groundwater supplies suffer in quality and quantity.

Cost estimates for developing new freshwater sources through reservoirs and desalinization are considerable. If Hampton Roads continues to grow as predicted, factors such as increased water withdrawal, limited groundwater recharge, and greater stormwater runoff will negatively influence the health of aquatic ecosystems.

Most of Virginia's prime farmland, such as this along the lower James River, is located adjacent to the major tributaries of the Chesapeake Bay.

AIR QUALITY

There is no consensus on the issue of global warming. Is the current warming trend a cyclical weather pattern or have we, as humans, changed Earth's climate through the misuse of our natural resources? No matter what you believe, the evidence is clear that the amount of carbon dioxide (CO_2) in Earth's atmosphere is greater now than ever measured. Science has shown that CO_2 is the most abundant greenhouse gas linked to global warming.

Through the process of plant photosynthesis, CO_2 is taken out of the atmosphere, into the plant and O_2 is expelled. The resulting carbon molecule is stored in the plant. This process occurs everyday and in every plant on Earth.

When a plant dies or, in the case of agriculture, is harvested, the plant residue falls to the ground. Depending on temperature and moisture, the residue is decomposed by soil dwelling microorganisms, which use the residue as a food source.

Carbon that was once stored in the plant is then located in the microorganism. Since the soil ecosystem is not disturbed in continuous no-till management, this carbon remains in the soil. Indications point to the possibility that the soil can hold carbon for centuries.

Conversely, when the soil ecosystem is disturbed through the use of conventional tillage, microbial activity is stimulated, causing increased decomposition of plant residue. This leads to a rapid oxidation of organic matter into CO_2, which is released into the atmosphere.

THE CHESAPEAKE BAY MODEL

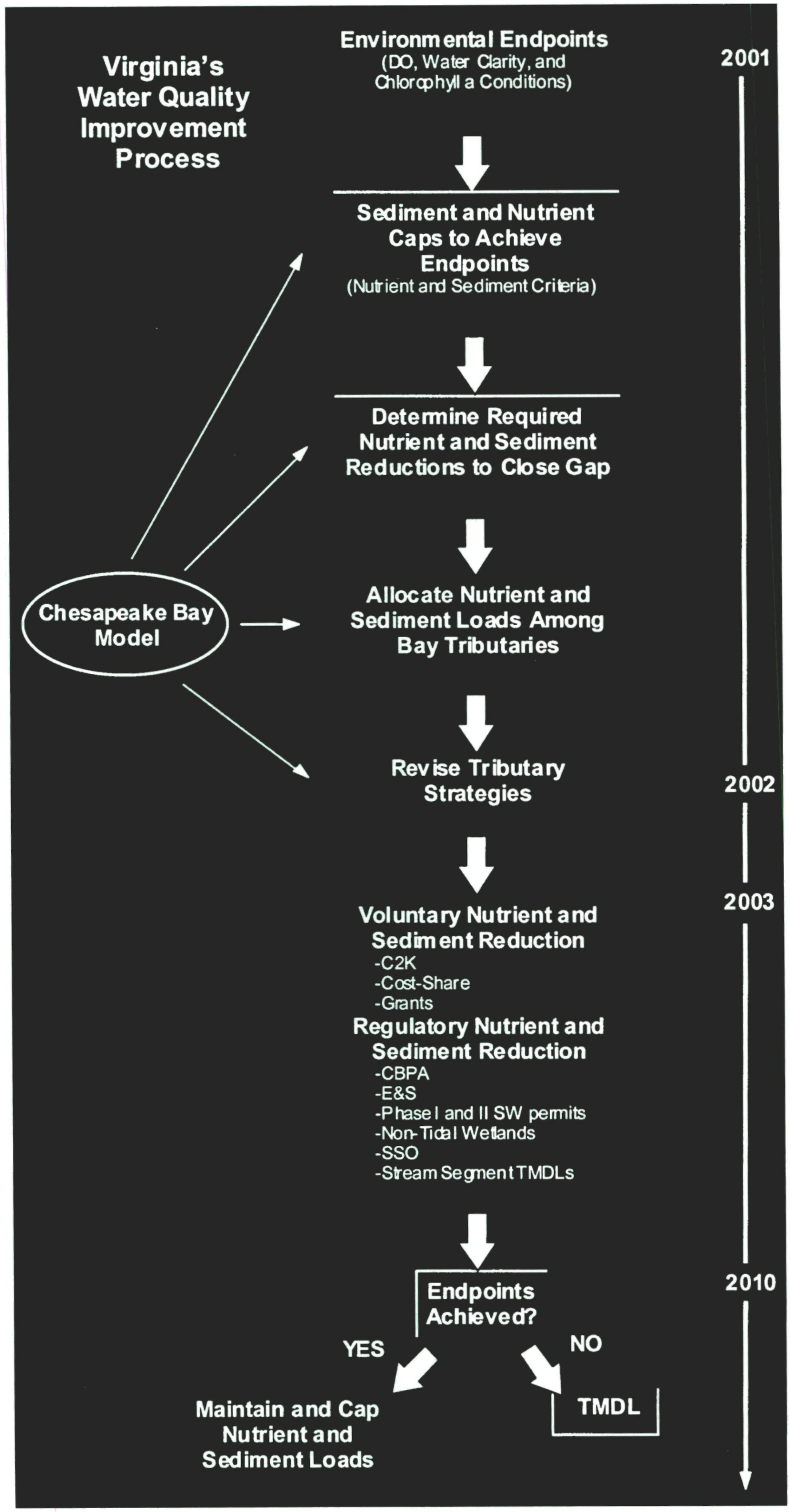
Virginia and the US Environmental Protection Agency have developed pollution loading data for each major tributary that flows to the Chesapeake Bay. Information about pollution loads from point and non-point sources, land use, air deposition and water quality are applied to a computer model to assess and predict the ecological health of the Chesapeake Bay tidal estuary. This multi-dimensional model is used as a primary planning tool for Bay cleanup programs.

THE LOWER TRIBUTARIES

Tributary planning is important for many reasons. The James and York Watersheds are prime examples of why each tributary should have a strategy to address the multitude of variables in that watershed. The York, for instance, suffers from low dissolved oxygen due to excessive nutrients despite maintaining historically forested cover. On the contrary, the James receives the highest sediment load of all the tributaries within Virginia. Pollution loads are just one of the many physical and social variables that must be factored into a watershed plan.

RESOURCE CONSERVATION IN VIRGINIA

Virginia has developed several programs and initiatives to meet water quality goals in the Chesapeake Bay by the year 2010. Voluntary and regulatory commitments include the Chesapeake Bay Agreement (C2K), Tributary Strategies, Chesapeake Bay Preservation Act, Virginia Erosion and Sediment Control Law, Stormwater Discharge Permits Phase 1 & 2, Clean Water Act, and Impaired Water TMDLs. Actions after 2010 are dependent on the status of predicted environmental endpoints.



Source: Hampton Roads Planning District Commission

ICS RESEARCH

In 2000, the partnership secured competitive grant funds to continue research on ICS in the form of rainfall simulator plots. Dr. Blake Ross, Extension Specialist with the Department of Biological Systems Engineering at Virginia Tech, conducted the study. Dr. Ross and his staff subjected plot areas of 7.5% slope to a simulated five-year storm event. The plots compared long-term (ten years) ICS and clean-tilled conventional small grain practices. This research clearly demonstrates the reductions achieved by ICS.

These flumes funnel excess stormwater from each research plot through a flow meter that measures the water's volume. Water samples from the flumes are used to evaluate the levels of sediment, nitrogen, and phosphorus washed from each plot.

The photo on the right depicts runoff from a no-till plot (Treatment C, below). The excess water appears to contain very little sediment, which was confirmed by data collected from each flume. In addition, the no-till plots yielded very low levels of nutrients in the stormwater runoff.

The photo on the left, an example of conventional tillage, clearly contains eroded sediment. Data collected from this plot (Treatment A) reveals substantial levels of sediment and nutrients in the runoff.

Average measured runoff, sediment yield, and nutrient losses by treatment on an areal basis (percent reductions relative to Treatment A in parentheses) - Renwood Farm, Charles City County, Virginia: August 9 - 10, 2000.

Treatment * (plot #s)	Runoff (cu. Ft/ac)	Sediment (lb/ac)	Nitrogen (lb/ac)	Phosphorus (lb/ac)
A (1 & 8)	6506 (-)	3176.3 (-)	9.17 (-)	3.65 (-)
B (2 & 6)	1547 (76.2)	30.5 (99.0)	0.54 (94.1)	0.38 (89.6)
C (3 & 7)	2014 (69.0)	18.5 (99.4)	0.49 (94.7)	0.27 (92.6)
D (4 & 9)	1573 (75.8)	5.4 (94.9)	0.47 (94.9)	0.26 (92.9)
E (5 & 10)	1373 (78.9)	16.0 (99.5)	0.46 (95.0)	0.25 (93.2)

*** Treatments: A– fertilizer, plowed; B– litter, no-till; C– control, no-till; D– fertilizer, no-till subsoiled; E– fertilizer, no-till**

ICS A TOOL TO ADDRESS MAJOR RESOURCE CONSERVATION CHALLENGES

One of the most promising aspects of continuous no-till agricultural production is its effect on the environment. The enhancement of soil quality is recognized as both a valuable tool in the protection of water quality and for its role in agricultural sustainability.

ICS encourages biological activity needed for soil restoration resulting in hydrologic/pollution control and regulation for the watershed.

If implemented on an agricultural land-use scale, this could address many critical resource conservation challenges such as availability of drinking water, flood control, and optimum stream flow. Furthermore, experts suggest that ICS may have potential for reducing air pollution by sequestering, in the soil, greenhouse gases responsible for global warming.

LOCAL OBSERVATIONS

The Good Luck Tract in Charles City, Virginia, has a combination of the most difficult conditions for soil resource conservation and water quality management in the Virginia Coastal Plain.

With an erodibility factor of 0.43 and 1,000-foot long slopes with average grades of 10%, soil loss predictions are high. The Universal Soil Loss Equation predicts soil losses of more than 44 tons per acre per year for this site using conventional management. These factors make the Good Luck Tract the most susceptible to extreme rainfall.

In 1999, several hurricanes devastated eastern Virginia, testing the assertions that ICS eliminates or drastically reduces runoff. Even through Hurricane Floyd, a 500+ year storm event, crop residue at Good Luck stayed intact without evidence of concentrated flow. A lack of downstream bank erosion, sediment deposition or affected vegetation was also observed. All the other long-term ICS fields exhibited the same phenomenon.

The Good Luck Tract is an example of the most difficult conditions faced by farmers in the Coastal Plain of Virginia, which makes the application of ICS on the Good Luck Tract a model of sustainability.

SOIL QUALITY

Soil is one of the most basic, fundamental compounds of life. Its main function is to support plant growth, but it also represents the living reservoir that buffers the flow of water, nutrients and energy through an ecosystem. A soil's quality is primarily determined by its texture, structure, water-holding capacity, porosity, organic matter content and pH. Research has shown that soil quality can be improved through continuous no-till management by recreating and then maintaining a natural balance in the soil ecosystem.

The improvement in soil quality is achieved primarily through the addition of crop residue and growing plant roots, which feed soil microorganisms. In turn, soil organisms decompose organic matter, cycle nutrients and enhance soil structure. Soil organic matter is the storehouse for the energy and nutrients used by plants and other organisms.

Reduced tillage and regular additions of organic material such as crop residue will raise the proportion of active soil organic matter. As the level of soil organic matter rises, soil organisms convert it to humus, a stable supply of carbon that can be sequestered in untilled soils for decades or centuries.

KEY CONCEPTS IN SOIL QUALITY

Erosion

Erosion and runoff are both detrimental to nutrient management. Nutrients contained in the topsoil, along with soil organic matter, can be carried away by erosion or washed out with runoff water. The organic matter is the first to be transported by water or wind because of its lower specific gravity. Additional nutrients are required to maintain productivity lost when topsoil is carried away by erosion.

Compaction

Compact soils restrict the movement of roots. Less root volume in the soil prevents nutrient uptake. Compaction also restricts the diffusion and flow of nutrients in the soil. Few roots and limited nutrient movement can result in stunted plant growth. Compacted soils retard air movement and gas exchange in the root zone, leading to denitrification or a build up of toxic gas near the roots.

Source: Soi Quality Institute

Increased efficiency and consistent yields will result in greater profitability, the primary incentive for implementation.

Infiltration, Soil Aggregation, and Bulk Density

Water is required to move surface-applied nutrients into the soil for plant use. Proper soil infiltration permits the movement of these nutrients into the root zone.

Improved soil aggregation affects water and nutrient movement through the soil by providing pore space for water infiltration and gas exchange. Soil aggregation is closely tied to the amount of active organic matter and biological activity.

Table of Contents

Day 1

Tuesday
May 21, 2002

Innovative Cropping Systems Incentive Program
Professional Development Training
May 21 & 22, 2002
Wyndham Hotel – Richmond
4700 S. Laburnum Ave.
(804) 226-4300

Tuesday, May 21, 2002

9:30 AM – Refreshments Sponsored by SARE

9:30 AM – 1:00 PM – Registration

10:00 AM - Early Bird Choice Breakout Sessions: 4 Concurrent Sessions

1) **No-Till Cotton Systems** – Jim Maitland, VA Tech Cotton Extension Specialist

2) **Soil Quality** –Bobby Brock, NRCS NC Soil Quality Team & Jim Wallace, Colonial Soil & Water Conservation District-Ag. Water Quality Specialist

3) **No-Till Equipment**– Dr. Bob Grisso, VA Tech Ag Biological Systems Engineering

4) **Utilizing Biosolids in No-Till Production** – Dr. Greg Evanylo, VA Tech Extension Waste Management Specialist

5) **No-Till Small Grains**– Dr. Dan Brann, VA Tech Extension Grains Specialist

6) **No – Till and Organic Nutrient Management**– Dr. Greg Mullins, VA Tech Nutrient Management Specialist

1st Session - 10:00 – 10:30	2nd Session - 10:40 – 11:10	3rd Session - 11:20 – 11:50
(Sessions 1, 2, 3, 4 offered)	(Sessions 3, 4, 5, 6 offered)	(Sessions 1, 2, 5, 6 offered)

12:00 Lunch Sponsored by SARE

General Session: Opportunities with No – Till Systems: Program Moderator- Brian Noyes, Colonial SWCD

1:00 PM **Welcome & Introduction -** Brian Noyes, Colonial SWCD

1:05 PM **Innovative Cropping Systems Incentive Program (ICS)-** Brian Noyes, Colonial SWCD

1:15 PM **Evolution of Local Farm Management Systems** - Paul Davis, VCE, New Kent Co.

1:30 PM **ICS No-Till Video**

1:45 PM **Conservation Tillage in the U. S. – Continuous No-Till vs. No-Till with Rotational Tillage -** Dan Towery, CTIC Natural Resources Specialist & Dave Schertz, USDA-NRCS National Agronomist

2:25 PM **Carbon as an Alternative Crop** – Dr. John Kimble, Research Soil Scientist, USDA/NRCS, National Soil Survey Center – Lincoln, NE

2:55 PM **Break** (Program Moderator Jim Wallace, Colonial SWCD)

3:10 PM **Nitrogen Fate & Transport in Agricultural Systems** - Dr. Ron Follett, Superviso Soil Scientist – USDA/ARS, Fort Collins, CO

3:40 PM **Carbon, Nitrogen & Phosphorus Stratification Under Conservation Tillage** – Dr. Alan Franzluebbers, Soil Ecologist, USDA/ARS-Watkinsville, GA

4:10 PM **Nutrient Trading: Bay & National Status** – David Batchelor, Senior Policy Advisor, US/EPA/Office of Water

4:40 PM **Virginia's Nutrient Trading Program Development Process** – Patricia Jackson, Executive Director, James River Association

4:55 PM **No-Till Corporate Perspective** – Bruno Alesii, Conservation Tillage/Ag. Systems Manager, Monsanto

5:15 PM **Chesapeake Bay Water Quality Model** – V'lent Lassiter, Data Management Analysis, VA Department of Conservation & Recreation.

5:30 PM **Adjourn**

6:00 PM **Social *Sponsored by Monsanto***

6:30 PM **Dinner Sponsored by SARE – Welcome and Invocation** - Dr. H. Jackson Darst Chairman, Colonial SWCD

7:20 PM **ICS- Not Just "No-Till"** – Brian Noyes, Colonial SWCD

7:35 PM **The Honorable W. Tayloe Murphy, Jr., VA Secretary of Natural Resources**

7:45 PM **Continuous No – Till Farmer Panel & Discussion** (Panel Moderator) Paul Davis

David Hula – Farmer, Board member of VA Corn Growers Assoc.
(Past President of VA Small Grains Association)
David Black- Farmer, Board Member of VA Small Grains Assoc.
(Past President of VA Small Grains Association)
Jon Black- Farmer, Treasurer of VA Cotton Growers Assoc.
Eric Randolph- Farmer, President of VA Corn Growers Assoc.
(Former Director of Colonial SWCD)

Question & Answer Period

All programs and services of the Colonial Soil and Water Conservation District are offered on a nondiscriminatory basis without regard to race, color, national origin, religion, sex, age, marital status or handicap.

BIOGRAPHIES

Bruno Alesii

Bruno A. Alesii is a manager in the Technology Development Department of Monsanto, Colorado. He is responsible for planning, coordinating and implementing conservation tillage and agronomic systems research and promotion programs for the US business of Monsanto Company. This entails developing various promotional programs that drive the growth of conservation tillage practices and evaluating the impact that various tillage systems, cultural practices, crop rotation and the application of new technologies such as biotech and precision agriculture have on a crop production via Monsanto's Centers of Excellence.

Bruno joined Monsanto in 1982 as a field product development representative in Illinois after working on his Ph.D. in Soil Fertility at Iowa State University. He also holds a Masters in Soil and Water Science and a BS in Agricultural Chemistry and Soils, both from the University of Arizona. Over the past 18 years he has held various positions of increasing responsibilities within Monsanto. He is well versed in the area of precision agriculture, biotechnology, conservation tillage practices, climate change and the use of herbicides in various cropping systems.

A strong supporter of sustainable farming practices; He is an active member of numerous conservation organizations including Conservation Technology Information Center (Chairman), National Association of Conservation District's Business Alliance Council (Member of the board), Soil and Water Conservation Society just to mention a few. He is a frequent speaker at conferences and meetings dealing with sustainable farming practices.

Daniel E. (Dan) Brann

Daniel E. (Dan) Brann was born on a grain crop farm in the Northern Neck of Virginia, obtained his B. S. in Agronomy at Virginia Tech in 1967 and his Ph.D. in Agronomy at West Virginia University in 1971.

He worked for a short time on the Allegheny Highland Project in Elkins, West Virginia and as a soybean specialist in the Arkansas Extension Service. In 1974, he returned to Virginia Tech as the Extension Grains Specialist located in Blacksburg, Virginia. Since 1974, his program has focused on multidisciplinary approaches to small grains and corn management and marketing. For the past decade he has coordinated the hybrid/variety evaluations for grain crops. He is a charter member of the Virginia Corn Growers Association and the Virginia Small Grains Association.

One of the greatest technical contributions is as a member of the team that increased statewide small grains yields from 35 bu/acre in the 1970's to above 65 bu/acre in the 1990's.

Bobby G. Brock

- Born and raised on general farm, Cumberland Co., NC.
- He was an honor graduate of NCSU in Ag. Education, with post baccalaureate studies in Agronomy and Soils.
- Began work with USDA-SCS, June 1962 as Student Trainee, Lillington, NC
- Soil Conservations, Statesville, NC 1963-64
- District Conservationist, Sanford, NC 1965-67
- District Conservationist, Goldsboro, NC 1968-74
- District Conservationist, Raleigh, NC 1975-83
- Conservation Agronomist, Raleigh, NC 1983 –
- Received Certificate of Merit 1966, 1971, 1980, 1984, 1991, 1996, 1999
- SWCS Member continuously since 1964
- Served as regional council member, Pres. Elect, Pres.
- Received Chapter Professional Achievement 1969
- International Merit Award 1971
- Superior Service Award (Chapter, 1992)
- Agency contact in NC on global climate change
- Regional soil quality contact
- Served on NRCS NEDS Soil Quality Course Development Group
- Instructor NEDS Soil Quality Course
- Served as instructor for several NEDS courses (mgmt., soil loss)
- Authored chapter in book *Soil Quality and Soil Erosion,* 1999
- Member American Society of Agronomy
- Member, Soil Science Society of NC
- Co-author of *History of Conservation Tillage in NC*

Certificates of Appreciation:

- NC Crop Residue Management Alliance
- Georgia Conservation Tillage Alliance
- Environmental Impact RC & D

Paul Davis

Mr. Davis obtained his Associate Degree from Ferrum College and his B. S. from Virginia Tech in integrated pest management. He received his M. S. in weed science at Virginia Teach. He has been an Extension agent in New Kent County for 20 years. He and his wife, Marian, have two daughters Trudy (attends Virginia Tech) and Tricia.

Greg Evanylo

Greg Evanylo is a Professor of Waste Management and Utilization in the Department of Crop and Soil Environmental Sciences at Virginia Tech. Greg received a B.A. in Biology from the University of Connecticut, an M.S. in Plant and Soil Sciences from the University of Massachusetts, and a Ph.D. in Agronomy from the University of Georgia. He conducted research in Soil Fertility and Water Quality as an Assistant Professor at the Eastern Shore Agriculture Experiment Station from 1984 to 1989. Since 1989, he has conducted extension and research programs designed to investigate and promote the processing and use of wastes for the protection and enhancement of soil and water quality. Greg's work particularly addresses the land application of composted and non-composted biosolids and other waste by-products and the use of composting as a tool to transform wastes into beneficial products.

Ronald F. Follett

Dr. Follett has been in research for 36 years; 34 with ARS during which he has served as research scientist in Mandan, ND and Ithaca, NY; National Program Leader for ARS programs on soil fertility, strip-mine reclamation, soil productivity, and environmental quality in Beltsville, MD and Fort Collins, CO; and Research Leader of the Soil Plant Nutrient Research Unit in Fort Collins, CO.

He has authored or coauthored over 200 scientific contributions, including and been lead editor for 6 books, co-author on one and co-editor on 5 others. He is a Fellow of the Amer. Soc. of Agron., Soil Science Soc. of Amer. and the Soil & Water Cons. Soc; he was elected to Gamma Sigma Delta in 1986 and to the NY Acad. of Science in 1989. He has been called upon to represent USDA and/or ARS on numerous foreign and domestic assignments.

Dr. Follett has twice (1984 and 1992) received USDA's highest award, the Distinguished Service Award, as a member of USDA teams that developed the Erosion Productivity Impact Calculator (EPIC) model and the Nitrate Leaching and Economic Analysis Package (NLEAP) model, respectively, and in 2000, received an Individual USDA Superior Service Award for his work on natural resources.

In 1991, he was invited to serve on the Council for Agricultural Science and Technology (CAST) task force that prepared Rpt. #119, "Preparing U.S Agriculture for Global Climate Change" that was the USDA position document for the 1992 International Framework Convention on Climate Change in Rio De Jenario, Brazil.

Dr. Alan J. Franzleubbers

Dr. Alan J. Franzleubbers is a research soil ecologist with the Agricultural Research Service (ARS) of the USDA in Watkinsville, GA. He holds degrees in Horticulture and Agronomy from the University of Nebraska and obtained his Ph.D. in Soil Science from Texas A & M University in 1995. He was a visiting fellow at the Northern Agriculture Research Centre in Beaverlodge, Alberta in 1995. Has conducted research to improve N fertilizer recommendations for crops, to characterize the biochemical and biophysical fractions of soil organic matter, to quantify soil organic C and N sequestration potential of land management systems and to refine and standardize protocols for assessing soil biological properties including soil microbial biomass determination.

Dr. Franzluebbers serves as Join-Editor-in-Chief of *Soils & Tillage Research,* as Editorial Board member of *Soil Biology & Biochemistry,* and as Associate Editor for the *Soil Science Society of America Journal.* Summaries of current project descriptions can be found at http://www.spcru.ars.usda.gov/AJF%20home.htm.

Dr. Robert Grisso

Professor in Biological System Engineering, he has a BS, MS from Virginia Tech, and PhD from Auburn University. He joined the VT faculty last year after 16 years at University of Nebraska - the "other: football school. He has educational responsibilities in precision farming, machinery management and farm safety.

Dr. D. Ames Herbert, Jr.

Dr. Herbert grew up in Auburn, Alabama. He received his B. S. degree in Biology from Johnson State College. He began his graduate work at Northern Arizona University in Flagstaff, Arizona, but later transferred Auburn University where he completed both his M. S. and Ph.D. degrees in Entomology. He came to Virginia Tech Tidewater Agricultural Research and Extension Center in August of 1988, where he currently resides as a member of the Department of Entomology. He is also the State IMP (Integrated Pest Management) Coordinator, a role he assumed in 1997, is the Extension Project Leader for the Department of Entomology and is an Adjunct Associate Professor at North Carolina State University.

Dr. Herbert's program focuses on developing ways to improve management of insect pests of soybean, small grains, peanuts and cotton. He works with Extension Agents, farmers and industry across the Commonwealth and is active in many regional and national groups, associations and professional societies. He resides in Franklin, Virginia with his wife Julee, a public school teacher, two sons (already 'left nest' for college) and one daughter.

Patricia A. Jackson

Patricia A. Jackson is the Executive Director of the James River Association. She as served in this capacity since January 1983. The Association is a non-profit organization with over 2,000 members dedicated to the conservation and responsible stewardship of the natural and historic resources of the James River Watershed.

Ms. Jackson's previous experience includes over six years on the staff of the Virginia Water Control Board and two years with Texaco Research Laboratories.
She has an MS in Environmental Sciences and Engineering from Virginia Tech and a BA in Environmental Studies from the University of Rochester, NY.

Ms. Jackson serves on the Boards of the Water Environment Federation, the Virginia Water Environment Association, and the Virginia Conservation Network. She is also on the Advisory Boards of the Friends of the Rivers of Virginia and the Center for Environmental Studies at Virginia Commonwealth University. In addition, she serves on the Boards of the Hanover Citizens for Quality of Life and the Mechanicsville Unit of the American Cancer Society.

Ms. Jackson and her husband have three daughters, and live in Hanover County.

John M. Kimble

John M. Kimble, Research Soil Scientist, National Soil Survey Center, Soil Survey Division, USDA, Natural Resources Conservation Service, Lincoln, Nebraska.

Extensive experience in the following areas: (1) Field Soil Mapping; (2) Soil Correlation; (3) Development of Soil Laboratory Procedures and Laboratory Design; (4) Soil Chemistry/Analytical Methods; (5) Soil Classification and Soil Genesis; (6) Environmental Problems Related to Global Climate Change; and (7) Program Management and Policy Development related to the items listed above. For the last 12 years, I have been a major player in the USDA Global Change Program as well as with many other groups. In doing this I have worked with many universities, government and non-government scientists, policy makers and program managers inside the United States and within several other countries.

I was an invited member of the United States National Agriculture Assessment Team to address "Climate Change and Changing Agriculture, a lead author on the IPCC Special Report on Land Use, Land-Use Change and Forestry which lead the basis for emissions trading through sequestration. I have testified in the Senate three times related to different aspects of carbon sequestration and I have given numerous talks on the subject of carbon sequestration. I have done research looking at the long-term effects of no-till, conservation tillage, effects of irrigation and manure application on carbon sequestration.

V'lent Lassiter

V'lent Lassiter is a Data Management Analyst with the Virginia Department of Conservation and Recreation (DCR). She assists DCR's Nonpoint Source Pollution Modeling Coordinator in tracking nutrient reductions through Virginia's Tributary Strategies program. V'lent has a B.S. in Sociology with a Certificate in Environmental Studies and is currently working on completing her Master's degree in Environmental Science at Virginia Commonwealth University.

James C. Maitland

Extension Cotton Specialist for Virginia 1995 to present.
County Agent Dinwiddie County 1981-1995
Vocational Agricultural Teacher Dinwiddie County 1967-1981

Brian Noyes

Brian Noyes currently is the District Manager for the Colonial Soil & Water Conservation District where he has served the localities of Charles City, New Kent, James City and York Counties and the City of Williamsburg in Virginia for 10 years.

Prior to working for the district Brian has approximately 12 years experience in farm management in Delaware, Maryland and Virginia as well as 6 years experience as a research field technician for the University of Delaware.

Brian holds a BS degree in agriculture from the University of Delaware.

The Colonial SWCD has been the principal administrator of a project known as the Innovative Cropping Systems Incentive Program (ICS). ICS promotes intensive Biomass cropping rotations, continuous No-Till and nutrient management systems for corn, soybean, wheat, Milo, cotton, and cover crops.

ICS accomplishments include numerous research and demonstration initiatives, technical exchange events, a pilot cost share program, video and promotional publication production, public awareness, resource conservation quantification, and watershed planning and extensive grassroots partnerships.

ICS has shown unprecedented potential for cost effective resource conservation in Virginia.

Dr. Steve Phillips

Dr. Steve Phillips is a soil fertility specialist located at the Eastern Shore Research and Extension Center in Painter, VA. His research interests include N and P use efficiencies for various field and vegetable crops and broiler litter management strategies. Another area that Steve is heavily involved is in the development of on the go, variable-rate N fertilization strategies for wheat and corn using sensors mounted directly on the fertilizer applicator. Although he is located on the Eastern Shore, Steve has conducted wheat fertility research in cooperation with agents and growers throughout the Coastal Plain, Piedmont and Valley regions of the state.

Prior to coming to Tech in 1999, Steve was employed for six years as a soil fertility research technician at Oklahoma State University, where he also received his M.S. and Ph.D. Steve is originally from Southwest Oklahoma where he grew up working on wheat, forage and cattle operations.

Erick L. Stromberg

Education:

- B.S., University of California, Riverside, California, 1968
- Ph.D., Oregon State University, Corvallis, Oregon, 1977

Professional Experience:

- Professor and Extension Plant Pathologist, Department of Plant Pathology, Physiology and Weed Science, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061-0331, 1994 to present.
- Associate Professor and Extension Plant Pathologist, Department of Plant Pathology, Physiology and Weed Science, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061-0331, 1986 to 1993.
- Assistant Professor and Extension Plant Pathologist, Department of Plant Pathology, Physiology and Weed Science, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061-0331, 1981 to 1985.
- Plant Pathologist and Adjunct Assistant Professor, USDA, APHIS, PPQ, Department of Plant Pathology, University of Minnesota, St. Paul, MN 55108.
- Graduate Teaching Assistant, Department of Botany and Plant Pathology, Oregon State University, Corvallis, OR 97331.

Recent Awards and Honors:

- 2000 – Distinguished Service Award, Potomac Division, And The American Psychopathological Society.
- 1997 - The Henderson Award, in Recognition as Outstanding Faculty Member,

Department of Plant Pathology, Physiology and Weed Science, Virginia Polytechnic Institute and State University.

- 1996 - The Virginia Small Grains Association, in Recognition for the Development in Implementing Scientifically Based Economic Recommendations for Wheat Disease Control.
- Gray leaf spot resistance in maize involves the evaluation of maize germplasm for resistance to gray leaf spot caused by *Cercospora zeae-maydis*.
- Reduction of the economic impact of take-all caused by *Gauemannomyces graminis* var. *tritici* on Virginia wheat production.
- Refinement of economic thresholds for the control of foliar diseases in wheat for powdery mildew, stagonospora leaf and glume blotch, and tan spot.
- Evaluation of various chemical and biological seed treatments for control of disease in wheat to control seedling diseases, improve seedling vigor, control powdery mildew, and barley yellow dwarf virus.
- Evaluation of wheat germplasm for resistance to fusarium head scab.

Dan Towery

Dan has been the CTIC natural resources specialist since 1995. As staff agronomist, his activities include managing the national crop residue management survey, and as a national resource on conservation tillage, precision farming, soil quality, and other Best Management Practices. Prior positions include United States Department of Agriculture/Natural Resources Conservation Service Illinois state agronomist, district conservationist in Springfield, Illinois, soil scientist, and fertilizer plant manager. Dan graduated from Western Illinois University, Macomb, Illinois with a BS in agronomy.

James Wallace

Jim currently serves as the Agricultural Water Quality Specialist for the Colonial Soil & Water Conservation District. While serving in this capacity, Jim writes Soil and Water Quality Conservation Plans that satisfy Chesapeake Bay Preservation Act ordinances for James City, York, New Kent, and Charles City Counties, along with the City of Williamsburg. Jim has also worked diligently to support the efforts of the Colonial SWCD, namely the Innovative Cropping Systems Incentive Program (ICS), and continues to pursue "alternative" benefits of ICS.

Prior to his employment with the Colonial SWCD, Jim worked for Chickahominy Ag Service and The Izaak Walton League of America, after earning a B.B.A. from James Madison University in 1991.

Jim and his wife Diane live in Providence Forge, VA with their two sons and expected daughter.

2002 IFA International Award

Professor Mark M. Alley
Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA
will receive the 2002 IFA International Award in Lisbon on 22 May 2002.

Professor Alley was nominated for the 2002 IFA International Award, which rewards research related to conditions in a developed country or a country in transition, by IFA member IMC Global. The company also put his name forward for the 2000 Award, when he was runner-up.

Alley is the W.G. Wysor Professor of Agriculture, an endowed chair in the Department of Crop and Soil Environmental Sciences at Virginia Polytechnic Institute and State University (Virginia Tech).

Alley's research has focused on the effective and efficient use of fertilizers in total crop management systems. He developed a series of experiments on the yield-limiting factors of nitrogen fertilizer rates and application timings, plant requirements for phosphorus and potassium, precision planting and lodging control. Alley's current work with soil moisture availability, plant populations and fertilizer rates suggests that increased nitrogen fertilization and plant populations can increase maize yields by 12 to 15 per cent on selected soil series compared to standard practices.

Contact Us

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Day 2

Wednesday May 22, 2002

Innovative Cropping Systems
Field Tour
Charles City & New Kent Counties

Wednesday, May 22, 2002

7:00 AM - **Breakfast**

8:00 AM - **Load Buses for Tour** (Wyndham Hotel Parking Lot)
Refreshments in transport *sponsored by Colonial Farm Credit*

8:45 AM - **Tour Stop 1: John Black & Sons**

- No – Till vs. Strip Till vs. Conventional Till Cotton, Dr. Jim Maitland, VA Tech Cotton Specialist & Vernon Heath, Charles City Cooperative Extension
- No – Till Wheat into Cotton Residue, Dr. Dan Brann, VA Tech Extension Grain Specialist
- Poultry Litter Amended No-Till Wheat after Cotton, Dr. Greg Mullins, VA Tech Nutrient Management Specialist

9:50 AM – **Leave John Black & Son**

10:00 AM - **Tour Stop 2:Good Luck Tract, George & David Black**

- No – Till Nitrogen Fertility Plots, Dr. Steve Phillips, VA Tech Soil Fertility Specialist
- No – Till Organic Nutrient (Chicken Litter) Amended Wheat, Dr. Greg Mullins
- Wheat Management: Conventional Till vs. Double Disk vs. Standing Stalks vs. Mowed Stalks, Ron Mulford, Univ. MD, Research and Extension Farm Mgr. – Poplar Hill Station, Maryland.

11:30 AM – **Leave Good Luck Tract**

12:00 Noon **Lunch at Parkers Ridge *sponsored by SARE***

1:00 PM – **Load Buses**

1:40 PM – **Tour Stop 3: Pamunkey Farms – Stanley, David & John Hula**

- No – Till Phosphorus Fertility Plots, Dr. Steve Phillips, & Dr. Greg Mullins
- No-Till Ryegrass Control in Wheat, Dr. Scott Hagood, VA Tech Weed Science Specialist & Dr. Kevin Bradley, Weed Science Research Associate.

2:25 PM – **Load Buses**

2:30 PM - **Tour Stop 4: L.C. Davis Farm (Sunny Side)** – Clifton, Paul, Preston, Randy, Ray, Vin and Wayne Davis

- Wheat Tillage vs. Variety vs. Population, Dr. Dan Brann, VA Tech Grain Specialist
- Tillage vs. Wheat Disease Control, Dr. Eric Stromberg, VA Tech Plant Pathologist

3:20 PM – **Load Buses**

3:30 PM - **L.C. Davis Farm (Hill Farm)**

- Corn Tillage Plots, Chris Lawrence, VA Tech King & Queen and King William Counties and Tillage Plots, Dr. Dan Brann and Paul Davis
- No-Till Drill Comparison, Dr. Bob Grisso, VA Tech Ag. Biological Systems Engineering

4:15 PM – **L.C. Davis Farm (Wesley's Farm)**

- No-Till Wheat Date of Planting Plots, Dr. Dan Brann & Paul Davis
- No-Till Wheat Speed of Planting Plots, Paul Davis
- No-Till Wheat Variety Trials, Paul Davis
- Seed Treatment Study, Dr. Ames Herbert, VA Tech Integrated Pest Mgmt. Specialist

5:00 PM – **Load Buses (One bus back to Wyndham or three buses to dinner)**

5:15 PM – **Dinner "Pig Pickin" on the Pamunkey – *sponsored by Gustafson***
(Tentative Equipment Demonstrations)

6:45 PM – **Load buses and depart for the Wyndham Hotel**

7:30 PM – **Arrive at Wyndham Hotel**

All programs and services of the Colonial Soil & Water Conservation District are offered on a nondiscriminatory basis without regard to race, color, national origin, religion, sex, age, marital status or handicap.

SARE

Sustainable Agriculture Research and Education

SOUTHERN REGION

The Innovative Cropping Systems Incentive Program Professional Development Training

Field Tour

May 22, 2002

Sponsored by a grant from the Southern SARE Program
In cooperation with

Virginia Tech
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Virginia Cooperative Extension
Knowledge for the CommonWealth

VIRGINIA STATE UNIVERSITY

&

VIRGINIA SOIL & WATER CONSERVATION

Colonial Soil and Water Conservation District

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Doswell
Millers Tavern
Dunnsville
Bowlers Wharf
Sharps
Kings Dominion
Dawn
Mangohick
Zoar State Forest
St. Stephens Church
Center Cross
Litwalton
Nuttsville
Moratticо
Bella Isle St. Pk.
Butylo
Lively
Randolph-Macon College
Ashland
Hanover
Aylett
Central Garage
Stevensville
Water View
Manquin
Walkerton
King William
King & Queen C.H.
Free Ferry
Church View
Remlik
Studley
Pamunkey River
Warner
Bertrand
Urbanna
Mattaponi Indian Res.
Old Church
Pamunkey Indian Res.
Rappahannock Com. Col. Glenns Campus
Saluda
MECHANICSVILLE
Chelsea Plantation
West Point
Glenns
RICHMOND
Bottoms Bridge
Talleysville
New Kent
Shacklefords
Adner
Sandston
Gressitt
Roxbury
Providence Forge
Barhamsville
York River State Park
Ark
Lanexa
Gloucester
Allmondsville
Virginia
Piney Grove
Toano
Norge
Lightfoot
Camp Peary
White Marsh
Pocahontas State Park
Chesterfield
James River Plantations
Edgewood
Holdcroft
Charles City
Chickahominy
Beach
Chester
Shirley
Evelynton
Berkeley
Westover
Gardens
North Bend
Sherwood Forest
Flowerdew Hundred
Brandon Gardens
Byway
Williamsburg
Colonial Pkwy
Colonial Heights
Hopewell
Busch Gardens
Matoaca
Fort Lee
Burrowsville
Claremont
Jamestown
Prince George
Free Ferry
Scotland
Hog Island Game Refuge
Sutherland
PETERSBURG
Cabin Point
Spring Grove
Smith's Fort
Surry
Ft. Eustis
Poplar Grove Nat'l Cem.
Disputanta
Bacon's Castle
Chippokes Plantation State Park
Miles B. Carpenter Museum
Elberon
Dinwiddie
Waverly
Dendron
NEWPORT NEWS
Carson
Rescue
Smithfield
Wakefield
Homeville
Benns Church
Stony Creek
Ivor
Isle of Wight
Sussex
Littleton
Zuni
Chuckatuck
Yale
Nottoway River
Blackwater River
Windsor
SUFFOLK
King William
King and Queen
New Kent
Charles City
Prince George
Surry
Sussex
Isle of Wight
Henrico
Hanover
Chesterfield
Middlesex
Gloucester

Tour Directions

Please refer to the map on the previous page for the tour route. While on the tour, look for the signs that say SARE TOUR. The signs are small, but they are florescent orange in color.

TOUR ROUTE

- **Wyndham to 1st stop:**

Leave Wyndham & turn left (north) on Laburnum Ave. & travel approximately 1/2 mile & enter the I 64 East ramp. Go past the I 295 interchange approximately 2 miles (1st exit after the interchange) & take the Bottoms Bridge Exit #205 (bear right on Rt. 249 south). Proceed approximately ¼ mile & turn left on Route 60 (east). Continue approximately 6 miles on Route 60 east & turn right on Route 106 – Roxbury RD. (south). Continue approximately 5 miles on Rt. 106 south to the 1st stop, J.W. Black's farm, which will be on the right.

- **J.W. Black's to 2nd stop:**

Continue south on Route 106 – Roxbury Rd. for approximately 1 mile and turn left on Route 650 Cattail Rd. (East) & travel approximately 2.5 miles and turn left on Route 655 – Salem Run Rd. and continue to the wheat field and the 2nd stop the Good Luck Tract.

- **Good Luck Tract to 3rd stop & lunch at Parkers Ridge:**

Go the same way out that you came in on Route 655 – Salem Run Rd. & turn right on Route 650 – Cattail Rd. (West) back to Route 106 – Roxbury Rd. Once you get to Route 106-Roxbury Rd. turn left & travel south approximately 7 miles to the traffic signal & turn left on Route 5 (East). Continue East for approximately 11 miles & turn left on Route 155 (north) at Charles City Courthouse. Continue north approximately 3 miles to Parkers Ridge (look for sign on left) turn into the Parkers Ridge entrance & proceed to the area where lunch is served.

- **Parkers Ridge to 4th stop at Pamunkey Farm:**

Turn left on Route 155 (North) out of Parkers Ridge & continue approximately 13 miles through Providence Forge to Route 249 & turn right (East). Continue approximately 2 miles through New Kent Courthouse & bear left on Route 623 – Cook's Mill Rd. (East). Continue approximately 5 miles & turn left on Route 625 - Farm Hill Rd. go to the top of the hill and make the 1st turn to the right. You have arrived at the 4th stop.

- **Pamunkey Farm to remaining stops and Dinner on L.C. Davis Farm:**

Continue straight & follow the signs to the various stops. Dinner will be 500 ft down the road after your 1st left hand turn.

This completes the tour. Please call any of the following mobile phones for tour directions or transit locations. Jim Wallace @ 356-1885, Paul Davis @ 514-8550 or
Kilby Majette @ 570-3688

Tour Stop 1

J.W. Black & Sons

John W. Black
Keith Black
Jon L. Black

Charles City, VA

The Blacks currently farm approximately 2,100 acres in Henrico, Charles City, and New Kent Counties. In 1995, the Blacks along with several other area farmers made a switch from a cash grain rotation of corn, wheat and double crop soybeans to a cotton, wheat, double crop soybean system. Since switching to cotton, the Blacks have been "tweaking" their management style to accomodate no-till planting methods on a continuous cycle. For the past 7 years, the Blacks have used a deep, sub soil ripper to relieve compacted soil conditions caused by years of conventional tillage.

Keith and Jon Black represent the 4th generation farmers in the Black family, and believe that the economic savings resulting from no-till management may be a key ingredient in allowing a fifth generation to continue farming.

Pre-Plant Tillage in Cotton Study

John W. Black & Sons
Charles City, VA

Jim Maitland, VA Tech Cotton Extension Specialist
Vernon Heath, VCE - Charles City County

Planting Date:	April 25, 2002
Soil Type:	Kempsville-Emporia Fine Sandy Loam
Previous Crop:	Double Crop Soybeans
Tillage:	No-Till vs. Min-Till vs. Deep Rip vs. Shallow Rip
Variety:	Stoneville 4892 BR
Population:	2.5 seeds per foot of row
Fertilizer:	Banded Starter 17-35-0 Apr. 25, 2002
Herbicides:	26 oz. Round-Up Ultra Apr. 2, 2002 1 qt. Prowl Apr. 2, 2002 1 qt. Cotoran Apr. 2, 2002
Fungicides:	
Nemacides:	5 lbs. Timek Apr. 25, 2002
Insecticides:	
Growth Regulator:	

Tillage Plots: 15' x 40' 4 reps

Poultry Litter Rates in No-Till Wheat, following No-Till Cotton Study

J.W. Black & Sons
Charles City, VA

Paul Davis, VCE New Kent County
Brian Noyes, Colonial SWCD

Planting Date:	October 18, 2001
Soil Type:	Kempsville-Emporia Fine Sandy Loam
Previous Crop:	Cotton
Tillage:	No Tillage on Wheat Plots
Variety:	Pioneer 2643
Population:	22 seed per foot of row
Fertilizer:	Pre-plant 1 ton poultry litter (31-71-31) **57 lbs TKN 2 tons poultry litter (62-142-62) ** 114 lbs. TKN Commercial (40-80-80) Winter 50# N– Jan. 27, 2002 Spring 50# N– Mar. 28, 2002
Herbicides:	1 qt. Round-Up Ultra Oct. 16, 2001 1/3 oz. Harmony Extra Jan. 27, 2002 1/3 oz. Harmony Extra Mar. 28, 2002
Fungicides:	4 oz. Tilt Apr. 28, 2002
Insecticides:	2 oz. Warrior Apr. 28, 2002
Growth Regulator:	1/2 pt. Cerone Apr. 18, 2002

Treatment Plots: Litter Plots 30' X 600' 3 reps
Commercial Plots 60' X 600'

Tour Stop 2

Heritage Farm, LLC

George and David Black

Good Luck Tract

Charles City, VA

As the name implies, farming is a family affair that has deep roots for father-son operation. Of the 900 acres that George and Dave farm, almost one half of the land has been farmed by this family for three generations. Three Hundred and fifty of the remaining acres are located at the Good Luck tract, which has become known as the "ICS Poster Child". The environmental challenges that the Blacks face at this tract are as complex and as difficult as any found in the Coastal Plain of Virginia. With highly erosive, as well as marginally productive soils, combined with steep slopes like those found on this tract, conventional agricultural systems (and BMPs) would be cost prohibitive. However, by using continuous no-till, intensive bio-mass rotations (including corn, wheat, soybeans, and milo), additions of sludge, and intensively managing crop nutrients, Dave Black says that "we are improving the soil from the top down", and that is why we have been successful. David has several crop yield titles to his credit including the 1992 National Wheat Yield Challenge.

As you visit the Good Luck tract, try to visualize the 18 inches of rain that fell during Hurricane Floyd, and the potential impact that could have happened...but didn't.

Poultry Litter in No-Till Wheat, following No-Till Corn

Heritage Farm, LLC
George & David Black
Charles City, VA

Paul Davis, VCE - New Kent
Brian Noyes, Colonial SWCD

Planting Date:	October 24, 2001
Soil Type:	Caroline Fine Sandy Loam
Previous Crop:	Corn
Tillage:	No Tillage in this study
Variety:	Pioneer 26R38
Population:	22 seeds per foot of row
Fertilizer:	Pre Plant 1 ton poultry litter (31-71-31) + 60 # K commercial ** 57 lbs. TKN 2 tons poultry litter (62-142-62) ** 114 lbs TKN Commercial 30-40-90-5s Winter 21 # N Dec. 4, 2001 Winter 50 # N Feb. 1, 2002 Spring 45 # N Mar. 30, 2002
Herbicides:	1 qt. Round-Up Ultra Oct. 4, 2001 2 pt. 2-4-D Oct. 4, 2001 4 oz. Banvel Dec. 4, 2001 1/3 oz. Harmony Dec. 4, 2001 1/2 pt. 2-4-D Feb. 1, 2002
Fungicides:	10 oz. Stratego Apr. 26, 2002
Insecticides:	2 oz. Warrior Dec. 4, 2001 2 oz. Warrior Apr. 26, 2002
Growth Regulator:	None

Test Plots: Litter Plots 30' X 900' (3 reps)
Commercial Plots 60' X 900' (3 reps)

Soil Nitrate Tests: Jan. 25, 2002
Top 12" sample

Treatment	PPM NO_3-N
1 Ton Litter	1
2 Ton Litter	2
Commercial	1

Pre Plant Tillage in Wheat following No-Till Corn Study

Heritage Farm, LLC
George & David Black
Charles City, VA

Paul Davis, VCE - New Kent
Brain Noyes, Colonial SWCD

Planting Date:	October 24, 2001
Soil Type:	Caroline Fine Sandy Loam
Previous Crop:	Corn
Tillage:	No-Till (mowed vs. standing stalks) vs. Double Disked vs. Conventional
Variety:	Pioneer 26R38
Population:	22 seeds per foot of row
Fertilizer:	Pre Plant Commercial 30-40-90-5s Winter 21 # N Dec. 4, 2001 Winter 50 # N Feb. 1, 2002 Spring 45 # N Mar. 30, 2002
Herbicides:	1 qt. Round-Up Ultra Oct. 4, 2001 2 pt. 2-4-D Oct. 4, 2001 4 oz. Banvel Dec. 4, 2001 1/3 oz. Harmony Dec. 4, 2001 1/2 pt. 2-4-D Feb. 1, 2002
Fungicides:	10 oz. Stratego Apr. 26, 2002
Insecticides:	2 oz. Warrior Dec. 4, 2001 2 oz. Warrior Apr. 26, 2002
Growth Regulator:	

Treatment Plots: 30' X 225' (3 reps)

Modification of the Nitrogen Fertilization Optimization Algorithm (NFOA)) for Winter Wheat Production in Virginia

Heritage Farm, LLC
George & David Black
Charles City, VA

Dr. Steve Philips, VA Tech

Planting Date: October 24, 2001

Soil Type: Caroline Fine Sandy Loam

Previous Crop: Corn

Tillage: No-Till

Variety: Pioneer 26R38

Population: 22 seeds per foot of row

Fertilizer: Pre Plant Commercial 30-40-90-5s

Herbicides:
1 qt. Round-Up Ultra Oct. 4, 2001
2 pt. 2-4-D Oct. 4, 2001
4 oz. Banvel Dec. 4, 2001
1/3 oz. Harmony Dec. 4, 2001
1/2 pt. 2-4-D Feb. 1, 2002

Fungicides: 10 oz. Stratego Apr. 26, 2002

Insecticides:
2 oz. Warrior Dec. 4, 2001
2 oz. Warrior Apr. 26, 2002

Growth Regulator:

Treatment Plots: 9' X 21'(3 reps)

Treatment #	GS 25 N rate	GS 30 N rate	Resolution
1	0	0	NONE
2	30	60	FLAT RATE
3	0	120	FLAT RATE
4	60	60	FLAT RATE
5	120	0	FLAT RATE
6	0	NFOA	$1m^2$
7	60	NFOA	$1m^2$
8	NFOA	NFOA	$1m^2$
9	Tiller Count	Tissue Test	FLAT RATE

- All plots received 30 lbs N/ acre pre-plant
- GS 25 N applied on a $1\text{-}m^2$ basis
- Variable N rate applied according to Virginia Tech standard recommendations.

Poultry Litter Source Evaluation for Topdress Fertilization of Winter Wheat

Heritage Farm, LLC
George & David Black
Charles City, VA

Dr. Steve Philips, VA Tech
Dr. Greg Mullins, VA Tech

Planting Date:	October 24, 2001
Soil Type:	Caroline Fine Sandy Loam
Previous Crop:	Corn
Tillage:	No-Till
Variety:	Pioneer 26R38
Population:	22 seeds per foot of row
Fertilizer:	Pre Plant Commercial 30-40-90-5s
Herbicides:	1 qt. Round-Up Ultra Oct. 4, 2001 2 pt. 2-4-D Oct. 4, 2001 4 oz. Banvel Dec. 4, 2001 1/3 oz. Harmony Dec. 4, 2001 1/2 pt. 2-4-D Feb. 1, 2002
Fungicides:	10 oz. Stratego Apr. 26, 2002
Insecticides:	2 oz. Warrior Dec. 4, 2001 2 oz. Warrior Apr. 26, 2002
Growth Regulator:	None

Treatment Plots: 10' X 20' (4 reps)

Treatment #	N Source	N Rate
1	None	0
2	UAN	30
3	UAN	60
4	UAN	90
5	Granular	60
6	Granular	90
7	Pellet	60
8	Pellet	90
9	Raw	60
10	Raw	90

- Applications made at GS 30

- UAN: 30-0-0
- Granular: 10-6-12
- Pellet: 3-3-3
- Raw: TBD

Tour Stop 3
Renwood Farm, Inc.
Stanley, David, and John Hula
at
Pamunkey Farm
New Kent, VA

Renwood Farm, Inc. is the largest grain producing operation in the Colonial Soil and Water Conservation District, at approximately 3,300 acres. The Hulas produce corn for cash grain, small grain for seed and soybeans for seed and direct export. David and John Hula represent the fourth generation of family farmers, and also the fourth generation of U.S. citizens, as their great, great grandfather immigrated to the U.S. and started farming.

Recognized as the area leaders in agriculture, Renwood Farm, Inc. has utilized some form of no-till management for over 25 years. No-till corn and soybeans had been adopted as a standard practice, but in 1987, the Hulas decided to try their luck with no-till small grain. David notes that, "Dad said to plant the field that was the furthest away from the road, so that if it didn't turn out, we wouldn't have to look at it everyday." The fact is that it did turn out, and thanks to their commitment and perseverance, that field has not been tilled for the past 15 years. Today, Renwood Farm uses continuous no-till as a tool to accomplish many goals such as reduce labor, reduce equipment needs, and conserve water.

David Hula has won the last two (2000 & 2001) National Corn Yield Contests in the No-Till Non Irrigated Class with 308 bushels and 309 bushels respectively. David also has several yield titles in Virginia Wheat Contests.

Renwood Farm, Inc. also has been the site of multiple demonstration and research plots, as well as agricultural field days such as the VA Ag Expo.

Evaluation of Foliar P Applications for Winter Wheat Production in Virginia

Renwood Farm, Inc.
Stanley, David & John Hula
New Kent, VA

Dr. Steve Philips, VA Tech

Planting Date	October 26, 2001
Soil Type:	Tetotum, silt loam
Previous Crop:	Corn
Tillage:	No-Till
Variety:	USG 3209 (treated with Raxil)
Population:	25 seeds per foot of row
Fertilizer:	Pre Plant 25-0-100 Oct. 25, 2001 Winter 31-0-0-4s Dec. 4, 2001 Winter 64--0-0-8s Feb. 5, 2002
Herbicides:	1.6 pt. Round-Up Ultramax Oct. 25, 2001 1/2 oz. Harmony Extra Dec. 4, 2001
Fungicides:	10 oz. Stratego Apr. 26, 2002
Insecticides:	1.0 oz Warrior Dec. 4, 2001 2.0 oz. Warrior Apr. 26, 2002
Growth Regulator:	None

Treatment Plots: 10' X 15' (4 reps)

Treatment #	Pre Plant	Topdress
	Lbs. P_2O_5	
1	0	0
2	0	4
3	0	8
4	0	12
5	90	0
6	90	4
7	90	8
8	90	12
9	0	8*
10	90	8*
11	0	8**
12	90	8**

- * - Applied at GS 55
- **- Applied at GS 60
- All others applied at GS 30

Development of a Phosphorus Fertilization Algorithm (PFOA) for Sensor-Based Wheat Fertilization in Virginia

Renwood Farm, Inc.
Stanley, David, & John Hula
New Kent, VA

Dr. Steve Philips, VA Tech

Planting Date	October 26, 2001
Soil Type:	Tetotum, silt loam
Previous Crop:	Corn
Tillage:	Double Disk
Variety:	USG 3209 (treated with Raxil)
Population:	25 seeds per foot of row
Fertilizer:	Pre Plant 25-0-100 Oct. 25, 2001 Winter 31-0-0-4s Dec. 4, 2001 Winter 64--0-0-8s Feb. 5, 2002
Herbicides:	1.6 pt. Round-Up Ultramax Oct. 25, 2001 1/2 oz. Harmony Extra Dec. 4, 2001
Fungicides:	10 oz. Stratego Apr. 26, 2002
Insecticides:	1.0 oz Warrior Dec. 4, 2001 2.0 oz. Warrior Apr. 26, 2002
Growth Regulator:	None

Treatment Plots: 16' X 30' (4 reps)

Phosphorous was incorporated

Treatment #	P2O5 Rate Lbs/acre
1	0
2	30
3	60
4	90
5	120

No-Till Wheat - Ryegrass Timing Study

Renwood Farm, Inc.
at Pamunkey Farm
New Kent, VA

Dr. Kevin Bradley, VA Tech

Planting Date	October 26, 2001
Soil Type:	Tetotum, silt loam
Previous Crop:	Corn
Tillage:	No-Till
Variety:	USG 3209 (treated with Raxil)
Population:	25 seeds per foot of row
Fertilizer:	Pre Plant 25-60-100 October 25 Winter 31-0-0-4s Dec. 4, 2002 Winter 64-0-0-8s Feb. 5, 2002 Spring 35-0-0-4.5s Mar. 19, 2002
Herbicides:	1.6 pt. Round-Up Ultramax Oct. 25, 2001 1/2 oz. Harmony Extra Dec. 4, 2001
Fungicides:	10 oz. Stratego Apr. 26, 2002
Insecticides:	1.0 oz Warrior Dec. 4, 2001 2.0 oz. Warrior Apr. 26, 2002
Growth Regulator:	None

Treatment Plots:

No-Till Wheat - Planting Population Study

Renwood Farm, Inc.
Stanley, David, & John Hula
New Kent, VA

Paul Davis, VCE - New Kent

Planting Date	October 26, 2001
Soil Type:	Tetotum, silt loam
Previous Crop:	Corn
Tillage:	No-Till
Variety:	USG 3209 (treated with Raxil)
Population:	Various
Fertilizer:	Pre Plant 25-60-100 October 25 Winter 31-0-0-4s Dec. 4, 2002 Winter 64-0-0-8s Feb. 5, 2002 Spring 35-0-0-4.5s Mar. 19, 2002
Herbicides:	1.6 pt. Round-Up Ultramax Oct. 25, 2001 1/2 oz. Harmony Extra Dec. 4, 2001
Fungicides:	10 oz. Stratego Apr. 26, 2002
Insecticides:	1.0 oz Warrior Dec. 4, 2001 2.0 oz. Warrior Apr. 26, 2002
Growth Regulator:	None

Treatment Plots: 30' X 2,640' (1 rep)

Treatment #	Planting Population
1	25 seed/ft. of row
2	20 seed/ft. of row
3	25 seed/ft. of row
4	30 seed/ft. of row

Tour Stop 4

L.C. Davis Farm

Preston, Clifton, Randy, Wayne and Paul, Ray and Vin Davis

The L.C. Davis Farm is operated by two different family farm operations. Ray and Vin Davis farm approximately 2000 acres across 4 counties, including approximately 175 acres of the L.C. Davis Farm in New Kent. L.C. Davis Sons operates the balance of the L.C. Davis Farm totaling about 400 acres. The current operators represent the third generation to farm the land that L.C. Davis bought to support his 14 children more than 100 years ago. Not only was L.C. prolific, but hard working, and forward thinking as all 14 of his children attended college. These traits have been passed down and are visible today, as both farming operations utilize many technological advances that have been made in the agricultural industry, such as continuous no-till and bio-technology.

Cash grain rotations of corn, wheat and soybeans are common on the farm, but watermelons, cantaloupes and pumpkins can be found as well. Many Best Management Practices (BMPs) can been seen around the farm, such as continuous no-till, buffer strips, wildlife strips, and intensive nutrient management. As a result, Ray and Vin Davis were awarded the 2001 New Kent County Clean Water Farm Award.

The L.C. Davis Farm has been the host site to many farmer field days, research and demonstration plots and "Ag in the classroom" type activities through the years. All of the Davis' have made a commitment to provide technical outreach and support to groups and individuals with agricultural backgrounds, as well as those without.

Wheat Tillage vs. Variety

Ray and Vin Davis
New Kent, VA

Dr. Dan Brann, VA Tech

Planting Date:	October 16, 2001
Soil Type:	Pamunkey, fine sandy loam
Previous Crop:	Corn
Tillage:	No-Till vs. Moldboard Plow vs. Double Disk
Variety:	12 different varieties
Population:	25 seeds per foot of row
Fertilizer:	Pre Plant 100# K + 12# S (received sludge in March of 2001) Winter 25# N Dec. 14, 2001 Winter 32# N Jan. 17, 2002 Spring 49# N Mar. 16, 2002
Herbicides:	26 oz. Round-Up Oct. 12, 2001 1/2 oz. Harmony Extra Jan. 30, 2002
Fungicides:	None
Insecticides:	None
Growth Regulator:	None

Variety Plots: 28' X 32'

	Tillage Practices		
	No-Till	Moldboard Plow	Double Disk
		Yields in Bu./Acre	
Variety Tested			
Southern States 520			
Featherstone 520			
USG 3209			
Pioneer 2643			
VA98W-593			
Sisson			
Pioneer 2684			
VA97W-24			
Southern States 550			
VA98W-591 (McCormick)			
Pioneer 26R24			
Roane			

No-Till Wheat
Planting Population Study

Ray and Vin Davis
New Kent, VA

Dr. Dan Brann, VA Tech

Planting Date:	October 16, 2001
Soil Type:	Pamunkey, fine sandy loam
Previous Crop:	Corn
Tillage:	No-Till
Variety:	Sisson
Population:	Various: from 15-30 seeds per foot of row
Fertilizer:	Pre Plant 100# K + 12# S (received sludge in March of 2001) Winter 25# N Dec. 14, 2001 Winter 32# N Jan. 17, 2002 Spring 49# N Mar. 16, 2002
Herbicides:	26 oz. Round-Up Oct. 12, 2001 1/2 oz. Harmony Extra Jan. 30, 2002
Fungicides:	None
Insecticides:	None
Growth Regulator	None

Treatment Plots:

Seeding Rate Seeds/ft. of row
15
20
25
30

No-Till Wheat - Seed Treatment Study

L.C. Davis Sons
New Kent, VA

Paul Davis, VCE - New Kent

Planting Date:	October 22, 2001
Soil Type:	Altavista, fine sandy loam
Previous Crop:	Corn
Tillage:	No-Till, 7" row spacing
Variety:	Century II
Population:	28 seeds per foot of row
Fertilizer:	Pre Plant None (received sludge in March of 2001) Winter None Spring 60# N Mar. 8, 2002
Herbicides:	1.5 pt. Round-Up Oct. 6, 2001 2 oz. Banvel Jan 30, 2002 1/2 oz. Harmony Extra Jan. 30, 2002
Fungicides:	4 oz. Tilt Apr. 9, 2002
Insecticides:	2.5 oz. Warrior Apr. 9, 2002
Growth Regulator:	12 oz. Cerone Apr. 9, 2002

Treatments: (20' X 1200')

1– Untreated
2- Raxil + Thiram
3- Raxil MD
4- Dividend (2 oz. Rate)
5- Baytan
6- Baytan + Gaucho
7- Gaucho XT

**2.5 oz. Warrior 11/15/01 across treatments (2-30' strips) at 2 leaf stage

No-Till Wheat - Date of Planting Study

L.C. Davis Sons
New Kent, VA

Paul Davis, VCE - New Kent

Soil Type:	Altavista, fine sandy loam
Previous Crop:	Corn
Tillage:	No-Till, 7" row spacing
Variety:	Century II
Population:	28 seeds per foot of row
Fertilizer:	Pre Plant None (received sludge in March of 2001) Winter None Spring 60# N Mar. 8, 2002
Herbicides:	1.5 pt. Round-Up Oct. 6, 2001 2 oz. Banvel Jan 30, 2002 1/2 oz. Harmony Extra Jan. 30, 2002
Fungicides:	4 oz. Tilt Apr. 9, 2002
Insecticides:	2.5 oz. Warrior Apr. 9, 2002
Growth Regulator:	12 oz. Cerone Apr. 9, 2002

Dates Planted: (20' X 300')

October 11

October 22

November 5

November 16

No-Till Wheat Speed of Planting Study

L.C. Davis Sons
New Kent, VA

Paul Davis, VCE - New Kent

Planting Date:	October 11, 2001
Soil Type:	Altavista, fine sandy loam
Previous Crop:	Corn
Tillage:	No-Till, 7" row spacing
Variety:	Sisson
Population:	28 seeds per foot of row
Fertilizer:	Pre Plant None (received sludge in March of 2001) Winter None Spring 60# N Mar. 8, 2002
Herbicides:	1.5 pt. Round-Up Oct. 6, 2001 2 oz. Banvel Jan 30, 2002 1/2 oz. Harmony Extra Jan. 30, 2002
Fungicides:	4 oz. Tilt Apr. 9, 2002
Insecticides:	2.5 oz. Warrior Apr. 9, 2002
Growth Regulator:	12 oz. Cerone Apr. 9, 2002

Treatments: (20' X 300') 4 reps

3 1/2 mph

4 1/2 mph

5 1/2 mph

Pre Plant Tillage in Corn Study

L.C. Davis Sons
New Kent, VA

Paul Davis, VCE - New Kent

Planting Date:	April 16, 2002
Soil Type:	Bojac, fine sandy loam Tetotum, silt loam
Previous Crop:	Double Crop Soybeans
Tillage:	No-Till vs. No-Till (ripped) vs. Double Disked
Variety:	Pioneer 3394
Population:	23,000 per acre
Fertilizer:	Pre Plant 60-40-60
Herbicides:	1.5 pt. Gramoxone 1.8 qts. Bicep
Fungicides:	None
Insecticides:	None
Growth Regulator:	None

Treatments: (15' X 2640') 2 reps

Research Papers and Supporting Documents

FINAL REPORT

Water Quality Improvement Resulting From Continuous No-tillage Practices

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Department of Biological Systems Engineering
Virginia Polytechnic Institute and State University
Blacksburg, VA

P. H. Davis
Virginia Cooperative Extension
New Kent County
New Kent, VA

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June 11, 2001

TABLE OF CONTENTS

LIST OF TABLES

ACKNOWLEDGEMENTS

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ABSTRACT

A rainfall simulator was used to demonstrate and evaluate the effectiveness, in terms of NPS pollution control, of various nutrient inputs, as well as corn pre-planting and post-harvest tillage operations in preparation for small grain planting. The study was conducted in Charles City, Virginia in conjunction with the 2000 Ag-Expo Field Day Program. An average of 85.9 mm (3.38 in) of artificial rainfall was applied to ten runoff plots during three separate runs conducted over a 2 day period. During the simulated rainfall events, runoff from the plots was measured and sampled for sediment and various forms of nitrogen and phosphorus. Plot yields for each water quality parameter were determined and averaged for a total of five treatments and two replications.

Differences between the one clean tilled treatment and the four continuous no-till treatments were statistically significant with average percentage loss reductions of 75, 99, 95, and 92 for runoff, sediment, nitrogen, and phosphorus, respectively. No statistically significant impacts were determined with regard to subsoiling (at the time of corn planting) vs. no subsoiling or, by the corn post-harvest stage evaluated, commercial fertilizer vs. poultry litter vs. no nutrient applications.

Water Quality Improvement Resulting From Continuous No-tillage Practices

B. B. Ross, P. H. Davis, and V. L. Heath

INTRODUCTION

Previous studies on the Chesapeake Bay have found that nitrogen (N) and phosphorus (P) are the primary pollutants responsible for declining water quality in the Bay (USEPA, 1983). The Chesapeake Bay study estimated that nonpoint source (NPS) pollution was responsible for approximately 67% of the N and 39% of the P entering the Bay during an average year. Furthermore, cropland was estimated to be responsible for 60% and 27% of the N and P, respectively (USEPA, 1983). In addition to commercial fertilizer application as a source of these nutrients, thousands of acres in Virginia are currently being fertilized with organic wastes annually.

In spite of this assessment, sediment continues to be the most significant pollutant by volume, from cropland alone and in an overall sense. For example, agricultural cropland is identified as the primary source of sediment loads in the Lower James (95%) and York (98%) Watersheds (Va. Tributary Nutrient & Sediment Reduction Strategies, York & James 2000). In addition to the adverse effects of transported soil particles, plant nutrients, which may have become adsorbed to these soil particles, can add to the overall pollution problem. Runoff is the primary force contributing to soil erosion in Virginia and provides a ready mechanism for transporting dissolved nutrient forms. A reduction in soil erosion and runoff from cropland should, therefore, result in a substantial decrease in the amount of nutrients entering the Bay and its tributaries.

One method of reducing soil erosion and runoff is the use of Best Management Practices (BMPs). These practices have long been promoted by soil and water conservation programs for maintaining or improving agricultural productivity. They are now being promoted for the additional benefit of downstream water quality protection. Implementation of BMP programs has not always been successful, however, because farmers and other land managers are often unaware of the impact of NPS pollution and the benefits to be derived from BMP implementation. Furthermore, policy makers and water quality professionals have been reluctant at times to support some BMP programs because there is little research information on the effectiveness of specific BMPs for water quality protection.

Efforts to promote cost effective and voluntary water quality goals in the tidal estuaries in each of the major tributaries that flow to the Chesapeake Bay are presently underway. The percent of pollutant removal associated with each goal is tracked and used to predict a level of ecological response. The prediction model is administered by the US Environmental Protection Agency and is known as the Chesapeake Bay Watershed Model. The model evaluates a multitude of variables and is used as a tool that can be applied at the Bay and or major tributary scale. Strategies developed for each of the major tributaries are incorporated through evaluation of local watershed planning; stakeholder input and cost effective implementation. This process is known as the Tributary Strategies Initiative in Virginia.

As part of the Innovative Cropping Systems Incentive Program a cooperative effort has worked to promote management systems that promote intensive cropping rotations and continuous no-till technologies. The clean till small grain seedbed represents the last major obstacle prohibiting long term continuous no-till. Continuous no-till (10 years) provides the benefit of a perpetual cycle of carbon production associated with an intensive cropping rotation without the tillage impacts that break the carbon supply.

In general, the water quality benefits of one major BMP, no-till row crop production, with commercial fertilizer application, have been fairly well-documented. However, organic waste, as an alternative amendment, also contains nutrients for plant growth (i.e., N and P), whose transport can detrimentally impact surface water quality and questions remain as to the fate of this material and the extent of associated nutrient losses. Normally surface-applied and incorporated into the soil by tillage for production of row crops (i.e., corn, wheat, soybean), this practice places the organic waste where odors will not be objectionable; however, conventional tillage (i.e., plowing and disking) increases the potential for runoff and the surface transport of sediment and sediment-bound organic waste constituents.

OBJECTIVE

The purpose of the study was to evaluate and demonstrate, at the post-harvest stage for corn and small grain land preparation stage specifically, the value of using continuous no-tillage practices with both commercial fertilizer and organic waste applications in row crop production.

METHODS

A rainfall simulation/runoff plot technique was utilized to collect water quality data under various cropland treatments and to visually demonstrate the effectiveness of continuous no-till production. A detailed description of the rainfall simulator, monitoring procedures, and analytical techniques in these types of studies is presented by Dillaha et.al. (1987) and Dillaha et al. (1988).

Site Description and Plot Treatments

The study site was selected by the Colonial Soil and Water Conservation District in consultation with local Virginia Cooperative Extension personnel and the Department of Biological Systems Engineering at Virginia Tech. Site selection, as well as the implementation schedule, was coordinated with the Virginia Ag-Expo Field Day Program, scheduled for August 10, 2000 at Renwood Farm in Charles City County. In early 2000, plot boundaries were defined in a barley planted cropfield to locate ten runoff plots adjacent to each other. This pattern aided in water sample collection and ultimately enabled observers to see runoff from all plots simultaneously. The plots were rectangular at 6.1 m x 18.3 m (20 ft x 60 ft) each. They were sited on a Pamunkey loam soil at a 7.5% slope. The USDA/Universal Soil Loss Equation predicts 11 tons of soil loss per acre per year on the site using standard tillage and management, which includes no-till double crop soybeans followed by no-till corn followed by clean till wheat every two years, and an 8% slope for a 150 ft slope length with a Pamunkey soil type in Charles City County (A=R-250 x K-28 x LS-1.21 x C-.13 x P-1= 11 tons/acre/year).

The ten plots accommodated two replications each of five different treatments randomly assigned to the plots. Treatments included a combination of nutrient inputs, as well as corn pre-planting and post-harvest tillage operations. The five plot treatments ultimately established were: (A) clean tilled (after corn harvest) w/fertilizer, (B) continuous no-till w/poultry litter, (C) continuous no-till w/o nutrient inputs, (D) continuous no-till, subsoiled (at corn planting), w/ fertilizer, and (E) continuous no-till w/fertilizer. Looking upslope from left to right, the plot numbers and their assigned treatments were as follows: (1) A, (2) B, (3) C, (4) D, (5) E, (6) B, (7) C, (8) A, (9) D, and (10) E. Virginia Cooperative Extension recommendations were followed regarding tillage, planting, and fertilization practices. A plot activity schedule is provided in Table A1 as well as the levels of nutrient inputs where applicable.

The corn crop was harvested during the week prior to the planned Field Day activity for which the rainfall simulator data collection runs were scheduled to coincide with. A few days before this event, plywood borders to contain and direct the runoff from each plot and instrumentation, as described below, were installed. The rainfall simulator set-up immediately followed.

Run and Monitoring Procedures

The Virginia Tech Department of Biological Systems Engineering's rainfall simulator was designed to apply artificial rainfall at 40-45 mm/hr (1.6-1.8 in/hr), a rate typical, for a 1 h duration, of a 2-5 year return period storm throughout much of Virginia (Shanholtz and Lillard, 1973). The rainfall simulator was used to apply rainfall in three separate applications over a two-day period (August 9-10). The rainfall simulator run sequence consisted of a 1 h run (R1) on the first day, followed approximately 24 h later by a 0.5 h run (R2), and an additional 0.5 h run (R3) after a 0.5-1 h rest interval. The three-run sequence was used in this manner to represent dry, wet, and very wet antecedent soil moisture conditions and is a commonly used artificial rainfall sequence for erosion research.

Rainfall simulator application rates, amounts, and uniformity were measured by placing 20 rain gauges throughout the ten plots (two per plot). Rain gauges were read after each run to determine the amount and uniformity of application. Runoff was collected at the base of each plot and channeled into a 150 mm (6 in) H-flume equipped with a 150 mm (6 in) stilling well and an FW-1 stage recorder.

Water samples were collected manually at 3 to 15 min intervals during the rainfall-runoff events. A mark was made on the state hydrograph chart when each sample was taken to record sampling time. Additionally, a water sample was drawn at the midpoint of the first run (R1) and again at the beginning of the third run (R3) directly from the rainfall simulator mainline piping to assess the "raw water" quality delivered to the system. (Water was obtained from the James River via a centrifugal pump at the shoreline.) Water quality samples were iced down immediately after collection and stored at 0 to 5 degrees C until analyzed. Samples were analyzed for total suspended solids (TSS), volatile solids (VS), total phosphorus (P), orthophosphorus (PO_4-P), nitrate (NO_3-N), total Kjeldahl nitrogen (TKN), filtered P (P_f), filtered TKN (TKN_f), and ammonium (NH_4-N). Total N (N) was obtained by summing NO_3-N and TKN. Water quality analyses were performed using standard analytical procedures (USEPA, 1979).

RESULTS AND DISCUSSION

The summarized results of the rainfall simulator study with respect to runoff, sediment, and nutrient yields are presented in Tables 1 and 2. The results of the statistical analysis are summarized in Table 3. Individual plot and run totals and average concentrations, as well as individual sample concentrations, are listed in the Appendix (Tables A2-4).

Rainfall

The rainfall simulator performed well with respect to rainfall amounts and uniformity of application. A total of 85.9 mm (3.38 in) was applied over the two-day period with 45.7 mm (1.80 in) being applied on the first day (R1) and 40.1 mm (1.58 in) the second day (R2 and R3). The mean application rate during the simulations was 42.9 mm/h (1.7 in/hr). The uniformity coefficient averaged across all plots and runs was 90.9%.

Runoff

As shown in Tables 1 and 2, overall runoff yield was greatest, by far, under treatment A. Significantly less runoff was observed under the four continuous no-till treatments (treatments B, C, D, and E) with percent reductions, compared to Treatment A, ranging from 69 to 79% (Table 1). As shown in Table 3, runoff differences among the continuous no-till treatments were statistically insignificant. The subsoiling of treatment D made no difference with respect to runoff possibly due, in part, to the fact that soil compaction was not substantial prior to subsoiling and/or the influence of subsoiling was minimized due to soil settling during the time elapsed prior to the data collection runs being conducted. Overall, differences among treatments were somewhat greater during R1 than for either R2 or R3 as the soil became saturated (Table 1).

Runoff as a percentage of rainfall for treatments A-E was 53.0, 12.7, 16.6, 12.7, and 11.2, respectively. These differences can be partly accounted for in that lag times from the initiation of "rainfall" until runoff was first observed leaving the plots was substantially different across treatments. This was particularly true for the first run (R1) in which runoff began, under the continuous no-till treatments, at an average of 36 min from the start of "rainfall" with 27.4 mm (1.08 in) applied, while, for treatment A, the lag time was 18 min, or 13.7 mm (0.54 in) applied. Furthermore, under saturated soil conditions, i.e., for R2 and R3, while runoff began in approximately 1 min in both cases under treatment A, lag times averaged 16 min and 8 min, respectively, under the continuous no-till treatments.

Sediment

Soil cover, as established in the continuous no-till treatments B, C, D, and E, proved to be very effective in reducing sediment loss as compared to the bare soil under the clean tilled treatment (treatment A). All of the former treatments had significantly less sediment loss (all reductions 99% or greater) than the latter (Tables 1 and 3). The greater runoff observed from treatment A above combined with much higher sediment concentrations in the runoff (Tables A3 and A4) to achieve this result. The average sediment concentration for treatment A was 7.83 g/L and, for the no-till treatments, ranged from 0.06 to 0.31 g/L (obtained from Table 1). With the exception of treatment A, sediment losses for all treatments were relatively low, even on an areal basis (Table 2), ranging from 5.4 to 34.2 kg/ha (6.0 to 30.5 lb/ac) for the continuous no-till treatments. Although not presented in Table 1, percent reductions were generally slightly less during the first run (R1) for each treatment and gradually increased during R2 and R3. While 10% of the sediment loss under treatment A was comprised of volatile solids, an average of 21% of the solids lost under treatments B, C, D, and E was non-soil material, such as crop residues and organic litter components (Table A4). It should be noted that, in some individual sample cases (Table A4), particularly at the lower concentrations, nearly all of the suspended solids were of a non-soil nature.

Nitrogen

As with runoff and sediment, the only significant differences between nitrogen losses were those of treatment A compared to treatments B, C, D, or E, with percent reductions of 94 to 95% (Table 1). On an areal basis, total N losses under all treatments were relatively low (Table 2). This is likely primarily due to the fact that nutrient applications had been made 3 to 4 months prior to the rainfall simulator run dates and much of the nitrogen had either been utilized by the crop, consumed by soil organisms, or lost to runoff and/or leaching from natural rainfall events during this time interval. Further evidence of this is the fact that total N loss under treatment C, for which no nutrients inputs were made, were comparable to N losses under the remaining continuous no-till treatments which received nutrient inputs.

Although the nitrogen loss under treatment A was significantly greater than under the other continuous no-till treatments, this was largely due to the fact that there was significantly more runoff under treatment A. Furthermore, N concentrations in individual samples (Table A4) were not substantially greater for treatment A as compared to the individual samples for the remaining four treaments. As indicated in Table A2, the vast majority (95%) of the N loss under treatment A was sediment-bound, while just over a third (34%) on the average, was lost under the continuous no-till treatments (estimates of sediment-bound nitrogen are equivalent to TKN – TKN_f and can be obtained from Table A2). Total Kjeldahl nitrogen, which includes organic nitrogen and NH_4, accounted for 98% of the total N loss under treatment A and only a slightly smaller percentage of total N losses under treatments B, C, D, and E, averaging 86% for all four continuous no-till treatments (obtained from Table A2).

Phosphorus

Although the total loadings were somewhat smaller, total P losses under all treatments followed the pattern of total N losses with similar significant percent reductions of 90 for treatment B and 93 for each of the remaining no-till treatments, compared to that for treatment A (Table 1). On an areal basis, P losses ranged from 0.28 to 0.43 kg/ha (0.25 to 0.38 lb/ac) for the continuous no-till treatments and was 4.09 kg/ha (3.65 lb/ac) for the clean tilled treatment A (Table 2).

No-till cover was expected to be effective in reducing total P losses since sediment losses were greatly reduced under the no-till treatments and total P loss is usually highly correlated with sediment loss. Phosphorus in the runoff under treatment A was predominantly sediment-bound at 95% while the average of the sediment-bound portion of the total P loss under the four continuous no-till treatments was 25% (estimates of sediment-bound P can be obtained from Table A2 and are equal to P – P_f).

Educational Aspects

The 2000 Virginia Ag-Expo field day was conducted as planned and the rainfall simulator study was established as one of the rotational tour stops. The first two tour stop runs were coordinated with the two scheduled data collection runs on August 10 (R2 and R3). The system was run an additional five times for demonstration purposes only to accommodate additional tour stop participants. The audience consisted of producers, agri-business personnel, water quality professionals, government officials, news media representatives, and the general public. Approximately 300 people witnessed the demonstrations. During the demonstration runs, visual differences in the quantity and quality (as indicated by turbidity) of the runoff were readily apparent, particularly in that of treatment A compared to the remaining four treatments, for which differences were not as discernable. In addition to the outreach provided at the Ag. Expo field day, the research results will be utilized by Federal and state agencies as a tool to implement the associated management systems. Innovative Cropping Systems Incentive Program cooperators will feature this research data in an ongoing manner that will reach numerous others through a variety of educational events.

SUMMARY AND CONCLUSIONS

A rainfall simulator was used to demonstrate and evaluate the effectiveness, in terms of NPS pollution control, of various nutrient inputs, as well as corn pre-planting and post-harvest tillage operations in preparation for small grain planting. An average of 85.9 mm (3.38 in) of artificial rainfall was applied to ten runoff plots during three separate runs conducted over a 2 day period. During the simulated rainfall events, runoff from the plots was measured and sampled for sediment and various forms of nitrogen and phosphorus. Plot yields for each water quality parameter were determined and averaged for a total of five treatments and two replications. A statistical analysis was performed on the results for comparison purposes.

While the rainfall simulator was operating and runoff from the plots was being measured and sampled, people were brought to the site to observe the rainfall simulator and to learn about NPS pollution and BMPs. Farmers, public officials, the new media, and the general public participated in the demonstrations.

Specific conclusions which can be drawn from this study include:

1. The use of a rainfall simulator for producing a controlled storm at a desired time and place for research, educational, and promotional purposes can be extremely effective. Field tours scheduled to coincide with rainfall simulator data collection runs provided dramatic demonstrations of the effectiveness of BMPs for water quality protection.
2. Under a corn post-harvest scenario, the undisturbed no-till cover was shown to be highly effective, with respect to reducing runoff, sediment yield, and nutrient losses, as compared to post-harvest corn clean tillage in preparation for small grain planting. Average percentage loss reductions of 75, 99, 95, and 92 were obtained for runoff, sediment, nitrogen and phosphorus, respectively, for the four continuous no-till treatments versus the clean tilled treatment.
3. There were no statistical differences noted among the four continuous no-till treatments indicating that various nutrient levels and sources (commercial fertilizer and poultry litter), as well as subsoiling at corn planting, resulted in no runoff, sediment yield, or nutrient loss impacts at the post-harvest corn/small grain land preparation stage of the demonstration.
4. While 95% of the phosphorus loss from the clean tilled treatment was sediment-bound, the same percentage was determined for sediment-bound nitrogen. For the four continuous no-till treatments, and average of 34% of the nitrogen loss was sediment-bound and 25% of the phosphorus loss was sediment-bound.

Table 1. Average measured plot runoff, sediment yield, and nutrient losses by treatment and run (percent reductions relative to Treatment A in parentheses) – Renwood Farm, Charles City County, Virginia: August 9-10, 2000.

TREATMENT* (PLOT #'s)	RUN	RUNOFF (cu. m)	SEDIMENT (kg)	NITROGEN (g)	PHOSPHORUS (g)
A (1 & 8)	1	1.81	16.34	49.4	18.8
	2	1.38	8.81	23.4	11.7
	3	1.88	14.54	41.9	15.1
	TOTAL	5.07 (--)	39.69 (--)	114.7 (--)	45.6 (--)
B (2 & 6)	1	0.40	0.24	2.8	2.1
	2	0.20	0.06	1.2	0.7
	3	0.61	0.08	2.8	1.9
	TOTAL	1.21(76.2)	0.38(99.0)	6.8(94.1)	4.7(89.6)
C (3 & 7)	1	0.46	0.14	2.4	1.5
	2	0.25	0.03	1.1	0.5
	3	0.86	0.05	2.5	1.3
	TOTAL	1.57(69.0)	0.22(99.4)	6.0(94.7)	3.3(92.6)
D (4 & 9)	1	0.24	0.03	1.5	0.9
	2	0.24	0.01	1.4	0.7
	3	0.75	0.03	2.9	1.6
	TOTAL	1.23(75.8)	0.07(99.8)	5.8(94.9)	3.2(92.9)
E (5 & 10)	1	0.40	0.15	2.6	1.5
	2	0.20	0.02	1.2	0.6
	3	0.47	0.02	1.8	1.0
	TOTAL	1.07(78.9)	0.19(99.5)	5.6(95.0)	3.1(93.2)

*Treatments: A – fertilizer, clean tilled; B – litter, no-till; C – no nutrients, no-till; D – fertilizer, no-till subsoiled; E – fertilizer, no-till

Table 2. Overall average measured runoff, sediment yield, and nutrient losses by treatment on an areal basis (English units in parentheses) – Renwood Farm, Charles City County, Virginia: August 9-10, 2000.

TREATMENT* (PLOT #'s)	RUNOFF	SEDIMENT		NITROGEN		PHOSPHORUS	
	mm (in)	kg/ha	(lb/ac)	kg/ha	(lb/ac)	kg/ha	(lb/ac)
A (1 & 8)	45.5 (1.79)	3557.5	(3176.3)	10.27	(9.17)	4.09	(3.65)
B (2 & 6)	10.9 (0.43)	34.2	(30.5)	0.60	(0.54)	0.43	(0.38)
C (3 & 7)	14.2 (0.56)	20.7	(18.5)	0.55	(0.49)	0.30	(0.27)
D (4 & 9)	10.9 (0.43)	5.4	(6.0)	0.53	(0.47)	0.29	(0.26)
E (5 & 10)	9.7 (0.38)	17.9	(16.0)	0.52	(0.46)	0.28	(0.25)

*Treatments: A – fertilizer, clean tilled; B – litter, no-till; C – no nutrients, no-till; D – fertilizer, no-till subsoiled; E – fertilizer, no-till

Table 3. Comparison of the effect of various treatments on runoff, sediment yield, and nitrogen and phosphorus losses.

Multiple Comparisons*
(Increasing Value of Property Being Compared)

Runoff	E	B	D	C	A
Sediment	D	E	C	B	A
Nitrogen	E	D	C	B	A
Phosphorus	E	D	C	B	A

*Treatments linked by an underbar are not significantly different at the 0.05 level according to Fishers Protected LSD test (SAS, 1985).

Treatments: A – fertilizer, clean tilled; B – litter, no-till; C – no nutrients, no-till; D – fertilizer, no-till subsoiled; E – fertilizer, no-till

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APPENDIX

Table A1. Site characteristics and activities - Renwood Farm, Charles City County, VA

Run Dates: August 9 and 10, 2000

Crop: Corn (post-harvest)

Treatments: (A) fertilizer, plowed; (B) poultry litter, no-till; (C) no nutrients, no-till; (D) fertilizer, no-till, subsoiled; (E) fertilizer, no-till

Plot dimensions: 10 plots (5 treatments x 2 replications), each 20' x 60'

Plot slope: 7.5%

Soil type: Pamunkey loam

Soil description: This soil is deep and poorly drained. Permeability is moderate in the solum and moderately rapid in the substratum. Surface runoff is slow. The soil is not highly erodible.

Plot preparation:

Date:	*Activity:*
April 12, 2000	Sprayed barley
April 12, 2000	Spread poultry litter (@ 3 t/ac (treatment B) - 156 lb N, 175 lb P, 144 lb K
May 1, 2000	Underrow ripped (treatment D)
May 1, 2000	Planted corn
May 10, 2000	Broadcast 10-10-10 @ 1500 lb/ac (treatments A, D, & E)
July 28, 2000	Harvested corn
July 31, 2000	Moldboard plowed and disked (treatment A)

Field history:

Year:	*Crop:*
1999	No-till barley/no-till soybeans
1998	No-till barley/no-till soybeans
1997	No-till corn
1996	No-till barley/no-till soybeans
1995	No-till barley/no-till soybeans
1994	No-till corn
1993	No-till barley/no-till soybeans
1992	No-till soybeans behind barley
1991	No-till corn—plowed for barley

Table A2. Measured plot runoff, sediment yield, and nutrient losses (run totals) – Renwood Farm, Charles City County, Virginia: August 9-10, 2000.

PLOT/ RUN	RUNOFF (L)	TSS (kg)	NO_3 (g)	NH_4 (g)	TKN (g)	TKN_f (g)	N (g)	OP (g)	P_f (g)	P (g)
P1R1	1945.5	19.089	1.512	0.827	54.994	1.977	56.506	0.126	0.794	21.768
P1R2	1588.7	11.822	0.637	0.494	28.045	1.072	28.682	0.064	0.580	12.605
P1R3	2327.0	20.992	0.924	0.531	56.907	1.082	57.829	0.179	1.012	19.345
P2R1	638.9	0.364	0.257	0.655	3.709	1.816	3.967	1.195	1.941	3.036
P2R2	262.1	0.048	0.209	0.099	1.069	0.578	1.278	0.384	0.694	0.918
P2R3	549.3	0.047	0.337	0.113	1.318	0.770	1.656	0.558	0.986	1.291
P3R1	765.7	0.249	0.197	0.777	3.623	2.061	3.819	1.002	1.652	2.471
P3R2	276.2	0.049	0.119	0.070	1.064	0.545	1.183	0.219	0.413	0.617
P3R3	797.2	0.067	0.314	0.132	1.797	0.992	2.112	0.472	0.921	1.283
P4R1	379.1	0.036	0.398	0.705	2.046	1.471	2.444	0.730	1.165	1.461
P4R2	314.2	0.014	0.470	0.298	1.342	0.893	1.812	0.398	0.710	0.858
P4R3	962.7	0.034	1.058	0.384	2.471	1.626	3.529	0.823	1.477	1.869
P5R1	186.5	0.020	0.109	0.391	1.338	0.840	1.446	0.419	0.686	0.891
P5R2	159.1	0.012	0.225	0.113	0.699	0.460	0.924	0.208	0.390	0.456
P5R3	350.0	0.010	0.365	0.150	0.924	0.681	1.288	0.359	0.652	0.788
P6R1	159.9	0.119	0.051	0.366	1.490	0.859	1.541	0.431	0.737	1.077
P6R2	130.9	0.065	0.251	0.094	0.867	0.465	1.119	0.197	0.357	0.569
P6R3	670.4	0.109	0.973	0.269	2.873	1.663	3.846	1.105	1.996	2.578
P7R1	159.9	0.025	0.003	0.204	0.895	0.552	0.898	0.185	0.377	0.434
P7R2	221.7	0.019	0.139	0.080	0.947	0.613	1.086	0.165	0.380	0.472
P7R3	919.9	0.032	0.694	0.182	2.280	1.344	2.973	0.442	1.078	1.396
P8R1	1681.2	13.593	1.180	0.725	41.151	1.380	42.331	0.040	0.625	15.913
P8R2	1174.7	5.801	0.450	0.317	17.656	0.499	18.107	0.092	0.489	10.685
P8R3	1427.1	8.082	0.390	0.285	25.476	0.572	25.866	0.087	0.841	10.860
P9R1	98.2	0.021	0.004	0.224	0.583	0.383	0.587	0.178	0.294	0.396
P9R2	165.4	0.011	0.309	0.157	0.766	0.477	1.074	0.207	0.382	0.479
P9R3	533.1	0.020	0.657	0.274	1.627	1.000	2.285	0.509	1.108	1.234
P10R1	606.9	0.282	0.191	1.125	3.501	1.871	3.692	0.751	1.291	2.177
P10R2	244.0	0.037	0.362	0.197	1.154	0.683	1.516	0.245	0.476	0.638
P10R3	593.2	0.030	0.582	0.376	1.792	1.121	2.374	0.555	1.251	1.280

Table A3. Average runoff and sediment and nutrient concentrations (by run) – Renwood Farm, Charles City County, Virginia: August 9-10, 2000.

PLOT/ RUN	RUNOFF (L)	TSS (g/L)	NO_3 (mg/L)	NH_4 (mg/L)	TKN (mg/L)	TKN_f (mg/L)	N (mg/L)	OP (mg/L)	P_f (mg/L)	P (mg/L)
P1R1	1945.5	9.812	0.777	0.425	28.268	1.016	29.045	0.065	0.408	11.189
P1R2	1588.7	7.441	0.401	0.311	17.653	0.675	18.054	0.04	0.365	7.934
P1R3	2327.0	9.021	0.397	0.228	24.455	0.465	24.851	0.077	0.435	8.313
P2R1	638.9	0.569	0.403	1.026	5.806	2.842	6.209	1.87	3.038	4.752
P2R2	262.1	0.183	0.799	0.376	4.079	2.203	4.877	1.464	2.646	3.501
P2R3	549.3	0.086	0.614	0.206	2.399	1.402	3.014	1.016	1.795	2.35
P3R1	765.7	0.325	0.257	1.015	4.732	2.692	4.988	1.309	2.158	3.227
P3R2	276.2	0.176	0.43	0.254	3.853	1.974	4.283	0.794	1.495	2.236
P3R3	797.2	0.084	0.394	0.165	2.254	1.244	2.649	0.592	1.155	1.61
P4R1	379.1	0.096	1.051	1.86	5.398	3.881	6.449	1.925	3.073	3.855
P4R2	314.2	0.043	1.495	0.949	4.27	2.842	5.766	1.267	2.259	2.731
P4R3	962.7	0.035	1.099	0.399	2.567	1.689	3.666	0.855	1.534	1.941
P5R1	186.5	0.109	0.583	2.098	7.172	4.505	7.755	2.246	3.678	4.779
P5R2	159.1	0.077	1.413	0.709	4.395	2.889	5.808	1.308	2.449	2.868
P5R3	350.0	0.029	1.042	0.43	2.639	1.946	3.681	1.025	1.863	2.251
P6R1	159.9	0.743	0.32	2.29	9.32	5.372	9.64	2.697	4.607	6.735
P6R2	130.9	0.497	1.92	0.718	6.629	3.55	8.549	1.502	2.73	4.348
P6R3	670.4	0.162	1.452	0.401	4.285	2.481	5.737	1.649	2.978	3.846
P7R1	159.9	0.159	0.017	1.278	5.599	3.449	5.616	1.156	2.356	2.716
P7R2	221.7	0.087	0.627	0.362	4.273	2.766	4.899	0.743	1.712	2.128
P7R3	919.9	0.035	0.754	0.198	2.478	1.461	3.232	0.481	1.172	1.517
P8R1	1681.2	8.085	0.702	0.431	24.477	0.821	25.179	0.024	0.372	9.465
P8R2	1174.7	4.938	0.383	0.27	15.03	0.425	15.414	0.078	0.416	9.096
P8R3	1427.1	5.663	0.273	0.2	17.852	0.401	18.125	0.061	0.589	7.61
P9R1	98.2	0.213	0.037	2.282	5.934	3.898	5.971	1.807	2.995	4.035
P9R2	165.4	0.066	1.866	0.947	4.629	2.885	6.495	1.252	2.309	2.894
P9R3	533.1	0.037	1.232	0.513	3.052	1.876	4.285	0.954	2.078	2.315
P10R1	606.9	0.465	0.315	1.854	5.768	3.083	6.083	1.238	2.127	3.587
P10R2	244.0	0.151	1.483	0.809	4.729	2.8	6.212	1.004	1.949	2.616
P10R3	593.2	0.05	0.981	0.633	3.021	1.89	4.002	0.935	2.109	2.158

Table A4. Individual water quality sample concentrations – Renwood Farm, Charles City County, Virginia: August 9-10, 2000.

PLOT/ RUN/ SAMPLE	TSS (mg/L)	VS (mg/L)	NO_3 (mg/L)	NH_4 (mg/L)	TKN (mg/L)	TKN_f (mg/L)	OP (mg/L)	P_f (mg/L)	P (mg/L)
P1R1S1	8182	854	1.809	0.464	23.38	1.14	0.09	0.36	9.325
P1R1S2	8814	828	1.349	0.431	25.34	1.11	0.063	0.405	10.31
P1R1S3	10118	902	0.991	0.488	27.425	1.54	0.075	0.43	10.95
P1R1S4	9466	924	0.855	0.419	29.425	1.085	0.059	0.425	11.175
P1R1S5	10954	992	0.677	0.353	30.47	0.89	0.052	0.37	11.515
P1R1S6	11366	1022	0.532	0.385	30.225	0.745	0.044	0.36	12.38
P1R1S7	2966	292	1.181	0.507	9.035	1.235	0.211	0.595	7.135
P2R1S1	1346	171	0.015	1.755	10.415	4.655	2.895	4.585	8.305
P2R1S2	2142	167	0.011	1.768	11.62	4.51	2.66	4.325	9.52
P2R1S3	745	84	0.021	1.528	7.595	3.775	2.599	4.175	6.4
P2R1S4	530	58	0.592	1.239	5.365	3.085	2.209	3.55	4.89
P2R1S5	556	52	0.331	1.093	5.195	2.625	1.926	3.045	4.6
P2R1S6	185	35	0.167	0.909	4.04	2.445	1.842	2.98	3.87
P2R1S7	62	27	0.297	0.965	3.81	2.555	1.928	3.09	3.66
P3R1S1	961	97	0.016	1.114	7.625	3.27	1.608	2.565	5.145
P3R1S2	1612	140	0.009	1.091	8.36	3.07	1.435	2.385	5.785
P3R1S3	580	56	0.008	1.623	7.08	3.975	1.84	3.015	4.645
P3R1S4	173	36	0.489	1.037	4.005	2.55	1.299	2.12	2.935
P3R1S5	86	29	0.01	0.856	3.525	2.275	1.223	1.995	2.575
P3R1S6	38	25	0.01	0.891	3.435	2.685	1.296	2.1	2.51
P4R1S1	142	38	0.009	2.946	8.71	5.98	2.639	4.335	5.38
P4R1S2	151	38	0.011	2.957	9.145	6.2	2.884	4.855	6.005
P4R1S3	68	31	0.088	2.497	6.53	4.705	2.474	3.905	4.715
P4R1S4	180	34	0.987	2.094	5.125	4.115	2.05	3.215	4.155
P4R1S5	58	33	1.34	1.835	4.82	3.535	1.868	2.92	3.54
P4R1S6	33	29	1.142	1.852	4.695	3.43	1.908	2.98	3.69
P5R1S1	383	77	0.02	3.152	9.955	6.205	2.93	4.825	6.55
P5R1S2	216	52	0.019	2.969	8.995	6.25	3.047	5.065	6.27
P5R1S3	118	38	1.241	2.712	11.035	4.725	2.563	4.125	6.565
P5R1S4	69	29	0.663	2.433	6.575	4.2	2.428	3.75	4.82
P5R1S5	27	13	0.023	2.227	5.45	4.91	2.417	3.945	4.33
P5R1S6	19	5	0.052	0.188	0.745	0.465	0.017	0.235	0.36
P6R1S1	1475	166	0.595	2.506	11.255	5.495	2.335	3.85	8.025
P6R1S2	1043	134	0.018	2.357	11.045	5.71	2.745	4.695	7.91
P6R1S3	869	97	0.021	2.555	9.635	5.65	2.923	4.93	7.025
P6R1S4	107	33	0.025	2.523	7.8	5.805	3.219	5.54	6.255
P7R1S1	366	69	0.043	2.132	7.685	4.215	1.254	2.26	3.445
P7R1S2	350	53	0.005	1.63	6.69	3.93	1.22	2.185	3.16
P7R1S3	241	47	0.005	1.616	5.76	3.54	1.317	2.31	2.945
P7R1S4	168	38	0.005	1.338	5.555	3.08	1.156	2.1	2.69
P7R1S5	29	19	0.005	1.385	4.34	3.375	1.172	2.19	2.4
P8R1S1	8145	876	0.785	0.913	25.11	1.38	0.029	0.355	9.225
P8R1S2	7383	720	1.01	0.645	23.895	1.215	0.026	0.44	9.465
P8R1S3	7657	738	0.909	0.563	23.995	0.98	0.019	0.39	9.54
P8R1S4	8245	782	0.745	0.494	26.115	1.195	0.011	0.365	9.765
P8R1S5	7931	726	0.739	0.369	26.45	0.665	0.011	0.38	10.21
P8R1S6	8565	758	0.553	0.4	23.32	0.67	0.027	0.375	9.285
P8R1S7	8985	884	0.648	0.314	21.77	0.615	0.016	0.355	9.055
P8R1S8	2863	298	0.78	0.284	7.505	0.555	0.011	0.32	5.955
P9R1S1	236	50	0.01	2.636	7.165	4.435	1.972	3.315	4.69
P9R1S2	260	48	0.046	2.268	5.825	3.895	1.767	2.915	3.98
P9R1S3	125	35	0.005	2.124	5.44	3.62	1.784	2.945	3.775
P9R1S4	48	25	0.005	2.111	5.055	3.45	1.801	2.95	3.6
P9R1S5	22	21	0.121	2.473	5.475	3.88	1.937	3.16	3.775

P10R1S1	565	107	0.995	4.351	10.755	6.32	1.89	3.1	5.485
P10R1S2	910	146	0.685	3.681	11.19	5.315	1.761	2.91	6.28
P10R1S3	643	107	0.015	2.967	9.42	5.055	1.911	3.18	5.615
P10R1S4	698	100	0.007	2.182	7.825	3.58	1.488	2.56	4.94
P10R1S5	648	93	0.438	2.165	6.655	3.31	1.346	2.295	4.395
P10R1S6	428	70	0.131	1.766	5.605	2.905	1.231	2.09	3.53
P10R1S7	412	62	0.094	1.762	5.13	2.95	1.206	2.065	3.19
P10R1S8	126	33	0.385	2.104	4.695	3.38	1.447	2.435	2.875
P1R2S1	9482	967	0.645	0.637	30.265	0.975	0.048	0.39	11.13
P1R2S2	6768	613	0.407	0.32	18.04	0.53	0.039	0.345	8.32
P1R2S3	8232	713	0.346	0.322	18.785	0.665	0.029	0.35	8.055
P1R2S4	7838	640	0.385	0.301	17.705	0.76	0.039	0.37	7.915
P1R2S5	2361	208	0.609	0.306	6.115	0.73	0.067	0.405	4.66
P2R2S1	940	114	0.883	0.572	7.395	2.585	1.059	1.88	4.605
P2R2S2	381	60	0.942	0.533	6.065	2.88	1.692	3.125	4.265
P2R2S3	90	31	0.841	0.418	3.69	2.18	1.448	2.61	3.225
P2R2S4	26	21	1.226	0.571	3.24	2.135	1.513	2.645	2.935
P3R2S1	917	110	0.505	0.38	6.445	2.18	0.685	1.315	3.385
P3R2S2	314	286	0.36	0.148	4.245	2.01	0.753	1.455	2.44
P3R2S3	98	81	0.722	0.37	3.86	2.025	0.819	1.51	2.14
P3R2S4	15	14	0.609	0.218	2.885	1.82	0.768	1.445	1.835
P4R2S1	83	38	1.248	0.957	6	3.54	1.347	2.395	3.28
P4R2S2	43	24	1.938	2.186	5.43	3.93	1.78	3.105	3.465
P4R2S3	18	17	1.635	0.707	3.445	2.52	1.143	2.005	2.285
P5R2S1	173	44	1.157	0.76	6.43	3.66	1.429	2.56	3.485
P5R2S2	92	31	1.678	0.899	4.49	2.89	1.298	2.365	2.745
P5R2S3	23	21	1.606	0.828	3.79	2.795	1.327	2.37	2.565
P6R2S1	615	90	2.1	0.909	7.105	3.165	1.217	2.245	4.055
P6R2S2	276	53	2.059	0.81	6.315	3.285	1.579	2.82	4.02
P6R2S3	86	37	1.973	0.801	5.815	3.525	1.83	3.315	3.925
P7R2S1	148	44	0.056	0.597	6.505	3.715	0.933	2.89	2.7
P7R2S2	105	41	1.027	0.487	4.64	2.725	0.792	1.585	2.13
P7R2S3	24	24	1.206	0.449	3.805	2.395	0.784	1.6	1.78
P8R2S1	7900	840	0.814	0.616	33.115	0.925	0.103	0.38	9.85
P8R2S2	5571	494	0.283	0.293	19	0.43	0.065	0.335	7.175
P8R2S3	4454	404	0.384	0.283	11.605	0.37	0.079	0.37	9.61
P8R2S4	4430	404	0.401	0.224	12.045	0.35	0.074	0.4	10.215
P8R2S5	1563	171	0.353	0.248	3.945	0.41	0.055	0.33	3.445
P9R2S1	123	46	3.262	1.262	6.575	3.69	1.363	2.825	3.6
P9R2S2	56	29	1.894	1.004	4.615	2.96	1.328	2.32	2.875
P9R2S3	29	26	2.004	1.031	4.33	3.08	1.391	2.355	2.82
P10R2S1	222	57	1.176	0.804	4.695	2.335	0.616	1.205	2.06
P10R2S2	217	49	1.499	0.802	5.33	2.975	1.019	1.875	2.69
P10R2S3	58	31	1.721	0.908	4.765	3.035	1.164	2.14	2.67
P10R2S4	66	28	1.877	0.881	5.025	3.26	1.288	2.305	2.81
P1R3S1	11042	780	0.513	0.261	27.515	0.41	0.081	0.465	10.7
P1R3S2	9838	760	0.412	0.205	25.14	0.365	0.076	0.535	9.985
P1R3S3	8932	750	0.36	0.254	25.61	0.54	0.08	0.395	7.23
P1R3S4	9842	807	0.372	0.216	28.27	0.43	0.074	0.4	7.975
P1R3S5	4885	348	0.488	0.243	9.09	0.61	0.083	0.43	7.945
P2R3S1	249	46	0.683	0.285	4.165	2.105	1.43	2.59	3.68
P2R3S2	176	34	0.64	0.19	2.915	1.58	1.112	1.995	2.74
P2R3S3	106	23	0.595	0.231	2.255	1.285	0.961	1.695	2.25
P2R3S4	38	21	0.613	0.187	2.2	1.36	0.985	1.73	2.195
P3R3S1	249	44	0	0.118	3.825	1.915	0.777	1.5	2.35
P3R3S2	90	27	0.24	0.159	2.605	1.38	0.651	1.24	1.805
P3R3S3	86	27	0.489	0.163	2.09	1.135	0.548	1.085	1.51
P3R3S4	28	22	0.477	0.186	1.835	1.14	0.565	1.11	1.42
P4R3S1	62	31	1.183	0.543	4.115	2.45	1.105	2.04	2.67
P4R3S2	42	29	1.084	0.407	2.735	1.71	0.897	1.59	2.015
P4R3S3	35	22	1.071	0.396	2.225	1.62	0.785	1.4	1.74
P4R3S4	18	16	1.115	0.354	2.24	1.51	0.8	1.445	1.825

P5R3S1	62	31	1.122	0.496	4.255	2.875	1.317	2.54	2.995
P5R3S2	37	26	1.073	0.468	3.115	2.155	1.104	2.005	2.49
P5R3S3	26	19	1.03	0.405	2.46	1.855	0.982	1.775	2.13
P5R3S4	13	12	1.021	0.43	2.27	1.795	0.994	1.82	2.145
P6R3S1	751	107	1.832	0.638	7.075	3.69	1.348	2.475	4.67
P6R3S2	380	57	1.843	0.537	6.2	3.485	1.742	3.275	4.54
P6R3S3	248	45	1.491	0.408	4.755	2.48	1.632	2.93	4.15
P6R3S4	35	27	1.333	0.361	3.44	2.25	1.654	2.975	3.435
P7R3S1	102	39	0.479	0.248	3.855	2.685	0.668	1.455	2.135
P7R3S2	66	31	0.837	0.227	2.91	1.63	0.538	1.225	1.695
P7R3S3	43	27	0.75	0.194	2.315	1.3	0.436	1.135	1.415
P7R3S4	9	8	0.765	0.178	2.08	1.195	0.428	1.105	1.345
P8R3S1	5948	593	0.421	0.284	21.705	0.64	0.097	0.645	7.85
P8R3S2	5598	517	0.279	0.193	18.085	0.41	0.087	0.575	7.32
P8R3S3	5075	520	0.277	0.242	20.21	0.43	0.062	0.585	7.6
P8R3S4	6385	560	0.254	0.166	19.465	0.37	0.049	0.59	7.745
P8R3S5	4169	328	0.291	0.245	7.86	0.395	0.047	0.605	7.605
P9R3S1	89	34	1.282	0.684	4.33	2.35	0.97	2.095	2.78
P9R3S2	79	34	1.248	0.683	4.405	2.71	1.161	2.415	3.135
P9R3S3	70	31	1.426	0.67	4.055	2.325	1.131	2.41	2.885
P9R3S4	36	26	1.211	0.512	2.95	1.82	0.917	2.01	2.205
P9R3S5	21	20	1.226	0.462	2.905	1.815	0.969	2.11	2.335
P10R3S1	309	62	0.864	0.616	4.21	2.09	0.591	1.515	2.425
P10R3S2	238	47	0.919	0.667	4.685	2.505	0.962	2.13	2.775
P10R3S3	99	32	1.081	0.67	3.82	2.065	0.943	2.06	2.365
P10R3S4	71	27	0.957	0.583	3.08	1.76	0.846	1.955	2.175
P10R3S5	22	18	0.958	0.644	2.68	1.88	0.975	2.2	2.065
R1RAW	20	17	0.336	0.18	0.83	0.47	0.011	0.235	0.26
R3RAW	25	21	0.054	0.091	0.27	0.225	0.034	0.3	0.245

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Chapter 2. Nitrogen Transformation and Transport Processes

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Nitrogen (N) is ubiquitous in the environment. It is one of the most important nutrients and is required for the survival of all living things. It is also central to the production of all crop plants. Nitrogen accounts for 78% of the atmosphere as elemental dinitrogen (N_2) gas. Elemental N_2 gas is inert, does not impact environmental quality, and is not directly available for plant uptake and metabolism. The purpose of this chapter is to review the fate and transport processes for N in agricultural systems. Some of the most mobile substances found in the soil-plant-atmosphere system contain N and the need to understand N transport and transformations in the environment has been the subject of several reviews (Follett, 1989; Follett et al., 1991; Hallberg, 1987, 1989; Keeney, 1982, 1989; Laegreid, et al., 1999; Mosier, et al., 1998; and Power and Schepers, 1989). Nitrogen represents the nutrient most applied to agricultural land. This is because available soil-N supplies are often inadequate for optimum crop production and because commercial fertilizer, manures, and other sources of N are generally easily and economically applied. An important consideration is to keep applied and residual sources of N within the soil-crop system by curtailing transport processes (leaching, runoff, erosion, and gaseous losses) that carry N into the surrounding environment. The objective is to lower the rate and duration of the loss processes themselves. Practices and concepts that lessen the opportunity for loss processes to occur help decrease the amount of N that may be lost. In some cases improved efficiency is achieved by using less N and in other cases it can be achieved by increasing plant growth while using the same amount of N input. The fate and transport of N from any of the various sources from which it may enter the environment must always be considered in the context of the N cycle. Often a N budget, or mass balance, approach is needed to understand the options to minimize and/or mitigate the environmental impacts of N that may occur and to improve N management in farming and livestock systems.

1. NITROGEN TRANSFORMATIONS

1.1. Biological nitrogen fixation

Through the process of biological nitrogen fixation (BNF), symbiotic and nonsymbiotic organisms can fix atmospheric N_2 gas into organic N forms (Figure 1). A few living organisms are able to utilize molecular N_2 gas from the atmosphere. The best known of these are the symbiotic Rhizobia (legume bacteria), nonsymbiotic free-living bacteria such as Azotobacter and Clostridium, and blue-green algae. Generally, in a symbiotic relationship, one organism contains chlorophyll and uses light energy to produce carbohydrates. The other organism receives some of the carbohydrates and uses them as an energy source to enzymatically fix atmospheric N_2 into the ammonia (NH_3) form of N and thence into amino acids and other nitrogenous compounds that are nutritionally useful to the chlorophyll containing organism. To agriculture, the most important type of BNF is symbiotic fixation by legumes (i.e. alfalfa, clovers, peas, beans, etc.). Follett et al. (1987) estimated that leguminous crops were returning about 700 Gg N yr^{-1} of symbiotically fixed N to cropland soils in the U.S. and the amount may now reasonably be more than 1000 Gg N yr^{-1}. Global N fixation estimates from the use of legumes in agriculture were recently reported as 40,000 Gg N yr^{-1} (Laegreid et al., 1999; from various sources). Even though fixed N resulting from BNF is initially within the non-symbiotic or symbiotic organism/plant system; the fate, transport and entry of this N into the environment must also be considered in the context of the N cycle.

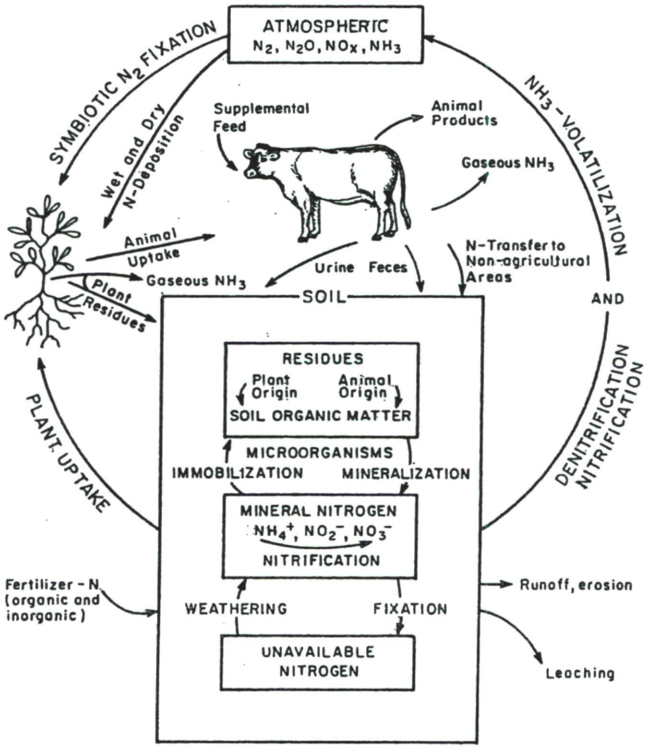

Figure 1. The Nitrogen cycle

1.2. Immobilization and mobilization of soil nitrogen

Nitrogen taken up by plants from the soil originates from indigenous organic and inorganic forms. Organic N occurs naturally as part of the soil's organic matter fraction; it can also be added to the soil from manure, symbiotic and nonsymbiotic biological N fixation, plant residues, and from other sources. Soil microorganisms and their activities are an integral part of immobilization and mineralization processes in soil (Figure 1); soil-organic N can be transformed to ammonium (NH_4^+) by the process of ammonification. Inorganic (mineral) forms of N include NH_4^+ or nitrate (NO_3^-), both readily taken up by crops, and nitrite (NO_2^-) that occurs as an intermediate form during mineralization of NH_4^+ to NO_3^-. Even though NH_4^+ is the preferred form, microbes in soil can convert either NH_4^+ or NO_3^- to satisfy their need for N, a process called immobilization. Immobilization of NO_2^- and NO_3^- back to organic forms of N can also occur through enzymatic activities associated with plant or microbial N uptake and N utilization processes. Microbes and soil animals use organic matter in soil as food and excrete nutrients in excess of their own needs. When NH_4^+ is released, it is called mineralization. When oxygen is present, microbes in the soil can readily transform NH_4^+ to NO_3^- with NO_2^- as an intermediate form, a process called nitrification. This is a fairly rapid process that, under aerobic conditions, can be completed in a few days. Although NO_2^- can potentially accumulate in soils under some conditions, it usually does not because it is rapidly transformed to NO_3^- as part of the nitrification process or else it is denitrified.

1.3. Gaseous transformations

1.3.1. Ammonia volatilization

Ammonium ions in the soil solution enter into an equilibrium reaction with NH_3 in the soil solution. The soil solution NH_3 is, in turn, subject to gaseous loss to the atmosphere. Soil pH and concentration of NH_4^+ in the soil solution are important factors affecting the amount of NH_3 loss to the atmosphere. As soil pH increases, the fraction of soil-solution NH_4^+ plus soil-solution NH_3 in the NH_3 form increases by an order of magnitude for every unit of pH above 6.0; thus, increasing the loss of soil-solution NH_3 to the atmosphere. As summarized by Stevenson (1986), NH_3 volatilization:

1. Is of most importance on calcareous soils, especially as soil pH exceeds 7;
2. Losses increase with temperature and can be appreciable for neutral or alkaline soil as they dry out;
3. Is greater in soils of low CEC, such as sands;
4. Losses can be high when high N organic wastes, such as manure, are permitted to decompose on the soil surface;
5. Losses are high from urea applied to grass or pasture as a result of hydrolysis of the urea to NH_3 by indigenous urease enzyme; and
6. Losses of soil and fertilizer N are decreased by growing plants.

Anhydrous, or gaseous, NH_3 is a very important direct-application N fertilizer. Gaseous NH_3, when in contact with moist soil, dissolves in, and reacts with, soil water to form NH_4^+ and OH^- ions. The pH is increased dramatically immediately around the application zone of anhydrous NH_3. Therefore, depending upon buffering capacity of the soil and the resulting soil pH, an equilibrium is approached between soil solution NH_4^+ and NH_3 in the soil solution and gaseous NH_3. If anhydrous NH_3 is placed in dry soil or at too shallow a depth, the NH_3 is also subject to volatilization. However, the N that is in NH_4^+ form is readily sorbed to the CEC of the soil.

1.3.2. Denitrification

As organic matter in soil decomposes, first NH_4^+, then NO_2^- and finally NO_3^- ions are formed by the process of nitrification (Figure 1). Nitrite usually does not accumulate in soils because it is rapidly transformed to NO_3^- or is denitrified to N_2 gas, nitrous oxide (N_2O), nitric oxide (NO), or one of the other gaseous N oxide (NO_x) compounds. Nitrate can also be lost to the atmosphere through the denitrification processes. Nitrous oxide is a product of incomplete denitrification, is a greenhouse gas that contributes to global climate change, and potentially to thinning of the ozone layer. Not only denitrification (a reductive process), but also the oxidative process of nitrification causes emission of a small amount of N_2O (Tortoso and Hutchinson, 1990). However, denitrification is the route for most losses of gaseous N compounds to the atmosphere. The potential for denitrification is increased as oxygen levels in the soil decreases. Under favorable environmental conditions, *Nitrosomonas* spp. bacteria in the soil readily transform NH_4^+ to NO_2^- that in turn is transformed by *Nitrobacter* spp. bacteria to NO_3^- (Figure 1). The small quantity of N_2O produced during nitrification of NH_4^+ in aerobic soils is a direct metabolic product of chemoautotrophic NH_4^+-oxidizing bacteria or results from other soil processes dependent upon these organisms as a source of NO_2^- (Tortoso and Hutchinson, 1990).

Table 1
Factors affecting the proportion of N_2O and N_2 produced during denitrification

Factor	Will increase N_2O/N_2
$[NO_3^-]$ or $[NO_2^-]$	Increasing oxidant
$[O_2]$	Increasing O_2
Carbon	Decreasing C availability
PH	Decreasing pH
$[H_2S]$	Increasing sulfide
Temperature	Decreasing temperature
Enzyme status	Low N_2O reductase activity

Biogenic production in soil is the principle source of atmospheric N_2O. In addition, several factors affect the ratio of N2O to N2 during denitrification (Table 1). Anaerobic soil processes, rather than nitrification (an aerobic process) are the principle biogenic sources of atmospheric N_2O (Freney et al., 1979; Goodroad and Keeney, 1984; Klemedtsson et al., 1988). Dinitrification is a bacterial process, during which NO_3^- or NO_2^- are reduced to gaseous N species NO, N_2O or N_2, and is capable of producing and consuming N_2O and NO. Nitrate is reduced first to NO_2^-, then to NO, next to N_2O and finally to N_2 (Eq. 1).

$$\begin{array}{c} \quad\quad\quad\quad\quad NO \\ \quad\quad\quad\quad\quad \uparrow \\ NO_3^- \rightarrow NO_2^- \rightarrow [X] \rightarrow N_2O \rightarrow N_2 \end{array} \qquad \text{(Equation 1)}$$

The general conditions required for denitrification to occur include: (a) presence of bacteria possessing the metabolic capacity; (b) availability of suitable reductants such as organic C; (c) restriction of O_2 availability; (d) availability of N oxides, NO_3^-, NO, or N_2O (Firestone and Davidson, 1989; Klemedtsson et al., 1988; Mosier, this volume). Either the NH_4^+ or NO_3^- form can potentially contribute to the release of N_2O to the atmosphere, especially where excess NO_3^- accumulates in the soil profile and is available for denitrification. Because N_2O is the greenhouse gas of concern, the proportion of N_2O produced relative to N2 under denitrifying conditions becomes of special concern. A number of factors affect the proportion of N_2O to N2. A model by Betlach and Tiedje (1981) predicts accumulation of N_2O whenever one of the factors shown in Table 1 slows the rate of overall reduction.

2. TERRESTRIAL TRANSPORT AND RELATED PROCESSES

2.1. Fertilizer and manure

For highly-water soluble compounds with NH_4 as part of their chemical formula (Table 2), the NH_4^+ cation can be sorbed to the CEC, incorporated (fixed) into clay and other complexes within the soil, released by weathering back into the available mineral pool, or immobilized into organic form by soil microbial processes. Ammonium that is associated with soil colloids can be transported into surface water during water or wind erosion of soil or, under certain conditions, can volatilize into the atmosphere as NH_3 gas and be aerially transported across the landscape, including into surface water. Gaseous NH_3 often is returned to the soil-plant system by direct uptake into plant leaves or dissolved in precipitation. Urea and calcium cyanamide (Table 2), are forms of N that, when applied to soil, are acted upon by enzymes in the soil to mineralize the N in them to NH_4^+ ions. Once in the NH_4^+ form and until nitrified to the NO_3^- ion form, the N in these two fertilizers is also sorbed to the CEC of the soil and is subject to the soil-erosion transport process described above. The N in organic materials such as crop residues is also first mineralized to NH_4^+, again being subject to sorption to the CEC of the soil until nitrified to the NO_3^-. The NO_3^- ion, when it is part of the chemical formula in compounds shown in Table 2, does not sorb to the CEC of the soil. Nitrate, a water-soluble anion, is very mobile, and moves readily with percolating water (leaching). It is not sorbed to the negatively charged sites on soil colloids, the cation exchange capacity (CEC) of the soil. The primary transport mechanism for NO_3^- ions is with percolating water by leaching or surface runoff (including return flow). Nitrate that is leached below the crop root zone often ends up as a pollutant in ground water supplies. Nitrate can also be dissolved in surface runoff water or in return-flow water that returns to the surface to become part of the runoff. Nitrate and NO_2^- ions can also be denitrified and lost to the atmosphere (Eq. 1) as NO, N_2O, or NO_x.

Table 2
Nitrogen fertilizer materials, their formulas and chemical analysis

Material	Chemical formula	Chemical analysis
		(%N)
Anhydrous ammonia	NH_3	83
Ammonium nitrate	NH_4NO_3	33.5
Ammonium sulfate	NH_4SO_4	21
Diammonium phosphate	$(NH_4)2H_2PO_4$	18-21
Monoammonium phosphate	$NH_4H_2PO_4$	11
Calcium nitrate	$Ca(NO_3)_2$	15
Calcium cyanamide	$CaCN_2$	20-22
Potassium nitrate	KNO_3	13
Sodium nitrate	$NaNO_3$	16
Urea	$CO(NH_2)_2$	45
Urea-ammonium nitrate	$CO(NH_2)_2+NH_4NO_3$	32

2.2. Runoff

Amount and timing of rainfall and soil properties are key factors that influence loss of dissolved N in runoff. Soils with low runoff potential usually have high infiltration rates, even when wet. They often consist of deep, well to excessively-drained sands or gravels. In contrast, soils with high runoff potential have one or more of the following characteristics: very slow infiltration rates when thoroughly wetted and containing high clay content possibly of high swelling potential, high water tables, a claypan or clay layer at or near the surface, or are shallow over a nearly impervious subsurface layer. A combination of soil conditions of high runoff potential and high precipitation amount are especially conducive to surface runoff losses. Steeper slope gradients increase amount and velocity of runoff, while depressions, soil roughness, and presence of vegetative cover or crop residue decrease runoff by improving the infiltration.

The dissolved concentration of N in surface runoff from soils under conservation or no-tillage often is higher than from soil under conventional tillage (McDowell and McGregor, 1984; Romkens, 1973). Reasons may include incomplete incorporation of surface-crop residues, and higher dissolved N concentration in the surface soil because of residue accumulation and decomposition. In addition, high concentrations of soluble N can occur when there is a soil horizon barrier (e.g. Fragipan) present in the soil profile that results in return flow of leached N back to the soil surface (Lehman and Ahuja, 1985; Smith et al., 1988).

Some of the effects on dissolved nutrients in surface and subsurface water discharges that are associated with agricultural nutrient management for crop production and the use of conservation tillage for erosion control, are illustrated (Figure 2) by the work of Alberts and Spomer (1985). Their study site, for this ten year study, was in the deep loess hills in western

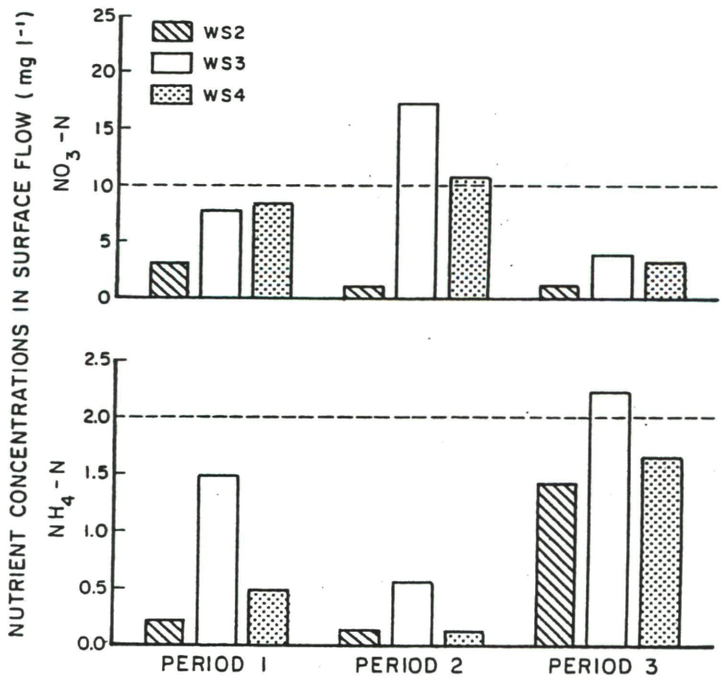

Figure 2. Runoff-weighted concentrations of NO_3^--N and NH_4^+-N in surface flow by seasonal period. Dashed lines represent current water quality standards (from Alberts and Spomer, 1985).

Iowa. The loess is underlain by nearly impervious glacial till at depths of 4.6 to 24.4 m. Lateral water movement occurs in a saturated soil zone that exists at the loess-till interface. Water from both surface runoff and subsurface flow was sampled. In their study, watershed 2 (WS2) was conventionally tilled (33.5 ha) while watersheds 3 and 4 (WS3 and WS4) were contour-till planted (43.3 ha) and terrace-till planted (60.8 ha), respectively. About sixty-five head of cattle gleaned the corn stalks from WS3 and WS4 from mid-November to March each year. Figure 2 shows the ten year, runoff-weighted concentrations of NO_3^- and NH_4^+ for three time periods; April through June (fertilization, seedbed preparation, and crop establishment period); July through November (crop reproduction and maturation period); and December through March (crop residue period) or periods 1, 2, and 3 respectively. Water quality criteria for NO_3^- and NH_4^+ are shown by dashed lines (Fletcher, 1991; U.S. EPA, 1982) in Figure 2 as 10.0 and 2.0 mg L^{-1}; respectively. Highest NO_3^- concentrations from the till-planted watersheds (WS3 and WS4) occurred during July through November (period 2), perhaps as a result of evaporative drying moving previously applied fertilizer salts to the soil surface. Preplant applications of fertilizer for the conventionally tilled watershed (WS2) had been incorporated with a disk. Ammonium N concentrations were generally from cattle manure and leaching of NH_4^+ from partially decomposed corn stalks. Issues illustrated by this study include the need to place fertilizer below the soil surface while still maintaining residue cover for soil erosion control. Fall and winter livestock grazing of crop residues likely contributes to N runoff since the manure and urine may be deposited on frozen ground.

2.3. Erosion

Detachment of sediments and nutrients from the parent soil is selective for soluble nutrients (such as NO_3^-) and for the fine soil fractions with which nutrients (such as NH_4^+ and the soil organic matter N) are associated. Therefore, N contained in runoff and/or associated with sediments is present in higher concentrations than in the parent soil. This difference is termed the enrichment ratio. Enrichment of sediment loads is a two-step process: enrichment during particle suspension and enrichment due to redeposition of coarser particles during overland and channel flows. In order for management practices to decrease the effect of water erosion processes on the production and transport of sediment associated N, they must directly influence the processes involved. Such practices need to protect against soil particle detachment, slow sediment transport, and enhance sediment deposition within the landscape rather than allowing the sediments to move into surface water.

Soil erosion is important to the movement of N into surface water which primarily occurs with soil erosion by water, rather than by wind. Briefly, soil erosion by water includes the processes of detachment, transport, and deposition of the soil particles by raindrops or surface flow (Foster et al., 1985). Some sediments may travel only a few millimeters while others may be transported long distances before either being deposited or reaching a surface water resource (i.e. a lake, reservoir, or stream). The movement of NH_4^+ results because it is sorbed to the surfaces of clays and finer sediments. The NO_3^- is completely water soluble and thus moves with the water until it re-enters the available soil pool, is utilized by microbes or plants, becomes denitrified, is possibly deposited and buried, or enters and possibly degrades surface- and/or ground-waters. A major source of the N that degrades surface water is that which is transported in soil organic matter. A large part of the soil organic matter and soil organic N (SON) contained in it are concentrated near the soil surface and are therefore vulnerable to erosional and oxidative (mineralization/nitrification) processes. Also, within the U.S., about 400 million m^3 of sediment are dredged each year in the maintenance and establishment of waterways and harbors (Sopper, 1993). Loss of topsoil and the SON contained in dredged sediments is a primary environmental impact of accelerated soil erosion. Two independent methods of estimating the amount of eroded SON are to utilize information about river sediment loads or to use estimates of amounts of eroded sediments themselves. To use the sediment load approach, data by Leeden et al. (1991) showed that the suspended load in 12 major U.S. rivers during 1991 was 336,000 Gg yr^{-1}. Assuming that 75% of the suspended load (mostly due to soil erosion) was contributed by cropland, then the sediment transport attributed to cropland is about 250,000 Gg yr^{-1}. Assuming a delivery ratio of 10% and SON content of sediment of 0.25% (Lal, 1995; Follett et al. 1987), the total SON displaced by soil erosion from cropland was about 6.25 Tg yr^{-1}. Alternatively, (Lal, et al., 1998) used an estimate of the amount of eroded sediments to calculate soil organic carbon (SOC) losses. By assuming a SOC:SON ratio of 110:9 in sediment (Follett et al. 1987) the total SON displaced by soil erosion would be about 9.6 Tg yr^{-1}. Thus considering only the U.S., soil erosion serves as an environmental source of 6 to 9 Tg N yr^{-1} as SON.

Much still needs to be learned about managing cropland soil erosion. For example, Follett et al. (1987) assessed effects of tillage practices and slope on amount of organic N in eroded sediments from cultivated land surfaces in Minnesota (USA) for major land resource areas (MLRAs) 102, 103, 104, and 105. Their estimates, using the Universal Soil Loss Equation (USLE), average organic matter in topsoil by slope category, and dominating slope gradient and soil series indicates that conservation tillage compared to conventional tillage decreases the amount of organic N associated with eroded sediments by about half with some additional decrease resulting from the use of no-tillage. One can assume that added fertilizer N responds similarly to organic N when it is sorbed to clay surfaces, finer sediments, or to soil organic matter.

2.4. Leaching

Nitrate is a negatively charged ion that is repelled by, rather than attracted to, negatively-charged clay mineral surfaces in soil (i.e. the CEC). It is the primary form of N leached into ground water, is totally soluble at the concentrations found in soil, and moves freely through most soils. As described by Jury and Nielson (1989), movement of NO_3^- through soil is governed by convection, or mass-flow, with the moving soil solution and by diffusion within the soil solution. The widespread appearance of NO_3^- in ground water is a consequence of its high solubility, mobility, and easy displacement by water. An extensive literature concerning N-management, leaching, and ground water quality exists including that assembled by CAST (1985), Follett (1989), Follett et al. (1991), and Follett and Wierenga (1995).

Juergens-Gschwind (1989) reported on leaching losses observed under widely varying conditions (lysimeters, drainage water measurements in field trials, catchment areas, profile and groundwater research in field trials) (Figure 3). The results were made comparable by referencing the N-losses at each site to an ~ 300 mm drainage level per year. The leaching risk was distinctly higher on arable land than on grassland, and on lighter textured soils than on heavy textured soils. An upward shift in the data was observed when going from lower nutrition rates obtained by normal fertilization practices to the very high rates that can result from excessive N-fertilization and animal manure disposal (rates in excess of the plant nutrient requirements) on agricultural lands. As shown in Figure 3, soil texture influences how rapidly NO_3^- leaching occurs. This influence of soil texture, in sandy soils is further documented by

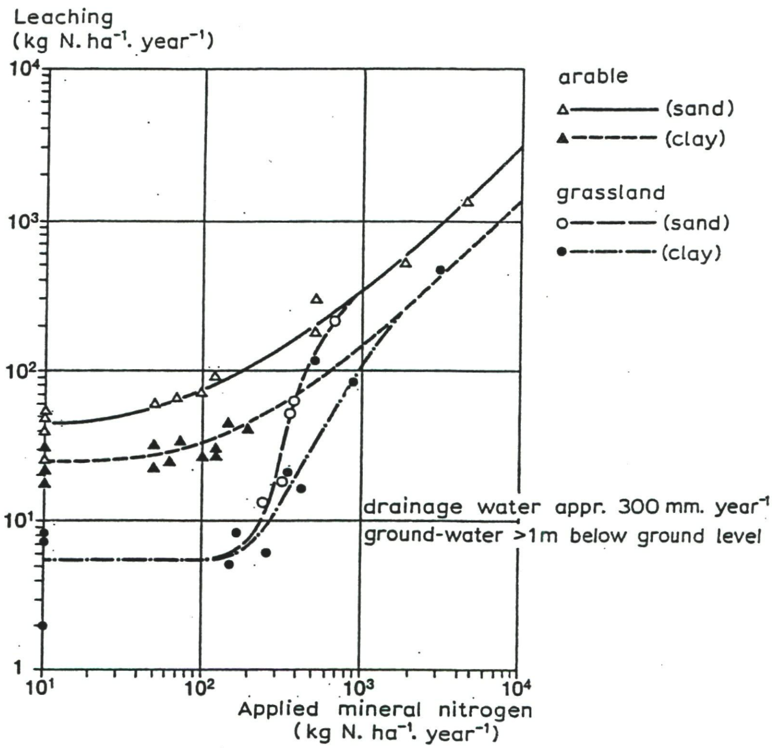

Figure 3. Leaching of nitrogen from arable and grassland systems (adapted from Juergens-Gschwind, 1989).

Delgado, et al. (1999) in which more NO_3^- leaching was observed on a loamy sand than on a sandy loam. Also, unless the soil is anaerobic, excess amounts of NO_3^- also leach on heavy-textured soils, as illustrated in an N-rate study with irrigated corn (*Zea mays L.*) by Godin (1999). Godin used ^{15}N-labeled fertilizer on a clay loam soil, he observed that the recommended fertilizer rate (135 kg N ha^{-1}) adequately satisfied the crop N requirement and resulted in higher percent recovery of N than did the excess N rate (200 kg N ha^{-1}). At the excess N rate, fertilizer ^{15}N had leached below the crop root zone (0.9 m) by harvest of the first year and to a depth of over 1.5 m by harvest of the second year.

3. NITROGEN CYCLING IN PASTURE SYSTEMS

Inputs are from fertilizers and manures, biological N fixation, wet and dry deposition, supplemental feed to livestock, and mineralization of soil organic matter (Figure 1). Losses may occur through harvest of animal or plant products, transfer of N within the pasture with animal excreta, fixation of N in the soil, soil erosion, surface runoff, leaching, volatilization, and denitrification. The soil compartment includes a pool of available N (NO_3^- and NH_4^+) for plant uptake that is in equilibrium with N in residues (organic N) and, especially for some soils, with fixed NH_4^+ which is held between mineral layers of the clay. Plant N uptake is from the available soil pool. The N in the herbage is then either harvested and removed from the field, returned to the soil as crop residue and root material, and/or eaten by grazing animals and either utilized by the animal or excreted as feces or urine and returned to the soil.

3.1. Role of soil organisms

Soil microfauna and microflora have a major role in N cycling. Release of N from plant and animal residue depends on microbial activity. Soil bacteria utilize the more readily available, soluble, or degradable organic fractions. Fungi and actinomycetes decompose the resistant cellulose, hemicellulose, and lignin. Dung beetles, earthworms, and other soil fauna increase the decomposition rates of feces and plant litter by mixing them with soil. Rhizobia and vesicular arbuscular mycorrhizae (VAM) associate with plant roots to fix N and increase nutrient and water scavenging ability, respectively. VAM infection of roots is considered more helpful for tap rooted pasture legume species than for fibrous rooted grasses. At any time, soil-microbial biomass contains much of the actively-cycling N of the soil and represents a relatively available N pool, capable of rapid turnover (Bristow and Jarvis, 1991). The energy flux through the soil microbial biomass (SMB) drives the decomposition of organic residues (Smith and Paul, 1990) and soil organic matter. Plant root biomass and soil microbial processes are intimately linked in grassland systems as described by Reeder et al. (2000). If decomposition exceeds C inputs, the soil organic matter will decline. The resulting mineralization of N (and other nutrients) will result in their becoming vulnerable to possible losses into the environment by leaching, denitrification, or other mechanisms (Follett, et al., 1995). Because its levels are relatively stable for a particular soil/land-use system, even though the SMB pool is very active for nutrient cycling, SMB can serve as a measure (index) of the effects of agricultural management practices on soil quality. In their study, Follett et al. (1995) utilized ^{15}N labeled fertilizer and followed the N in the SMB fraction under no-till in a 4 yr (winter wheat-sorghum-fallow-winter wheat) cropping sequence. Their conclusion was that, under no-till, biological processes conserved the N by accumulation of crop residue carbon (C) and N near the soil surface, recycling of N through the crop-SMB system, and maintenance of N in organic forms.

3.2. Role of the grazing animal

Grazing animals affect plant growth by defoliation, traffic patterns, herbage fouling, partitioning of ingested N to body weight, feces, and urine, redistribution of herbage N in excreta, and N turnover rate. Defoliation by grazing animals prevents senescence of plant tissue, removes N in animal products, changes the N pathway from internal plant recycling or leaf fall to return as feces and urine, increases light penetration into the canopy and, through selective grazing, may alter botanical composition by promoting one species over another. Animal traffic compacts soil, sometimes making soil characteristics for plant growth less desirable. Herbage fouling by feces reduces its acceptability for grazing, thereby increasing maturity and reducing forage quality and/or consumption by grazers. Urine does not cause herbage to be unacceptable for grazing. Livestock recycle much of the N that they consume from forage back to the soil. The N retention of forage N by livestock, as a percentage of dietary intake, ranges from about 8+ % of live weight gain (LWG) (e.g. in steers) to 20 % (Follett and Wilkinson, 1995) in high producing animals (e.g. milk cows). For example, a 250 kg steer that ingests 6 kg forage d^{-1} (containing 3% N in the forage) and gaining 0.8 kg d^{-1} may ingest 180 g N d^{-1}, retain about 20 g in LWG (12 % retention) and excrete the remainder, about 160 g N d^{-1}. Excretion as feces and urine both result in volatile losses of NH_3. About 74% of the total N excreted is in the urine (Follett and Wilkinson, 1995) and a single urine spot can have an N concentration corresponding to more than 600 kg N ha^{-1} (Whitehead, 1995). Some of the N is released to the atmosphere as volatile NH_3, while the N remaining in the excreta and its associated plant residues return to available nutrient pools in the soil.

Animals on range may utilize more of the forage near watering points. Greater density of dung and increased levels of soil-profile NO_3^- are frequently observed in areas near watering and shade points (Haynes and Williams, 1993; Wilkinson et al., 1989). Even without transfer of N to unproductive areas such as woods, shade, watering points, fence lines, and paths, consumption and excretion of N by ruminants results in gathering of N from large areas of the pasture, and deposition of the N to smaller areas. This concentrating effect frequently means that N cycled through livestock cannot be used efficiently by forage plants. On an annual basis, less than 35% of pasture areas receives excretal N; some areas receive one or more applications (overlapping of excreta). This uneven distribution means some of the pasture will be under fertilized and some over fertilized.

4. PRIMARY AND SECONDARY FLOWS OF NITROGEN

Primary and secondary flows of N are very much a part of the animal/plant N cycling ecosystem as discussed above. The following discussion is focused upon cropland and surrounding ecosystems but also relates to a livestock system. Figure 4 from Duxbury et al. (1993) illustrates some of the flows of N following input of 100 kg of fertilizer N. The primary flows are shown by dashed lines. In this example, fifty of the 100 kg are harvested in the crop and fifty are lost by the combination of leaching (25 kg), surface runoff (5 kg), and gaseous loss (20 kg, primarily denitrification). If 10% of the gaseous N loss is N_2O, then 2 kg N_2O-N would be generated in the primary cycle.

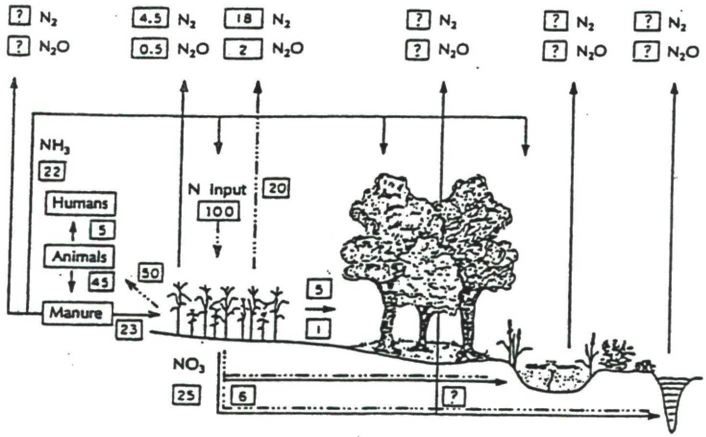

Figure 4. A simplified flow of nitrogen fertilizer through the environment (from Duxbury et al., 1993).

Mosier et al. (1998) evaluated the International Panel on Climate Change (IPCC) methodolgy (IPCC 1997) as part of an effort to provide a more comprehensive N_2O emission calculation methodology. Using mid-point values, they recommended that the emission factor relating N_2O directly from soil to fertilizer-N application should be 1.25 $\pm$ 1% N_2O-N of the applied fertilizer N. If both direct and indirect emissions are considered about 2.0% of N input into agricultural system would be emitted as N_2O-N annually.

Secondary flows, shown by the solid lines in Figure 4, include feeding of the 50 kg of harvested N to animals, which might generate about 45 kg of manure N. The manure is returned to cropland to create a secondary flow of the original fertilizer N. Part of this secondary flow of applied fertilizer N is again removed from the field by the harvested crop; through gaseous losses as NH_3, N_2O, NO_x, and as N_2 gas, surface runoff, and NO_3^- leaching. However, about half of the manure N is volatilized as NH_3 prior to or during manure application. Volatilized NH_3 is aerially dispersed to eventually be returned to and cycled through both natural ecosystems and cropland (Duxbury et al., 1993). Estimates are that, over the course of about fifty years, more than 80% of the N applied to a field will eventually return to the atmosphere through denitrification (Cole et al., 1993). Generally, greater than 95% of this N returns to the atmosphere as N_2 gas but some unknown amount is released as N_2O.

5. GROUND AND SURFACE WATER

5.1. Ground water

Nitrate that moves below the crop root zone is totally soluble and can potentially leach into ground water. Ground water flows within permeable geologic formations called aquifers.

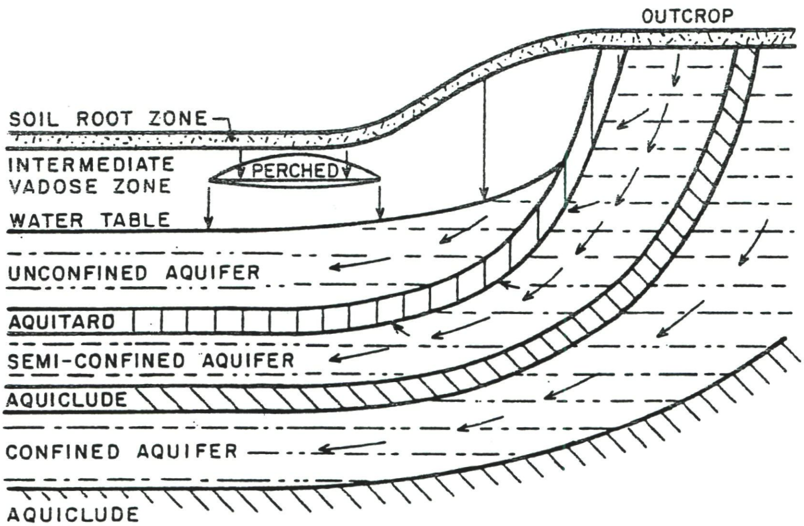

Figure 5. Schematic of vadose zone, aquifer system, and flow direction (from Pionke and Lowrance, 1991).

Aquifers are natural zones beneath the earth's surface that often yield economically important amounts of water. In a very simple system, water and dissolved NO_3^- percolate below the root zone and through the intermediate vadose zone to an aquifer. From there, these waters can recharge deeper aquifers or discharge to streams or water bodies.

Aquifers are subdivided based upon geology. A meaningful division, from the perspective of ground water quality, is between confined and unconfined aquifers. Confined aquifers are separated from the earth's surface by flow-impeding layers that, depending upon the degree of flow impedance, are referred to as aquicludes or aquitards (Figure 5). Unconfined aquifers are not separated from the earth's surface by a flow-impeding layer, and are therefore in contact with the atmosphere through the unsaturated zone. Aquifer systems are often complex. To minimize the amount of NO_3^- that may enter ground water, it is necessary to understand the aquifer system and then to identify and apply improved N management practices to the recharge area of the aquifer. Structure of the aquifer system and subsequent flow patterns affect NO_3^- dilution, transport, and removal.

Ground water can rejoin the ground surface downslope and adjacent to a perennial stream, often along a riparian zone similar to that shown in Figure 6. In a riparian zone, that water table moves progressively toward the land surface and the intermediate vadose zone is lost as the stream channel is approached. During storms or wet periods, the water table can rise rapidly to intersect the land surface at some distance from the stream - discharge of ground water to the soil surface results. The system can be dynamic, with water table levels, extent of the saturated zone, and flow directions changing substantially and rapidly with precipitation (Pionke and Lowrance, 1989). As the ground water and its dissolved NO_3^- move into the more biologically and chemically active soil zones, the NO_3^- becomes available for uptake by riparian vegetation. Also, if oxygen levels become limited, activation of soil biological and chemical regimes result in denitrification.

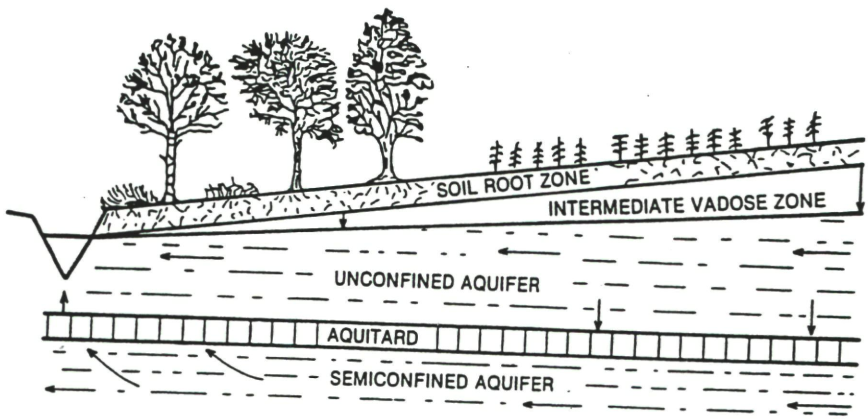

Figure 6. Schematic of the vadose zone, aquifers, and flow directions in a typical riparian zone subject to a humid climate (from Pionke and Lowrance, 1991).

Nitrogen is the nutrient of most concern in the contamination of ground water, primarily resulting from NO_3^- leaching. Leaching of NH_4^+ is generally not important since it is strongly adsorbed by soil, except for sands and soils having low retention (cation exchange) capacities. However, NO_3^- is readily leached deeper into the soil profile, below the bottom of the root zone, and may eventually leach into ground water supplies.

Water quality impact zones for N are wells, ground water supplies, streams, and surface water bodies. Because 95% of rural inhabitants and substantial livestock populations consume ground water, NO_3^- concentration is most important and can cause both human and animal health effects (Chapter this book, by Follett and Follett). Those factors that control NO_3^- concentration in groundwater, such as dilution and well position relative to the primary source areas for NO_3^-, can greatly affect their impact on ground water quality. In contrast, stream flow tends to mix ground water discharge and surface runoff from different land uses and time periods, thus causing generally much lower and more stable NO_3^- concentrations. Although elevated concentrations of NO_3^- are most often observed at shallow water table depths, long term increases in deeper wells are possible where deep aquifers are recharged by NO_3^--rich waters. Movement of NO_3^- with percolating water, through the unsaturated zone, can be very slow and time required for present-day inputs of NO_3^- to reach the ground water reservoir may be many years. Shuman et al. (1975) observed an average rate of NO_3^- movement through silt soils (loess) of about one meter per year for Iowa. Where 168 kg N ha^{-1} (the recommended N rate) was applied, N did not accumulate beneath the crop-root zone. Ground water flows from areas of high pressure toward areas of low pressure (hydraulic head). Generally movement is slow and there is little mixing of contaminated with uncontaminated ground water as they flow through the saturated zone, contaminants tend to remain concentrated in zones. However, because of the slow rate of movement and lack of dilution, contamination may persist for decades and centuries, even if input sources of NO_3^- are decreased or eliminated. Unfortunately, reclamation is technically and economically impossible in most cases (Keeney, 1982).

Many sites of excessive NO_3^- accumulation are recognized. Viets and Hageman (1971) conducted a comprehensive review of studies in the U.S. Substantial accumulations of NO_3^- were found in deep profiles of irrigated Colorado soils, except where alfalfa was the crop (Stewart et al., 1967). Muir et al. (1973) conducted a study of factors influencing NO_3^- content of ground water in Nebraska. Their data indicated that the quality of Nebraska water was not being materially influenced by agricultural use of commercial fertilizers previous to that time except on sites of intensively irrigated sandy soils and in valley positions with a shallow underlying water table.

There are numerous sources of N in the environment. Keeney (1986) identified intense land-use activities (e.g. irrigation farming of high value crops, high density of animal operations, or septic tank systems) as causes of excessive NO_3^- in ground water. Irrigation of cropland is widely practiced in the U.S., particularly in the more arid west and in the southeast where economic returns are high. The review by Pratt (1984) shows that in situations where roots have access to the entire soil solution, NO_3^- is not leached unless excess fertilizer N is added or the soils are over-irrigated.

Because the subsurface system is generally large and not uniform in structure, function, or efficiency, it is much easier to focus on source areas rather than on the whole system. The source area is a bounded area or volume within which one or a set a of related processes dominate to provide excessive production (source), permanent removal (sink), detention (storage), or dilution of NO_3^-. Source area effects, by definition, are disproportionately large relative to the area or volume occupied. If the source area(s) can be identified, then positioned relative to the generalized flow pattern within the system, a basis is possible for estimating effects on an impact zone.

Systematic data on production practices, input use, and management systems are insufficient to do many of the assessments that are needed. However, quantity and quality of soil survey data, climate data, and assessments of NO_3^- concentrations in various aquifers are increasing. Statistical techniques and simulation models used in conjunction with Geographical Information Systems (GIS) technology show promise in identifying and assessing NO_3^- leaching across regions (Christy, 1992; Wylie et al., 1994). Models such as the Nitrate Leaching and Economic Analysis Package (NLEAP) (Shaffer et al., 1991; Delgado et al., 2000) use farm management, soil, and climate information to estimate NO_3^- leaching at a farm or even the soil series level. Thus, allowing determination of potential landscape NO_3^--leaching hot spots when sufficient information is available. As technology continues to improve, the targeting of improved practice to those areas, farm enterprises, fields within a farm, or even locations (hot spots) within a field that cause the most damage should become possible for decreasing losses of N to the environment.

Two general approaches to minimize NO_3^- leaching into ground water are: 1) optimum use of the crop's ability to compete with processes whereby plant available N is lost from the soil-plant processes themselves. Key elements of the first approach are to assure vigorous crop growth and N assimilation capacity, and to apply N in phase with crop demand; 2) The second approach might include use of nitrification inhibitors or delayed release forms of N to directly lower potential leaching losses. In addition, realistic crop-yield goals must be selected. Olson (1985) emphasizes that a realistic yield goal would be no more than 10% above recent average yield for a given field or farm. Such a yield goal will still likely be difficult to achieve because of limitations imposed by environmental factors and/or the farmers own operational skills.

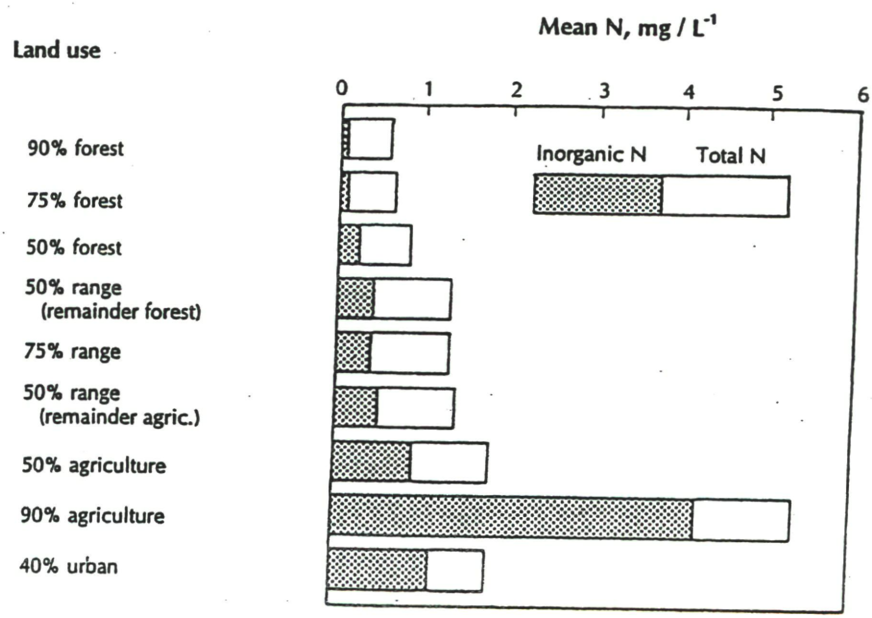

Figure 7. Land use and mean inorganic and total nitrogen concentrations from stream data from 904 nonpoint source-type watersheds (from Omernik, 1977).

The high NO_3^- flux that often occurs in streams draining agricultural land, does not come from the overland runoff, but primarily from the ground water contributions (including tile-drainage effluent) to stream flow. During discharge events, the ground water and its NO_3^- load will include shallow interflow (sometimes referred to as subsurface runoff). However, during the majority of time, deeper baseflow that rejoins surface water provides the major contribution of NO_3^- (Hallberg, 1989).

Stream water quality data from 904 nonpoint source-type watersheds across the U.S. were summarized by Omernik (1977). The watersheds ranged in character from forested areas, to urbanized regions, to areas dominated by row-crop agriculture. The data were compared to landuse and, as shown in Figure 7, especially the inorganic N concentrations are directly related to the amount of the watershed used for agriculture.

The data in Figure 7 are over two decades old now; however, reviews of temporal trends since then also show significant increases in NO_3^- (Hallberg, 1989). Referring to Figure 7, long-term environmental concern about the impact may not only need to be the increasing loads of soluble N, but also the dramatic change in the proportion of the particulate and soluble N concentrations. In forest and range systems the major N load was as organic N, much of it in the particulate fraction (related to organic matter); but now the major load in agricultural areas is as soluble NO_3^-.

5.2. Surface water

Agricultural production has been identified as a major nonpoint source of pollution in U.S. lakes and rivers that do not meet water quality goals. Nitrogen can be transported into aquatic systems from airborne, surface, underground, and in situ sources (Table 3). Sediment is the largest single type of pollutant followed by nutrients (NRC, 1993). As discussed above, much of the N that enters lakes and rivers is associated with eroding sediments (NH_4^+), eroding soil organic matter (organic forms of N and NH_4^+), and dissolved in surface runoff (primarily NO_3^-). The water that runs over the soil surface during a rainfall or snowmelt event, by rill or sheet flow, or even high-order channelized flow, may have a relatively high concentration of organic N related to suspended particulate matter, but it is typically quite low in NO_3^- concentration.

Agricultural sources of N can arrive in surface water via airborne dust from wind erosion, through gaseous transport of NH_3 volatilized from livestock manure or from some fertilizer materials. Surface sources of N from agriculture are perhaps the best understood, and N delivered with eroded soil sediments is a major source.

Ground water delivery of NO_3^- to lakes and streams is no doubt very important but difficult to gauge. In situ sources include biological N fixation, such as by blue-green algae and the leaching of N from lake sediments. An additional source of N and other nutrients is from wild aquatic birds; however, their role in the nutrient regime of a water body may be more that of cycling agents than of direct sources.

Table 3
Sources and sinks for the nitrogen budgets of aquatic systems

Sources	Sinks
Airborne	Effluent loss
Rainwater	
Aerosols and dust	Ground water recharge
Leaves and miscellaneous debris	
	Fish harvest
Surface	
Agricultural drainage, including tile drainage	Weed harvest
Water erosion of sediment from agricultural land	
Animal waste runoff	Insect emergence
Marsh drainage	
Runoff and erosion from forest and rangeland	NH_3 volatilization
Urban storm water runoff	
	Evaporation (aerosol formation from surface foam)
Domestic waste effluent	
Industrial waste effluent	
Wastes from boating activities	Denitrification
Underground	Sediment deposition of detritus
Natural ground water	
Subsurface agricultural and urban drainage	
Subsurface drainage from septic tanks	Sorption of ammonia onto sediments
In situ	
Nitrogen fixation	
Sediment leaching	

When waters become too enriched by nutrients, the aquatic environment can become eutrophic - a result of the ensuing luxuriant growth of algae and macrophyte growth to levels that can choke navigable waterways, increase turbidity, and depress dissolved oxygen concentrations. Rapid growth of algae is the greatest and most widespread eutrophication problem. When a large mass of algae dies and begins to decay, the oxygen dissolved in water is depleted and certain toxins are produced, both of which can kill fish. The complexities of eutrophication are that nutrient status of various species of algae can vary from lake to lake or even from different areas and depths of the same lake on the same day. Excess algal growth can create obnoxious conditions in ponded waters, increase water treatment costs by clogging screens and requiring more chemicals, and cause serious taste and odor problems.

Sawyer (1947) was the first to propose quantitative guidelines for lakes. He suggested that 0.3 mg L^{-1} of inorganic N and 0.015 mg L^{-1} of inorganic phosphorus are critical levels above which algal blooms can normally be expected in lakes. However, development of nutrient criteria or recommended methodologies for protecting waterbodies from excessive nutrient loading are very much needed. National criteria that are available for NO_3^-, NO_2^-, and NH_3 are generally established to protect human health and aquatic life from toxic eutrophication, or impairments to recreational uses such as swimming, fishing, and boating (Tetra Tech, Inc., 1994).

Under natural conditions, NO_3^- and NO_2^- occur in moderate concentrations and have little toxicological significance for aquatic life. Because the levels that are toxic to aquatic life are much higher than those expected to occur naturally in surface waters, restrictive water quality criteria for these elements have not been recommended. Two of the main concerns about the impacts of NO_3^- and NO_2^- on the environment are the primary water quality concern about their potential health effects on humans and ruminant animals associated with contaminated drinking water.

On the other hand, NH_3 is highly toxic to aquatic organisms. Acute toxicity in fish causes loss of equilibrium, hyperexcitability, increased breathing, cardiac output, convulsions, coma, and death, if concentrations are extreme. Chronic toxic effects include reduced hatching success, growth rates, and developmental or pathological changes in gill, liver, and kidney tissues (U.S. EPA, 1982).

6. WITHIN AGRICULTURAL SYSTEMS

6.1. Accounting for all Nitrogen Sources

Nitrogen budgets provide a valuable framework to quantify and examine N inputs and losses for agricultural production systems (also see Figure 1). Accounting for the major sources of N to cropping systems and into the envionment, in general, is especially important. The following are some of the sources that should be considered.

1. Fertilizer N inputs and amounts are easily determined and can be managed.
2. Organic wastes are an important N source. Organic wastes available for use on cropland in the U.S. include livestock wastes, crop residues, sewage sludge and septage, food processing wastes, industrial organic wastes, logging and wood manufacturing wastes, and municipal refuse. Animal manures and crop residues account for the majority of organic wastes applied to agricultural land.
3. Manure N inputs are uncertain because the N content is related not only to livestock type, age, and health, but also to variations in N content. Once excreted, the N content can change considerably depending on type and amount of bedding, type and time of manure storage, and manure management and placement when being applied. The best way to overcome these uncertainties is through the use of manure analysis and calibration of application equipment. Manure credits are often used to try to account for N that becomes available from applied manure.
4. Biological N fixation (BNF), especially by legumes, can be an especially important source of N. Although the importance of BNF has been known for centuries, there are

few quantitative methods for estimation of BNF. Currently, the method most used is that of recognizing BNF by legumes with legume credits.

5. Nitrate contained in irrigation water is available to the crop and should be considered when making fertilizer recommendations. Crop utilization of NO_3^- from irrigation water is greatest when plant-N requirement is greatest and other N sources are not excessive.

6. Atmospheric additions, including volatilized NH_3 from livestock operations, are another source of N to agricultural systems and to the environment. The mechanisms of additions that are identified include N dissolved in precipitation, dry deposition, and direct plant absorption of gaseous NH_3.
7. Contributions of residual soil N require soil testing for NO_3^- and NH_4^+ within the root zone and will be discussed below.
8. Nitrogen mineralization is the term given to biological decomposition of organic material in soils and their conversion and contribution to inorganic forms is significant.

6.1.1. Soil nitrogen availability tests

Available soil N represents residual N in the soil profile, plus N mineralized from the soil organic matter during the growing season. While residual N has proven to be a useful index in certain regions of the U.S., no generally accepted index exists for N mineralization. Obviously, such a development would represent a major advance for avoidance of excessive fertilizer N applications. A complement to a soil N test may be a plant tissue N test. An attractive feature of tissue tests is that the plant root system tends to integrate spatial variability of soil N supplying power over a relatively large field volume.

6.1.2. Soil organic nitrogen availability

A significant portion of plant-N requirements are supplied by mineralization of soil organic matter during the growing season. Various N availability indexes exist, but they typically provide qualitative rather than quantitative measures of SON availability. Early concepts of a N availability index have been modified; but to date, no soil organic N availability procedure has received general acceptance from a soil test standpoint. Ultimately, a systems-type, mass balance N approach may be the best alternative. The present recommendation is to follow pertinent N fertilizer guides which have been developed locally for specific crop needs and soil areas.

6.2. Agricultural practices

6.2.1. Nitrification inhibitors

The NH_4^+ ion is sorbed to the CEC of the soil; whereas, NO_3^- ion is not and can be readily leached or denitrified. Both forms can be readily utilized by crops. Nitrification inhibitors include chemicals added to soils to stabilize fertilizer applied as NH_3 or in the NH_4^+ form by inhibiting the activity of the *Nitrosomonas* bacteria in the first step of the nitrification process.

6.2.2. Control/slow release fertilizer

Methods of altering the release of N from soluble materials has been to coat water-soluble N fertilizer with less water-soluble materials in order to retard entry of water into the particle and the movement of N out. Coatings applied to soluble N materials generally have been of three types: 1) Impermeable coatings with small pores that allow slow entrance of water and slow passage of solubilized N out of the encapsulated area; 2) Impermeable coatings that require breakage by physical, chemical, or biological action before the N is dissolved; and 3) Semipermeable coatings through which water diffuses and creates internal pressures sufficient to disrupt the coating. Sulfur-coated urea (SCU) has been developed for a number of years as a product with characteristics of slow-N release. Elemental sulfur (S) was chosen because of its relatively low cost and ease of handling. Newer control-release N fertilizer materials are also being developed and marketed (Shaji and Gandeza, 1992). These newer materials have polyolefin resin coatings. The coatings can be tailored to provide a range of N release rates that are suitable for a variety of cropping systems. However, further field research is needed to insure the utility of these newer materials for cropping systems.

6.2.3. Conservation tillage

Use of conservation or reduced tillage (including no-till) continues to increase as an alternative for nearly all forms of crop production. Management systems which maintain crop residues at or near the soil surface have several attractive features, including less on-farm fuel use and its associated carbon dioxide emissions (Follett, 2001), more available soil water, and reduced soil erosion. However, adoption of conservation tillage practices may result in some N moving from the soil-plant systems into the environment under certain conditions.

There is no question that conservation tillage is effective in decreasing particulate N losses associated with soil erosion and surface water runoff as discussed above. However, effects of conservation tillage on leachable N are not so well delineated as are surface losses. Generally, conservation tillage provides a wetter, cooler, more acidic, less oxidative soil environment. Under such conditions, processes of ammonification and denitrification may be favored over nitrification. Conversely, for NO_3^- that is already present, the leaching potential may be greater under conservation tillage. This is because more undisturbed soil-macropores exist for NO_3^- and water movement. Increased water flow, into and through the root zone, has been observed under no-till compared to conventional-tillage soils. This higher flow has been attributed to decreased water evaporation because of surface residues and increased numbers of undisturbed channels (e.g. earthworm and old roots) continuous to the soil surface. The surface mulch enhances the environment for earthworms and the lack of tillage preserves existing channels for several years.

6.2.4. Rotations, cover crops, and nitrogen-scavenging crops

Rotations and cover crops, historically used as a means of conserving soil and/or providing an organic N source, have received renewed interest as an aid in avoiding excessive N losses to the environment. Whereas monocultures of grain crops (e.g. corn and wheat) require high inputs of fertilizer N, such inputs can be decreased with crop rotations which require less, or fix atmospheric N. Because less excess profile N may be expected with a rotation, there should be less potential for N leaching. An exception may be under certain rotation-fallow conditions designed to conserve water in drier areas.

Winter cover crops can be effective in absorbing both NO_3^- and available water during the fall, winter, and spring, thereby decreasing the N leaching potential. When the cover crop is returned to the soil, some of the absorbed N is then available to the following crop. Both legumes and non-legumes are used from a strictly N leaching standpoint. While an annual crop such as rye can be effective in scavenging excess available N from within crop rooting zones, deep-rooted perennials should be considered for NO_3^- accumulation below normal rooting depths. Alfalfa, with a potential rooting depth in excess of fifteen feet, is a crop which merits particular attention.

6.2.5. Filter strips

Vegetative filter strips, also referred to as buffer strips and riparian zones, remove sediment, organic matter, and other pollutants from runoff and waste waters. Under field conditions, excess runoff from terraces is frequently diverted to a strip. Upon entering the strip, both the flow velocity and transport capacity of the runoff are reduced. The sediment and its associated pollutants are then removed from the runoff by filtration, deposition, infiltration sorption, decomposition, and volatilization processes. The effectiveness of filter strips in removing sediment and particulate N is well established. Less certain is the effectiveness of filter strips for removing soluble N in runoff. Uptake by filter strip vegetation of mineral N transported by runoff water may occur during times of active growth but less during other times of the year. Also, some denitrification may be occurring. Scavenging of N from underground water and the vertical horizon by riparian vegetation, especially by deeper rooted plants, also may be important for removing dissolved N in surface and subsurface flows before the N is transported into streams and lakes.

7. SUMMARY

Nitrogen (N) is ubiquitous in the environment. It is also one of the most important nutrients and is central to the growth of all crops and other plants. However, N also forms some of the most mobile compounds in the soil-plant-atmosphere system; and there is mounting concern about agriculture's role in N delivery into the environment. Nitrogen represents the mineral fertilizer most applied to agricultural land. This is because available soil-N supplies are often inadequate for optimum crop production. This manuscript reviews the fate and transport of N from the various sources used to supply the N-requirements of crops in the context of the N cycle. Use of N budgets or a mass balance approach is needed to understand the options for improving management of N in farming and livestock systems and for mitigating the environmental impacts of N. Fertilizing crops for crop N uptake that will be near the point of maximum yield generally is an economically and environmentally acceptable practice. The objective is to lower the rate and duration of the loss processes themselves. Practices and concepts that lessen the opportunity for loss processes to occur and that help decrease the amount of N that may be lost to the environment are considered. In some cases improved efficiency is achieved by using less nutrients and in other cases it can be achieved by increasing the yield while using the same amount of N-input. In either case, the goal is to decrease the total residual mass of N in the soil. Another approach is to keep the residual N in the soil-crop system by curtailing the transport processes (leaching, runoff, erosion, and gaseous losses) that carry pollutants out of the soil crop.

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No-till Wheat Grain Yields And Nitrate Leaching Losses Related to Early Season Fertilizer N Application Rates and Timings.

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ABSTRACT

Early season fertilizer N, including a December N application, is applied in the Virginia Coastal Plain region to promote fall tiller development and increase yields in no-till wheat (*Triticum aestivum*). Elevated early season N applications can impact economic optimum and potential nitrate leaching losses. Our objectives were to: 1) measure yield and NO_3 leaching losses under selected N management strategies, and 2) determine economic optimum pre-plant, and December or Zadok's growth stage (GS) 25 N application rates and timings in no-till winter wheat planted in Virginia Coastal Plain soils. Research was conducted at 4 farm field sites following corn grain production in the Virginia Coastal Plain over 6 site-years during the 1998-99 and 1999-00 growing season. Nitrogen fertilizer was applied at selected pre-plant rates, and in combination with December or GS 25 N application rates, in a randomized complete block design. Total N application rates ranged from 0 to 224 kg/N ha. Economic optimum N application rates and timings were obtained from least-squares response surfaces, which estimated profit as a function of pre-plant and December or GS 25 N applications. Timely planting improved tillering, yield, NO_3 leached and economic return over both growing seasons. However, at economic optimum N rates and timings, NO_3 leaching losses in either timely or late-planted wheat, were not different than check plot NO_3 leaching losses at all but one site. December N applications improved yield and profit, and when combined with timely planting, and did not lead to excess NO_3 leaching losses under timely-planted wheat.

INTRODUCTION

A major beneficiary of the use of inorganic N fertilizers in the mid-Atlantic region is grain crop production, including no-till winter wheat production. Nitrogen inputs to the mid-Atlantic region in the early 1990's were estimated at 500 million kg/yr from manure (Puckett, 1995) and 422 million kg/yr from inorganic fertilizers (Battaglin and Goolsby, 1994). Leaching of NO_3 to ground water has become an increasing environmental concern related to the use of agricultural fertilizers and application of animal wastes.

Increasing N applications at pre-plant, in December and at Zadoks growth stage (GS) 25 (Zadoks et al., 1974) to promote tiller development and improve wheat yields, is an increasingly common practice in the Coastal Plain region of Virginia. Scharf and Alley (1993) found that N applications at Zadoks GS 25 improved tiller development at GS 30 and grain yield if tiller densities at GS 25 were less than 1000 tillers/m^2, in the mid-Atlantic region. Timing of early season N was also important in a Canadian study by Johnston and Fowler (1991), which found delaying spring fertilizer N by 3 weeks

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severely limited grain yield in winter wheat because it failed to correct early season N deficiencies until after yield potential was established.

However, precipitation exceeds evapotranspiration during the winter months in the Coastal Plain region, leading to an increased risk of N loss through leaching in the sandy textured soils. Chichester (1977) found that the highest levels of NO_3-N flux in soil percolate occurs in winter months when evapotranspiration has reached a minimum due to cessation of crop growth and percolation rates are at a maximum. Francis (1992), and Ottman and Pope (2000), found that increasing N fertilizer use efficiencies through various application rates and timings could reduce NO_3 leaching

The objectives of this research were to measure yield and NO_3 leaching losses, and determine economic optimum pre-plant, December and GS 25 N application rates and timings in no-till winter wheat for the Virginia Coastal Plain.

MATERIALS AND METHODS

Sites

Six N fertilization rate and timing experiments were conducted during the 1998-99 and 1999-00 growing seasons in no-till winter wheat on the Coastal Plain region of Virginia. Experiments were conducted on uniform soil types typical of Eastern Coastal Plain soils in grain crop production. Soils represented included: Suffolk and Kempsville sandy loam (fine-loamy, siliceous, thermic Typic Hapludults), Eunola sandy loam (fine-loamy, siliceous, thermic Aquic Hapludults), and Bojac loamy sand (fine-loamy, siliceous, thermic, Typic Hapludults). Seeding rate was 553 seed/m^2 on all soils except the Bojac loamy sand, which had a seeding rate of 516 seeds/m^2. All experimental sites were planted into corn stubble and had been in continuous no-till production for at least 2 seasons. Planting dates ranged from October 14 to November 6.

Experimental design

The experiment was a complete factorial design with 4 levels of pre-plant N applications and 4 levels of Zadoks growth stage (GS) 25 N applications at sites I and II (Table 1). Sites V and VI were complete factorial designs with 3 levels of pre-plant N applications and 4 levels of December N applications. Sites III and IV consisted of 4 combinations of equal pre-plant and GS 25 N applications. Treatments were arranged in a randomized complete block design with four replications at each site. Individual plots measured 5 by 5.5-m with 2.1-m alleyways between each replication. Ceramic suction lysimeters were placed in selected treatments to sample soil solute NO_3-N concentrations during the growing season.

Table 1. Nitrogen rate and timing treatments by site for no-till winter wheat planted in Virginia Coastal Plain soils.

Sites I and II†			Sites III and IV†			Sites V and VI‡		
Trt.	Pre-Plant	GS 25	Trt.	Pre-Plant	GS 25	Trt.	Pre-Plant	December
	-----kg/N ha-----			-----kg/N ha-----			-----kg/N ha-----	
1¶	0	0	1¶	0	0	1¶	0	0
2	0	22	2¶	22	22	2	0	22
3	0	45	3¶	45	45	3¶	0	45
4	0	67	4¶	67	67	4¶	0	67
5	22	0	5§¶	0	0	5¶	34	0
6¶	22	22				6	34	22
7	22	45				7¶	34	45
8	22	67				8¶	34	67
9	45	0				9¶	67	0
10	45	22				10	67	22
11¶	45	45				11¶	67	45
12	45	67				12¶	67	67
13	67	0						
14	67	22						
15	67	45						
16¶	67	67						
17§¶	0	0						

† Uniform application of 34 kg/N ha applied at GS 30 to all treatments
‡ Uniform application of 45 kg/N ha applied at GS 25 and GS 30 to all treatments
§ Check plot, no N applications
¶ Ceramic suction lysimeters installed at 1.2-m

Urea ammonium nitrate (30% N) was used as the N source for all treatment N applications. The N solution was applied with a carbon dioxide pressurized backpack sprayer. The sprayer boom was fitted with Teejet 'raindrop' tips. Flow rates for each tip size were measured at each experimental location prior to N application. Proper walking speed to obtain the desired application rate was calculated, and a stopwatch and metronome were used to calibrate and maintain the proper walking speed during N application.

Soil Sampling, Analysis and Tiller Counts

Soil samples were taken in early October to characterize soil texture and measure residual soil mineral N. Mass soil mineral N (NH_4^+ and NO_3^-) concentrations (kg/ha) were estimated from soil samples taken at depths of 0- to 0.15-, 0.15- to 0.30-, 0.30- to 0.61-, 0.61- to 0.91-, and 0.91- to 1.20-m. Soil samples were extracted in duplicate with 2 M KCl and filtered prior to analysis (Keeney and Nelson, 1982). Nitrate and NH_4^+ were determined colorimetrically on a Lachat Instruments Automated Analyzer using QuikChem Methods 12-107-04-1-B and 12-107-06-2-A, respectively (Lachat Instruments, Milwaukee, WI).

Tillers per 0.91 meters of row were counted at GS 25 for each of the treatments to determine tiller response to fall N application rates. Eight counts were conducted at each site with locations for each measurement selected randomly within the site boundaries.

Soil Water Monitoring

Soil water was monitored using time domain reflectometry (TDR) moisture probes (ESI, Vancouver, B.C.), installed at each site in early November. The probes were installed into plots receiving 45 kg N/ha at pre-plant and at GS 25, with the uniform application of 34 kg N/ha at GS 30 at sites I through IV. At sites V and VI, moisture probes were installed in plots receiving 34 kg N/ha at pre-plant and 45 kg N/ha in December with the uniform application of 45 kg N/ha at GS 25 and GS 30. Volumetric water content (%) was measured at 0- to 0.15-, 0.15- to 0.30-, 0.30- to 0.61-, 0.61- to 0.91-, and 0.91- to 1.20-m depths. Measurements were taken periodically after precipitation events and prior to each soil water sampling between November and May of each growing season.

Soil Water Sampling

Ceramic suction lysimeters were used to monitor NO_3-N concentrations (mg/l) in soil water, with minimal disturbance to the surrounding soil and wheat crop. One bar, high flow, ceramic suction lysimeters (Soil Moisture Equipment Corporation, Santa Barbara, CA) were installed at 1.2-m depths between wheat rows in November in selected treatments and check plots. Lysimeter installation and sampling followed the procedures outlined by Linden (1977) and Wu et al. (1995). Soil water sampling began when TDR moisture probe measurements indicated soil water had reached field capacity to a depth of 1.2-m. Field capacity was defined as the water content at which internal drainage ceased. Soil water was sampled 48 to 72 hours following precipitation events using a vacuum pump (12-volt, 1 Bar maximum) attached to a battery. Solid stoppers were removed from the tops of the 5-cm diameter lysimeters at the time of sampling. Lysimeters were evacuated of any residual moisture and rubber stoppers, fitted with tubing and a clamp, were attached to the lysimeters and vacuum applied. The tubing was clamped and the lysimeters were allowed to remain with the applied vacuum for approximately 1.5 hours before the water sample was removed by siphon. Soil water samples were immediately chilled. Nitrate and NH_4^+ were determined colorimetrically on a Lachat Instruments Automated Analyzer using QuikChem Methods 12-107-04-1-B and 12-107-06-2-A, respectively (Lachat Instruments, Milwaukee, WI).

Determination of Soil Water Balance and Nitrate Leaching

Daily soil water storage and drainage were determined using the water balance equation of Martin et al. (1991):

$\Delta S = P - Et + (R + D)$ where,
ΔS = Change in soil water storage (1.2m),
P = Precipitation,
Et = Evapotranspiration,
R = Surface Run-off,
D = Drainage.

No-till field sites were level, and precipitation events did not exceed soil infiltration rates, which ranged from 5 to 15 cm/hr (National Cooperative Soil Survey, 1982); therefore, surface run-off was assumed to be zero. Precipitation (mm) was measured by on-site weather stations (Spectrum Technology Weather Monitor II^{tm}). Evapotranspiration was calculated using potential pan evaporation measured in the Virginia Coastal plain, 161 kilometers south of the experimental sites. Potential pan evaporation field measurements were not taken from November through February of each growing season due to errors associated with freezing and thawing. Therefore, for this time period, potential pan evaporation was calculated using a modified Penman-Montieth equation (Allen et. al., 1998). Actual evapotranspiration (ET_a) was calculated using the method of Allen et al. (1998):

$ET_a = Et_o * K_c$ where;
ET_a = actual evapotranspiration,
ET_o = potential evapotranspiration,
K_c = crop coefficient.

Crop coefficient estimates were based on the FAO guideline (Allen et al., 1998). Values of K_c used for timely-planted wheat over each season were: 0.8 from October through February, 1.0 for March through May, and 0.25 in June. Values of K_c used for late-planted wheat over each season were: 0.7 from October through February, 0.8 in March, 1.0 in April and May, and 0.25 in June. Slightly higher crop coefficients were used for timely-planted wheat due to the greater biomass observed in timely-planted fields. Using the calculated ET_a, daily water balance was solved by adjusting available water content with inputs from rainfall and losses from ET_a.

Time series water content at each site was interpolated to a daily basis based on the procedures described by Schwab et al. (1993) and utilized by Sadler et al. (2000). Calculated daily soil water storage was verified using TDR moisture probe field measurements taken throughout the growing season. When predicted daily water content exceeded field capacity at the 1.2 m depth, the excess was considered drainage.

Nitrate leaching estimates were determined according to the procedure of Hook and Kardos (1978) and Hook and Burton (1979), who utilized porous cup sampling along with water balance to estimate NO_3 leaching below 1.2 m on municipal sewage application sites. Soil water NO_3-N concentrations were interpolated to a daily basis through the growing season (Schwab et al., 1993). Nitrate N leached was calculated from the drainage volume and NO_3 concentration for each lysimeter and summed for the growing season. The resulting data were analyzed using SAS ANOVA procedure (SAS Institute, 1999). Treatment mean separation was determined using Duncans multiple range test.

Grain Yields

Wheat grain was harvested in a 1.5 m wide area of each plot with a plot combine. Grain yields were adjusted to 13.5% moisture content. Profit was estimated for each plot as wheat value (yield x price) – N fertilizer cost (N rate x N price) – other fixed production costs. For the 1998-99 season, N fertilizer cost estimates were \$0.53/kg, wheat grain was \$0.077/kg, and fixed costs were estimated at \$313/ha (Virginia Cooperative Extension, 1998). For the 1999-00 season, N fertilizer cost estimates were \$0.44/kg, wheat grain was \$0.074/kg, and fixed costs were estimated at \$313/ha (Virginia Cooperative Extension, 1998). These costs and returns reflect actual conditions for each growing season. The least-squares quadratic response surface was calculated for estimated profit and yield as a function of N rate for sites V and VI (SAS Inst., 1999).

RESULTS AND DISCUSSION

Planting Date, Tillering and Grain Yield

Planting date affected tiller densities at GS 25 and grain yield. The recommended planting date for the Virginia Coastal Plain is between October 15th and 30th, to optimize conditions for emergence and fall tiller development (Alley et al., 1993). Yields for no-till wheat planted timely were higher for almost all treatments except check plots, when compared to late-planted wheat (Figures 1 and 2). Studies have reported late planting increases wheat's susceptibility to winter injury due to poorly developed root systems and may result in yield reduction (Pittman and Andrews, 1961; Knapp and Knapp, 1978; Rocheford et al., 1988; Winter and Musick, 1993).

Treatments receiving no pre-plant N and increasing N rates at GS 25 or December N (Figures 1A and 2), exhibited an increasing yield response. The response to these N applications was greater for timely-planted wheat. In Louisiana, Shah et al. (1994) reported additional spring N increased grain yield of early-planted wheat, but was not beneficial for late-planted wheat.

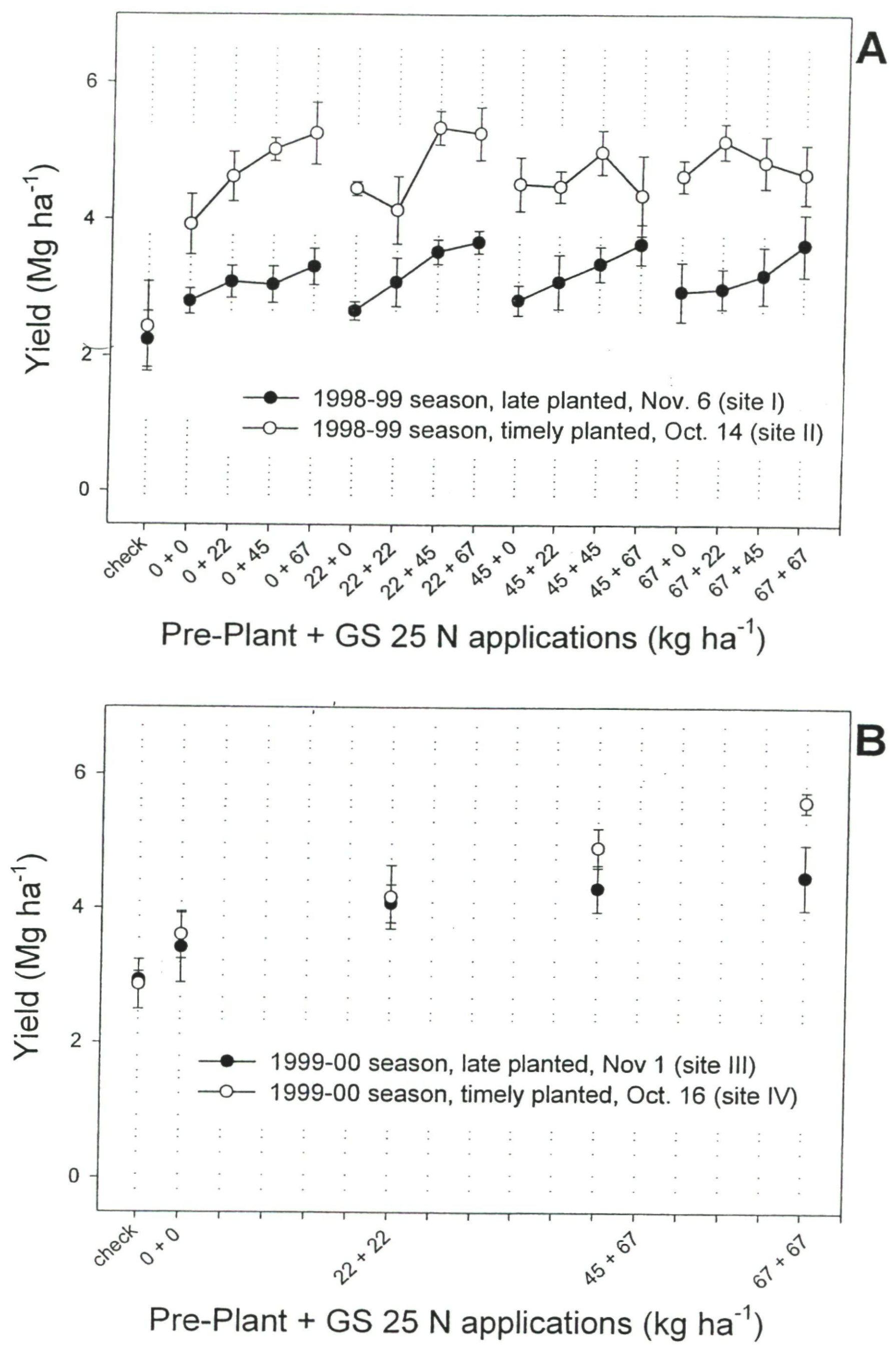

Figure 1. Pre-plant plus GS 25 N rate and timing effect on yield with standard deviations for timely and late-planted no-till wheat in the Virginia Coastal Plain during the A) 1998-99 and B) 1999-00 growing season.

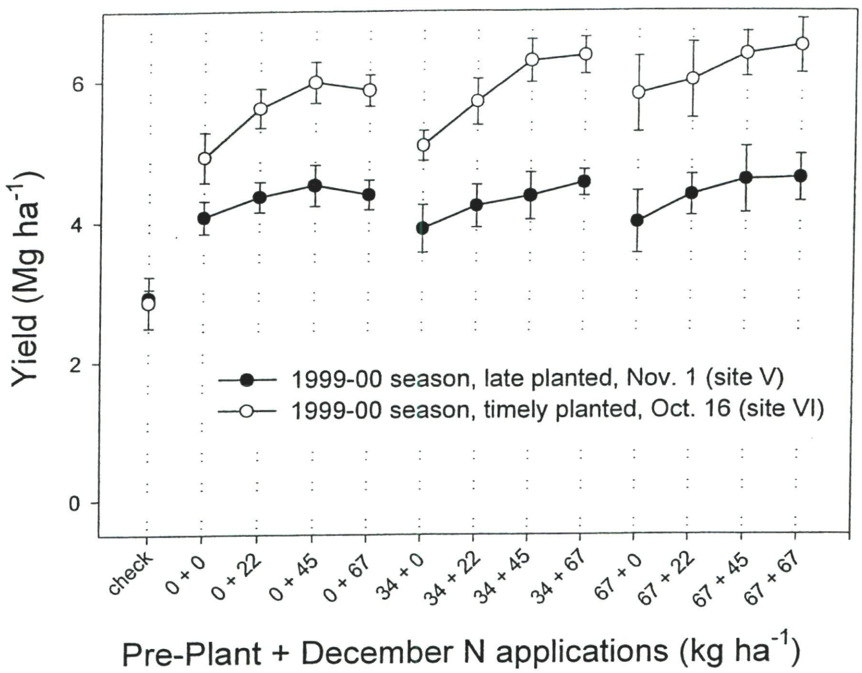

Figure 2. Pre-plant plus December N rate and timing effect on yield with standard deviations for timely and late-planted no-till wheat in the Virginia Coastal Plain during the 1999-00 growing season.

Nitrogen applications only at pre-plant (0, 22, 34, 45 and 67 kg N/ha) did not affect yield for either timely or late-planted wheat (Figures 1A and 2). The exception was the timely-planted wheat during the 1999-00 season (site VI), where N application of 67 kg N/ha only at pre-plant produced higher yields than other pre-plant-only N application rates (Figure 2).

Planting date also affected tiller densities at GS 25 (Figures 3 and 4). Sites II, IV, and VI were planted within the recommended planting period and had an average 695 tillers/m^2, compared to sites I, III and V, which were planted after the recommended planting period and had an average 444 tillers/m^2 at GS 25.

Tiller densities across treatments were variable, possibly due to heavy residue that caused inconsistencies in planting, stand development, and errors counting tillers. Yields quadratically regressed against tiller densities at GS 25 produced low regression coefficients ($0.10 < r^2 < 0.47$), possibly due to a combination of variability in tiller density and compensatory growth after GS 25. Scharf et al. (1993) reported that GS 25 N applications did stimulate formation of additional tillers and increased yield if GS 25 tiller densities were below 1000 m^2.

Timely-planted check plots (no N applications), had higher tiller densities (665 tillers/m^2) compared to late-planted wheat check plots (399 tillers/m^2). However, yield for check plots was not different between timely (2718 kg/ha) and late (2697 kg/ha) planted wheat (Figure 1), indicating insufficient spring N was more influential to yield than planting date in check plots. Furthermore, treatments receiving only GS 25 and/or GS 30 N applications had higher yields than check plots. This yield response indicates early spring N applications alone maintained tillers and contributed to grain production.

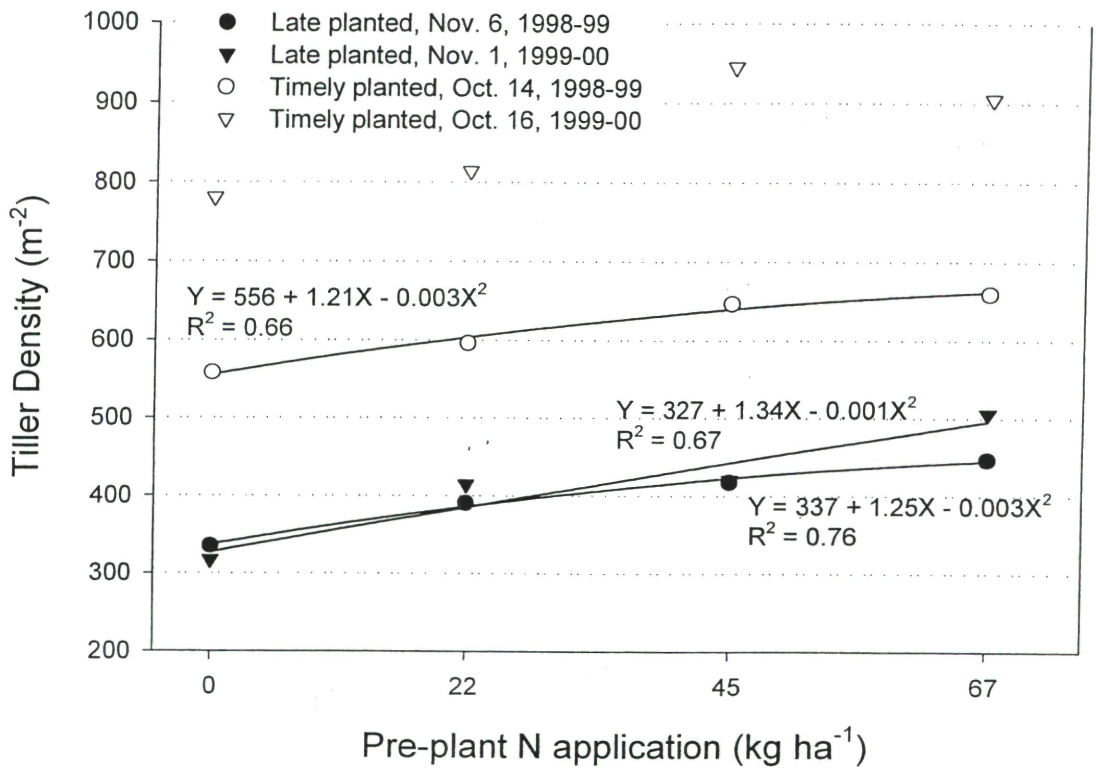

Figure 3. Tiller densities at GS 25 for various pre-plant N application rates in timely and late-planted no-till winter wheat over 1998-99 and 1999-00 growing seasons. Regression analysis performed using all treatment replications. Points shown are treatment averages. Treatments with no regression line are not significantly different.

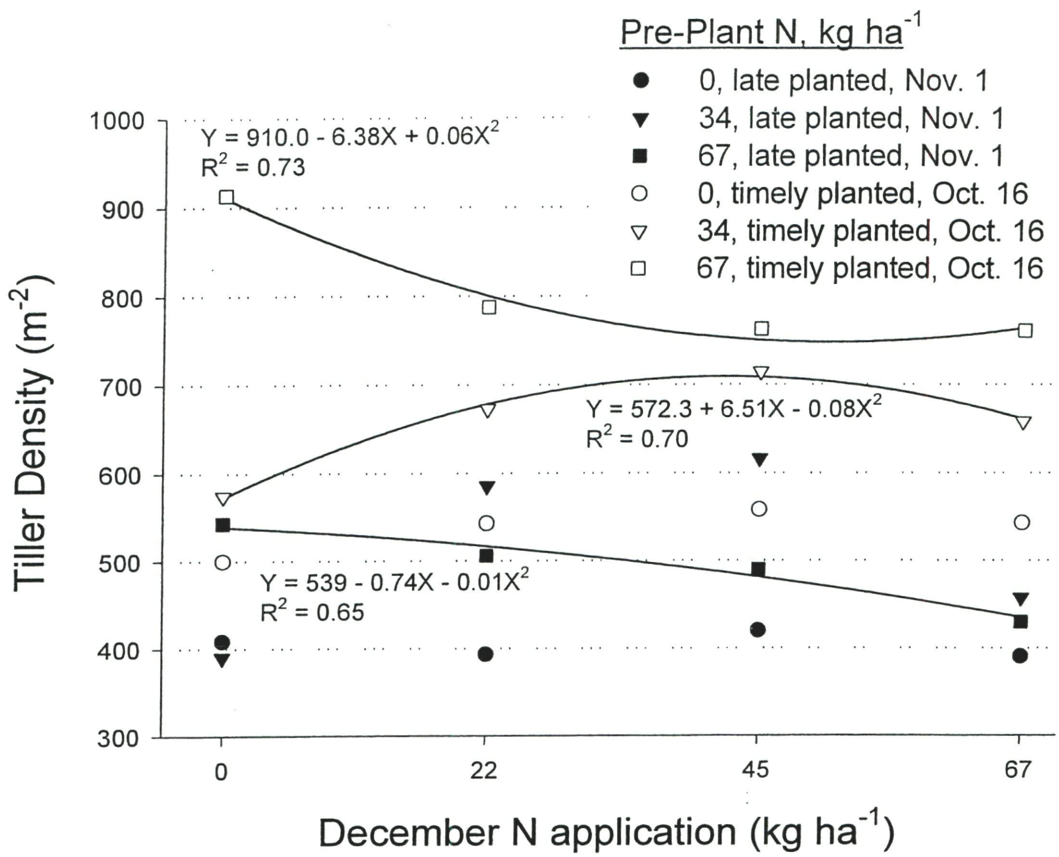

Figure 4. Tiller densities at GS 25 for various pre-plant and December N application rates in timely and late-planted no-till winter wheat for the 1999-00 growing season. Regression analysis performed using all treatment replications. Points shown are treatment averages. Treatments with no regression line are not significantly different.

Soil Water

Between November and June, the precipitation was 559 mm and 660 mm during the 1998-99 and 1999-00 seasons, respectively, which was comparable to the 30-year average of 608 mm for the same time period (National Weather Service, 2001). The precipitation was well distributed throughout both growing seasons (Figure 5). However, soil profiles were dry during the beginning of the seasons due to late summer droughts, and soil water content did not reach field capacity to a depth of 1.2 meters until late December. Field capacity from 0 to 1.2m ranged from 298 to 377-mm for the various soils.

Soil water holding capacity based on laboratory measurements was calculated to a depth of 1.2 meters and compared with the average TDR measurements for each soil type. The calculated soil water values followed TDR field measurements, indicating valid estimates of drainage at 1.2-m were obtained. Actual soil water measurements were higher than

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Research objectives

Conduct experiments in forage-grazing and crop production systems for the development of sustainable agricultural systems as part of an interdisciplinary team. Specific components of this research are part of the CRIS Project:

"Enhancing soil–water–nutrient processes in Southern Piedmont pasture and crop systems"