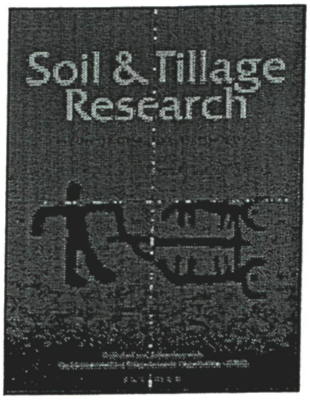
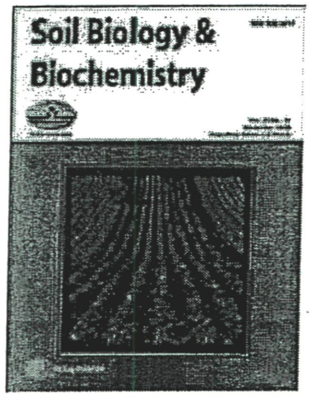
Editorial responsibilities

[STILL]



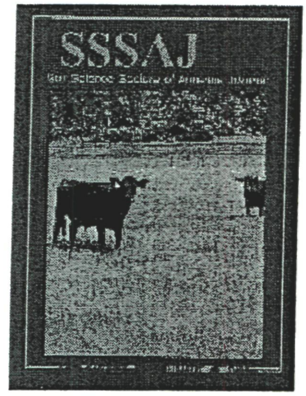
Joint Editor-in-Chief of *Soil & Tillage Research*

[SBB]



Subject Editor for *Biology & Biochemistry*

[SSSAJ]



Associate Editor for Biology & Biochemistry division of *Soil Science Society of America Journal*

Active projects

G Salem Road grazing study [Salem Road]

G Dawson Field grazing study [Dawson Field]

G Pasture–crop rotation study [Rotation]

Research areas

G I. Recommendations for N fertilizer

G II. Distribution and ecological role of various soil organic matter fractions

G III. Soil microbial biomass

G IV. Soil C sequestration

G V. Standardized protocols for assessing soil biological properties

G VI. Soil responses to conservation tillage

G VII. Soil responses to pasture management

G VIII. Soil biological activity influenced by environmental factors

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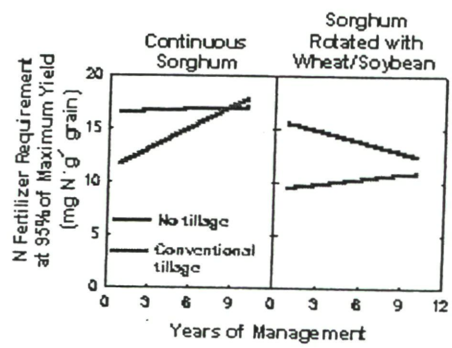
Research Area I:

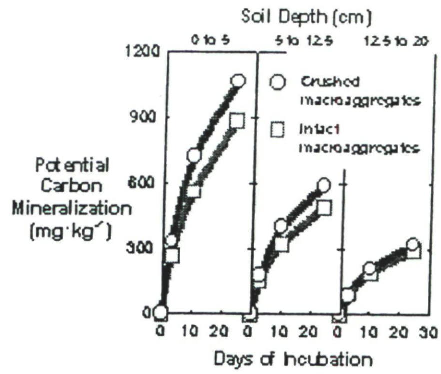
Nitrogen fertilizer is one of the most expensive monetary and energy inputs in the production of cereal grains. *Recommendations for N fertilizer* in most states are based on data from conventional cropping systems, which include monoculture and clean tillage. N fertilizer recommendations are needed for corn and sorghum in rotation with soybean and forage legumes and for sorghum during transition to no tillage. A simple biological tool to quantitatively estimate N mineralization from soil organic matter is needed.



[Publications I]

Research Area II:

Detailed characterization of the *distribution and ecological role of various soil organic matter (SOM) fractions* has allowed soil scientists to move beyond mere conceptual ideology of agricultural sustainability towards practical evaluation of management impacts on important long-term soil functioning. A better definition and understanding of the role of various physically and chemically defined pools of soil organic matter on nutrient cycling and soil structural development under different climatic conditions is needed. Biological and physical fractions of SOM (i.e., potential C mineralization, microbial biomass, particulate organic matter, and macroaggregate-protected organic matter) could be used during the first few years of a change in management as sensitive indicators to predict decade-long changes in total SOM.

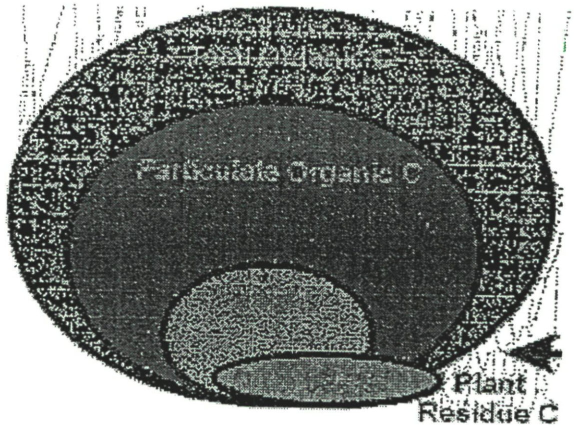


Organic matter is not evenly distributed in soil. Soil organic matter in aggregates can be protected from decomposition until the soil is disturbed.

[Publications II]

Research Area III:

Soil microbial biomass is an important metabolic component of soil organic matter dynamics. However, reliable measurement of microbial biomass has been debated, because of methodological limitations under certain environmental conditions. The original chloroform fumigation-incubation method can be modified to produce reliable estimates of microbial biomass under diverse environmental conditions when dried soil is preincubated as a standard protocol and no control is subtracted.



Soil microbial biomass C (SMBC) is the living pool of organic matter in soil.

[Publications III]

Research Area IV:

Soil C sequestration has the potential to partially mitigate rising atmospheric CO_2 concentration, which contributes to the greenhouse effect on global warming. Land management systems that increase soil C storage have been identified. Development of effective strategies to increase soil C sequestration potential, include (1) reducing soil disturbance to avoid stimulation of decomposition and reduce erosion, (2) increasing length of time during the year that a crop extracts moisture and fixes C, and (3) returning as much plant residue C back to the soil. Although total organic C has been shown to increase dramatically with adoption of conservation tillage in temperate-moist climates, research has shown that only small changes in total organic C will occur under extremes of cold-dry and warm-moist climates due to changes in

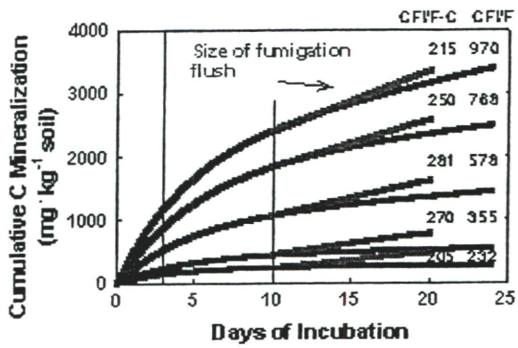

Storage of C in soil can not only improve soil fertility, but also effectively reduce the concentration of CO_2 in the atmosphere.

microclimatic conditions of surface soil. Further, latest research findings have shown the previously unrecognized benefits of animal grazing systems on potential soil C sequestration.

[Publications IV]

Research Area V:

Standardized protocols for assessing soil biological properties have been previously suggested using field-moist soil for immediate analysis. However, assessing spatial variability with a large number of samples would be better served using dried soil so that storage conditions do not alter biological properties. The effects of drying, sieving, water content during incubation, and length of preincubation on microbial biomass and potential C and N mineralization have been described in a range of soils varying in texture and organic matter.



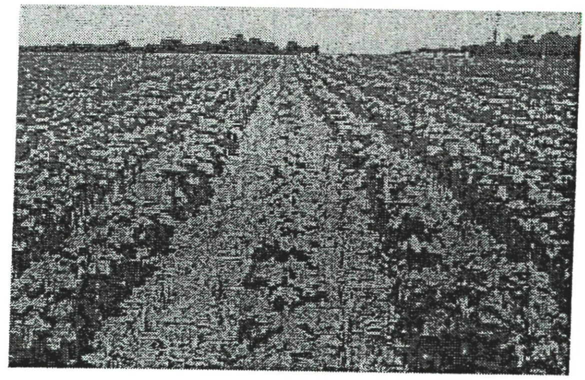
The flush of CO_2 following rewetting of dried soil is consistent with longer term potential C and N mineralization and reflects the contribution of soil microbial biomass C.

[Publications V]

Research Area VI:

Soil responses to conservation tillage are not equal across climatic regions, because temperature and moisture determine plant biomass production and its decomposition by soil organisms. Tillage-induced changes in soil organic matter and soil structure in different ecological zones have been attributed to differences in climate, the effect of which was previously unexplained.

[Publications VI]

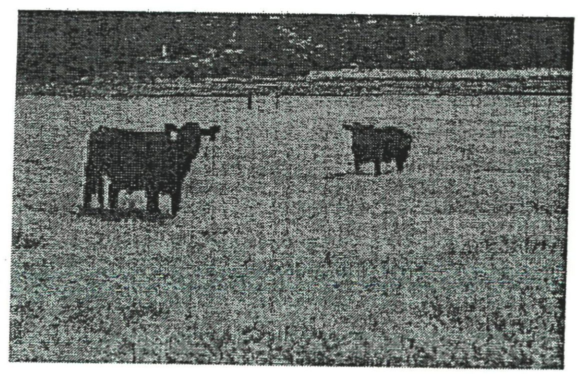


Conservation tillage feeds the soil surface with plant residues throughout the year, more similar to that which occurs in natural systems.

Research Area VII:

Previously, pasture management research in the eastern USA focused on plant and animal responses. *Soil responses to pasture management* (i.e., total and biologically active soil C and N, aggregation, and porosity) are being described as a function of grazing pressure, type of harvest management, level of fertilization, type of grass species, and stand age of grass.

[Publications VII]

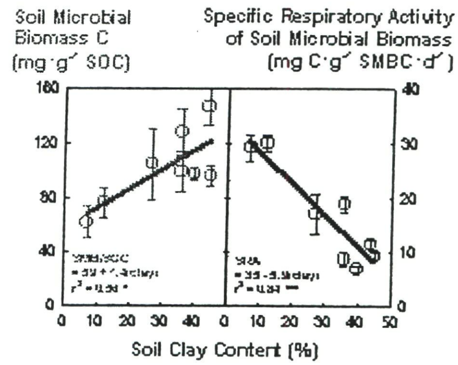


Cattle production on pastures can increase soil organic matter, because of the return of undigested plant material via feces to soil.

Research Area VIII

Soil biological activity is influenced by environmental factors, including substrate source, microbial community, physical soil conditions, and gross climatic conditions. Soil microbial activity was closely tied to soil microbial biomass, but both were shown to be greatly affected by gross climatic differences. The portion of soil organic matter as microbial biomass is greater in warmer climates than in colder climates.

[Publications VIII]



Size of soil separates (i.e., whether sand, silt, or clay) can affect soil microbial biomass and activity by altering soil moisture regime, competition for substrates, and physical exclusion of predators.

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calculated values during mid-March because field measurements were taken less than 24 hours after several large precipitation events when the soil was saturated and thus above field capacity (Figure 5).

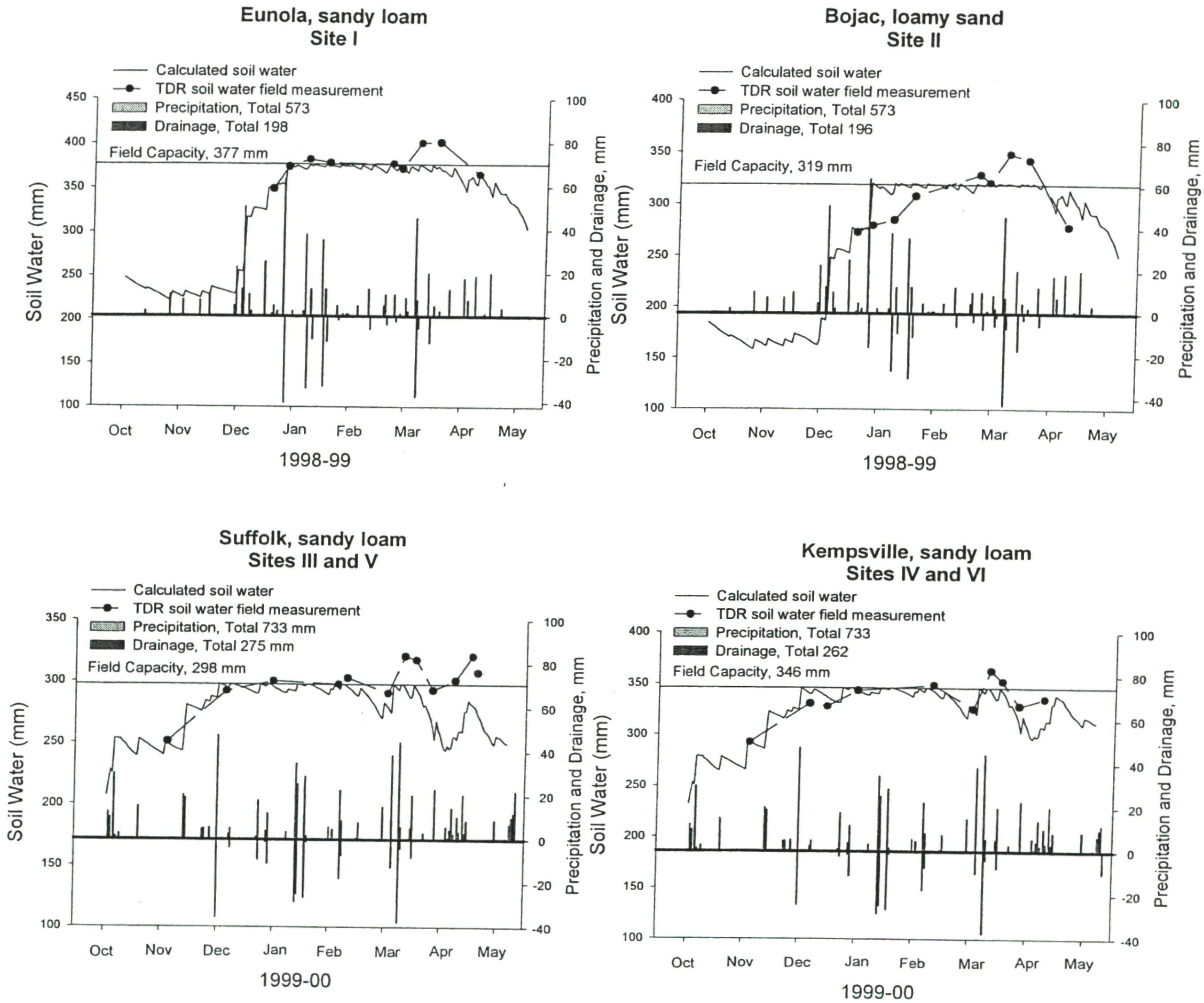


Figure 5. Actual and calculated soil moisture at 1.2-m, precipitation and drainage for each of 4 soil types during the 1998-99 and 1999-00 growing seasons.

Drainage, calculated using the equation of Martin et al. (1991), occurred between November and April at all sites over both seasons, and total drainage ranged from 196 to 275 mm. Lord and Mitchell (1998) reported over-winter drainage to 0.9 m from winter wheat on sandy loam and loamy sand soils between 242 and 296 mm during average seasons in England. Precipitation was not reported. Jaakkola (1984) reported seasonal drainage rates of 225 mm to a depth of 1.7-m from precipitation rates of 630 mm under winter wheat in a clay soil. These studies indicate current field drainage calculations for winter wheat in Virginia Coastal Plain soils appear to be reasonable estimates.

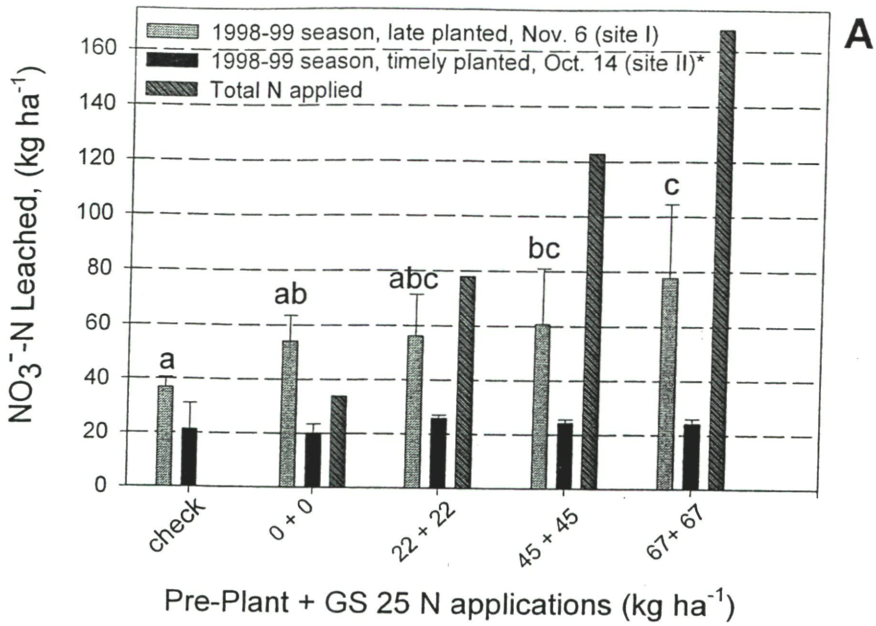
Nitrate Leaching

Nitrate leached at 1.2 meters was lower under timely-planted wheat at all sites over both the 1998-99 and 1999-00 growing seasons (Figures 6 and 7). Nitrate leached under check plots was similar between timely and late-planted wheat at sites III through VI, during the 1999-00 growing season. This is reasonable considering residual soil N was similar between all sites (24 ± 4 kg N/ha). There was a difference between nitrate leached from check plots at sites I and II (Figure 6A) despite similar total residual soil N to 1.2-m, possibly due to higher yields from the previous corn crop (8040 kg/ha at site I, compared to 5375 kg/ha at site II) leading to greater surface residue subjected to mineralization during the growing season. However, NO_3 leached under late-planted treatments at site I were still higher than the check plot, while NO_3 leached under timely-planted wheat treatments at site II were not different than check plots.

There were no effects of fertilization rate or timing on NO_3 leaching compared to background levels in check plots for the timely-planted sites II and VI, with NO_3 leaching amounts ranging from 20 to 37 kg/ha over a growing season (Figure 6 and 7). However, NO_3 leached under pre-plant and GS 25 N application of 22 and 22 kg/ha at timely-planted site IV were lower than other treatments, possibly due to an error in N application.

Nitrogen fertilization rate and timing affected NO_3 leached at all late-planted sites when compared to background levels measured from check plots. Pre-plant and GS 25 N application rates of 67 and 67 kg N/ha at site I produced NO_3 leaching amounts of 78 kg N/ha over the 1998-99 growing season. The same treatment at site III produced similar NO_3 leaching amounts of 83 kg/ha over the 1999-00 growing season. Comparatively, the NO_3 leached for the same treatment under timely-planted wheat was 24 and 29 kg/ha, respectively, for the 1998-99 and 1999-00 seasons (sites II and IV).

The highest NO_3 leaching rates in late-planted no-till wheat occurred under pre-plant and GS 25 N management strategies of 22 and 22, 45 and 45 or 67 and 67 kg N/ha respectively, during both the 1998-99 and 1999-00 growing seasons. Pre-plant and December N management produced the highest NO_3 leaching at the higher N application rates of 67 and 45 kg N/ha, and 67 and 67 kg N/ha, respectively. Applying 0 and 67 kg N/ha at pre-plant and December, respectively, also produced higher NO_3 leaching rates. This result is probably a product of the timing of the N application. In the mid-Atlantic region, the highest risk of leaching NO_3 below the wheat root zone occurs between December and March, when mean monthly precipitation exceeds potential evapotranspiration (Smith and Cassel, 1991; Staver and Brinsfield, 1998). Therefore, December N applications are more vulnerable to leaching loss, especially in late-planted wheat.



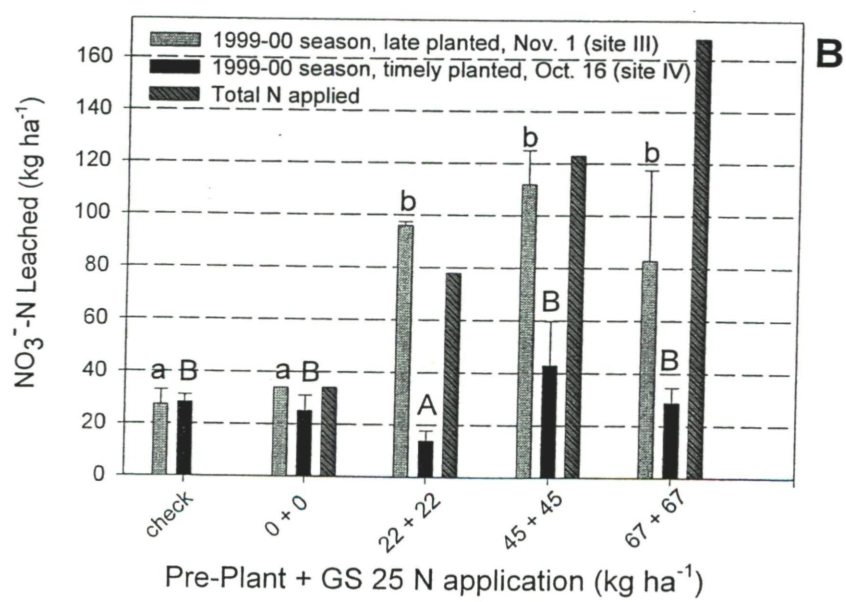


Figure 6. Nitrate leached between December and May at 1.2-m under various pre-plant and GS 25 N applications rates in no-till wheat during the A) 1998-99 and B) 1999-00 growing season. Treatments within the same site, marked by different letters, differ significantly at P = 0.05 by Duncan's multiple range test.

***NS = not significantly different at P= 0.05.**

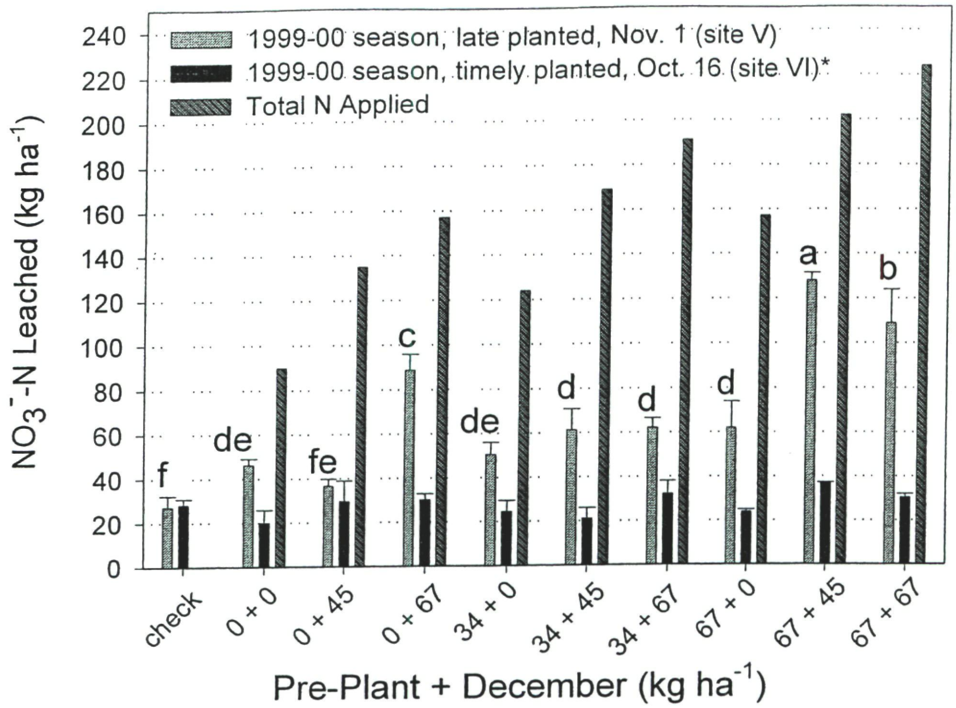


Figure 7. Nitrate leached between December and May at 1.2-m under various pre-plant and December N applications rates in no-till wheat during the 1999-00 growing season. Treatments within the same site, marked by different letters, differ significantly at P = 0.05 by Duncan's multiple range test.

***NS = not significantly different at P= 0.05.**

Lord and Mitchell (1998) reported average NO_3 leaching losses over winter from cereal grain crops planted in sandy soil of 51 kg N/ha for N fertilizer inputs of 154 kg N/ha applied in 6 steps. The use of 6 applications might lead to improved plant use efficiency and decreased NO_3 leaching loss. However, NO_3 leaching losses in Lord and Mitchell's experiment were comparable to data from the current study where N was applied in 3 or 4 steps. Jaakkola (1984) reported NO_3 leaching losses of 30 and 43 kg/ha for winter wheat on clay soil with 100 kg/ha total N fertilizer applied in 3 steps. Clay soils have higher water holding capacities and therefore may leach less NO_3 compared to sandier soils, making Jaakkola's results also comparable with the range of NO_3 leaching losses measured in the current study.

Economic Optimum N Fertilization Rates and Timings and Nitrate Leaching

Timely-planted wheat more efficiently utilizes applied N to produce higher yields, lower NO_3 leaching rates, and ultimately, higher profitability (Table 2). Variations in soil types can influence yield and NO_3 leaching, but sites selected for these studies had similar soils. Economic optimum N application rates produced an average of 1745 kg/ha higher yields under timely-planted wheat and averaged 30 $/ha in profits compared to an average of 53 $/ha loss under late-planted wheat. Economic optimum N application rates at all sites produced NO_3 leaching rates that were not significantly different than check plot NO_3 leaching rates in the same experiment, with the exception of site III. The higher NO_3 leaching rate at site III may be a product of higher soil water movement coinciding with high NO_3 concentrations in the soil water during March of the 1999-00 growing season. However, with the exception of site III, economic optimization of N fertilizer application rates and timings in timely-planted no-till wheat also decreased the risk of NO_3 leaching loss, averaging 34 kg N/ha NO_3 leaching loss (Table 2). These results are supported by Lord (1992), who estimated average NO_3 leaching losses from winter cereals in England at around 35 kg N/ha with optimum N fertilization rates.

Table 2. Economic optimum† early season N rate and timings for treatments with NO_3 leaching data.

Site	Planting	Season	Pre-plant	Dec.	GS 25	Yield	Profit (loss)	Nitrate Leached
			-------kg N/ha------			kg/ha	$/ha	kg N/ha
I§	Late	98-99	22	--	22	3090	(110)	56
II§	Timely	98-99	45	--	45	4989	12	24
III§	Late	99-00	22	--	22	4072	(50)	96‡
IV§	Timely	99-00	67	--	67	5595	29	29
V¶	Late	99-00	0	45	45	4435	(0)	36
VI¶	Timely	99-00	0	67	45	6250	50	24

† Economic optimum N rates were calculated in the 1998-99 season using: UAN = 0.53$ kg/N, grain = 0.077$/kg, variable cost = 313$/ha; and in the 1999-00 season: UAN = 0.44$˙kg/N, grain = 0.74$/kg, variable cost = 313$/ha.
‡ Significantly different from check plots ($P<0.05$).
§ 34 kg N/ha applied at GS 30.
¶ 45 kg N/ha applied at GS 30.

December N applications affected yield and profitability. December N applications, in addition to pre-plant and GS 25 and 30 N applications, produced 906 kg/ha higher yields and 55 $/ha more profit, on average, than pre-plant, GS 25 and 30 N applications only. These data indicate that the inclusion of December N applications is more profitable, and when combined with timely planting, can be managed to prevent excess NO_3 leaching losses in Virginia Coastal plain soils.

SUMMARY

Timely-planted no-till winter wheat in the Virginia Coastal Plain region consistently produced higher yields and greater profitability with minimal NO_3 leaching losses under selected N rates and timings over three growing seasons when compared to late-planted wheat. Timely planting allows for greater root development, more effectively capturing plant available N throughout the growing season and leading to higher yields. Increasing N fertilization rates at selected times did not overcome the negative effects of late planting, but instead, led to increased NO_3 leaching loss.

December N applications, in conjunction with pre-plant, GS 25 and GS 30 N applications were effective in improving yield. December N applications produced greater yield response in timely planted wheat, but showed more vulnerability to leaching in late-planted wheat. Pre-plant N applications alone did not affect yields for either timely or late-planted wheat.

Finally, economic optimum N rates and timings also produced minimal NO_3 leaching losses at all but one site. Timely planting appeared to maximize economic return while minimizing NO_3 leaching losses. Late-planted wheat requires more intensive management to prevent NO_3 leaching loss and improve profitability. However, further research is needed to more completely understand the processes and impacts of various crop management strategies on no-till wheat and NO_3 leaching in the Virginia Coastal Plain.

Acknowledgements

Funding for this study was provided by the Natural Resources Conservation Service and the Virginia Small Grains Board. Assistance with plot management and data collection was provided by J. Hammons, M. Lewis and the staff at the Eastern Virginia Agriculture Research and Extension Center.

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Agroecology News

Working to enhance the sustainability of South Carolina's cropping systems Spring, 2000

Advisory Panel Supports Agroecology Systems Research Approach

Figure 1. Agroecology panel and researchers meeting at Pee Dee REC last summer

Agroecology scientists met with members of their advisory panel last July to discuss the future of row crop production in South Carolina and to obtain suggestions for crop production research. The panel consists of leaders from many diverse areas of South Carolina agriculture, including farmers; representatives from government agencies, commodity groups and organizations, agricultural corporations, and local agribusiness enterprises; as well as specialists from universities in other southeastern states.

The consensus of the panel was that it is vital to support research programs that focus on ways to increase yields, lower input costs, conserve natural resources, and reduce the potential for agrichemical and sediment movement from crop fields. There was general agreement that these are the essential components for a sustainable agriculture in South Carolina. The drought-induced low yields and low commodity prices that our state's farmers have experienced the past several years left no doubt that research on crop productivity and profitability is needed. Improving the quality of our soils in an environmentally friendly way was given as an example of needed research geared towards conserving and improving our natural resources.

See **Advisory Panel** *on page 4*

The Agroecology team is a multi-disciplinary group working together to identify innovative combinations of ecologically friendly production practices for increasing farmer profits. We are also developing Extension and classroom teaching programs related to agroecology projects and issues. This is the fifth in a series of newsletters about our activities. For an on-line copy of our previous newsletters plus additional information about agroecology program activities, visit our website at http://agroecology.clemson.edu.

New Cropping System Yields Cleaner Water

During the 1999 corn growing season, Agroecology researchers Jeff Novak of the USDA-ARS lab in Florence, SC, and John Hayes of Clemson University, in collaboration with other Agroecology scientists, collected and analyzed runoff water from the split-landscape field at the Pee Dee REC near Florence. Their results showed that an innovative crop production system involving conservation tillage markedly reduced losses of soil, nitrogen, and phosphorus in runoff water, as compared to a traditional system in which the soil surface was disturbed by disking and cultivation.

Corn was grown in the split-landscape field in two production systems. One-half of the field contained the "Innovative" production system, with corn planted in 15" rows using conservation tillage (deep tillage with a Paratill*, but no disking or other surface disturbance of the soil). In addition, P was precision-applied to the Innovative system at rates varying from 0 to 50 lb/ac, based on the results of grid soil sampling. The other ("Traditional") half of the field was disked, and corn was planted in 30" rows with in-row subsoiling. No phosphorus was applied to this half of the field, because results from a bulk soil sample showed no P was needed.

Runoff water and sediment were collected from three plots

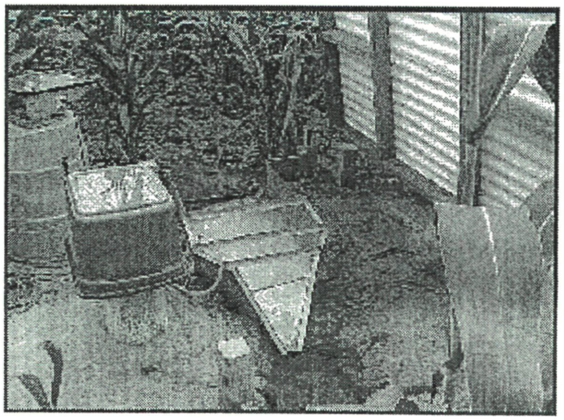

Figure 2. Flumes for collecting runoff water from plots in the split-landscape field

See **Innovative** *on page 2*

*Names are necessary to report factually on available data; however, Clemson University and the USDA neither guarantee nor warrant the standard of the product, and the use of the name by Clemson University and the USDA implies no approval of the product to the exclusion of others that may also be suitable.

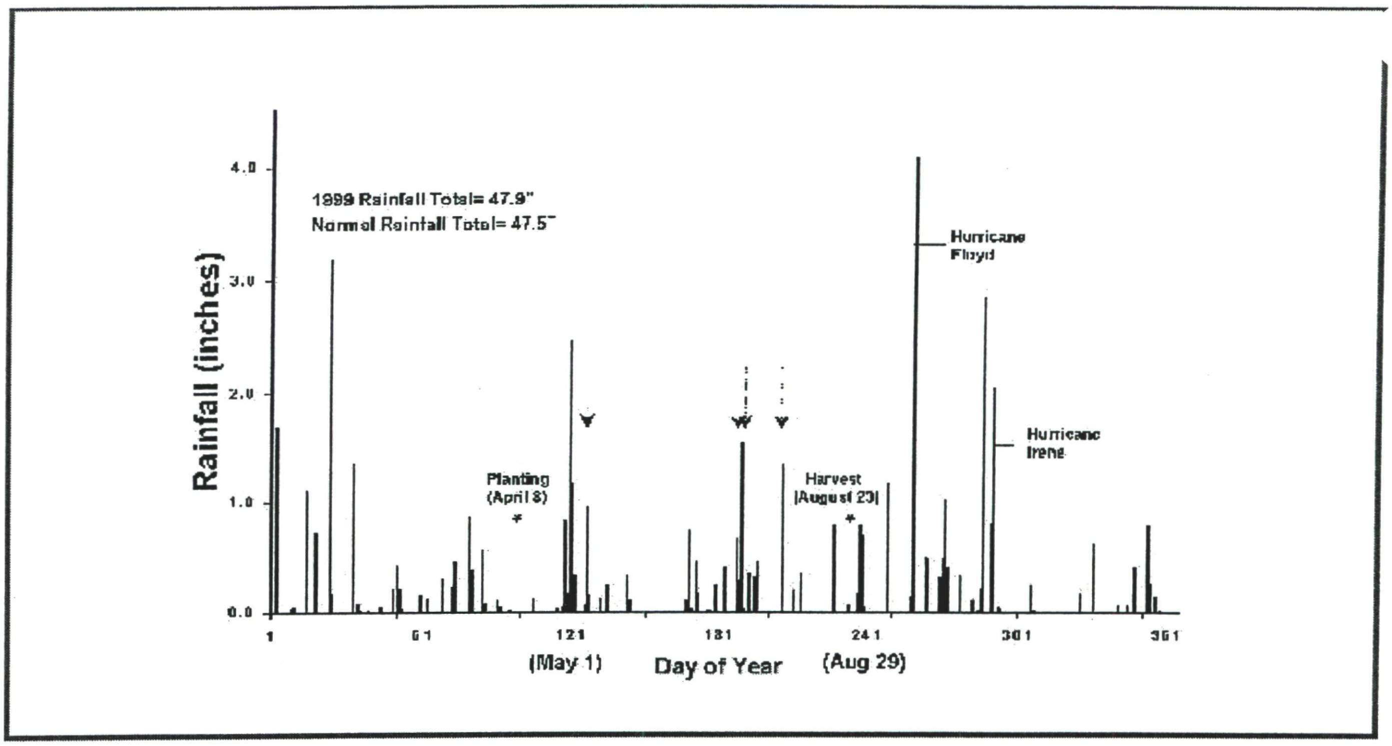

Figure 3. Rainfall for 1999 at the split-landscape field; arrows indicate the 4 rainfall events that produced measurable runoff

on each side of the split-landscape field (Fig. 2), allowing for comparison of the two crop production systems. Only four rainfall events produced measurable runoff during the growing season (Fig. 3). Rainfall intensity and soil water content were the two factors that had the greatest effect on whether runoff occurred or not. Although Hurricanes Floyd and Irene delivered substantial amounts of rainfall, rainfall intensities were not sufficient to produce runoff from either weather event.

Table 1 shows the combined results from the runoff events. The amount of runoff from the Innovative production system was near zero, and runoff was minimal even in the Traditional production system. Considerably less soil and greatly reduced amounts of nitrogen (both nitrate and ammonium) and phosphorus were lost from the System, as compared with the Traditional system. It should be pointed out, however, that runoff and chemical losses from the Traditional system were well within tolerable water quality limits.

Agroecology researchers were very encouraged by these results. According to Novak, more runoff was measured from plots grown with traditional cropping practices than for plots grown with innovative management. He pointed out that almost no water ran off the Innovative plots. This was a result of good ground cover which slowed surface water movement and allowed for the rain water to infiltrate into the soil. "Slowing down surface water movement reduces runoff and keeps water, sediment, and nutrients in farmers' fields where they belong," Novak stated.

Soil erosion is a major problem in many areas of the United States, including the Southeast. "It has been estimated that in the Coastal Plain, an acre can potentially lose 1 to 2 tons of soil each year through water and wind erosion," stated Hayes. "Sediment from erosion is also the number one water pollutant, by weight, in US surface waters. In addition, there is concern that fertilizers and other agricultural chemicals can potentially end up in our lakes, streams, and rivers, which are vital to our tourism industry and other interests in the state."

Results such as those in Table 1 show than runoff and associated erosion, chemical loss, and pollution can be greatly reduced by innovative crop production practices, even when the amount that occurs with traditional practices is within tolerable limits. "Crop management practices like conservation tillage can not only preserve the soil and produce good yields, they can also keep our waters cleaner. This is a win-win situation for everyone," Novak added.

Cotton will be grown on the split-landscape field this summer. Along with evaluation of crop growth and yields, pest management, soil characteristics, and other factors, Agroecology researchers will continue to compare soil and water quality effects of the Innovative and Traditional crop production systems.

Table 1. Influence of cropping system on loss of soil (sediment), nitrogen, and phosphate in runoff water collected from the split-landscape study. The values are totals for the 4 rainfall events that produced runoff during the 1999 growing season.

Crop production system	Runoff water (in/ac)	Soil loss (lbs/acre)	Nitrogen		o-Phosphate (grams/acre)
			nitrate (grams/acre)	ammonium (grams/acre)	
Innovative	0.0006	0.13	0.08	0.13	0.03
Traditional	0.175	301	49	105	4.9

(As a point of reference, a 5-cent "nickel" coin weighs about 5 grams.)

Conservation Tillage Can Decrease Thrips and Increase Beneficial Insects in Cotton

As cotton acreage planted in conservation tillage continues to increase, researchers and farmers need to become more aware of the effects of this practice on arthropod pests and their natural enemies. In particular, more information is needed about the interactions of conservation tillage, rotation, soil-applied insecticide, and soil type on the population dynamics of insect pests and beneficials. According to Gloria McCutcheon, Agroecology scientist located at the Coastal REC in Charleston, SC, "we should develop integrated pest management strategies as we manipulate cultural practices. This will reduce our dependence on traditional pest control methods, particularly the use of broad-spectrum pesticides." For three years, McCutcheon and other Agroecology researchers have investigated the effects of conservation tillage on natural enemies of major insect pests of cotton.

Major pests of cotton include thrips, tobacco budworms, cotton bollworms, soybean looper, beet armyworms, fall armyworms, cotton aphids, and stink bugs. "Of these pests, the only ones that appear to be affected by conservation tillage are the thrips," said McCutcheon. "Densities of tobacco thrips can be influenced significantly by cropping/tillage practices and also by aldicarb, but these factors do not interact in a significant way. Aldicarb can significantly reduce densities of thrips, and no-till practices can also reduce thrips."

Some insects in the ecosystem are very beneficial in that they help regulate pest populations. Many of them are parasitoids that are quite inconspicuous. The parasitoids in the cotton ecosystem are mostly tiny parasitic wasps (Fig. 4.), although some may be flies. These "good guys" develop in or on their host, which is the insect pest. They spend part of their life as immature larvae feeding on the host, and the other part as free-living adults feeding on plant pollen and nectar and searching for other suitable hosts to lay eggs in or on. According to McCutcheon, "one of the major parasitoids can attack the egg stage of budworms and bollworms, thus preventing hatching of the egg into small caterpillars. *Trichogramma* spp. can kill up to 50% of the eggs of the bollworm during late July when pest populations are highest. No trends were observed in the incidence of parasitism among tillage treatments in our study. To get a clearer picture of the effects of conservation tillage and other factors on this organism, the treatments would have to be examined in much larger plots than we have been using, because of the motility of the parasitoid from plot to plot."

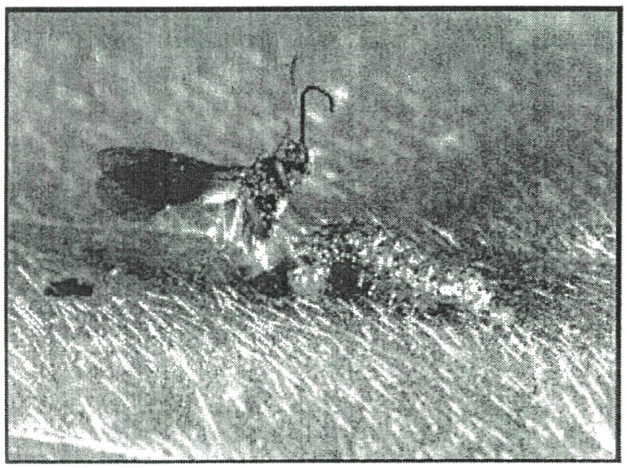

Figure 4. Parasitic wasp attacking cotton bollworm

McCutcheon added that the red imported fire ant is a very important insect in conservation tillage cotton. "While it is well-known as a pest that inflicts a 'fiery' sting and builds mounds that can damage farm machinery, it is also a voracious predator of insect pests," she said. It has been shown that the red imported fire ant can regulate population dynamics of fall armyworms. Because the ants work together (Fig. 5.), they can kill larger sized caterpillars that may be unconquerable by many

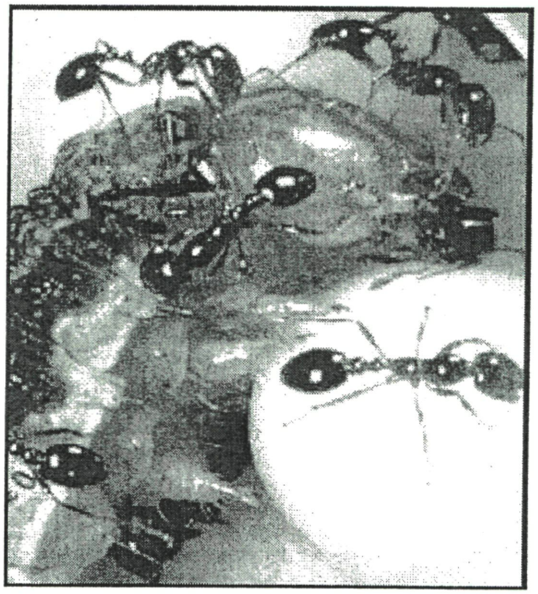

Figure 5. Red imported fire ants devouring tobacco budworm

of the other predators such as the big-eyed bug. Data in South Carolina and Georgia have repeatedly shown that the ants are more abundant in conservation tillage cotton than in fields where conventional tillage is used. In South Carolina, the ants were found in greater numbers in no-till plots with a rye cover crop than in any of the other treatments.

Results such as these underscore the fact that tillage can make a difference in specific pest and beneficial insect populations. Data from this study indicate that the difference is positive, because conservation tillage was found to cause a decrease in the thrips populations and an increase in populations of a major predator, the red imported fire ant. Because pest control measures are major inputs for crop production in South Carolina, Agroecology researchers will continue to gather information about the effects of production practices on pests and their natural enemies.

Pee Dee REC Annual Field Day. September 14

The Pee Dee Research and Education Center's Annual Field Day will be held on September 14. Many Agroecology research studies will be highlighted during this event. More details will be released in upcoming months.

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CLEMSON
UNIVERSITY
Crop and Soil Environmental Science
Box 340359
Clemson University
Clemson, South Carolina 29634-0359

Editor: Susan Wallace
Contributors:
Jim Frederick
John Hayes
Gloria McCutcheon
Jeff Novak

For more information about this publication contact:
James Frederick
Pee Dee REC
2200 Pocket Road
Florence SC 29506-9706
e-mail: jfrdrck@clemson.edu

Fig. 3: Sue Robinson
Design & Layout: Shelby Hull
Logo: Kate Palmer
& Susan Wallace

Advisory Panel *from page 1*

The importance of obtaining data to address the question of whether or not row crop production in South Carolina contributes to environmental harm was illustrated by examples from North Carolina, where farmers have been blamed for causing pollution problems. Advisory panel members also pointed out that the greatest breakthroughs from private industry will most likely be in the area of new technologies, including biotechnology and precision farming. For this reason, the panel agreed that another priority should be to develop crop production systems that will take full advantage of the benefits of these new technologies.

Panel members stated that the multi-disciplinary, multi-commodity systems approach that Agroecology scientists have been taking is exactly the type of research that is needed to solve today's problems. As one advisory panel member stated, "researchers generally take a reductionist approach and try to solve only one problem at a time. Unfortunately, it is often left up to the farmer to try to pull all the solutions together into a single system that can be put to practical use. We need research to examine what happens when all the components are put together into a new production system. Researchers need to identify which components of a new system do not work very well because these are the 'weak links' that can block further progress."

Developing new cropping systems that will increase crop productivity and profitability, protect the environment, and maximize the benefits of new technologies will continue to be the main focus of the Agroecology program. Agroecology scientists and the advisory panel are also interested in what traditional and new cropping systems will do to the ecology of the crop community. "It is important that we understand the ecological changes that will occur in the crop community when farmers adopt new crop production practices. Changes can potentially occur in soil chemical and physical properties, pest and beneficial insect populations, soil microorganisms, and wildlife populations," stated Agroecology scientist Jim Frederick. "We need to monitor these changes not only over the course of a year or two, but for five to 10 years or more. Only with this long-term understanding can we make predictions as to the long-range sustainability of our crop production practices."

AgroecologyNews

"Working to enhance the sustainability of South Carolina's cropping systems".

Spring, 2001

Cotton Conservation Tillage Results

Traditional cotton production practices used in the Southeast include intensive tillage both for seedbed preparation and weed control. Although effective for these purposes, intensive tillage also increases soil erosion, the decomposition of soil organic matter (leading to reduced soil productivity), and labor, equipment, and fuel costs.

Recent improvements in planting equipment and new weed control technologies have allowed conservation tillage to be successfully used for cotton production. Conservation tillage is defined as any production system that keeps at least 30% of the soil surface covered with plant material or residues. This level of surface coverage frequently can not be achieved with continuous cotton so an additional source of plant residues may be needed (for example, from a cover crop or through crop rotation). Research results from throughout the Southeast suggest that increasing the amount of surface residues can improve cotton productivity in conservation-tillage systems.

One of the Agroecology Program's research studies is focused on examining how different residue management strategies affect cotton productivity on different soil types within a field. This experiment was started in the fall of 1996 at the Pee Dee Research and Education Center near Florence, SC. Three residue management strategies are being examined using both conventional (incorporating plant residues with a disk) and conservation-tillage (leaving plant residues on the surface) practices. The three residue management treatments are continuous cotton only, continuous cotton with a rye winter cover crop, and cotton rotated with corn (corn grown in 1997 and 1999). The experimental plots are 400 to 700 feet long, so several soil types are present within each plot. The plots are harvested in 50-ft sections so the effects of these management strategies can be determined for each soil type within each plot. Conventional cotton varieties are being used in this study.

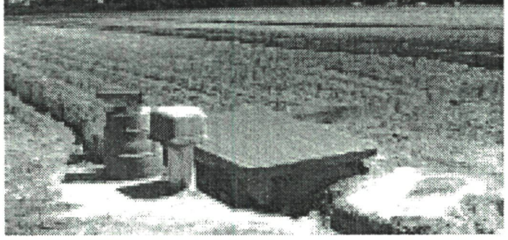
See **Cotton** *on page 2*

Cleaner Water With New Cropping Practices

With the tourism industry on the Coastal Plain heavily dependent on the region's water bodies, it is essential that this water be free of sediment, nutrients, pesticides, and pathogens. Although farmers are good stewards of their land, they are frequently blamed for water-quality problems when they arise. One objective of the Agroecology Program is to determine whether traditional crop production practices contribute to water-quality problems on the southeastern Coastal Plain and to quantify the level of water-quality protection that can be achieved with new cropping practices and technologies.

During the 2000 cotton growing season, USDA-ARS soil scientist Jeff Novak and Clemson University agricultural engineer John Hayes collected and analyzed runoff water from a split-landscape study being conducted at the Pee Dee Research and Education Center. The treatments used to produce cotton on the two sides of the split-landscape field are shown in Table 2. Runoff water was collected from three plots on each side of the field. Runoff occurred during 19 rainfall events on the Traditional side in 2000, but only during 9 events on the Innovative side. The combined results from all runoff events are shown in Table 3. There was very little water runoff with the Innovative production system. In contrast, a total of 2.4 inches of water moved off the field

See **Water** *on page 3*



Collected runoff samples (left) are being analyzed for sediment (right) and chemical concentrations.

*Names are necessary to report factually on available data, however, Clemson University and the USDA-ARS neither guarantee nor warrant the standard of the product, and the use of the name by Clemson University and the USDA-ARS implies no approval of the product to the exclusion of others that may also be suitable.

Cotton *from page 1*

Table 1. Effect of tillage on cotton lint yield (average over all three residue management systems). Asterisks (*) indicate years where significant yield differences between surface-tillage systems occurred.

Year	Conventional Tillage	Conservation Tillage
	lbs/Acre	
1997	875	830
1998	574	785*
1999	285	354*
2000	596	687*

The yields of cotton grown with conventional versus conservation tillage averaged over all residue management systems are shown in Table 1. Conservation tillage and conventional tillage did not differ for yield in 1997, which was a good year for rainfall at the Pee Dee Research and Education Center. When conditions were drier in 1998, 1999, and 2000, cotton grown with conservation tillage had higher yields than cotton grown with conventional tillage (averaging 25% higher yield over the 3 years).

Data of Figure 1 show how the residue-management treatments influenced conservation-tillage cotton yield for two of the major soil types found in the experimental field. The data are averaged over 1998 and 2000 (the two years where cotton was grown following corn). The Bonneau sand is more drought-prone than the Norfolk loamy sand, which would explain the lower lint yields of the Bonneau sand. For both soil types, continuous cotton without a winter cover crop (the fallow bar on the graph) had the lowest yield of the three treatments. Cotton grown following a rye winter cover crop had the same yield as cotton grown in rotation with corn (a high residue-producing crop). These results suggest that methods to increase plant residues may be an important part of conservation-tillage cotton production on the Coastal Plain.

The Agroecology split-landscape study was also planted in cotton in 2000. This long-term study was initiated three years ago to evaluate the economic, ecological, and environmental benefits of new or innovative cropping practices, compared to traditional practices. Treatments used in the split landscape study are shown in Table 2. Cotton lint yield was 29% higher with the innovative cropping system than with the traditional cropping system (Figure 2). A significant portion of this yield increase was probably due to the conservation tillage practices since lint yield was 15% greater with conservation tillage than with disking in the replicated plot study in 2000 (Table 1). Differences between the two sides of the split landscape field for lint yield were greatest on the Norfolk loamy sand and Bonneau sand soil types.

"As research shows the value of conservation tillage for cotton production, we should see a greater number of farmers adopting these practices".

"Conservation tillage can be a big benefit to cotton producers on the Coastal Plain", states USDA-ARS cotton agronomist Phil Bauer. Conservation tillage accounted for only 13% of the South Carolina's cotton acres in 2000, although Bauer notes that the percentage of total acres in conservation tillage is increasing at a faster rate for cotton than most other crops. "As research shows the value of conservation tillage for cotton production, we should see a greater number of farmers adopting these practices".

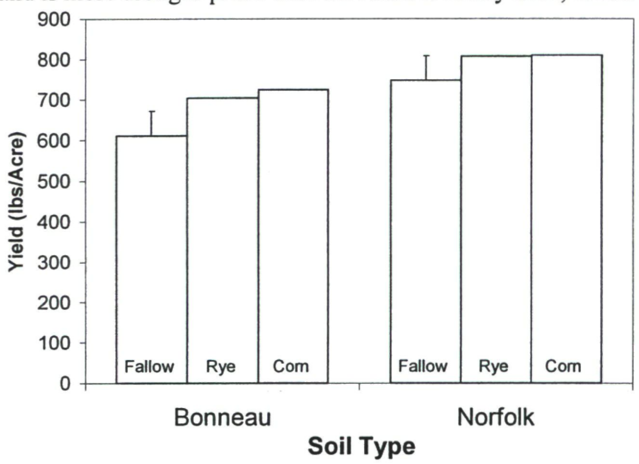


Figure 1. Average lint yields for 1998 and 2000 (years following corn used in rotation treatment) for cotton grown with conservation tillage. Fallow represents continuous cotton with no winter cover crop, Rye represents continuous cotton grown with rye winter cover crop, and Corn represents cotton rotated with corn (with no winter cover crop). The vertical bars indicate LSD.

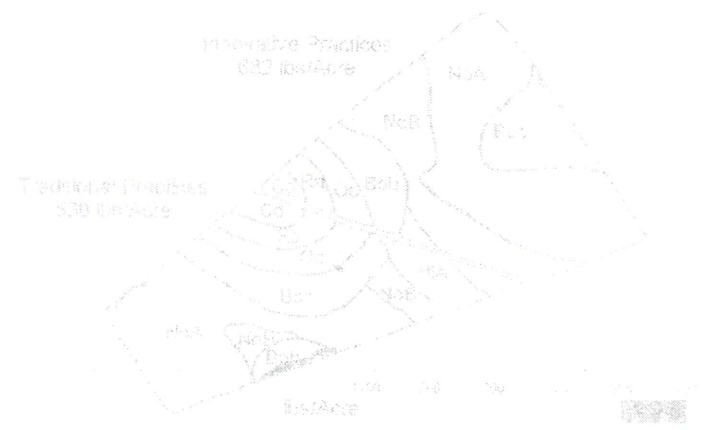


Figure 2. Cotton yield map from split-landscape study in 2000. Soil types shown in map are: NoA=Norfolk loamy sand 0-1% slope, NoB=Norfolk loamy sand 1-3% slope, NiA=Nobocco sandy loam 0-1% slope, Oc=Ocilla sand 0-3% slope, Bob=Bonneau sand 0-3% slope, Co=Coxville sandy loam, Ra=Rains sandy loam.

Water *from page 1*

with the Traditional production system. Considerably less soil and greatly reduced amounts of nitrogen (ammonium and nitrate) and phosphorus were lost from the Innovative production system, compared to the Traditional system. All water samples collected are currently being analyzed for herbicide concentrations. Such contrasting differences between production systems were also found in 1999 when the split-landscape field was planted in corn (see Agroecology News, Spring 2000).

It has been suggested that the greater rainwater infiltration with the Innovative practices may increase the movement (leaching) of some agrichemicals through the soil profile and potentially into the groundwater. However, as Novak points out, "the 2.3-inch difference in runoff water

Table 2. Treatments used in split landscape study in 2000 to produce cotton using innovative versus traditional practices.

Traditional Practices	Innovative Practices
Disking, bedding, cultivating	No surface tillage
In-row subsoiling	Broadcast deep tillage with ParaTill
Conventional variety	Bt/Roundup Ready equivalent variety
Broadcast P application	Precision application of P using GPS
Fluometuron, pendimethalin, sethoxydim, pyrithiobac, cyanazine herbicides	Glyphosate, pendimethalin herbicides

Table 3. Amount of water, sediment, and nutrient runoff for each cropping system during the cotton growing season in 2000.

Cropping System	Water Runoff	Suspended Solids (Sediments)	Total Nitrogen	Dissolved Phosporous
	inches	lbs/Acr		
Innovative	0.1	12	0.09	0.00
Traditional	2.4	1176	5.5	0.05

between the two sides of the field was a total for the whole season and an accumulation over a large number of rainfall events. This being the case, we feel there is probably little difference in leaching losses between the two cropping systems, although we intend to begin monitoring nutrient and pesticide movement in the soil profile this coming year."

Both Novak and Hayes were very encouraged by the findings. "It is impressive to find these types of results in two years with two different crops," notes Hayes. "Less water runoff, higher yields, and lower costs are exactly what the farmer needs to remain sustainable".

Precision Application of Phosphorus Fertilizer

Phosphorus (P) usually remains near the soil surface, making it susceptible to movement off agricultural fields in runoff water during rainstorm events. At high concentrations, P can cause the eutrophication of surface waters, such as ponds and lakes. Using global positioning systems and computer technologies, it is now possible to precision apply P at different rates across a field (variable-rate application) based upon soil test results from samples taken in a grid pattern or by soil type. Precision-applying P prevents the under application of P fertilizer to high-yielding areas of fields (thereby increasing crop yields) and the over application of P fertilizer to low-yielding areas of fields (saving farmers money and reducing the risk of P contamination of surface waters). In the Agroecology split-landscape study, P was precision applied each year to the Innovative side of the field based upon soil test results from samples collected in a grid pattern. On the Traditional side, P was broadcast applied across the whole field at one rate based upon test results from a bulk soil sample. Phosphorus levels have become low in many areas on the Traditional side, whereas areas high in P have slowly decreased in value but still remain relatively high (Fig. 3). On the Innovative side, soil P levels have become more uniform across the field and closer to what is considered a medium level of fertility (Fig. 3). These results indicate that precision P application can prevent both the over and under application of fertilizer on the Coastal Plain, but it may take 5 or more years for P levels to become relatively uniform across a field.

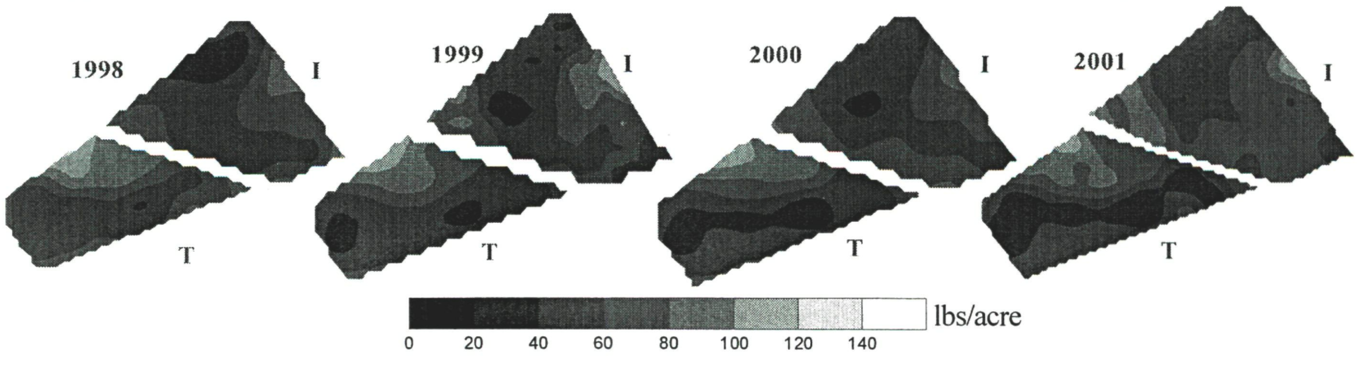


Fig. 3. Soil P levels with Innovative (I) and Traditional (T) management in 1998, 1999, 2000, and 2001.

CLEMSON
UNIVERSITY
Crop and Soil Environmental Science
Box 340359
Clemson University
Clemson, South Carolina 29634-0359

Learn more about the Agroecology Program's research and outreach activities at http://agroecology.clemson.edu

Editor: Jim Frederick
Contributors:
Phil Bauer
Jim Frederick
John Hayes
Jeff Novak

For more information about this publication contact:
Jim Frederick
Pee Dee REC
2200 Pocket Road
Florence SC 29506-9706
e-mail: jfrdrck@clemson.edu

Fig.2, 3: Sue Robinson
Layout: Sue Robinson
Logo: Kate Palmer
& Susan Wallace

Agroecology Project Coordinator Jim Frederick explains to REACH students how agriculture impacts the environment (*left*). Frederick and GPS/GIS Specialist Sue Robinson also demonstrated to Hanna-Pamplico students how plants and tillage practices impact global warming, and the use of GPS/GIS technologies for research and precision farming purposes (*right*).

Soil Quality Information Sheet

Soil Quality - Introduction

USDA Natural Resources Conservation Service **April 1996**

What is soil?

Soil is a living, dynamic resource that supports plant life. It is made up of different size mineral particles (sand, silt, and clay), organic matter, and numerous species of living organisms. Soil has biological, chemical, and physical properties that are always changing.

What does soil do for us?

Soil provides a physical matrix, chemical environment, and biological setting for water, nutrient, air, and heat exchange for living organisms.

Soil controls the distribution of rainfall or irrigation water to runoff, infiltration, storage, or deep drainage. Its regulation of water flow affects the movement of soluble materials, such as nitrate nitrogen or pesticides.

Soil regulates biological activity and molecular exchanges among solid, liquid, and gaseous phases. This affects nutrient cycling, plant growth, and decomposition of organic materials.

Soil acts as a filter to protect the quality of water, air, and other resources.

Soil provides mechanical support for living organisms and their structures. People and wildlife depend on this function.

What is Soil Quality?

Soil quality is the fitness of a specific kind of soil to function within its surroundings, support plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation.

How is soil quality important to landowners?

Soil quality enhancement is important to support crop, range, and woodland production and to sustain water supplies. Enhanced soil quality can help to reduce the onsite and offsite costs of soil erosion, improve nutrient use efficiencies, and ensure that the resource is sustained for future use. It is also essential to maintain other resources that depend on the soil, such as water quality, air quality, and wildlife habitat.

How can soil quality be evaluated?

Soil quality and soil health can be evaluated by monitoring several indicators. The type of indicator chosen depends on the soil function and scale (i.e. field, farm, watershed, or region) in which the evaluation is made. For example, an indicator of soil loss by erosion may be the thinning of the surface layer or visual and physical evidence of gullies, small rills, adjacent sediment, etc. Indicators for physical, chemical, and biological conditions can be simple field tests or sophisticated laboratory analyses.

Soil quality indicators may be considered diagnostic tools to assess the health of the soil or else as a cause for concern to the farmer, producer, rancher, woodland manager, or gardener, to stimulate a change in management. Trends in soil health can help in planning and evaluating current land use practices. The information gathered from monitoring soil health can be used to improve conservation recommendations.

How can my awareness of soil quality be applied?

Soil quality can be applied through several natural resource approaches:

-- Data from soil surveys, fertility labs, and field tests can help identify areas where natural soil properties (texture, drainage, etc.) or management related problems currently exist. Once these conditions are identified, corrections can be planned.

-- Areas with potential resource problems can be identified and shown on soil interpretive maps. These fragile areas that can easily be damaged may need more intensive management to prevent damage or be converted to a less demanding land use.

-- After installing conservation practices, trends in soil quality can be tracked to show the success of the practice or the need for other management changes.

What concerns are addressed by soil quality?

Loss of soil material by erosion

Deposition of sediment by wind or floodwaters

Compaction of layers near the surface

Soil aggregation at the surface

Infiltration reduction

Crusting of the soil surface

Nutrient loss or imbalance

Pesticide carryover

Buildup of salts

Change in pH to an unfavorable range

Loss of organic matter

Reduced biological activity and poor residue breakdown

Infestation by weeds or pathogens

Excessive wetness

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA)

Soil Quality Information Sheet

Soil Quality Resource Concerns: Soil Biodiversity

USDA Natural Resources Conservation Service **January 1998**

What is soil biodiversity?

Soil biodiversity reflects the mix of living organisms in the soil. These organisms interact with one another and with plants and small animals forming a web of biological activity.

Soil is by far the most biologically diverse part of Earth. The soil food web includes beetles, springtails, mites, worms, spiders, ants, nematodes, fungi, bacteria, and other organisms. These organisms improve the entry and storage of water, resistance to erosion, plant nutrition, and break down of organic matter. A wide variety of organisms provides checks and balances to the soil food web through population control, mobility, and survival from season to season.

What are the benefits of soil organisms?

Residue decomposition
Soil organisms decompose plant residue. Each organism in the soil plays an important role. The larger organisms in the soil shred dead leaves and stems. This stimulates cycling of nutrients. The larger soil fauna include earthworms, termites, pseudoscorpions, microspiders, centipedes, ants, beetles, mites, and springtails.

When mixing the soil, the large organisms bring material to smaller organisms. The large organisms also carry smaller organisms within their systems or as "hitchhikers" on their bodies.

Small organisms feed on the by-products of the larger organisms. Still smaller organisms feed on the products of these organisms. The cycle repeats itself several times with some of the larger organisms feeding on smaller organisms.

Some larger organisms have a life span of two or more years. Smaller organisms generally die more quickly, but they also multiply rapidly when conditions are favorable. The food web is therefore quick to respond when food sources are available and moisture and temperature conditions are good.

Infiltration and storage of water
Channels and aggregates formed by soil organisms improve the entry and storage of water. Organisms mix the porous and fluffy organic material with mineral matter as they move through the soil. This mixing action provides organic matter to non-burrowing fauna and creates pockets and pores for the movement and storage of water. Fungal hyphae bind soil particles together and slime from bacteria help hold clay particles together. The water-stable aggregates formed by these processes are more resistant to erosion than individual soil particles. The aggregates increase the amount of large pore space which increases the rate of water infiltration. This reduces runoff and water erosion and increases soil moisture for plant growth.

Nutrient cycling
Soil organisms play a key role in nutrient cycling. Fungi, often the most extensive living organisms in the soil, produce fungal hyphae. Hyphae frequently appear like fine white entangled thread in the soil. Some fungal hyphae (mycorrhizal fungi) help plants extract nutrients from the soil. They supply nutrients to the plant while obtaining carbon in exchange and thus extend the root system. Root exudates also provide food for fungi, bacteria, and nematodes.

When fungi and bacteria are eaten by various mites, nematodes, amoebas, flagellates, or ciliates, nitrogen is released to the soil as ammonium. Decomposition by soil organisms converts nitrogen from organic forms in decaying plant residues and organisms to inorganic forms which plants can use.

Management considerations

Cultivation

The effects of cultivation depend on the depth and frequency of the cultivation. Tilling to greater depths and more frequent cultivations have an increased negative impact on all soil organisms. No-till, ridge tillage, and strip tillage are the most compatible tillage systems that physically maintain soil organism habitat and biological diversity in crop production.

Compaction

Soil compaction reduces the larger pores and pathways, thus reducing the amount of suitable habitat for soil organisms. It also can move the soil toward anaerobic conditions, which change the types and distribution of soil organisms in the food web. Gaps in the food web induce nutrient deficiencies to plants and reduce root growth.

Pest control

Pesticides that kill insects also kill the organisms carried by them. If important organisms die, consider replacing them. Plant-damaging organisms usually increase when beneficial soil organisms decrease. Beneficial predator organisms serve to check and balance various pest species.

Herbicides and foliar insecticides applied at recommended rates have a small impact on soil organisms. Fungicides and fumigants have a much greater impact on soil organisms.

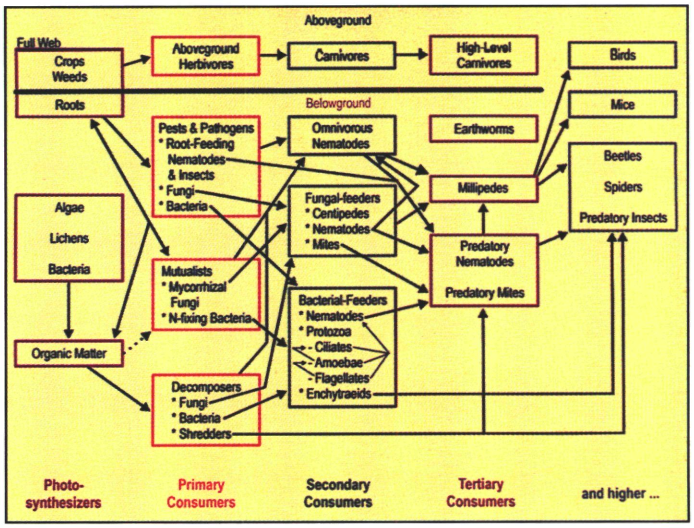
Fertility

Fertility and nutrient balances in the soil promote biological diversity. Typically, carbon is the limiting resource to biological activity. Plant residue, compost, and manure provide carbon. Compost also provides a mix of organisms, so the compost should be matched to the cropping system.

(Prepared by the National Soil Survey Center, NRCS, USDA in cooperation with the Soil Quality Institute, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA).

Cover crops and crop rotations

The type of crops that are used as cover or in crop rotations can affect the mix of organisms that are in the soil. They can assist in the control of plant pests or serve as hosts to increase the number of pests. Different species and cultivars of crops may have different effects on pests. However, the organisms and their relation to the crop are presently not clearly understood.



Crop residue management

Mixing crop residue into the soil generally destroys fungal hyphae and favors the growth of bacteria. Since bacteria hold less carbon than fungi, mixing often releases a large amount of carbon as carbon dioxide (CO_2). The net result is loss of organic matter from the soil.

When crop residue is left on the soil surface, primary decomposition is by arthropod shredding and fungal decomposition. The hyphae of fungi can extend from below the soil surface to the surface litter and connect the nitrogen in the soil to the carbon at the surface. Fungi maintain a high C:N ratio and hold carbon in the soil. The net result is toward building the carbon and organic matter level of the soil. In cropping systems that return residue, macro-organisms are extremely important. Manage the soil to increase their diversity and numbers.

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Soil Quality Information Sheet

Soil Quality Resource Concerns: Compaction

USDA Natural Resources Conservation Service April 1996

What is compaction?

Soil compaction occurs when soil particles are pressed together, reducing the pore space between them. This increases the weight of solids per unit volume of soil (bulk density). Soil compaction occurs in response to pressure (weight per unit area) exerted by field machinery or animals. The risk for compaction is greatest when soils are wet.

Why is compaction a problem?

Compaction restricts rooting depth, which reduces the uptake of water and nutrients by plants. It decreases pore size, increases the proportion of water-filled pore space at field moisture, and decreases soil temperature. This affects the activity of soil organisms by decreasing the rate of decomposition of soil organic matter and subsequent release of nutrients.

Compaction decreases infiltration and thus increases runoff and the hazard of water erosion.

How can compacted soils be identified?

- platy or weak structure, or a massive condition,
- greater penetration resistance,
- higher bulk density,
- restricted plant rooting,
- flattened, turned, or stubby plant roots.

The significance of bulk density depends on the soil texture. Rough guidelines for the minimum bulk density at which a root restricting condition will occur for various soil textures are (g/cc stands for grams per cubic centimeter):

Texture	Bulk Density (g/cc)
Coarse, medium, and fine sand and loamy sands other than loamy very fine sand	**1.80**
Very fine sand, loamy very fine sand	**1.77**
Sandy loams	**1.75**
Loam, sandy clay loam	**1.70**
Clay loam	**1.65**
Sandy clay	**1.60**
Silt, silt loam	**1.55**
Silty clay loam	**1.50**
Silty clay	**1.45**
Clay	**1.40**

What causes soil compaction?

Soil compaction is caused by tilling, harvesting, or grazing when the soils are wet.

Soil water content influences compaction. A dry soil is much more resistant to compaction than a moist or wet soil.

Other factors affecting compaction include the texture, pressure exerted, composition (texture, organic matter, plus clay content and type), and the number of passes by vehicle traffic and machinery. Sandy loam, loam, and sandy clay loam soils compact more easily than silt, silt loam, silty clay loam, silty clay, or clay soils.

Compaction may extend to 20 inches. Deep compaction affects smaller areas than shallow compaction, but it persists because shrinking and swelling and freezing and thawing affect it less. Machinery that has axle loads of more than 10 tons may cause compaction below 12 inches. Grazing by large animals can cause compaction because their hooves have a relatively small area and therefore exert a high pressure.

How long will compaction last?

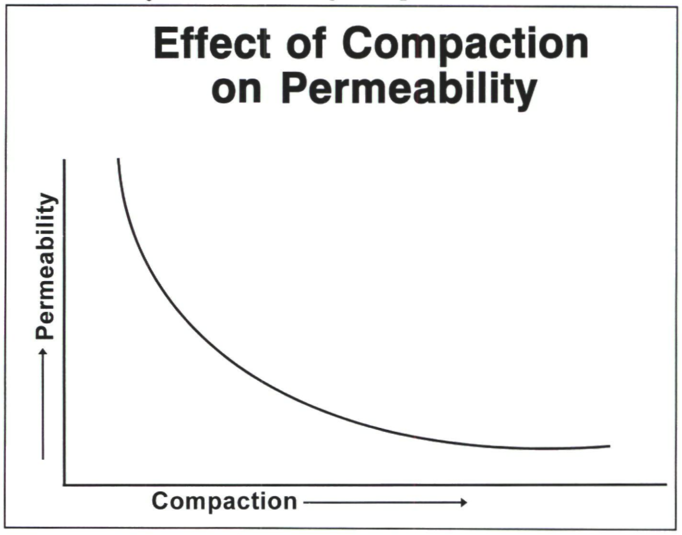
The persistence of soil compaction is determined by the depth at which it occurs, the shrink-swell potential of the soil, and the climate. As the depth increases, the more persistent the condition. The type and percentage of clay determine the shrink-swell potential. The greater the shrink-swell potential and number of wet/dry cycles, the lower is the duration of compaction at a particular depth. Freeze/thaw cycles also help decrease near-surface compaction.

How do organic matter and compaction interact?

Soil organic matter promotes aggregation of soil particles. This increases porosity and reduces bulk density (i.e., compaction). It also increases permeability and may increase plant available water.

Addition of manure, compost, or other organic materials including newspaper, woodchips, and municipal sludge can improve soil structure, helping to resist compaction.

Thick layers of forest litter reduce the impact of machinery, thus reducing compaction.



How can compaction be reduced?

- Reduce the number of trips across the area.
- Till or harvest when the soils are not wet.
- Reduce the pressure of equipment.
- Maintain or increase organic matter in the soil.
- Harvest timber on frozen soil or snow.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA)

Soil Quality Information Sheet

Soil Quality Concerns: Pesticides

USDA Natural Resouces Conservation Service January 1998

What are pesticides?

Pesticides are synthetic organic chemicals used to control weeds in fields and lawns, and unwanted or harmful pests, such as insects and mites that feed on crops. Pesticides are divided into categories according to the target organisms they are designed to control (e.g., insecticides control insects).

Herbicides are by far the most commonly used pesticides in the United States. They range from non selective to highly selective for control of specific weeds in specific crops, with different products having postemergence, preplant, and preemergence uses. Insecticides are second in usage, and fungicides are third.

Effects of Pesticides on Soil Quality

The capacity of the soil to filter, buffer, degrade, immobilize, and detoxify pesticides is a function or quality of the soil. Soil quality also encompasses the impacts that soil use and management can have on water and air quality, and on human and animal health. The presence and bio-availability of pesticides in soil can adversely impact human and animal health, and beneficial plants and soil organisms. Pesticides can move off-site contaminating surface and groundwater and possibly causing adverse impacts on aquatic ecosystems.

What are pesticide formulations?

The formulation is the chemical and physical form in which the pesticide is sold for use. The active ingredient (a.i.) is the chemical in the formulation that has the specific effect on the target organism. The formulation improves the properties of the pesticides for storage, handling, application, effectiveness, or safety. Examples of formulated products are wettable powders and water-dispersible granules. A single pesticide is often sold in several different formulations, depending on use requirements and application needs.

Pesticide mode of action

Mode of action refers to the mechanism by which the pesticide kills or interacts with the target organism.

- Contact pesticides kill the target organism by weakening or disrupting the cellular membranes; death can be very rapid.
- Systemic pesticides must be absorbed or ingested by the target organism to disrupt its physiological or metabolic processes; generally they are slow acting.

How effective the pesticides are at killing the target organisms (efficacy) depends on the properties of the pesticide and the soil, formulation, application technique, agricultural management, characteristics of the crop, environmental or weather conditions, and the nature and behavior of the target organism.

Fate of pesticides in the environment

Ideally, a pesticide stays in the treated area long enough to produce the desired effect and then degrades into harmless materials. Three primary modes of degradation occur in soils:

- biological - breakdown by micro-organisms
- chemical - breakdown by chemical reactions, such as hydrolysis and redox reactions
- photochemical - breakdown by ultraviolet or visible light

The rate at which a chemical degrades is expressed as the half-life. The half-life is the amount of time it takes for half of the pesticide to be converted into something else, or its concentration is half of its initial level. The half-life of a pesticide depends on soil type, its formulation, and environmental conditions (e.g., temperature, moisture). Other processes that influence the fate of the chemical include plant uptake, soil sorption, leaching, and volatilization. If pesticides move off-site (e.g., wind drift, runoff, leaching), they are considered to be pollutants. The potential for pesticides to move off-site depends on the chemical properties and formulation of the pesticide, soil properties, rate and method of application, pesticide persistence, frequency and timing of rainfall or irrigation, and depth to ground water.

Retention of pesticides in the soil

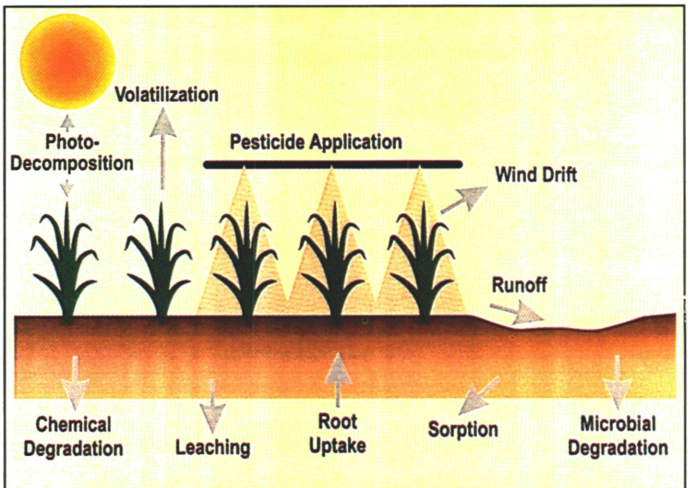
Retention refers to the ability of the soil to hold a pesticide in place and not allow it to be transported. Adsorption is the primary process of how the soil retains a pesticide and is defined as the accumulation of a pesticide on the soil particle surfaces. Pesticide adsorption to soil depends on both the chemical properties of the pesticide (i.e., water solubility, polarity) and properties of the soil (i.e., organic matter and clay contents, pH, surface charge characteristics, permeability). For most pesticides, organic matter is the most important soil property controlling the degree of adsorption.

For most pesticides, the degree of adsorption is described by an adsorption distribution coefficient (K_d), which is mathematically defined as the amount of pesticide in soil solution divided by the amount adsorbed to the soil.

Pesticide toxicity

The toxicity level of a pesticide depends on the deadliness of the chemical, the dose, the length of exposure, and the route of entry or absorption by the body. Pesticide degradation in soil generally results in a reduction in toxicity; however, some pesticides have breakdown products (metabolites) that are more toxic than the parent compound.

Pesticides are classified according to their potential toxicity to humans and other animals and organisms, as restricted-use (can only be purchased and applied by certified persons who have had training in pesticide application), and general use (may be purchased and applied by any person).



Fate of pesticides in the environment (after Aislabie and Lloyd-Jones).

Use and application considerations

- Apply pesticides at the lowest effective level.
- Avoid unnecessary pesticide treatments.
- Use Integrated Pest Management.
- Follow all label instructions.
- Apply proper rates and times as label indicates.
- Calibrate application equipment.
- Apply formulations that minimize drift.
- Use safety equipment when handling.
- Store and dispose of pesticide containers properly.
- Use biological controls when appropriate.
- Alter farming or cropping systems to control pests.
- Use disease and insect resistant crop varieties.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA).

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Soil Quality Information Sheet

Soil Quality Resource Concerns: Soil Erosion

USDA Natural Resources Conservation Service **April 1996**

What is erosion?

Wind or water erosion is the physical wearing of the earth's surface. Surface soil material is removed in the process.

Why should we be concerned?

Erosion removes topsoil, reduces levels of soil organic matter, and contributes to the breakdown of soil structure. This creates a less favorable environment for plant growth.

In soils that have restrictions to root growth, erosion decreases rooting depth, which decreases the amount of water, air, and nutrients available to plants.

Erosion removes surface soil, which often has the highest biological activity and greatest amount of soil organic matter. This causes a loss in nutrients and often creates a less favorable environment for plant growth.

Nutrients removed by erosion are no longer available to support plant growth onsite, but can accumulate in water where such problems as algal blooms and lake eutrophication may occur.

Deposition of eroded materials can obstruct roadways and fill drainage channels. Sediment can damage fish habitat and degrade water quality in streams, rivers, and lakes.

Blowing dust can affect human health and create public safety hazards.

What are some signs of erosion?

Wind erosion:

- dust clouds,
- soil accumulation along fencelines or snowbanks,
- a drifted appearance of the soil surface.

Water erosion:

- small rills and channels on the soil surface,
- soil deposited at the base of slopes,
- sediment in streams, lakes, and reservoirs,
- pedestals of soil supporting pebbles and plant material.

Water erosion is most obvious on steep, convex landscape positions. However, erosion is not always readily visible on cropland because farming operations may cover up its signs. Loss of only 1/32 of an inch can represent a 5 ton per acre soil loss.

Long-term soil erosion results in:

- persistent and large gullies,
- exposure of lighter colored subsoil at the surface,
- poorer plant growth.

How can soil erosion be measured?

Visual, physical, chemical, and biological indicators can be used to estimate soil surface stability or loss.

Visual indicators

- comparisons of aerial photographs taken over time,
- presence of moss and algae (crypotogams) crusts in desert or arid soils,
- changes in soil horizon thickness,
- deposition of soil at field boundaries.

Physical indicators

- measurements of aggregate stability,
- increasing depth of channels and gullies.

Chemical indicators

- decreases in soil organic matter content,
- increases in calcium carbonate content at the surface, provided greater content exists in subsurface layers,
- changes in cation-exchange capacity (CEC).

Biological indicators

- decreased microbial biomass,
- lower rate of respiration,
- slower decomposition of plant residues.

What causes the problem?

Water erosion

- lack of protection against raindrop impact,
- decreased aggregate stability,
- long and steep slopes,
- intense rainfall or irrigation events when plant or residue cover is at a minimum,
- decreased infiltration by compaction or other means.

Mechanical erosion

- removal by harvest of root crops,
- tillage and cultivation practices that move soil downslope.

Wind erosion

- exposed surface soil during critical periods of the year,
- occurrence of wind velocities that are sufficient to lift individual soil particles,
- long, unsheltered, smooth soil surfaces.

How can soil erosion be avoided?

Soil erosion can be avoided by:

- maintaining a protective cover on the soil,
- creating a barrier to the erosive agent,
- modifying the landscape to control runoff amounts and rates.

Specific practices to avoid water erosion:

- growing forage crops in rotation or as permanent cover,
- growing winter cover crops
- interseeding,
- protecting the surface with crop residue,
- shortening the length and steepness of slopes,
- increasing water infiltration rates,
- improving aggregate stability.

Specific practices to avoid wind erosion:

- maintaining a cover of plants or residue,
- planting shelterbelts,
- stripcropping,
- increase surface roughness,
- cultivating on the contour,
- maintaining soil aggregates at a size less likely to be carried by wind.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA)

Soil Quality Information Sheet

Indicators for Soil Quality Evaluation

USDA Natural Resources Conservation Service **April 1996**

What are indicators?

Soil quality indicators are physical, chemical, and biological properties, processes, and characteristics that can be measured to monitor changes in the soil.

The types of indicators that are the most useful depend on the function of soil for which soil quality is being evaluated. These functions include:

- providing a physical, chemical, and biological setting for living organisms;
- regulating and partitioning water flow, storing and cycling nutrients and other elements;
- supporting biological activity and diversity for plant and animal productivity;
- filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials; and
- providing mechanical support for living organisms and their structures.

Why are indicators important?

Soil quality indicators are important to:

- focus conservation efforts on maintaining and improving the condition of the soil;
- evaluate soil management practices and techniques;
- relate soil quality to that of other resources;
- collect the necessary information to determine trends;
- determine trends in the health of the Nation's soils;
- guide land manager decisions.

What are some indicators?

Indicators of soil quality can be categorized into four general groups: visual, physical, chemical, and biological.

Visual indicators may be obtained from observation or photographic interpretation. Exposure of subsoil, change in soil color, ephemeral gullies, ponding, runoff, plant response, weed species, blowing soil, and deposition are only a few examples of potential locally determined indicators. Visual evidence can be a clear indication that soil quality is threatened or changing.

Physical indicators are related to the arrangement of solid particles and pores. Examples include topsoil depth, bulk density, porosity, aggregate stability, texture, crusting, and compaction. Physical indicators primarily reflect limitations to root growth, seedling emergence, infiltration, or movement of water within the soil profile.

Chemical indicators include measurements of pH, salinity, organic matter, phosphorus concentrations, cation-exchange capacity, nutrient cycling, and concentrations of elements that may be potential contaminants (heavy metals, radioactive compounds, etc.) or those that are needed for plant growth and development. The soil's chemical condition affects soil-plant relations, water quality, buffering capacities, availability of nutrients and water to plants and other organisms, mobility of contaminants, and some physical conditions, such as the tendency for crust to form.

Biological indicators include measurements of micro- and macro-organisms, their activity, or byproducts. Earthworm, nematode, or termite populations have been suggested for use in some parts of the country. Respiration rate can be used to detect microbial activity, specifically microbial decomposition of organic matter in the soil. Ergosterol, a fungal byproduct, has been used to measure the activity of organisms that play an important role in the formation and stability of soil aggregates. Measurement of decomposition rates of plant residue in bags or measurements of weed seed numbers, or pathogen populations can also serve as biological indicators of soil quality.

How are indicators selected?

Soil quality is estimated by observing or measuring several different properties or processes. No single property can be used as an index of soil quality.

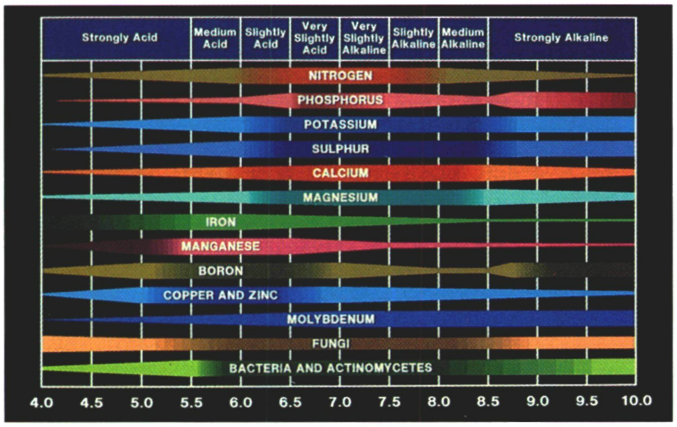
The selection of indicators should be based on:
- the land use;
- the relationship between an indicator and the soil function being assessed;
- the ease and reliability of the measurement;
- variation between sampling times and variation across the sampling area;
- the sensitivity of the measurement to changes in soil management;
- compatibility with routine sampling and monitoring;
- the skills required for use and interpretation.

When and where to measure?

The optimum time and location for observing or sampling soil quality indicators depends on the function for which the assessment is being made. The frequency of measurement also varies according to climate and land use.

Soil variation across a field, pasture, forest, or rangeland can greatly affect the choice of indicators. Depending on the function, such factors as the landscape unit, soil map unit, or crop growth stage may be critical. Wheel tracks can dramatically affect many properties measured for plant productivity. Management history and current inputs should also be recorded to ensure a valid interpretation of the information.

Monitoring soil quality should be directed primarily toward the detection of trend changes that are measurable over a 1- to 10-year period. The detected changes must be real, but at the same time they must change rapidly enough so that land managers can correct problems before undesired and perhaps irreversible loss of soil quality occurs.



Soil reaction influence on availability of plant nutrients.

What does the value mean?

Interpreting indicator measurements to separate soil quality trends from periodic or random changes is currently providing a major challenge for researchers and soil managers. Soils and their indicator values vary because of differences in parent material, climatic condition, topographic or landscape position, soil organisms, and type of vegetation. For example, cationexchange capacity may relate to organic matter, but it may also relate to the kind and amount of clay.

Establishing acceptable ranges, examining trends and rates of change over time, and including estimates of the variance associated with the measurements are important in interpreting indicators. Changes need to be evaluated as a group, with a change in any one indicator being evaluated only in relation to changes in others. Evaluations before and after, or with and without intervention, are also needed to develop appropriate and meaningful relationships for various kinds of soils and the functions that are expected of them.

The overall goal should be to maintain or improve soil quality without adversely affecting other resources.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA)

Soil Quality Information Sheet

Soil Quality Indicators: Aggregate Stability

USDA Natural Resources Conservation Service April 1996

What are soil aggregates?

Soil aggregates are groups of soil particles that bind to each other more strongly than to adjacent particles. The space between the aggregates provide pore space for retention and exchange of air and water.

What is aggregate stability?

Aggregate stability refers to the ability of soil aggregates to resist disruption when outside forces (usually associated with water) are applied.

Aggregate stability is not the same as *dry aggregate stability*, which is used for wind erosion prediction. The latter term is a size evaluation.

Why is aggregate stability important?

Aggregation affects erosion, movement of water, and plant root growth. Desirable aggregates are stable against rainfall and water movement. Aggregates that break down in water or fall apart when struck by raindrops release individual soil particles that can seal the soil surface and clog pores. This breakdown creates crusts that close pores and other pathways for water and air entry into a soil and also restrict emergence of seedlings from a soil.

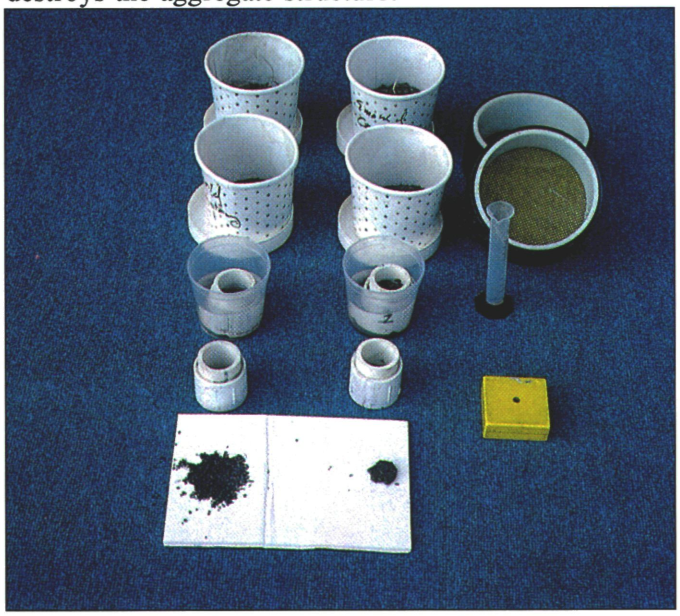
Optimum conditions have a large range in pore size distribution. This includes large pores between the aggregates and smaller pores within the aggregates. The pore space between aggregates is essential for water and air entry and exchange. This pore space provides zones of weakness through which plant roots can grow. If the soil mass has a low bulk density or large pore spaces, aggregation is less important. For example, sandy soils have low aggregation, but roots and water can move readily.

How is aggregate stability measured?

Numerous methods measure aggregate stability. The standard method of the NRCS Soil Survey Laboratory can be used in a field office or in a simple laboratory. This procedure involves repeated agitation of the aggregates in distilled water.

An alternative procedure described here does not require weighing. The measurements are made on air-dry soil that has passed through a sieve with 2-millimeter mesh and retained by a sieve with a 1-millimeter mesh. A quantity of these 2-1 millimeter aggregates is placed in a small open container with a fine screen at the bottom. This container is placed in distilled water. After a period of time, the container is removed from the water and its contents are allowed to dry. The content is then removed and visually examined for the breakdown from the original aggregate size. Those materials that have the least change from the original aggregates have the greatest aggregate stability.

Soils that have a high percentage of silt often show lower aggregate stability if measured air-dry than the field behavior would suggest, because water entry destroys the aggregate structure.



What influences aggregate stability?

The stability of aggregates is affected by soil texture, the predominant type of clay, extractable iron, and extractable cations, the amount and type of organic matter present, and the type and size of the microbial population.

Some clays expand like an accordion as they absorb water. Expansion and contraction of clay particles can shift and crack the soil mass and create or break apart aggregates.

Calcium ions associated with clay generally promote aggregation, whereas sodium ions promote dispersion.

Soils with over about five percent iron oxides, expressed as elemental iron, tend to have greater aggregate stability.

Soils that have a high content of organic matter have greater aggregate stability. Additions of organic matter increase aggregate stability, primarily after decomposition begins and microorganisms have produced chemical breakdown products or mycelia have formed.

Soil microorganisms produce many different kinds of organic compounds, some of which help to hold the aggregates together. The type and species of microorganisms are important. Fungal mycelial growth binds soil particles together more effectively than smaller organisms, such as bacteria.

Aggregate stability declines rapidly in soil planted to a clean-tilled crop. It increases while the soil is in sod and crops, such as alfalfa.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA)

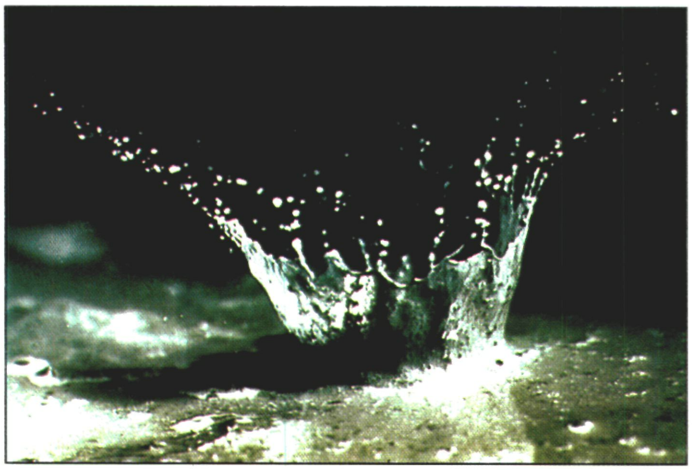
Soil Quality Information Sheet

Soil Quality Indicators: Infiltration

USDA Natural Resouces Conservation Service | January 1998

What is Infiltration?

Infiltration is the process of water entering the soil. The rate of infiltration is the maximum velocity at which water enters the soil surface. When the soil is in good condition or has good soil health, it has stable structure and continuous pores to the surface. This allows water from rainfall to enter unimpeded throughout a rainfall event. A low rate of infiltration is often produced by surface seals resulting from weakened structure and clogged or discontinuous pores.



Why is infiltration a concern?

Soil can be a excellent temporary storage medium for water, depending on the type and condition of the soil. Proper management of the soil can help maximize infiltration and capture as much water as allowed by a specific soil type.

If water infiltration is restricted or blocked, water does not enter the soil, and it either ponds on the surface or runs off the land. Thus, less water is stored in the soil profile for use by plants. Runoff can carry soil particles and surface applied fertilizers and pesticides off the field. These materials can end up in streams and lakes or in other places where they are not wanted.

Soils that have reduced infiltration have an increase in the overall amount of runoff water. This excess water can contribute to local and regional flooding of streams and rivers or results in accelerated soil erosion of fields or streambanks.

In most cases, maintaining a high infiltration rate is desirable for a healthy environment. However, soils that transmit water freely throughout the entire profile or into tile lines need proper chemical management to ensure the protection of groundwater and surface water resources.

Soils that have reduced infiltration can become saturated at the surface during rainfall. Saturation decreases soil strength, increases detachment of particles, and enhances the erosion potential. In some areas that have a steep slope, surface material lying above a compacted layer may move in a mass, sliding down the slope because of saturated soil conditions.

Decreases in infiltration or increases in saturation above a compacted layer can also cause nutrient deficiencies in crops. Either condition can result in anaerobic conditions which reduce biological activity and fertilizer use efficiencies.

What factors influence infiltration?

A number of factors impact soil infiltration. Some of these are:

- **Texture:** The type of soil (sandy, silty, clayey) can control the rate of infiltration. For example, a sandy surface soil normally has a higher infiltration rate than a clayey surface soil. A soil survey is a recorded map of soil types on the landscape.

- **Crust:** Soils that have many large surface connected pores have higher intake rates than soils that have few such pores. A crust on the soil surface can seal the pores and restrict the entry of water into the soil.

- **Compaction:** A compacted zone (plowpan) or an impervious layer close to the surface restricts the entry of water into the soil and tends to result in ponding on the surface.

- **Aggregation and Structure:** Soils that have stable strong aggregates as granular or blocky soil structure have a higher infiltration rate than soils that have weak, massive, or platelike structure. Soils that have a smaller structural size have higher infiltration rates than soils that have a larger structural size.

- **Water Content:** The content or amount of water in the soil affects the infiltration rate of the soil. The infiltration rate is generally higher when the soil is initially dry and decreases as the soil becomes wet. Pores and cracks are open in a dry soil, and many of them are filled in by water or swelled shut when the soil becomes wet. As they become wet, the infiltration rate slows to the rate of permeability of the most restrictive layer.

- **Frozen Surface:** A frozen soil greatly slows or completely prevents water entry.

- **Organic Matter:** An increased amount of plant material, dead or alive, generally assists the process of infiltration. Organic matter increases the entry of water by protecting the soil aggregates from breaking down during the impact of raindrops. Particles broken from aggregates can clog pores and seal the surface and decrease infiltration during a rainfall event.

- **Pores:** Continuous pores that are connected to the surface are excellent conduits for the entry of water into the soil. Discontinuous pores may retard the flow of water because of the entrapment of air bubbles. Organisms such as earthworms increase the amount of pores and also assists the process of aggregation that enhances water infiltration.

How can infiltration be increased?

A number of management options can help increase soil infiltration:

- Decrease compaction by reducing tillage and by avoiding the use of machinery when the soils are wet. Keep the number of trips across a field to a minimum and follow the same wheel tracks for all operations, if posssible.
- Decrease the formation of crusts by maintaining plant cover or by practicing residue management to reduce the impact of raindrops. Use a rotary hoe or row cultivator to shatter crust.
- Increase the amount of organic materials added to the soil to increase the stability of soil aggregates.
- Decrease or eliminate tillage operations to help maintain surface connected pores and encourage biological activity.

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(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA).

Soil Quality Information Sheet

Soil Quality Indicators: Organic Matter

USDA Natural Resources Conservation Service **April 1996**

What is soil organic matter?

Soil organic matter is that fraction of the soil composed of anything that once lived. It includes plant and animal remains in various stages of decomposition, cells and tissues of soil organisms, and substances from plant roots and soil microbes. Well-decomposed organic matter forms *humus*, a dark brown, porous, spongy material that has a pleasant, earthy smell. In most soils, the organic matter accounts for less than about 5% of the volume.

What does organic matter do?

Organic matter is an essential component of soils because it:

- provides a carbon and energy source for soil microbes;
- stabilizes and holds soil particles together, thus reducing the hazard of erosion;
- aids the growth of crops by improving the soil's ability to store and transmit air and water;
- stores and supplies such nutrients as nitrogen, phosphorus, and sulfur, which are needed for the growth of plants and soil organisms;
- retains nutrients by providing cation-exchange and anion-exchange capacities;
- maintains soil in an uncompacted condition with lower bulk density;
- makes soil more friable, less sticky, and easier to work;
- retains carbon from the atmosphere and other sources;
- reduces the negative environmental effects of pesticides, heavy metals, and many other pollutants.

Soil organic matter also improves tilth in the surface horizons, reduces crusting, increases the rate of water infiltration, reduces runoff, and facilitates penetration of plant roots.

Where does it come from?

Plants produce organic compounds by using the energy of sunlight to combine carbon dioxide from the atmosphere with water from the soil. Soil organic matter is created by the cycling of these organic compounds in plants, animals, and microorganisms into the soil.

What happens to soil organic matter?

Soil organic matter can be lost through erosion. This process selectively detaches and transports particles on the soil surface that have the highest content of organic matter.

Soil organic matter is also utilized by soil microorganisms as energy and nutrients to support their own life processes. Some of the material is incorporated into the microbes, but most is released as carbon dioxide and water. Some nitrogen is released in gaseous form, but some is retained, along with most of the phosphorus and sulfur.

When soils are tilled, organic matter is decomposed faster because of changes in water, aeration, and temperature conditions. The amount of organic matter lost after clearing a wooded area or tilling native grassland varies according to the kind of soil, but most organic matter is lost within the first 10 years.

Rates of decomposition are very low at temperatures below 38 ^{O}F (4 ^{O}C) but rise steadily with increasing temperature to at least 102 ^{o}F (40 ^{o}C) and with water content until air becomes limiting. Losses are higher with aerobic decomposition (with oxygen) than with anaerobic decomposition (in excessively wet soils). Available nitrogen also promotes organic matter decomposition.

What controls the amount?

The amount of soil organic matter is controlled by a balance between additions of plant and animal materials and losses by decomposition. Both additions and losses are very strongly controlled by management activities.

The amount of water available for plant growth is the primary factor controlling the production of plant materials. Other major controls are air temperature and soil fertility. Salinity and chemical toxicities can also limit the production of plant biomass. Other controls are the intensity of sunlight, the content of carbon dioxide in the atmosphere, and relative humidity.

The proportion of the total plant biomass that reaches the soil as a source of organic matter depends largely on the amounts consumed by mammals and insects, destroyed by fire, or produced and harvested for human use.

Practices decreasing soil organic matter include those that:

1. **Decrease the production of plant materials by**
   - replacing perennial vegetation with short-season vegetation,
   - replacing mixed vegetation with monoculture crops,
   - introducing more aggressive but less productive species,
   - using cultivars with high harvest indices,
   - increasing the use of bare fallow.

2. **Decrease the supply of organic materials by**
   - burning forest, range, or crop residue,
   - grazing,
   - removing plant products.

3. **Increase decomposition by**
   - tillage,
   - drainage,
   - fertilization (especially with nitrogen).

Practices increasing soil organic matter include those that:

1. **Increase the production of plant materials by**
   - irrigation,
   - fertilization to increase plant biomass production,
   - use of cover crops
   - improved vegetative stands,
   - introduction of plants that produce more biomass,
   - reforestation,
   - restoration of grasslands.

2. **Increase supply of organic materials by**
   - protecting from fire,
   - using forage by grazing rather than by harvesting,
   - controlling insects and rodents,
   - applying animal manure or other carbon-rich wastes,
   - applying plant materials from other areas.

3. **Decrease decomposition by**
   - reducing or eliminating tillage,
   - keeping the soil saturated with water (although this may cause other problems),
   - keeping the soil cool with vegetative cover.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA). Animal waste photo courtesy University of Nebraska-Lincoln, Institute of Agriculture and Natural Resources

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Soil Quality Information Sheet

Soil Quality Indicators: pH

USDA Natural Resources Conservation Service January 1998

What is pH?

Soil pH is a measure of the acidity or alkalinity in the soil. It is also called soil reaction.

The most common classes of soil pH are:

Extremely acid	3.5 – 4.4
Very strongly acid	4.5 – 5.0
Strongly acid	5.1 – 5.5
Moderately acid	5.6 – 6.0
Slightly acid	6.1 – 6.5
Neutral	6.6 – 7.3
Slightly alkaline	7.4 – 7.8
Moderately alkaline	7.9 – 8.4
Strongly alkaline	8.5 – 9.0

What is the significance of pH?

Availability of Nutrients
Soil pH influences the solubility of nutrients. It also affects the activity of micro-organisms responsible for breaking down organic matter and most chemical transformations in the soil. Soil pH thus affects the availability of several plant nutrients.

A pH range of 6 to 7 is generally most favorable for plant growth because most plant nutrients are readily available in this range. However, some plants have soil pH requirements above or below this range.

Soils that have a pH below 5.5 generally have a low availability of calcium, magnesium, and phosphorus. At these low pH's, the solubility of aluminum, iron, and boron is high; and low for molybdenum.

At pH 7.8 or more, calcium and magnesium are abundant. Molybdenum is also available if it is present in the soil minerals. High pH soils may have an inadequate availability of iron, manganese, copper, zinc, and especially of phosphorus and boron.

Micro-organisms
Soil pH affects many micro-organisms. The type and population densities change with pH. A pH of 6.6 to 7.3 is favorable for microbial activities that contribute to the availability of nitrogen, sulfur, and phosphorus in soils.

Pesticide Interaction
Most pesticides are labeled for specific soil conditions. If soils have a pH outside the allowed range, the pesticides may become ineffective, changed to an undesirable form, or may not degrade as expected, which results in problems for the next crop period.

Mobility of heavy metals
Many heavy metals become more water soluble under acid conditions and can move downward with water through the soil, and in some cases move to aquifers, surface streams, or lakes.

Corrosivity
Soil pH is one of several properties used as a general indicator of soil corrosivity. Generally, soils that are either highly alkaline or highly acid are likely to be corrosive to steel. Soils that have pH of 5.5 or lower are likely to be highly corrosive to concrete.

What controls soil pH?

The acidity or alkalinity in soils have several different sources. In natural systems, the pH is affected by the mineralogy, climate, and weathering. Management of soils often alters the natural pH because of acid-forming nitrogen fertilizers, or removal of bases (potassium, calcium, and magnesium). Soils that have sulfur-forming minerals can produce very acid soil conditions when they are exposed to air. These conditions often occur in tidal flats or near recent mining activity where the soil is drained.

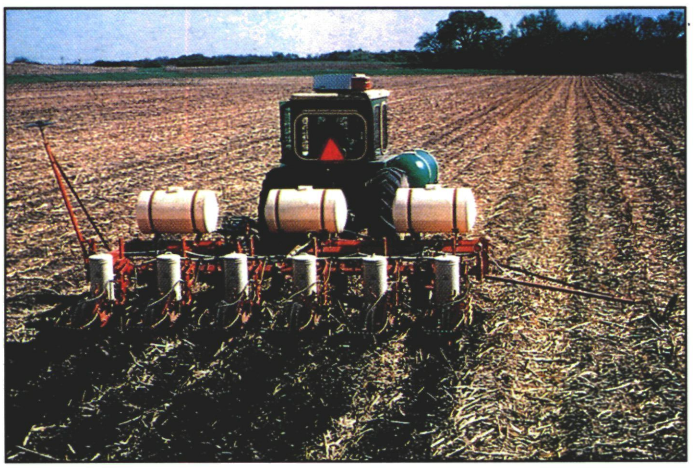
The pH of a soil should always be tested before making management decisions that depend on the soil pH.

How is pH measured?

A variety of kits and devices are available to determine the pH in the field. The methods include:

- dyes
- paper strips
- glass electrodes.

Soil pH can change during the year. It depends on temperature and moisture conditions, and can vary to as much as a whole pH unit during the growing season. Since pH is a measure of the hydrogen ion activity [H^+], many different chemical reactions can affect it. Temperature changes the chemical activity, so most measurements of pH include a temperature correction to a standard temperature of 25 degrees C (77°F). The soil pH generally is recorded as a range in values for the soil depth selected.



(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA).

How is soil pH modified?

A soil pH below about 5.6 is considered low for most crops. Generally, the ideal pH range is between 6.0 and 7.0. Liming is a common method to increase the pH. It involves adding finely ground limestone to the soil. The reaction rate for limestone increases when soil temperatures are warm and soil moisture is high. If the limestone is more finely ground, the reaction is faster.

The amount of limestone to apply depends on the amount of organic matter and clay as well as the pH. Fertility testing laboratories that have local experience make this determination.

A soil pH that is more than about 8.0 is considered high for most crops. Soils that have a pH in this range are often also calcareous.

Calcareous soils have a high content of calcium carbonate. The pH of these soils does not change until most of the calcium carbonate is removed. Acids that are added to the soil dissolve the carbonates and lower the soil pH. Treatments with acid generally are uneconomical for soils that have a content of calcium carbonate of more than about 5%. Because phosphorus, iron, copper, and zinc are less available to plants in calcareous soils, nutrient deficiencies are often apparent. Applications of these nutrients are commonly more efficient than trying to lower the pH.

When the soil pH is above 8.6, sodium often is present. These soils generally do not have gypsum or calcium carbonates, at least not in the affected soil horizons. Addition of gypsum followed by leaching using irrigation is a common reclamation practice. However, salts flushed into drainage water may contaminate downstream waters and soils.

The application of anhydrous ammonia as a nitrogen fertilizer contributes to lowering the soil pH. In some parts of the country, applications of ammonia lower the surface soil pH from ranges of 6.6 to 7.3 to below 5.6. This reduction can be easily overlooked in areas of no-till cropping unless the pH is measured in the upper 2 inches.

Chemical amendments that contain sulfur generally form an acid, which lowers the soil pH.

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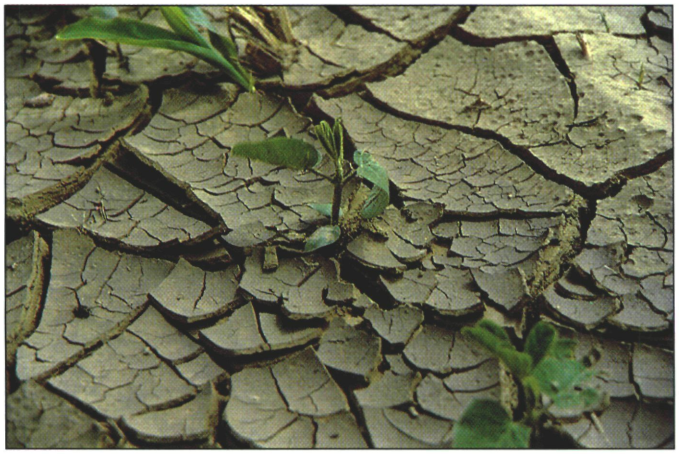
Soil Quality Information Sheet

Soil Quality Indicators: Soil Crusts

USDA Natural Resources Conservation Service **April 1996**



What are soil crusts?

Soil crusts are relatively thin, somewhat continuous layers of the soil surface that often restrict water movement, air entry, and seedling emergence from the soil. They generally are less than 2 inches thick and are massive.

Crusts are created by the breakdown of structural units by flowing water, or raindrops, or through freeze-thaw action. Soil crusts are generally only a temporary condition. Typically, the soil immediately below the surface layer is loose.

Why are soil crusts a concern?

Crusts reduce infiltration and increase runoff. Rainfall and sprinkler irrigation water impart a large amount of impact energy onto the soil surface. If the soil is not protected by a cover of growing plants, crop residue or other material, and if soil aggregates are weak, the energy can cause a soil crust to form.

If a crust forms, individual soil particles fill the pore space near the surface and prevent the water from entering (infiltrating) the soil. If the infiltration is limited, water accumulates and flows down slope, causing movement of soil particles. Thus water erosion is initiated.

Crusts restrict seedling emergence. The physical emergence of seedlings through a soil crust depends on the:

- thickness of the crust,
- strength of the crust,
- size of the broken crust pieces,
- water content, and
- type of plant species. Non-grass plant species, such as soybeans or alfalfa, exert less pressure under identical conditions than grasses such as corn.

Crusts reduce oxygen diffusion to seedlings. Seed germination depends on the diffusion of oxygen from the air through the soil. If soil crusts are wet, oxygen diffusion is reduced as much as 50 percent.

Crusts reduce surface water evaporation. The reflectance of a crusted surface is higher than that for an uncrusted surface. Higher reflectance results in less absorption of energy from the sun. This results in a cooler soil surface and decreases the rate of evaporation.

Crusts decrease water loss because less of their surface area is exposed to the air than a tilled soil. When crusts become dry, they become barriers to evaporation by retarding capillary movement of water to the soil surface.

Crusts affect wind erosion. Crusts increase wind erosion in those soils that have an appreciable amount of sand. Rainfall produces clean sand grains that are not attached to the soil surface. These clean sand grains are subject to movement by air along the smooth surface of the crust. The sand breaks down the crust as it moves across the soil surface. Cultivation to break the crust and increase the surface roughness reduces wind erosion on sandy soils.

For soils that have a small amount of sand, crusts protect the soil surface and generally decrease the hazard of wind erosion.

How do crusts form?

Soil crusts and associated cracks form by raindrop impact or freeze-thaw processes.

Raindrop impact breaks soil aggregates, moves clay downward a short distance leaving a concentration of sand and silt particles on the soil surface.

Raindrop-impact crusts break down to a granular condition in many soils that have a high shrink-swell potential and experience frequent wetting and drying cycles.

Freeze-thaw crusts are formed by the puddling effect as ice forms, melts, and reforms. The temperature and water regimes and parent material control freeze-thaw crust formation. These crusts are generally 3/8- to 5/8-inch thick, compared to 1/4-inch commonly for raindrop-impact crusts.

The size and behavior on wetting of cracks associated with raindrop-impact and freeze-thaw crust differ. Both extend to the base of the crust. The cracks in raindrop-impact crust are 1/4 inch wide. They close on wetting and hence are ineffective in increasing infiltration. The cracks in freeze-thaw crust are 1/4- to 3/4-inch wide. They do not close on wetting and hence increase infiltration.

How are soil crusts measured?

Soil crusts are characterized by their thickness and strength (air dry rupture resistance). Crust air dry rupture resistance can be measured by taking a dry piece about 1/2 inch on edge and applying a force on the edge until the crust breaks. In general, more force is required for crusts that are thick and have a high clay content. Other means of measurement, such as a penetrometer, may be used.

How can the problem be corrected?

- Maintain plant cover or crop residues on the soil surface to reduce the impact of raindrops.

- Adopt management practices that increase aggregate stability.

- Use practices that increase soil organic matter content or reduce concentrations of sodium ions.

- Use a rotary hoe or row cultivator to shatter crusts and thus increase seedling emergence and weed control.

- Employ sprinkler water to reduce restriction of seedling emergence.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA). Soil crust photo courtesy of University of Nebraska-Lincoln, Institute of Agriculture and Natural Resources.

Virginia Cooperative Extension

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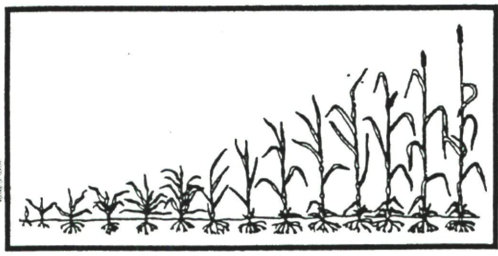


Crop & Soil Environmental Sciences

PUBLICATION 424-026

Nitrogen Management for Winter Wheat: Principles and Recommendations

M. M. Alley, D.E. Brann,
J. L. Hammons, Peter Scharf, and W. E. Baethgen*

Introduction

Efficient nitrogen (N) fertilization is crucial for economic wheat production and protection of ground and surface waters. Excessive plant-available N produces wheat plants that are susceptible to lodging and disease with resulting decreased yields and increased input costs. The potential for enrichment of ground and surface waters with nitrates also increases with excessive N fertilizer applications. However, insufficient N availability to wheat plants results in low yields and significantly reduced profits compared to a properly fertilized crop. Nitrogen fertilizer rate and timing are the major tools available after planting to manipulate wheat to produce higher yields per acre. Nitrogen affects heads/sq. ft., seeds/head, and kernel size. A harvest objective with current varieties grown in Virginia should be 60-70 heads/sq. ft. with at least 30 kernels/head. Our wheat fertility research program has been concentrating during the last several seasons on proper N fertilization because of the major role this nutrient plays in profitable wheat production and environmental concerns. This paper reports on our current conclusions and recommendations with regard to N fertilization of wheat.

General Principles

Autumn

The winter wheat plant has a generalized N uptake pattern that is depicted by the curve shown in Fig. 1. A crop that is planted on time for a particular location germinates, emerges, and tillers prior to the dormancy period that generally begins in December in Virginia. Dry matter production and thus N requirement is rather low during the autumn, but N is required to establish the crop and promote the production of fall tillers. Fall tillers are those that will begin growth first in the spring, and generally produce heads with more kernels. Root systems are also developed in the autumn, and are generally larger than the top growth. Well-developed roots reduce winter-kill and prepare the plant to efficiently utilize nutrients and moisture from the soil. Nitrogen fertilization in excess of the amount which the plant can utilize prior to dormancy creates the potential for leaching losses of the N. Plants with excessive fall growth are also more susceptible to disease infection and winter-kill. Hence, a moderate amount (15-30 lbs of N/acre) is all that is needed for establishing a timely-planted winter wheat crop.

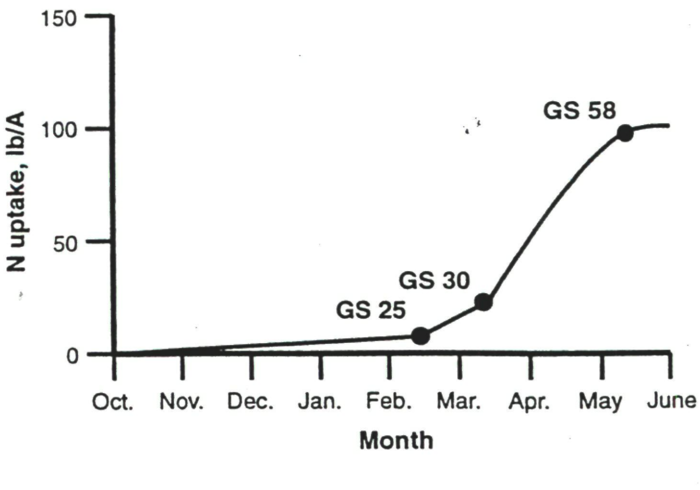


Figure 1. Nitrogen uptake pattern for winter wheat grown in the Coastal Plain region of Virginia.

*Soil and Crop Management Research, Extension Agronomist, and Field Research Supervisor, respectively, Virginia Tech; Extension Specialist, Soil Fertility, University of Missouri and Soil Scientist, International Fertilizer Development Center, Alabama, respectively

Winter

The wheat crop utilizes very little N during winter dormancy. Nitrogen applied early in the dormancy period is subject to leaching and/or run-off losses. Applying large amounts of N during January on frozen ground, and expecting this N to be available for producing grain in April and May, is not reasonable because of our climatic conditions and the growth pattern of wheat. However, there are situations, particularly on very sandy soils in the Coastal Plain region, in which a small N application in January may be beneficial. If all of the following conditions are met, some N fertilization in January may be useful. First, significant leaching rains between October and December, for example, > 3.5 inches of precipitation during one rainfall event. Second, a thin stand of wheat with pale green color due to lack of available N. Third, an expectation for the specific site that several growing days (temperatures of 50°F or greater) will occur in January and early February. Temperatures in January will likely exceed 50°F several days in the Coastal Plain and Southern Piedmont areas, but not in Northern Virginia or the Valley region. Such conditions might warrant an application of 30 lbs of N per acre to encourage tillering and root growth. However, potential losses to the environment are great with such applications, and they should be made only after careful consideration of the specific field conditions, and the N application should not exceed 30 lbs N/acre.

Late Winter/Early Spring

The wheat crop breaks dormancy in late February/ early March in most areas of Virginia. As growth begins so does the crop's requirement for N. Late winter/early spring growth is characterized by further tillering of the crop prior to stem elongation (Zadoks growth stage 30, Figure 2). Since the initial growth is usually rather slow because of cool temperatures, the initial N fertilizer application should be as near to the initiation of growth as it is possible to estimate for the specific site. It is important, however, to realize that fields with low tiller numbers should receive the first N applications so that spring tiller production is not delayed due to a lack of plant-available N. Reference to Figure 1 shows that N uptake is usually not great during the period of mid-February to mid-March. Again, this closely matches the growth or dry-matter production pattern for the crop.

Excessive N applications during the early-spring tillering phase can result in spindly plants that are more likely to lodge and be susceptible to diseases such as powdery mildew. Nitrogen applications during this period should not exceed 60 lbs N/acre if split-spring N applications are planned. Applications greater than 60 lbs N/acre during late winter have not increased yields when followed with appropriate N fertilization at GS 30.

Stem Elongation

The leaf sheath erection growth phase, GS 30, signals the beginning of stem elongation and the most rapid phase of wheat growth. Two important factors are occurring during this time. First, the potential number of kernels per head is being established during the embryonic formation of the head. Second, rapid N uptake begins (Figure 1).

Management must now be directed to maintaining developing heads. Inadequate available N causes tiller abortion with resulting lowered harvest population. Some tillers will always be lost. However, stands with marginal populations at the end of tillering are likely to have lower yields due to low numbers of heads/sq. ft. at harvest.

The initial phase of head development is occurring at GS 30. The late winter/early spring N application should be adequate to develop the embryonic head. Visually, the crop should have a medium to dark green color and be vigorously growing by GS 30. If the crop is beginning to show signs of chlorosis (yellowing), then the application of N at this stage is critical for the development of adequate head size. Priority should be given to N treatments for crops showing a lack of adequate N at this stage of growth. The question of N fertilizer amounts at this growth stage will be discussed in a later section of this report.

Finally, GS 30 indicates that the wheat plant is about to embark on its most rapid period of vegetative growth in order to build a structure for producing carbohydrate to fill the grain. Figure 1 clearly illustrates the large N uptake from the beginning of April (approximately GS 30) through the first two weeks of May (flowering) for a well-fertilized crop grown under Virginia climatic conditions. Nitrogen fertilizer management must provide for the crop requirement during this phase in order to have adequate leaf area for producing profitable yields. Also, there is very little chance for leaching loss of N fertilizer applied near the beginning of this growth phase due to the extensive nature of the wheat root system by GS 30, relatively high rates of evapotranspiration, and the large amount of N uptake during this time period.

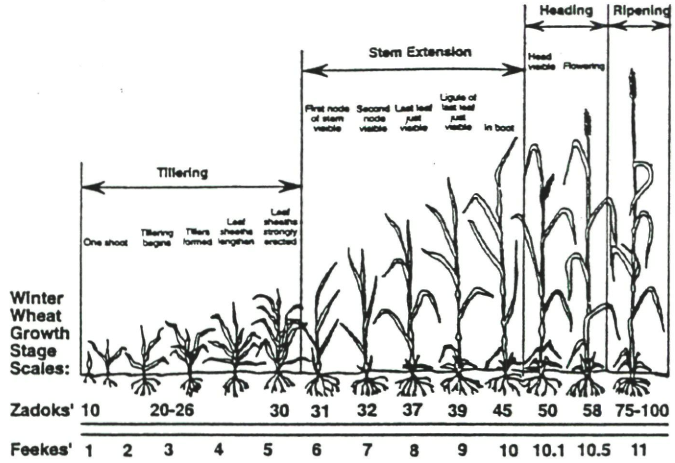


Figure 2. Growth stages of wheat according to the Zadoks and Feekes scales.

Grain Fill

Nitrogen uptake during the grain-fill period (Figure 1, early May through June) is relatively low compared to uptake during the stem elongation phase of growth. Plant tissue N is mobilized and translocated to the grain during this period with only small additions coming from available soil N. Our research has shown no yield increases from N fertilizer applications at or after flowering. Foliar applications (10 to 20 lbs N/acre) of urea at this growth stage have been shown to increase grain protein but not yield. If such applications are made, they should be made in sufficient volumes of water (20 to 30 gallons/acre) to reduce the potential for foliar burn.

N Fertilizer Recommendations

Our N fertilizer rate recommendations are based on research in which a significant amount of variability was observed—at some locations optimum N rates were 20 lb higher or 20 lb lower than those indicated by the graphs in this section. Past experience with a particular field or the climatic conditions of a particular year are legitimate reasons to adjust the N rate recommendations obtained from the graphs.

Autumn

Plant available N is needed in the surface soil during the germination and development of the wheat seedling in order to promote tillering and root development. Observations have shown that if soil nitrate levels are less than 10 ppm NO_3^--N in the top 6 inches of soil, the emerging seedlings are likely to exhibit N deficiency symptoms. Extractable nitrate levels of 30 ppm NO_3^--N in the surface 6 inches of soil indicate a high level of N availability and no fertilizer N application is required.

Apply 15 to 30 lbs N/acre just before planting to stimulate tillering and root development in those situations where residual N availability is less than desired. The N fertilizer should be incorporated in the surface 2 to 4 inches for conventional tillage systems. Surface applications have been found to be adequate for no-till.

Late Winter/Early Spring N Applications

The flow chart in Fig. 3 summarizes our overall approach to determining the optimum economic late winter/early spring N rates for winter wheat. The system relies on tests which are field specific and is flexible to be able to be used by growers who will split their late winter/early spring N applications as well as those growers who choose not to split their N fertilizer application. As shown in Figure 3, all growers, whether they plan to split their N or not, should start by making tiller counts to determine whether an early N application is needed to stimulate tiller development. The rate of the first application of a split is based on a tiller count and the rate of the second application is based on a tissue test. For growers not willing to split, when tiller numbers are low a single application should be made at growth stage 25 with rate based on a soil nitrate test; and when tiller numbers are adequate a single application should be made at growth stage 30 with rate based on a tissue test.

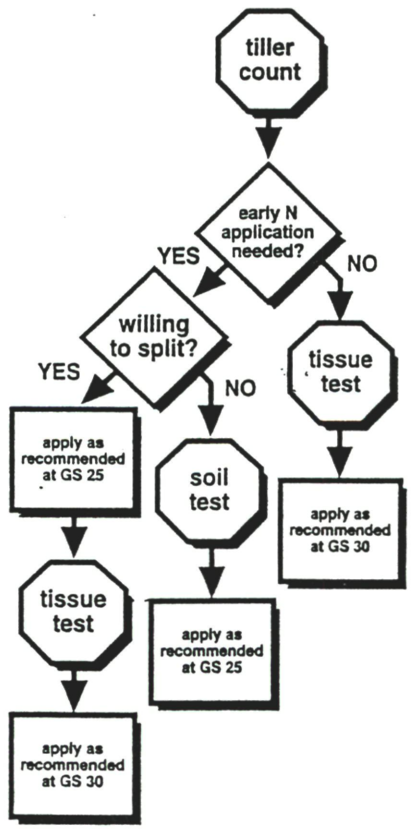


Figure 3. Flow chart showing how to obtain field-specific N rate recommendations for late winter/early spring N applications. A tiller count should be the first step in all fields, regardless of whether spring N applications will be split or not; then follow the arrows.

First application in a split

The first application in a split is made when the wheat crop breaks dormancy and begins active growth. This usually occurs in late February in Virginia, and is also known as growth stage 25 (GS 25) or "spring greenup." The purpose of the first N application in a split is to stimulate formation of additional tillers when such stimulation is necessary to achieve optimum tiller density. The main nutritional needs of the crop will be supplied by the second application in the split.

Our rate recommendation for the first application in a split is based on tiller density measurements. To measure tiller density,

1) cut a dowel rod to a 3-foot length
2) lay the dowel down next to an average-looking row and count **all** tillers with three or more leaves that are found in the 3-foot length; record this number
3) repeat this count in **at least** five other locations that are well-spaced around the field
4) average all tiller counts from the field
5) calculate tiller density (in tillers per square foot) with the following equation: tiller density=average tiller count x 4 / row width (in inches)

Use the graph in Figure 4 to get a rate recommendation from the tiller density measurement. If tiller numbers are low, 50/sq. ft. or less, N fertilization at this time is critical for the crop to develop any reasonable yield potential. Fields with low tiller counts should be fertilized before fields with more tillers, if possible. If tiller numbers are high, 100/sq. ft. or more, no N application is needed at this time. When winter rainfall/precipitation is above average and may have lowered the level of residual soil N, you should consider adjusting the recommendation upward.

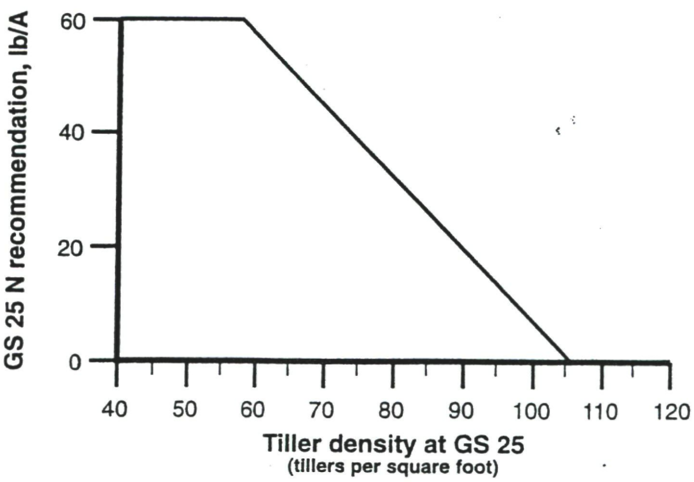


Figure 4. N rate recommendations for the first application in a split based on tiller density measurements.

Second application in a split

The second application in a split is made just prior to the period of maximum N uptake (Figure 1). Its purpose is to supply the main nutritional needs of the crop to the extent that they are not already satisfied by soil N and the first N application (if any).

Eight years of research in Virginia has shown that tissue N content at growth stage 30 (GS 30) is a reliable indicator of how much additional N fertilizer is needed to ensure that the nutritional needs of the crop are met. Use the graph in Figure 5 to obtain a rate recommendation from tissue test results. Up to 120 lbs N/acre may be applied at growth stage 30 if no N was applied at growth stage 25 (due to high tiller density) and tissue N measured at growth stage 30 is low. Total spring N applications (growth stage 25 plus growth stage 30) should not exceed a total of 120 lbs N/acre in order to avoid problems with lodging and yield loss. For example, if 40 lbs N/acre was applied at growth stage 25, and tissue test results give a recommendation from Figure 5 of 100 lbs N/acre at growth stage 30, only 80 lbs N/acre should be applied at growth stage 30.

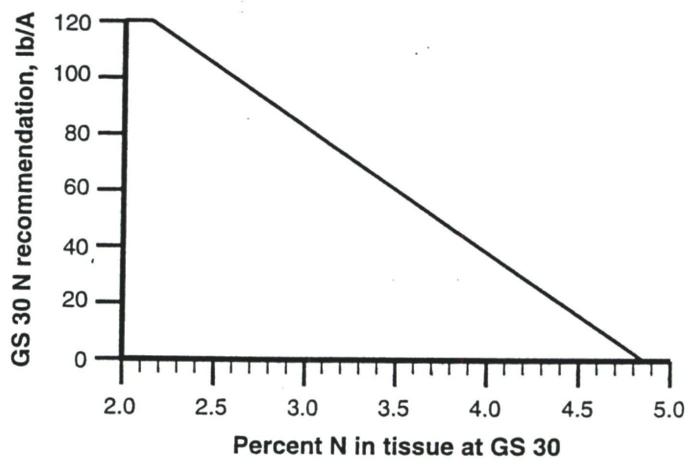


Figure 5. N rate recommendations for the second application in a split or a single late application based on tissue N content at growth stage 30.

The first requirement for obtaining a good plant tissue sample for use in estimating N fertilizer requirement at GS 30 is to be certain that the wheat is in growth stage 30. Figure 2 illustrates the various growth stages of wheat according to the Zadoks and Feekes scales. Growth stage 30 is when the leaf sheaths of the wheat are strongly erected and splitting the stem shows a hollow internode area about 1/2 inch in length. GS 31 has been reached when the first node of the stem is visible at the base of the plant (Figure 2). Sampling at the correct stage of growth is very important. Rapid growth during this time results in the N content being diluted by increases in dry matter production. Samples taken earlier than GS 30 will generally show higher concentrations of N than will be found at GS 30. If these higher %N values were used for predicting the N fertilizer needed on a given field, a less than optimum N fertilizer recommendation would result. Samples taken after GS 30 will usually show lower percent N concentrations which can result in higher than needed N fertilizer recommendations. Thus, proper identification of GS 30 is essential to making good use of this system.

A representative tissue sample from the field is essential for accurately predicting fertilizer N requirement at GS 30. Obtaining a representative tissue sample is similar to obtaining a representative soil sample. Unusual areas of the field should be avoided. If major differences in top-growth and apparent residual N availability are evident in large areas of the field, the areas should be sampled (and fertilized) separately.

The sample is taken by cutting a handful of wheat tissue at 20 to 30 representative areas in the field. The top-growth should be cut at approximately 1/2 inch above ground; soil particles clinging to the tissue must be brushed from the tissue; and dead leaf tissue must be removed from the sample. The individual samples should be placed in a paper bag large enough to allow good mixing of the tissue.

After thorough mixing of the tissue sample, take approximately three handfuls of tissue from the mixed sample and place in the sample bag provided by the laboratory, or in a clean paper bag. Samples should go directly to the laboratory. If samples cannot be analyzed within 24 hours from the time they are taken, they must be dried to prevent spoilage. Tissue samples should never be packaged in plastic bags due to condensation that can initiate sample decay.

The plant tissue sample taken at GS 30 can also be analyzed for nutrients other than N. These analyses can be useful in detecting nutritional problems which can possibly be corrected at the time of making the GS 30 N application. The following table contains values for sufficiency levels of selected nutrients. These values are considered sufficient based on limited research and numerous observations of data from tissue samples taken at GS 30 in intensive wheat management demonstrations.

Table 1. Nutrient sufficiency levels from whole wheat plant tissue samples taken at GS 30.

	Nutrient							
	S*	P	K	Mg	B	Zn	Mn	Cu
	%				ppm			
"Sufficient level"	0.25	0.25	2.0	0.10	3	12	20	3

**An N/S ratio of less than 15 indicates adequate sulfur content in relation to N content of the tissue.*

In situations where heavy rains occur during the several weeks prior to taking the GS 30 tissue sample, recommendations should probably be adjusted upward. This is especially true on sandy-textured soils. Situations in which a downward adjustment of the recommendation should be considered include soils that have received manure or sludge applications, soils with high organic matter levels, and clayey-loamy textured soils.

Single-application management

Split spring N applications often produce higher yields than can be produced with any rate or timing in a single application. We recommend splitting spring N applications wherever possible. However, logistical reasons prompt some growers to make only a single late winter/early spring N application on some or all of their wheat acreage. Our observation is that, if you can split on only part of your acreage, splitting is more likely to be beneficial on sandier land. This is because leaching potential is greater on sandier land, and a large early application is more likely to be lost than on heavier-textured soils.

For the same reason, it is preferable to make single N applications late (growth stage 30) rather than early (growth stage 25). If a field is low in tillers, however, waiting until growth stage 30 (when tillering has ended) to make a single N application can seriously damage yield potential.

The first step in single-application N management is to determine whether there are an adequate number of tillers in a particular field. Count tillers and calculate tiller density as described in the above section, "First application in a split." If you have 90 or more tillers per square foot, we strongly recommend waiting until growth stage 30 and making a single N application then based on a tissue test. With 90 or more tillers per square foot, delaying your single application until growth stage 30 is beneficial not only because it reduces the chance of N loss by leaching, but because a single early application will result in too many tillers, leading to spindly shoots, too many leaves, and increased probability of disease and lodging. In most cases, a single N application at growth stage 30 is economically superior to a single application at growth stage 25 when tiller density is between 70 and 90 tillers/square foot at growth stage 25. How to take a tissue sample and obtain an N rate recommendation for growth stage 30 are described in the above section, "Second application in a split."

When tiller density at growth stage 25 is below 70 tillers/square foot, "single-shot" N applications should be made at growth stage 25. Fields with the lowest tiller densities should be fertilized first, where possible. The rate of N to be applied can be based on a measurement of soil nitrate to a 3-foot depth, as shown in Figure 6. This graph, while producing recommendations that are economically superior to a fixed rate of 80 lb N/acre, is not as reliable as the growth stage 30 tissue-test graph. This is another reason why a single late application is preferable when tiller numbers are adequate.

To measure soil nitrate (in lb N/acre) to 3 feet, sample cores should be taken with a Hoffer tube or similar apparatus to a 3-foot depth in at least 15 widely-spaced locations around the field. Avoid sampling from any unusual-looking areas. All cores should be mixed thoroughly in a bucket, then several large handfuls removed and stored in a labeled plastic bag. As soon as possible, spread the soil out to dry in a thin layer on brown paper. When dry, send to a lab for analysis. Convert ppm from lab results to lb N/acre by multiplying by 13. This factor assumes a bulk density of 1.6 g/cm^3, which is the average of measurements that we have made in fields cropped to winter wheat in the Coastal Plain.

If desired, samples may be divided into three 1-foot increments to determine the nitrate distribution in the soil profile. Results (in ppm) from each 1-foot layer should be multiplied by 4.4 to convert to lb N/acre. Also, we have found that the nitrate quick-test kits are reasonably accurate and can be used to measure soil nitrate on the farm instead of sending samples to a lab.

If soil nitrate levels are very high, i.e. 120 to 150 lbs nitrate-N per acre, then little if any yield response will be expected from applying additional fertilizer N in a single application program. Such soil nitrate levels are most likely to be found in loam and silt loam soils or soils with sandy surface textures and high levels of clay in the subsoil; tiller numbers for a timely planted crop will generally be high on these soils.

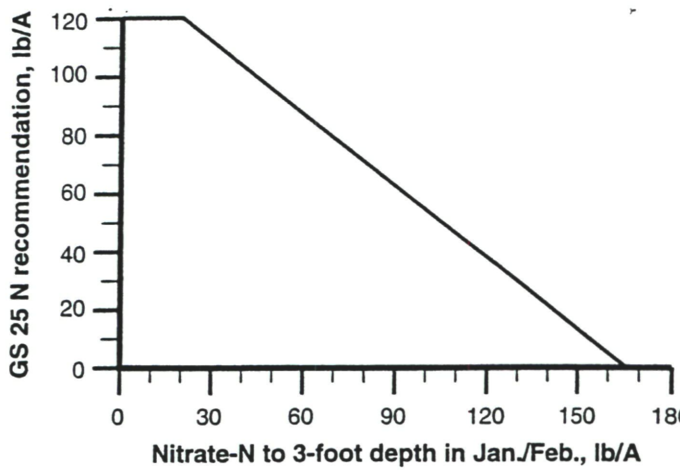
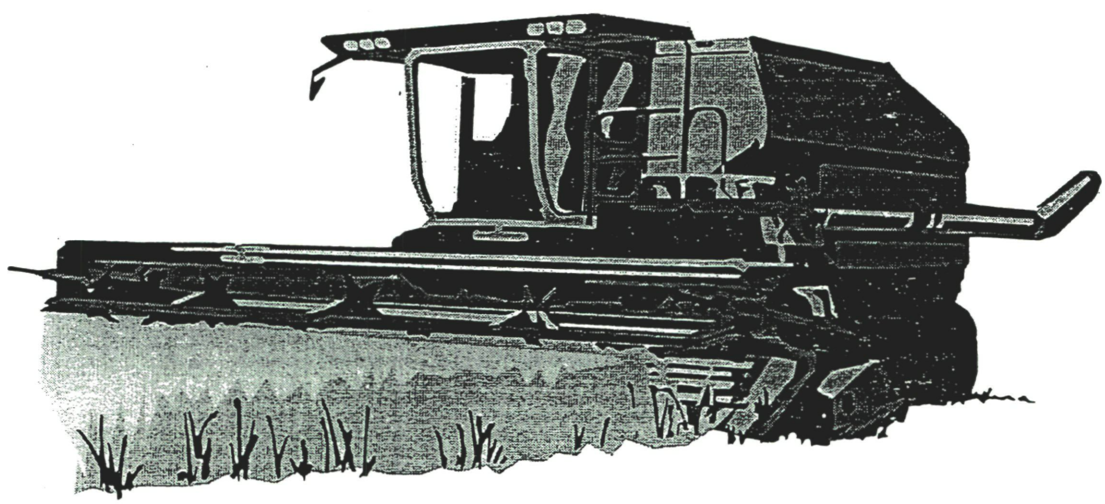


Figure 6. N rate recommendations for single early (growth stage 25) N applications based on soil nitrate to a 3-foot depth.

[1] Contribution of the Department of Crop & Soil Environmental Sciences, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061. This research was supported by grants from the USDA-CSRS Water Quality Research Program and the Virginia Department of Conservation and Historic Resources, Division of Soil and Water Conservation.

VIRGINIA TECH
ON-FARM SMALL GRAIN TEST PLOTS
Northern Neck and Middle Peninsulas
July 2001

A Summary of Replicated Research and Demonstration Plots
Conducted by Virginia Cooperative Extension
In Cooperation with Local Producers



CONDUCTED AND SUMMARIZED BY:

Keith Balderson, Extension Agent, Essex County
Paul Davis, Extension Agent, New Kent County
David Moore, Extension Agent, Middlesex County
Glenn Chappell, Extension Agent, Prince George County
Dan Brann, Extension Agronomist, Grains, Virginia Tech

FINANCIAL ASSISTANCE PROVIDED BY:
VIRGINIA SMALL GRAINS BOARD

AIGNER'S 2000-2001 WHEAT PLOTS
OAKLAND FARM, HENRICO, VA

Cooperators:	Louis and Randolph Aigner, Paul Davis, VCE/New Kent
Planted:	November 16, 2000
Soil Type:	Angie loam
Previous Crop:	No-Till Corn into surface applied biosolids
Tillage:	No-Till (8" row spacing) at 26 seed/ft. of row
Fertilizers:	Preplant: 30-30-144 – 5S
	Winter: 30# N February 1, 2001
	Spring: 30# N February 21, 200
Herbicides:	Axiom 8 oz. - November 18, 2000
Fungicides:	None
Insecticide:	None
Growth Regulators:	None
Harvest Date:	June 25, 2001

Tillage Study

	Treatments	**Yield bu/a**	**% Moisture**
Rep 1	Conventional	55.3	12.5
	No-Till (stalks chopped @ 3 mph)	55.1	12.2
	No-Till (stalks chopped @ 6 mph)	52.8	12.7
Rep 2	Conventional	65.0	12.6
	No-Till (3 mph)	51.9	12.6
	No-Till (6 mph)	57.9	12.7
Rep 3	Conventional	53.8	12.8
	No-Till (3 mph)	51.7	12.3
	No-Till (6 mph)	57.5	12.7
AVG	**Conventional**	**58.0**	**12.6**
	No-Till (3 mph)	**52.9**	**12.4**
	No-Till (6 mph)	**56.1**	**12.7**

Plant Population Study

	Treatments	**Yield bu/a**	**% Moisture**
Rep 1	26 seed/ft	69.2	13.3
	22 seed/ft	55.4	12.8
	30 seed/ft	64.2	12.8
Rep 2	26 seed/ft	59.2	12.7
	22 seed/ft	62.0	12.6
	30 seed/ft	61.4	12.4

Plant Population Continued

		Yield bu/a	%Moisture
Rep 3	26 seed/ft	58.8	12.3
	22 seed/ft	58.4	12.9
	30 seed/ft	60.1	13.1
Rep 4	26 seed/ft	53.3	12.4
	22 seed/ft	54.4	12.9
	30 seed/ft	57.5	12.8
AVG.	**26 seed/ft**	**60.1**	**12.8**
	22 seed/ft	**57.6**	**12.8**
	30 seed/ft	**60.8**	**12.8**

Date of Planting Study

	Treatments	Yield bu/a	% Moisture
Rep 1	Nov 16	46.5	11.9
	Nov 30	61.6	13.1
Rep 2	Nov 16	56.4	11.9
	Nov 30	66.2	13.2
Rep 3	Nov 16	53.6	13.0
	Nov 30	65.5	11.9
Rep 4	Nov 16	58.0	12.5
	Nov 30	59.8	11.8
AVG	**Nov 16**	**53.6**	**12.3**
	Nov 30	**63.3**	**12.5**

Discussion:
These 3 studies plus a poultry litter, speed of planting and foliar fungicide treatment plots were flagged off to be planted on October 11, 2000 but we thought it was too dry to plant. It did not rain until November 14 (34 days later) and we got less than .50 inch then. Planting conditions were still too dry to plant but we felt it was now or never, so we planted all 6 studies then came back on November 30 to plant the other date of planting plot. Between November 15 and November 30 we received 2 inches of rain so the November 30 planting had great moisture conditions thus a much better stand. By waiting for correct planting conditions, even though it was late November, yields were increased by 10 bu./ac.

The take home point from these studies is -- when planting No-Till small grain, soil moisture conditions are extremely important in getting a stand. Increasing the seeding rate up by 4 seeds/ft still did not make a significant difference. Take time to check and double check that your drill is getting the seed into the soil and not leaving it on the crop residue.

We plan on looking at these types of No-Till small grain plots across different soil types, crop residues, and No-Till drills again this fall.

WHEAT PRODUCTION WITH PRE-PLANT POULTRY LITTER VS. COMMERCIAL FERTILIZER PLOT
RIVERSIDE FARM, CHARLES CITY, VA

Producers:	Frank & Mick Hula
Cooperators:	Tom Hall, Chickahominy Ag. Services; Randy Shank, Extension/DCR; Vernon Health and Paul Davis/VCE Ag Agents
Planting Date:	4 November 2000
Variety:	FFR 555
Fertilizer:	Preplant - 25-80-80-S5 (Commercial Fertilizer plots only) Winter - 25 lbs. N/December Spring - 40 lbs N/February N P K Ca Mg
Poultry Litter:	2 tons/ac on 3 November 2000, analysis – plant available/ton: 29- 76- 42- 20-17
Soil Type:	Pamunkey, fine sandy loam
Tillage:	No-Till into cotton stubble
Previous Crop:	Cotton
Herbicides:	Axiom – 8 oz. at planting
Insecticides:	2 oz. Karate at planting + 2 oz. in April
Growth Regulator:	8 oz. Cerone
Harvested:	June 18, 2001

Treatments	% Moisture	Test wt.	Yield (bu/acre @ 13.5%)
2 tons Litter	13.2	58.0	86.9
2 tons Litter	13.5	58.0	85.0
Commercial Fertilizer	13.2	59.0	90.2
Commercial Fertilizer	13.4	59.5	93.4
2 tons Litter	13.3	57.5	89.9
2 tons Litter	13.5	58.0	89.7
AVG			
2 tons Litter	**13.4**	**58.0**	**87.9**
Commercial Fertilizer	**13.3**	**59.25**	**91.8**

Discussion:

There was no significant yield difference between the poultry litter and commercial fertilizer pre-plant applications. Soil nitrate samples and plant tissue samples at G.S. 30 were the same. The litter will cost between $10-$16/ton delivered and another $5-$8/ton spread. Unless you can work out a deal at the lower cost for delivery and spreading and/or you can pencil out a profit using litter you may want to wait for the supply to pile up and for the cost to become more affordable when selling $2.25/bu wheat. Please compare this data with other similar studies.

WHEAT PRODUCTION WITH PRE-PLANT POULTRY LITTER VS. COMMERCICAL FERTILIZER STUDY
GOOD LUCK FARM, CHARLES CITY, VA

Producers:	David & George Black
Cooperators:	Tom Hall, Chickahominy Ag. Services; Randy Shank, Extension/DCR; Vernon Heath and Paul Davis, VCE Ag. agents
Planted:	October 25, 2000
Soil Type:	Craven/Emporia, fine sandy loam
Variety:	Pioneer 2643
Previous Crop:	No-Till Corn
Tillage:	No-Till into standing corn stalks
Fertilizers:	Preplant: 40-80-80 (Commercial Fertilizer plots only) Winter: 60 lbs. N January Spring: 50 lbs N March
Poultry Litter:	2 tons/Ac on 11/2/00 N- P- K- Ca-Mg Analysis – Plant Available/ton 29-76-42-29-17
Herbicides:	2/3 oz. Harmony Extra – January w/ 60 lbs. N application
Fungicides:	4 oz. Tilt - April w/Warrior application
Insecticide:	2 oz. Warrior - April
Harvest Date:	June 21, 2001

	Treatments	Yield bu/A	% Moisture
Rep 1	2 tons litter	68.7	10.1
	Commercial fertilizer	54.6	10.4
Rep 2	2 tons litter	64.5	10.0
	Commercial fertilizer	56.9	10.1
Rep 3	2 tons litter	68.7	9.9
	Commercial fertilizer	53.8	10.1
AVG.	**2 tons litter**	**64.7**	**10.0**
	Commercial fertilizer	**55.1**	**10.2**

Discussion:

Plots were harvested with a calibrated yield monitor on the combine. Yields were running in the low 80's bu/ac range on the flat land but dropped down in the 40 and 50 bushel per acre range on the hill sides. The drop in yield was due to poor stands because of extremely dry soil conditions at planting and manganese deficiencies on the hillsides only. The 9.6 bushels per acre yield advantage on the litter plots is significant but the other variables such as stand and nutrient deficiency also played a role in the yields. Compare this study with Riverside Farms Poultry Litter plot where yields were not significantly different.

These studies show that poultry litter can be used successfully in growing a crop of wheat. The problem may be getting poultry litter delivered and spread at a price that is competitive with commercial fertilizers.

Agronomy Guide

Purdue University Cooperative Extension Service

SOILS/PHYSICAL CONDITION AY-279

Earthworms and Crop Management

Eileen J. Kladivko, Soil Scientist, Department of Agronomy

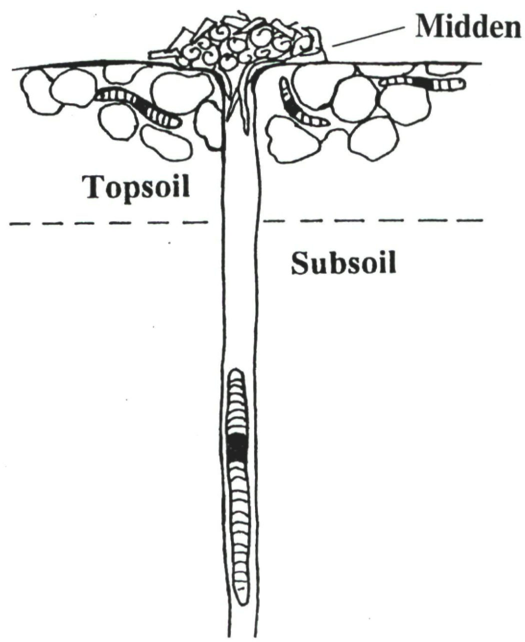
Earthworms have long been associated with healthy, productive soils. In his 1881 book entitled "The Formation of Vegetable Mould through the Action of Worms," the great biologist Charles Darwin stated that, "It may be doubted whether there are many other animals which have played so important a part in the history of the world, as have these lowly, organized creatures." Although earthworms are known to be beneficial to soils, their degree of importance in different agricultural systems is poorly understood. This publication provides basic information on earthworm ecology, the effects of earthworms on soil properties and processes, and the influence of soil management practices on earthworms. It concludes with a section on how to encourage the buildup of earthworm populations in agricultural fields, as well as some remaining questions that require further study.

General Ecology

There are thousands of species of earthworms in the world. Those that live in the soil can generally be grouped into three major behavioral classes: the litter-dwellers, shallow soil dwellers, and deep-burrowers. The litter-dwelling species live in the litter layer of a forest, for example, and are generally absent from agricultural fields. Typical agricultural fields may have one to five different shallow-dwelling species and perhaps one deep-burrowing species.

The deep-burrowers ("nightcrawlers") build large, vertical, permanent burrows that may extend 5 to 6 feet deep or more. They pull plant residues down into the mouth of their burrow, where the residues soften and can be eaten at a later time. Nightcrawlers construct *middens* over the mouth of their burrows. Middens are a mixture of plant residues and castings (worm feces) and probably serve as protection as well as a food reserve. Because nightcrawlers require residues at the surface to pull down into their burrows, we do not expect to find any nightcrawlers in fields which routinely leave no surface residue cover (i.e. moldboard-plowed). The species of nightcrawler in the north-central region is *Lumbricus terrestris*. The length of adult nightcrawlers is usually 4 to 8 inches or more.

Figure 1.



The shallow-dwelling worms (known as redworms, grayworms, fishworms, and many other names) are comprised of many species that live primarily in the top 12 inches of soil. Adult length is usually 3 to 5 inches. They do not build permanent burrows, but instead they randomly burrow throughout the topsoil, ingesting residues and mineral soil as they go. Because they do not require residues at the surface specifically, we do not expect them to be as sensitive to residue management as are the nightcrawlers. However, they are affected by the amount of surface mulch because of the impact on soil temperature and moisture extremes. This is discussed in more detail in the section on tillage.

Earthworms are seasonal in their activity. The shallow-dwellers are active in spring and fall but generally enter a resting state in summer and winter. As the soil starts to heat up and dry out in late spring (typically May in the North Central states), the shallow-dwellers move a little deeper (perhaps 18 inches), curl up in a ball, and secrete a mucus to try to keep from drying out. They spend most of the summer in that state. In fall, when the soil starts to cool and become wetter, they become active again, but then often enter into a hibernation state for the winter. The nightcrawlers also tend to be more active in spring and fall, but they may not go into a complete resting state in summer or winter since they can retreat to the bottom of their burrows during extremes of heat or cold. The best time to observe or count earthworm populations is early- to mid-spring (often April in North Central states), or late fall (November).

Earthworms have both male and female sexual organs. Most species require a partner for mating. During mating, sperm are exchanged and stored in one of the segments of the worm. The cocoon casing is then produced by the *clitellum* (the band seen on mature worms), and the worm "backs out" of the casing, depositing the sperm and eggs into the casing as it passes over the appropriate segments. The cocoon (2-4 mm in diameter) then incubates in the soil for several months, depending on soil conditions, before one young worm (or two for some species) emerges. New worms will generally only emerge when soil moisture and temperature conditions are suitable.

Effects on Soil Properties

The degree of importance of earthworms in maintaining soil and crop productivity will vary depending on circumstances. Earthworms are almost always beneficial, when present, but they may not be necessary. Some soils can be very productive without the presence of earthworms. The worms have sometimes been shown to improve crop growth and yield directly, but more often their activity affects crop growth indirectly through their effects on soil tilth and drainage.

Earthworms can have significant impacts on soil properties and processes through their feeding, casting, and burrowing activity. The worms create channels in the soil, which can aid water and air flow as well as root development. The shallow-dwelling worms create numerous small channels throughout the topsoil, which increases overall porosity and can help improve water and air relationships. Nightcrawlers create large vertical channels, which can greatly increase water infiltration under very intense rainfall or ponded conditions. Nightcrawler channels can also aid root proliferation in the subsoil, due both to the ease of root growth in a pre-formed channel and the higher nutrient availability in the cast material that lines portions of the burrow. Earthworm casts, in general, are higher in available nutrients than the surrounding mineral soil, because the organic materials have been partially decomposed during passage through the earthworm gut, converting the organic nutrients to more available forms.

Earthworms improve soil structure and tilth. Their casts are an intimate mixture of organic material and mineral soil and are quite stable after initial drying. The burrowing action of the worms moves soil particles closer together near burrow walls, and the mucus secreted by the worms as they burrow can also help bind the soil particles together. Increased porosity, plus mixing of residues and soil, are additional ways that earthworms improve soil structure.

The mixing of organic materials and nutrients in the soil by earthworms may be an important benefit of earthworms in reduced tillage systems, especially no-till. The earthworms may, in effect, partially replace the work of tillage implements in mixing materials and making them available for subsequent crops. In *natural* ecosystems such as forests, organisms recycle last year's leaf litter into the soil for release of nutrients. With no-till planting we may also depend more on earthworms and other soil organisms to do this mixing for us. It seems appropriate, therefore, to try to determine how we can manage soils to encourage the organisms and their activity.

Management Impacts on Earthworms

When we manage soils for crop production, we are also managing the habitat in which earthworms and other organisms live. Management practices affect earthworm populations by affecting food supply (location, quality, quantity), mulch protection (affects soil water and temperature), and chemical environment (fertilizers and pesticides). By considering how these factors are changed in different management systems, we can often predict the general effects on earthworm populations for systems that have not been studied.

Productive pasture fields will usually have much higher earthworm populations than row-cropped fields, primarily because of the large amounts of organic materials that are continually being added to the soil. Continuous root growth and subsequent death and decay, plus animal manure, provide a large food supply that can maintain high earthworm populations. In addition, the pasture plants act as a mulch to buffer the soil against rapid changes in temperature. Pasture fields are also not usually tilled, and thus burrow systems are left undisturbed.

Within row-cropping systems, using tillage systems which leave surface residue, is one of the most important ways that earthworm populations can be influenced. No-till systems usually have higher earthworm populations than do conventional moldboard plow systems, due to increased food supply and mulch protection. With residues on the soil surface, the food supply is available to the earthworms for a longer time than if residues are incorporated with a tillage implement. In addition, the surface residues act as a mulch and slow the rate of soil drying in late spring and freezing in late fall. This can lengthen the active periods for the worms, allowing them to feed and reproduce a little longer in both spring and fall. Surface residue also gives the earthworms more time to acclimate to the summer or winter and move down into their resting state. No-till is even more important for nightcrawlers than for the shallow-dwelling worms. Because nightcrawlers feed primarily on residues at the surface, pulling them into their permanent burrows, a clean-till system is not very conducive to nightcrawlers. The surface food supply is not present in plowed soils, and the top portion of the permanent burrow must be reformed after any tillage operation. Although a few nightcrawlers may be present in plowed fields, often they will not be present at all.

Tillage systems that are intermediate between the extremes of moldboard plowing and no-till will tend to have intermediate populations. The amount of surface residue cover is the key factor to consider when assessing different possible tillage practices for a field, as well as establishing conditions which encourage earthworm populations.

Data collected in Indiana and Illinois over the past 10 years confirms the generalizations just discussed. Earthworm populations were counted after 10 years of tillage plot history on a dark, poorly-drained silty clay loam soil near West Lafayette (Table 1). Very few worms were found in the continuous corn plots under either plow or no-till, and there were no statistically significant differences between the two treatments. Populations were surprisingly low and may have been affected by drought conditions the summer before the survey.

The continuous soybean plots had higher populations than continuous corn, with no-till having more than twice the worm population that moldboard plowing had. Earthworms generally prefer legumes as a food source over grasses, and this is probably the main reason for the higher populations found in the soybean plots. The continuous corn plots also received applications of corn rootworm insecticide and anhydrous ammonia, both of which can kill some earthworms. However, the effect of these chemicals on overall field populations of worms is probably small. Ammonia will kill a few worms right in the zone where it is injected, but some limited observations and counts before and after injection have suggested that less than 10% of the population is affected. Likewise, some corn rootworm insecticides kill earthworms, as can be seen by dead earthworms at the soil surface over the seed row. The overall effect on field populations is probably small, however, as long as the material is banded or in-furrow so that only a small zone of soil is affected. A rotation of corn and soybeans will generally have higher earthworm populations than continuous corn, probably due in part to elimination of the rootworm insecticide use, but mainly due to inclusion of a legume in the system.

Earthworm populations were much higher in a pasture than in the row-cropped fields (Table 1). Where the manure of the grazing animals was augmented by heavy applications of manure from the barnyard, populations were very high. Animal manures, sewage sludges, and other organic wastes will usually help build earthworm populations, although there may be an initial detrimental effect if there is a high concentration of ammonia in a slurry material.

Data from a poorly drained silt loam soil, low in organic matter, in southeastern Indiana illustrates some intermediate tillage practice effects as well as

Table 1. Earthworm populations on silty clay loam soil near West Lafayette, IN.

Crop[a]	Management[a]	Earthworms/m^2
Cont. corn	Plow	10
Cont. corn	No-till	20
Cont. soybeans	Plow	60
Cont. soybeans	No-till	140
Bluegrass-Clover	Alleyway	400
Dairy pasture	Manure	340
Dairy pasture	Manure (heavy)	1300

[a]Crop and management systems had been continuous for at least 10 years.

Table 2. Earthworm populations (April) under corn-soybean rotation on silt loam soil in southeastern IN.

Tillage	Earthworms/m2		
	1987	1988	1989
Chisel	—	44	67
Ridge-till	—	189	178
No-till	156	133	211

year-to-year variations (Table 2). Earthworm populations were counted in spring in a corn-soybean rotation. The fall chisel system had less worms than either ridge-till or no-till, due to much less residue cover. Ridge-till and no-till populations were comparable, with ridge-till having slightly more worms in 1988 and no-till slightly higher in 1989. *Populations will vary from year to year as well as within a year, due to weather conditions and food availability.* There were no nightcrawlers present in any of these plots.

In April 1992 earthworm populations were surveyed on 14 pairs of farmers' fields in central Indiana and Illinois. Each pair consisted of a no-till and tilled (usually chiseled) field on the same soil type, in a corn-soybean rotation, as close together as possible (usually less than 1 mile apart). Most of the no-till fields had been in no-till for at least 5 years. Soil types included two sandy loams, one loam, and the rest silt loams and silty clay loams. Shallow-dwelling earthworms were counted by excavating and hand-sorting soil. The presence or absence of significant nightcrawler populations was determined by observing whether nightcrawler middens were present in the field.

Results of the survey confirmed that no-till management generally leads to increases in earthworm populations. Eight of the 14 sites had higher populations in no-till than in tilled fields, with increases ranging from 25% higher to 10 times higher. Four sites had roughly equal populations under both systems, and two sites had slightly lower populations with no-till. Populations ranged from a low of 2 to a high of 340 earthworms per square meter over all the sites and tillage systems surveyed. In addition, nine no-till and only three tilled sites had significant nightcrawler activity, again confirming the strong influence of surface residues on nightcrawlers. We don't know whether or not the other no-till sites will develop nightcrawler populations after more time in the system.

Managed and/or ChemicallyTreated Fields

As discussed earlier, there are many conven' fields where nightcrawlers are completely absent, presumably due to lack of surface food supply. When these fields are switched to a no-till system, the habitat is better for the nightcrawlers, but the only way a population can get started is by overland movement from nearby places that have nightcrawlers, such as fencerows, roadsides, grass waterways, etc. This is a slow process and may take many years before a field is populated. In addition, not all roadsides and fencerows have nightcrawlers either, so there may not be a "source" of nightcrawlers adjacent to every field. Finally, we don't know whether or not nightcrawlers will survive in all soil types, so some fields may be unsuitable even when *managed* for the worms. Much more study and observation of nightcrawlers in agricultural fields is needed in order to answer these questions.

The impact of agricultural chemicals on earthworm populations varies with the chemical. Inorganic nitrogen fertilizers promote greater plant production than in unfertilized fields and therefore higher earthworm populations. Although anhydrous ammonia will kill a few worms in the narrow band where injected, field effects are probably minimal due to the small area affected. There is little information on other nitrogen sources commonly used in the Midwest, but effects are probably small when used at typical field rates. *Most herbicides used in crop production in the Midwest are harmless or only slightly toxic to worms and should not be a great concern.* As discussed earlier, some corn rootworm insecticides are toxic to worms, but their effects can be reduced by keeping the application band as narrow as possible. In general, the organophosphate and pyrethroid insecticides are harmless to moderately toxic, while the carbamate insecticides and fungicides are highly toxic. Nematicides in general are also highly toxic.

How to Encourage Earthworms

Earthworm populations can be increased by applying the concepts discussed earlier about food supply and surface mulch protection (Table 3). Leaving a surface mulch, by no-till or other conservation tillage systems with plenty of residue cover, will generally increase populations. Growing winter cover crops may augment the mulch protection as well as provide additional food for the worms. Adding or growing organic matter is a great way to build earthworm populations. Animal manures and sewage sludges, and rotations with hay or set-aside fields, are also possible ways to provide more food for the earthworms and help increase populations. Soil pH should be maintained between 6.0 and 7.0

Table 3. Methods to increase earthworm populations.

Leave surface mulch:	
	no-till
	ridge-till
	cover crops
Add or grow organic matter:	
	manure
	hay
	set-aside
	cover crops

for optimum conditions, although lower pH's are tolerated by most species. Although management can increase earthworm populations on many soils, some soils will not support high earthworm populations, regardless of management, due to inherent soil texture and drainage properties. Very coarse sands and perhaps high water table heavy clays are two examples.

The question often arises, "Is it worthwhile to "seed" earthworms in fields with low populations?" The first principle to remember is that the shallow-dwelling species are already established, and their current population is what can be supported by the current management system. If the management system is changed to something more suitable for the worms, their populations will increase quickly (1 or 2 years) to the level that can be supported by the new practices. Thus, there is little evidence to suggest that seeding these worms is worthwhile.

Nightcrawlers, however, may be a slightly different story. Since many conventional fields have no nightcrawlers present, a change in management from conventional to no-till does not guarantee that nightcrawlers will become established (see earlier discussion). Under these circumstances, there may be some benefit from establishing a few sources of nightcrawlers in the field, and several farmers have claimed success in establishing nightcrawlers in this way. Whether nightcrawlers would have established themselves in these fields without the farmer's assistance is not known. If you want to try this practice, collecting local nightcrawlers from country roads or pastures on rainy spring nights or mornings is a good way to start. Purchasing nightcrawlers is expensive, and they may not be adapted to local soils and climates. A small-scale, low-cost trial is highly advisable, since we don't know whether or not nightcrawlers will survive on all soils. Protect the worms from the sun, and place 4 or 5 together under some mulch or residue in a spot every 30 or 40 feet in the field, preferably on a cloudy, wet, cool day. Record the location of the seeded spots, and then observe those spots for evidence of midden activity over the year to determine whether the nightcrawlers survived and if the patches are growing.

Remaining Questions and Further Information

Many questions about earthworms and agricultural fields remain to be explored. How much do earthworms contribute to nutrient cycling and availability to an annual crop? How much improvement in soil physical properties can be expected from both shallow-dwelling species and nightcrawlers? Why are nightcrawlers present in some no-till fields and not others? What practical management strategies might be used to help establish nightcrawlers in areas that have none? These and other questions have potential importance for increasing the sustainability of agricultural systems.

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More detailed information about earthworms can be found in the books listed below.

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Lee, K. E. 1985. *Earthworms: Their Ecology and Relationships with Soils and Land Use.* CSIRO, Sydney Australia. 411 pp.

Reynolds, J.W. 1977. *The Earthworms of Ontario.* Royal Ontario Museum, Toronto. 141 pp.

This last book includes primarily morphology and taxonomy, including diagrams and a taxonomic key, for serious students of earthworm speciation. Most of the common species in agricultural fields of the central Cornbelt are included.

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EARTHWORM POPULATIONS AND SPECIES DISTRIBUTIONS UNDER NO-TILL AND CONVENTIONAL TILLAGE IN INDIANA AND ILLINOIS

EILEEN J. KLADIVKO,[1]* NEELA M. AKHOURI[1] and GLENN WEESIES[2]

[1]Agronomy Department, 1150 Lilly Hall, Purdue University, West Lafayette, IN 47907-1150, U.S.A.
[2]USDA-SCS National Soil Erosion Research Laboratory, Purdue University, West Lafayette, IN 47907-1150, U.S.A.

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Summary—Earthworms often play an important role in maintaining or improving soil physical conditions, and earthworm populations often increase under reduced tillage systems. The objective of our study was to determine earthworm populations and species distributions under long-term no-till vs conventional tillage on a variety of soil types in the states of Indiana and Illinois, U.S.A. Fourteen paired sites were located on farmers' fields. Each paired site consisted of a no-till and conventional tillage field on the same soil type, located as close together as possible. Fields were in corn (*Zea mays* L.)–soybean (*Glycine max*) rotation, and earthworm counts were made in the spring following a soybean crop. Populations of shallow-dwelling earthworms (endogees) ranged from 2 to 343 earthworms per m^{-2}. Of the 14 paired sites, eight sites had higher earthworm populations in no-till than conventional, four sites had roughly equal populations in both systems, and two sites had slightly lower populations in no-till than conventional. At most sites, shallow-dwelling species were dominated by *Apporectodea tuberculata* and *A. trapezoides*. Some of the sites also had significant populations of *Lumbricus rubellus*. The presence or absence of significant *L. terrestris* populations was noted by observing middens. Nine no-till and three conventional sites showed significant activity of *L. terrestris*. Implications for tillage management and the need for additional applied research are discussed. © 1997 Elsevier Science Ltd

INTRODUCTION

Earthworms can play an important role in maintaining or improving soil physical conditions such as tilth, aeration and water infiltration. One of the advantages of conservation tillage systems, particularly no-till, is that earthworm populations will often increase compared with conventional tillage systems. Generally, water infiltration rates have been found to increase under no-till compared with conventional tillage, but occasionally they have been found to stay the same or decrease. The presence or absence of a "significant" earthworm population may be an important determiner of whether infiltration rates increase or decrease in no-till vs conventional systems.

Measurements of earthworm populations on a range of tillage systems in Indiana have been restricted to the work at two Purdue Agricultural Research Centers (Mackay and Kladivko, 1985; J.B. Dickey, unpublished Ph.D thesis, Purdue University, 1990). In order to more confidently extend these results to a wider variety of soils in Indiana and the Midwest in general, earthworm population measurements from a much wider array of long-term no-till fields managed by farmers is required. The objectives of this work were: (1) to determine earthworm populations under no-till vs conventional (moldboard or chisel plow) systems on a variety of soils and sites in Indiana and Illinois and (2) to determine the relationship between selected soil properties and earthworm populations.

METHODS

Fourteen paired sites were located on farmers' fields in Indiana and Illinois. A variety of soil types within the Wisconsin-age glaciated region of these states were represented. Soil series names, texture and drainage class of each site are listed in Table 1. Each paired site consisted of a no-till and conventional tillage (chisel or moldboard plow) field on the same soil type, located as close together as possible (within 1 km distance of each other). Most of the no-till fields had been managed in no-till for at least five years. Fields were in a corn (*Zea mays* L.)–soybean (*Glycine max*) rotation, and counts were made in the spring following a soybean crop.

Earthworm counts and observations were made during April 1992, when earthworms were active and the water content of the soil (near field ca-

*Author for correspondence. Fax: (317) 496-2926.

Table 1. Soil description and soil properties of 14 no-till and conventional tillage sites where the earthworm survey was conducted

Site No.	Soil series	Classification	Texture[1]	Drainage[2]	pH NT[3]	pH CN	OM% NT	OM% CN	Sand (%)	Silt (%)	Clay (%)
5	Crosby	Aeric Ochraqualf	SiL	SPD	6.3	6.2	3.1	1.6	10.6	70.3	19.2
6	Fincastle	Aeric Ochraqualf	SiL	SPD	6.3	7.1	2.1	2.5	13.5	66.6	20.0
7	Owosso	Typic Hapludalf	SL	WD	6.7	7.5	1.4	1.4	63.0	30.0	7.1
8	Martinsville	Typic Hapludalf	SiL	WD	6.4	6.3	2.0	1.3	31.0	57.7	11.4
9	Ockley	Typic Hapludalf	SiL	WD	7.0	7.3	2.2	2.3	15.5	72.5	12.0
10(1)	Darroch	Aquic Argiudoll	L	SPD	6.1	6.6	3.8	4.0	37.1	41.2	21.7
10(2)	Onargo	Typic Argiudoll	SL	MWD	5.9	6.5	3.1	2.5	61.6	25.7	12.8
11	Pewamo	Typic Argiudoll	SiCl	PD	7.5	7.1	2.5	3.5	17.7	58.6	23.8
12	Crosby	Aeric Ochraqualf	SiL	SPD	6.6	6.6	3.3	2.4	18.8	65.0	16.2
13	Treaty	Typic Argiaquoll	SiCl	PD	6.6	6.3	4.3	4.5	12.2	58.1	29.8
15(1)	Saybrook	Typic Argiudoll	SiL	SPD	6.6	7.1	4.6	4.8	3.2	70.7	26.1
15(2)	Saybrook	Typic Argiudoll	SiL	SPD	7.1	7.1	2.5	1.9	4.2	74.2	21.7
15(3)	Drummer	Typic Argiaquoll	SiCl	PD	8.0	6.7	5.4	7.3	1.5	68.4	30.1
20	Flood-plain		SiCl		8.0	7.8	6.2	2.2	26.4	44.0	29.6

1L — Loam; SL — Sandy loam; SiL — Silt loam; SiCl — Silty clay loam
2PD — Poorly drained; SPD — Somewhat poorly drained; MWD — Moderately well drained; WD — Well drained
3NT — No-till; CN — Conventional

pacity) favored shallow (0–25 cm depth) activity of "shallow-dwelling" (endogeic) species. At each field, 12 soil samples (45 × 10 × 25 cm deep) were taken with a specially designed metal "cookie cutter" sampler (similar to one described by Zicsi, 1962) and were then hand-sorted for earthworms. Total soil area sampled was therefore 0.54 m^2 per field. At several sites the sampling procedure was modified to include six of the metal box samples and two soil columns (50 × 30 × 25 cm deep) excavated with a spade, for a total sampled area of 0.57 m^2 per field. These sampling procedures are suitable for shallow-dwelling earthworm species but do not quantitatively recover deep-burrowing species ("nightcrawlers," or *Lumbricus terrestris*). *L. terrestris* activity was estimated from the presence or absence of middens in the field. A subsample of the adult earthworms recovered during sorting was identified to genus (*Octolasion*) or species either in the field or in the lab within two days of sampling. Exact percentages of species distributions are not presented, because, for several reasons, not all adults were identified. Partial or injured worms could sometimes not be identified, some worms died while being brought back to the lab and then could not be identified, and at some sites with larger numbers of worms, a subsample was deemed sufficient to determine the approximate species distributions. Juveniles were not identified, as this cannot be done visually in the field for many species. The results therefore represent an approximation of the species distributions of adults in these fields.

Subsamples of the sorted soil were analyzed for sand, silt, clay, organic matter, pH, lime index, available P, available K, Ca, Mg, and cation exchange capacity by standard soil testing procedures. A two-tailed *t*-test was used to test the effect of tillage system on earthworm populations.

Table 2. Total number of shallow-dwelling earthworms, and evidence of *L. terrestris* ("nightcrawler") activity under 14 no-till and conventional tillage sites

		Earthworms m^{-2}						*L. terrestris* middens present?	
		No-till			Conventional			No-till	Conventional
Site No.	Years no-till	Total	Adult	Juv.	Total	Adult	Juv.		
5	9	159	81	78	63	43	20	Yes	No
6	7	58	24	34	29	10	19	Yes	Yes
7	6	41	28	13	39	21	18	No	No
8	2	2	2	0	16	5	11	No	No
9	3	39	18	21	70	32	38	Yes	Yes
10(1)	7	27	11	16	26	14	12	No	No
10(2)	ND	24	2	22	50	28	22	Yes	Yes
11	6	168	72	96	107	88	19	Yes	No
12	8	296	111	185	115	46	69	No	No
13	7	343	89	254	35	28	7	Yes	No
15(1)	17	259	119	140	119	39	80	Yes	No
15(2)	12	170	22	148	19	8	11	Yes	No
15(3)	8	109	31	78	16	7	9	Yes	No
20	9	237	33	204	196	3	193	No	No

Correlation coefficients between earthworm populations and soil properties were calculated within each tillage system.

RESULTS AND DISCUSSION

Shallow-dwelling earthworm species populations ranged from 2 to 343 earthworms per m^2 at the time of sampling (Table 2). Of the 14 paired sites, eight sites had more worms in no-till than conventional, four sites had roughly equal populations in both systems, and two sites had slightly lower populations in no-till than conventional. A paired *t*-test confirmed a significant difference in populations with tillage system. The result in 57% of the sites confirmed previous research findings that, compared with conventional tillage, no-till generally leads to increased earthworm populations.

Significant *L. terrestris* midden activity was noted on nine no-till and three conventional sites (Table 2). On some fields almost every piece of crop residue that was present on the soil surface had been pulled into a midden by *L. terrestris*. This observation suggests that knowing the percentage of the soil surface covered with residues, may not be adequate to determine compliance with erosion control standards (high infiltration, less runoff, less erosion), once sufficient time has elapsed for *L. terrestris* populations to build up.

Within the no-till fields, earthworm (shallow-dweller) counts were significantly correlated with only a few of the measured soil properties. Earthworm numbers were positively correlated with clay content ($r = 0.62$; $P < 0.05$) and negatively correlated with sand content ($r = -0.56$; $P < 0.05$). The range of clay contents represented in this study is relatively narrow, however (7–30% clay, see Table 1). Earthworm numbers were also positively correlated with organic matter content and available K ($r = 0.46$ and 0.45, respectively; $P < 0.10$). There was no significant correlation of earthworm numbers with any of the other measured variables. Within the conventional sites, earthworm numbers were not correlated with any measured soil variable.

Sites 7, 8, 9, 10-1, and 10-2 all had low earthworm (shallow-dweller) populations ($< 45\ m^{-2}$) in the no-till fields (Table 2). These sites also had either equal or lower populations in no-till than in the corresponding conventional fields. Four of these five sites were the well drained and moderately well drained sites and also had the lowest clay content (< 13%) of all sites. Two of the four well or moderately well drained sites had been under no-till management only two or three years, while the majority of the sites had a no-till history of six years or more. Thus the observed low numbers of shallow-dwelling worms in some no-till sites appeared to be related to low clay content, good internal drainage characteristics, and a short time under no-till management. The range of site characteristics sampled in this study is not broad enough to clearly distinguish which of these factors may be the most important in influencing earthworm numbers.

The two dominant species over all sites were *Apporectodea tuberculata* and *A. trapezoides*. *Lumbricus rubellus* was found at four sites (sites 5, 6, 12 and 13), and more frequently in the no-till than in the conventional fields. It was the most prevalent species in the no-till fields of Crosby silt loam (sites 5 and 12). Three of the four sites where *L. rubellus* was found were the light-colored, somewhat poorly drained Alfisols in the survey (Aeric Ochraqualf, see Table 1). A species of *Octolasion* comprised almost half the population at the Pewamo no-till field of site 11, and several other sites had a few individuals. *A rosea* was present in small numbers in all three no-till fields in Illinois (sites 15-1,2,3).

The population differences among locations are certainly due to a complex mix of factors including soil type, tillage and crop history, chemical (insecticide) history, number of years in no-till, climate and weather, etc. A more detailed field history may be able to explain some of the differences.

Much more work is needed on earthworm distributions in agricultural fields, particularly on the *L. terrestris*. Why are there *L. terrestris* in some no-till fields and not others? Is it simply a matter of time before they have moved back into a field from fencerows, etc., and rebuilt the populations? Or are there soils in which they will not survive, even if placed into them? Are there some fields and areas where they never have been introduced and so there is no supply in the fencerow to begin with? Do they migrate great distances into a field on a rainy spring night, and thereby repopulate the interior of the field (Mather and Christensen, 1988)? Answers to these questions would help farmers who want to improve soil quality and long-term productivity.

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SOIL QUALITY: ARE IMPROVED STRUCTURE, CARBON SEQUESTTRATION AND PLANT AVAILABLE WATER DUE TO CHOPICE OF CROP OR TILLAGE?

J.H. Grove, M. Diaz-Zorita, E. Perfect and D. Call
Agronomy Department, University of Kentucky
Lexington, Kentucky 40546-0091
Contact: J.H. Grove (859-257-5852)
Email: jgrove@ca.uky.edu

Previous work in the United States and Europe has found that the physical quality of the soil, the structure and strength and water retention properties that relate most strongly to root growth and plant available water, is also often related to the process of carbon sequestration. Earlier work in our laboratory has shown that soil carbon levels are strongly related to the amount of carbon fixed in the crop rotation and the amount of carbon destroyed due to the duration and aggressiveness of soil tillage. In this paper we report further on our work. We tested the hypothesis that carbon sequestration was related to the quality of soil physical properties, especially the geometric mean diameter of a soil's aggregate size distribution, and the distribution of soil pore sizes.

We evaluated soil carbon and soil physical properties of Maury silt loam soils, at the close of the growing season, in two field experiments. The first experiment involved four corn-based rotations, all produced with continuous no-tillage soil management. The second experiment investigated three tillage sequences within a single crop rotation. We sampled the surface 8 inches of soil in two increments, 0-4 and 4-8 inches. We measured soil texture, organic carbon, bulk density, the pore size distribution, and dry aggregate size distribution.

Early results from the rotation experiment suggest that cereal components to the crop rotation (corn, wheat, etc.) contribute positively to soil carbon levels. Bulk density, total porosity, and volumetric water content at sampling were little different among the sampled plots. The geometric mean diameter of aggregates was smaller in strongly cereal-based rotations. In the tillage sequence experiment, we found little difference in soil carbon concentrations, probably because of the short duration of this trial. We did find that the more recently tilled soils had reduced bulk densities, greater total porosities, and lower volumetric soil moisture retention.

We conclude that the continuous application of no-tillage soil management causes changed conditions in soil physical quality (greater bulk density, more continuous porosity, loss of larger pores in favor of smaller ones) that favor greater soil moisture retention and carbon sequestration in cereal-based rotations.

QUANTIFICATION AND ASSESSMENT OF SOIL CARBON SEQUESTRATION AT NATIONAL AND REGIONAL SCALES

Keith Paustian[1], Marlen Eve[1,2], John Brenner[1,3], Mark Sperow[1], Kendrick Killian[1], Mark Easter[1] and Steve Williams[1]
[1]Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, Colorado 80523
[2]USDA/Agricultural Research Service, Fort Collins, Colorado 80523
[3]USDA/Natural Resource Conservation Service, Fort Collins, Colorado 80523

Background

The rapid increase in atmospheric carbon dioxide (CO_2) and other greenhouse gases (GHG) over the past century, and the potential threat of these increases on the earth's climate, is now widely recognized. Agriculture is a significant emitter of greenhouse gases but also has the potential to contribute substantially to the mitigation of increasing GHG levels (Paustian et al. 1998, Bruce et al. 1999). Carbon sequestration has emerged as one of the main avenues by which agriculture can help mitigate GHG and at the same time accrue benefits of improved soil and water quality.

Soil carbon (C) sequestration, in simple terms, is the buildup of C levels in soil, mainly in the form of soil organic matter (SOM). Since soil organic carbon is derived from the atmosphere via plant uptake of CO_2 and the subsequent incorporation of that plant C into the soil, net increases in the amount of C stored in SOM are directly equivalent to a reduction in the amount of C (as CO_2) in the atmosphere. Various agricultural practices, including type and level of crop production, tillage type and intensity, residue management, water management, and manuring, influence the amount of C stored in soils. By choosing appropriate practices that either increase the amount of plant residues returned to soils and/or reduce the decomposition rate of residues and soil organic matter, C can be sequestered.

Key to the implementation of C sequestration as a mitigation strategy, is the ability to quantify the changes in soil carbon as a function of agricultural management, including the variability in responses for different soil types and climate regimes which also affect soil processes controlling C levels. Quantification is needed 1) at the national level, to meet GHG reporting requirements for Framework Convention on Climate Change (FCCC) and to support national policy, 2) at state and regional levels to support assessment, planning and decision making on GHG mitigation and 3) at local levels to aid decision making by individual land managers and to support carbon sequestration projects. This presentation describes on-going work in our laboratory to do quantification and assessment of soil C sequestration at national and regional scales.
We have applied the IPCC (Intergovernmental Panel on Climate Change) C inventory approach (IPCC, 1997) to assess soil carbon changes associated with agricultural management and land use change for the coterminous US. Analyses include estimates of the 1990 baseline year (Eve et al., 2000a,b), as specified by the FCCC, as well as estimates of the potential for carbon sequestration with widespread adoption of improved agricultural management and land use practices (Sperow et al. 2001).

National level assessments

Input data to the analysis includes information on management and land use change from the USDA/National Resource Inventory (NRI), collected every five years since 1982, and comprised of 800,000 sites that were individually analyzed for the estimation of C sequestration rates. Additional data on soils, climate and tillage practices were used from national USDA/Natural Resource Conservation Service databases and from the Conservation Tillage Information Center.

Our estimates (Eve et al. 2000a) suggest that in 1990, US soils were sequestering C at the rate of 14 million metric tonnes (MMT) per year, largely in the temperate moist regions of the central and eastern US, due primarily to reduced tillage practices and land use changes such as the Conservation Reserve Program. However, high CO_2 emissions (6 MMT C/yr) from organic soils used for agriculture, primarily in the southeast, partially offset these gains, yielding a net sequestration rate for US soils of about 8 MMT C in the baseline year.

Extending this methodology, we estimated the potential for C sequestration in US agricultural soils, if existing 'best management practices' were adopted on all lands currently used for agricultural production (Sperow et al. 2001).

We estimate a national potential of about 85 MMT C/year, through complete adoption of no-till on annual crop lands (40 MMT C/year), improved crop rotations (26 MMT C/year), particularly addition of cover crops on continuous row crop area and elimination of summer fallowing in semi-arid environments, and converting all highly erodible land (HEL) to perennial grass cover (19 MMT C/year). These estimates represent an upper limit for existing practices – less than full adoption of BMP's, due to economic and other constraints, would act to reduce these values, while new or improved technology could act to increase them.

Regional level assessments

In a collaborative effort between university researchers, state NRCS personnel, national and state associations of Conservation Districts and other state conservation partners, we are assessing current and potential rates of soil carbon change in several states, including Iowa, Indiana and Nebraska. Data are presented on results recently completed in Iowa (Paustian et al. 2001).

A multi-phase and multi-scale approach was used which employed spatial databases of climate, soils, land cover and land use, together with other data on agricultural management practices from a variety of sources, to estimate current rates of soil carbon sequestration using the Century ecosystem/soil organic matter model. Following an initial, Stage-1, assessment using existing data, a new survey instrument was designed to collect more detailed data on historical management practices (e.g. crop rotations, drainage, fertility management) and the adoption of conservation practices (e.g. tillage reduction, grass buffers, filter strips, terraces and waterways, CRP). Local Conservation District personnel for each county in Iowa collected data for the more detailed, Stage-II assessment.

We conclude that agricultural soils in Iowa are currently a net sink for carbon of about 2.5 million metric tonnes per year. The increasing soil carbon stocks are due to increasing productivity and residue returns over the past several decades, an overall trend of reduced tillage intensity, and the adoption of a variety of conservation management practices over the past 10-15 years. Increasing soil carbon levels are mainly associated with non-hydric soils. We estimate that with an aggressive adoption of the best conservation practices to sequester carbon, Iowa has to potential to be a sink for several million tonnes of carbon over the next few decades.

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AGRICULTURE PRACTICES TO SEQUESTER CARBON IN SOILS

Charles W. Rice
Department of Agronomy, Kansas State University, Manhattan, KS 66506-5501
Phone 785-532-7217, Fax: 785-532-6094
E-mail: cwrice@ksu.edu

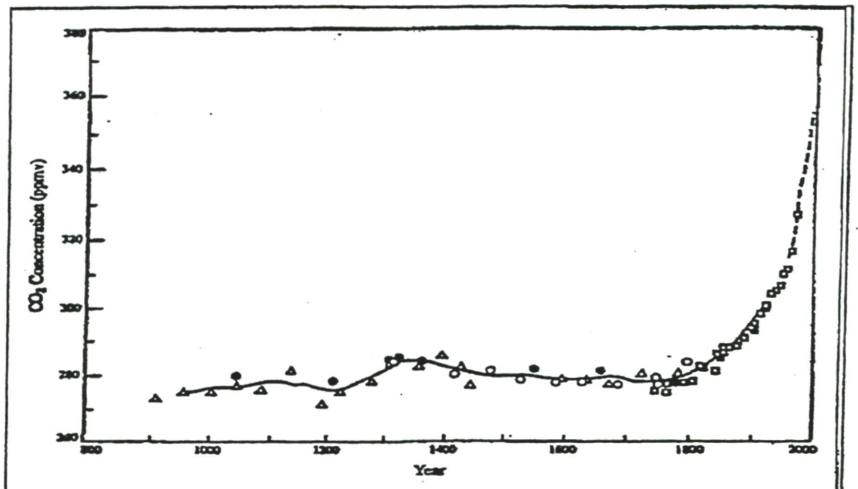


Figure 1. Temporal changes in atmospheric concentration of CO_2 (IPCC, 1995).

Since the late 1800's atmospheric CO_2 has increased from 260 ppm to current levels >370 ppm. Most of the recent increase in CO_2 has been attributed to combustion of fossil fuels for energy and transportation, but changes in land use also contribute to atmospheric CO_2. This increase in atmospheric CO_2 potentially impacts climate, as it is a greenhouse gas.

Recent models of land use suggest terrestrial systems can mitigate the increase of atmospheric CO_2 by sequestering C into vegetation and soils. Carbon sequestration by soils occurs primarily through plants where decomposition by soil microorganisms converts some of the plant C into soil organic matter sometimes referred to as "humus." Some of this carbon can persist in soils for hundreds and even thousands of years. The estimated amount of C stored in world soils is about 1100 to 1600 Pg, more than twice the C in living vegetation (560 Pg) or in the atmosphere (750 Pg) (Sundquist, 1993). Hence, even relatively small changes in soil C storage per unit area could have a significant impact on the global C balance. Approximately 50% of the soil organic carbon (soil organic matter) has been lost from soil over a period of 50 to 100 years of cultivation. However, this loss of soil carbon also represents the potential for storage of C in agricultural soils. While previous cultivated agricultural practices have decreased soil C, advancements in crop and soil management practices have the potential to increase soil C. In recent decades, higher yields, return of crop residues, and development of conservation tillage practices have increase soil carbon. Table 1 lists several practices affecting the soil's ability to sequester C (Lal et al., 1998).

Table 1. Land Use for C Sequestration in agricultural systems(Lal et al., 1998)

Management Strategies	
Soil Management	Crop Management
• Tillage • Residue Management • Fertility • Water Management • Erosion Control	• Varieties • Crop Rotations • Cover Crops

Estimates of C sequestration have been made by Lal et al. (1998) (Table 2).

In one study in Kansas, we have measured an increase of 2 Mt C ha^{-1} (1 ton C a^{-1}) after 10 years of no-tillage c... Cropping sequences can also affect soil C. In Kansas, intensifying cropping systems by conversion from wheat-fallow rotation to wheat-grain sorghum-fallow rotation in western Kansas increased soil C levels. Proper selection of cropping systems with the climate and soil can prevent the lost of soil C. After 10 years of a wheat-sorghum rotation in western KS, soil C was not different than the native sod with no-tillage and minimum tillage systems. The C was more protected in the no-tillage system indicating greater stabilization than the tilled system.

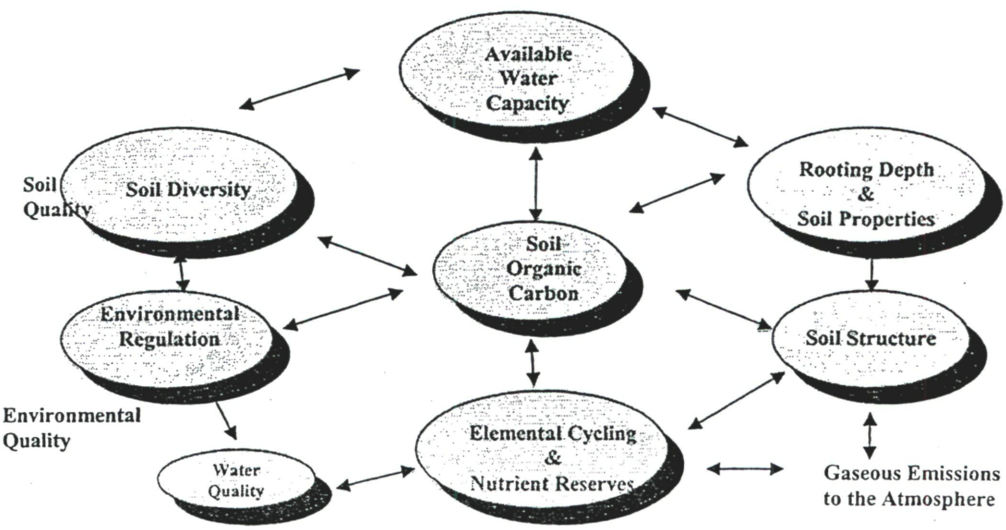
While much of the discussion of carbon sequestration has been directed to forests, global estimates for C sequestration for indicate the agricultural lands are 45 to 90 % of forests. If grasslands and rangelands are considered, then managed lands contributions to carbon sequestration are greater than forests.

Table 2. Estimates of C sequestration potential of agricultural practices of U.S. cropland (Lal et al., 1999).

Agricultural practice	(Tons C/a/y)
Conservation Reserve Program	0.15 – 0.30
Conservation tillage	0.10 – 0.20
Fertilizer management	0.02 – 0.07
Rotation with winter cover crops	0.05 – 0.15
Summer fallow elimination	0.05 – 0.15

Additional benefits

Managing agricultural soils for sequestering C will result in additional benefits.



Increasing soil organic C include increased crop productivity and enhanced soil, water, and air quality. In addition, management practices that increase soil C also tend to reduce soil erosion, reduce energy inputs, and improve soil resources.

AGRONOMIC PRACTICES TO DELAY HERBICIDE RESISTANCE IN JOINTED GOATGRASS

Carol Mallory-Smith*, D. Eric Hanson*, Daniel Ball*, and Robert Zemetra**
***Oregon State University; ** University of Idaho**
Contact: Carol Mallory-Smith 541-737-5883
Carol.Mallory-Smith@orst.edu

Jointed goatgrass (*Aegilops cylindrica*) is an especially problematic weed in wheat because of its close genetic relationship with wheat. There are no selective herbicides that can be used to control jointed goatgrass in wheat. The introduction of herbicide resistant wheat will provide an option to control jointed goatgrass. However, the introduction of herbicide resistant wheat also will increase the probability of producing herbicide resistant jointed goatgrass. Herbicide resistant jointed goatgrass biotypes could be produced in two ways, either by selection with the herbicide or by transfer of the herbicide resistant gene from wheat to jointed goatgrass through crossing between the two species. Growers will need to assess their production practices and determine how changes can be made to decrease the risk of producing a herbicide resistant jointed goatgrass. In simulation models, continuous, no-till herbicide resistant wheat resulted in rapid development of resistant jointed goatgrass populations. However, alternating herbicide resistant wheat with non-resistant wheat in combination with fallowing prevented establishment of resistant jointed goatgrass populations and showed a decline in the susceptible seed population as well. This model was based on the use of Clearfield® wheat. The risk of selecting Round Up® resistant jointed goatgrass biotypes would be lower; however, the probability of crosses occurring between the two species would be the same. There are some possible safeguards to prevent gene movement such as placing the resistance gene on genomes that are not shared by wheat and jointed goatgrass. This approach is being evaluated but the outcome is not yet known.

BREEDING FOR HEAD SCAB RESISTANCE IN THE MID-SOUTH

John Kelly[1], Robert Bacon[1], and Gene Milus[2]
[1]Department of Crop, Soil, and Environmental Sciences
[2]Department of Plant Pathology
University of Arkansas, Fayetteville, AR
Contact: Robert Bacon (501-575-5725)
E-mail: rbacon@uark.edu

Following a severe outbreak in 1991 of Head Scab (also known as Fusarium Head Blight), the breeding program at the University of Arkansas initiated a crossing program between adapted soft wheat lines and 22 scab-resistant lines. The resistant lines came from the International Center for Maize and Wheat Improvement (CIMMYT) in Mexico and various countries in Eastern Europe. These crosses were advanced as bulk populations for 5 years.

In 1998 the program received a grant from the U.S. Wheat and Barley Scab Initiative to pursue the development of resistant varieties. Experimental lines were developed from the populations using pedigree selection and were evaluated in the field as single rows for their agronomic adaptability and resistance to other diseases for two years. Over 200 lines representing 50 populations were selected and evaluated for scab resistance along with resistant and susceptible check varieties in an inoculated screening nursery in the field in 2000. Selected lines with good adaptability and high grain yield are being tested in a replicated inoculated nursery in 2001. Four of the highest yielding lines were also entered in the regional Winter Wheat Scab nursery. All four lines have a different resistant parent in the pedigree. In addition to field tests, the selected lines will be evaluated in the greenhouse for Type II scab resistance. Lines from crosses between adapted genotypes and scab resistance sources are being selected for both agronomic traits and resistance to scab in order to release resistant varieties adapted to the mid-south as soon as possible.

The program is also working to develop adapted germplasm lines with high levels of scab resistance that can serve as breeding material for future variety development efforts. The goal of this effort is to develop lines with scab resistance as well as more durable types of resistance to leaf rust, stripe rust, and leaf blotch. Sources of these resistances (primarily CIMMYT spring wheat lines) were crossed in 1995 to two adapted varieties with short vernalization requirement (to facilitate multiple generations per year) and photoperiod sensitivity (to confer wide adaptation). In 1999, 120 heads were selected from 117 of the best populations and grown in the field as single rows in 2000. Over 500 lines were advanced to greenhouse and multi-location testing. Those lines showing promise will be made available to breeders and intercrossed to combine resistances.

FUSARIUM HEAD BLIGHT RESISTANCE IN SPRING WHEAT AND BARLEY: EFFECTIVE SCREENING NURSERIES

W.G. Thompson and J.V. Wiersma, NWROC, UM, Crookston, MN

Introduction: Environments that provide a range of fusarium head blight (FHB) infection pressure are required for selecting stable host resistance (Mesterhazy, 1995; Miedaner, 1997). Most often these environments are realized by growing FHB nurseries at several locations for several years. One of our criteria for an effective FHB screening nursery has been that the nursery must provide a wide range of FHB intensity at one location each year. Previously (1995 to 1999), we have attempted to do this using different kinds and amounts of inoculum, but have had limited success. This report describes our 2000 approach of using fungicides and supplemental misting to vary the length of time FHB is allowed to progress.

Objective: Establish an effective FHB screening nursery that provides a range of environments with moderate to severe FHB disease pressure at one location in one year.

Materials and Methods: Separate nurseries were established for spring wheat and barley, each using a split-plot arrangement of a randomized complete block design with four replications. Six infection periods were whole plots and 20 cultivars/lines were subplots. Advanced lines and newly released varieties from wheat and barley breeding programs in Manitoba, North and South Dakota, and Minnesota were included. Inoculum (inoculated corn grain) was applied at the 5-6 leaf stage. At heading, misting was initiated to provide 0, 5, 10, 15, 20, and 25 days of supplemental moisture after heading for FHB infection and progression. After allowing the appropriate time for disease progression, misting was discontinued and FHB was controlled by spraying designated whole plots with fungicide. Once initiated, spraying was repeated every 5 days until maturity.

Results: The percentage of infected spikes and spiklets increased with progressively longer infection period for both spring wheat and barley (Fig. 1 & 2). The lag in percent infected spikes for wheat during the first 5 days after

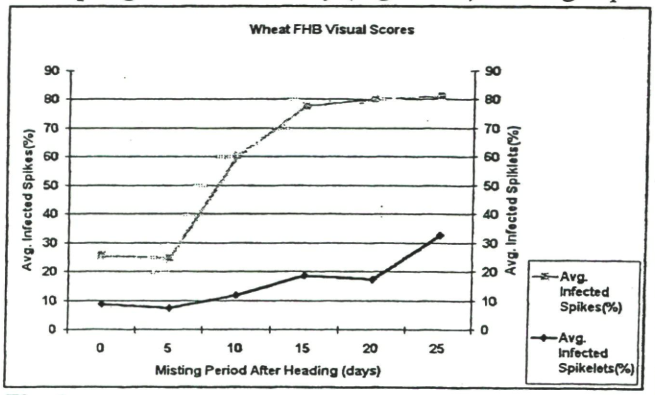


Fig. 1

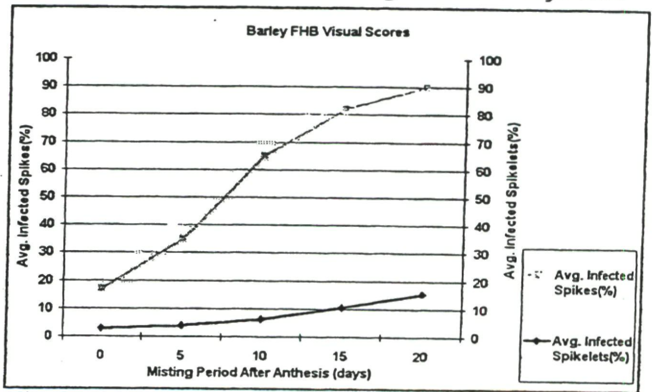


Fig. 2

heading may be related to the delay in onset of anthesis after heading. Barley normally begins anthesis at or before heading. Kernel infection also increased when additional days were allowed for disease progression for both spring wheat and barley (Fig. 3 & 4). Furthermore, when the entries were separated into susceptibility classes on the basis of regression slopes, as described by Eberhart and Russell (1966), each class retained the same ranking with extended infection period.

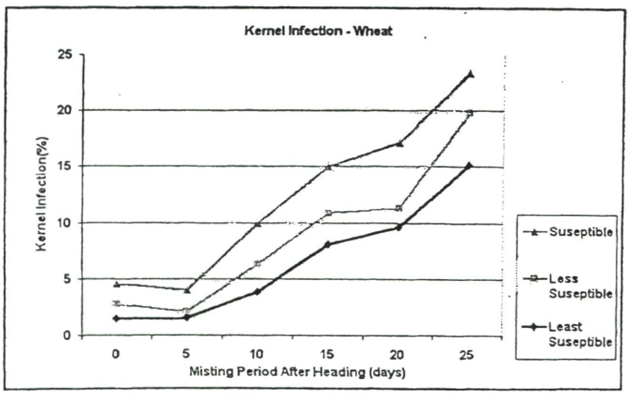


Fig. 3

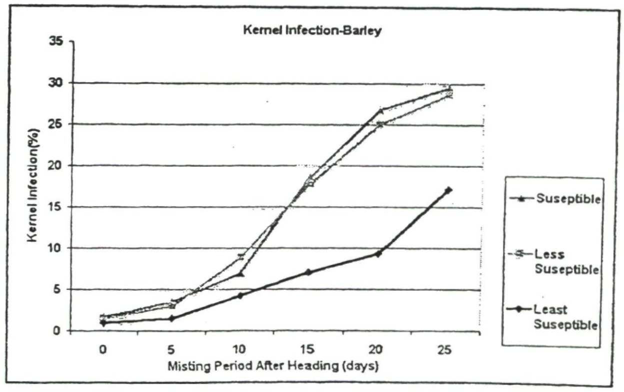


Fig. 4

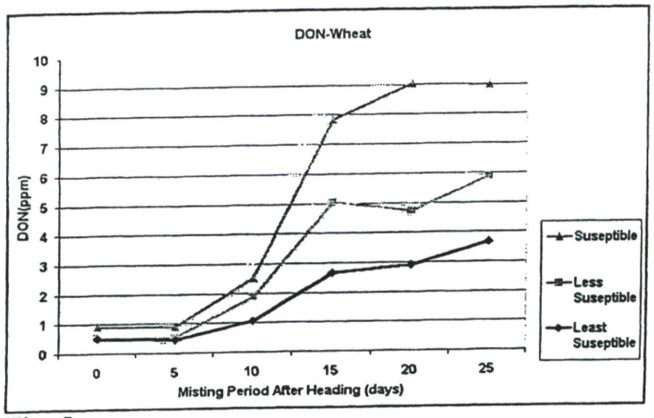


Fig. 5

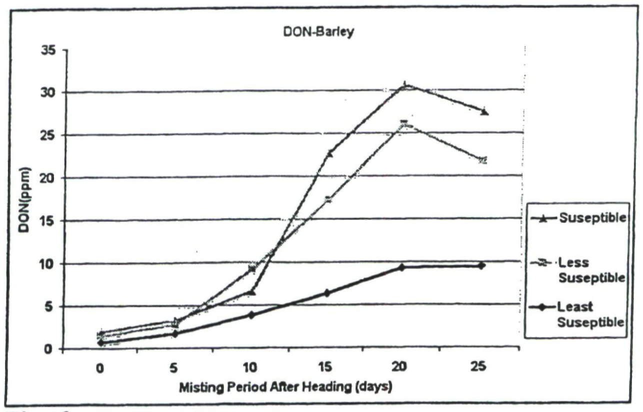


Fig. 6

DON concentration followed a similar pattern of higher accumulation with time for both spring wheat and barley (Fig. 5 & 6). Again, susceptibility classes retained their separation over most infection periods. The protocol used this past year provided both an adequate range of disease levels and measures of disease resistance (DON, KI, and visual ratings). Increases in KI and DON concentration likely were affected by new infections that occurred throughout the entire 20 or 25 day infection period. New infections are indicated by the increase in percentage of spikes infected over the entire infection period (Fig. 1 and 2). Therefore, misting duration from anthesis to at least 20 days postanthesis is especially important in determining final disease severity. However, additional environmental factors such as rain may also influence FHB disease levels from year to year.

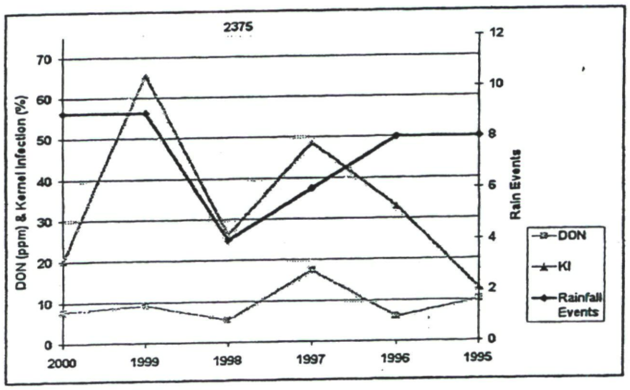


Fig. 7

Substantial yearly variation of DON concentration and KI is exemplified by 2375 (Fig. 7). The variety 2375 has grown in misted screening nurseries at Crookston, MN since 1995. Kernel infection (KI) and DON levels are influenced by factors other than the moisture provided by artificial misting. (Fig. 7). The number of rain events occurring during the 25 day period commencing at heading appears to affect both KI and DON. The duration of the rain events and time (early, medium, late) during the 25 days following heading appear to modify the effect of the number of rain events. These effects were also noted for other varieties.

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MANAGING ITALIAN RYEGRASS IN WHEAT AND NO-TILLAGE CORN

James R. Martin, Dorothy Call, and William W. Witt
University of Kentucky, Princeton, KY
Contact: James R. Martin (502-365-7541 ext. 203)
Email: jamartin@ca.uky.edu

Introduction

Although Italian ryegrass (*Lolium multiflorum*) is an excellent companion plant for establishing waterways or similar areas, it occurs as a problem weed in wheat and corn. One method for spreading this weed is with combines operating in seeded waterways and field borders during wheat harvest. Once the Italian ryegrass seeds has been scattered out into the field, many will germinate that fall and evolve into a problem in fields that are rotated to no-tillage corn the next spring. The fact that a portion of Italian ryegrass seed can survive more than one year helps prolong the problem where it can spread further once the field is rotated back to wheat.

Kentucky grain crop producers typically grow three crops in two years with a cropping sequence of corn/wheat/ double-cropped soybeans. The use of reduced tillage practices in this cropping sequence provides a favorable environment in which Italian ryegrass can survive and spread.

Because of the increasing concern with this weed, a number of field studies have been conducted at the University of Kentucky Research and Education Center to investigate methods for managing Italian ryegrass as a problem weed in both wheat and no-tillage corn.

Wheat

Selective Control with Preemergence and Postemergence Herbicides in Wheat

This study was conducted to compare and evaluate crop injury and Italian ryegrass control using soil-residual and postemergence herbicides in wheat. Results and comments on herbicides evaluated in this experiment are as follows:

Achieve 40WG: Achieve contains the active ingredient tralkoxydim which is similar to the ingredient in Hoelon. Achieve is manufactured by Syngenta (formerly Zeneca) and is registered for postemergence applications in wheat. Based on June 16 ratings, Achieve applied at 7 or 9.5 oz/A to 2-LF ryegrass resulted in 67% control of ryegrass. Control was similar when Achieve was applied at the same rates to 4-LF ryegrass. Slight injury in the form of discolored plants was observed in a few of the plots initially, but gradually decreased over time.

Axiom 68WG: Axiom is developed by Bayer as a premix of flufenacet (54.4%) plus metribuzin (13.6%). Although Axiom is registered for use in field corn and soybeans, it is currently NOT labeled for use in wheat. Axiom should be applied prior to emergence of most weed species since its control focuses primarily on soil-residual activity. The performance of Axiom for controlling ryegrass depended largely on timing of application. The use of Axiom prior to crop and weed emergence provided 88% control of ryegrass, compared with 60% and 63% for applications made to emerged wheat and 1-tillered wheat. The 1.4 inches of rainfall that occurred on November 2, 1999 (i.e. 6 days after the preemergence application) played a major role by moving Axiom from the soil surface and into the top of the soil profile where it could control ryegrass before it emerged. However, by delaying the Axiom application until wheat emergence or 1-tillered wheat resulted in substantially less control compared with the preemergence treatment. Slight injury in the form of discolored and stunted plants did occur with all Axiom treatments, however symptoms decreased over time.

Everest 70 WG: Everest contains the experimental herbicide flucarbazone-sodium (MKH 6562). It is being developed by Bayer for use in wheat. Some of the early research with Everest indicates it has the potential to control several cool-season grasses in wheat. Results of this experiment indicate that applying Everest at 1-tillered wheat stage provided 88% ryegrass control during the Dec 30 ratings, however, by June 16, control decreased to 77%. Applying Everest as a tank-mix partner or in sequential sprays with other herbicides provided mixed results. Including Axiom with Everest at the 1-tillered wheat stage helped maintain control throughout the season and resulted in 90% control by June 16. Applying Sencor as a tank-mix partner with Everest at the 1-tillered wheat stage resulted in 70% ryegrass control by June 16. Applying Axiom at the 1-tillered wheat stage followed by Everest at the 4-leaf ryegrass stage resulted in 77% ryegrass control.

Hoelon 3EC: Hoelon contains the active ingredient diclofop-methyl. It is manufactured by Aventis and is registered for preemergence and postemergence control of annual ryegrass in wheat. According to the June 16 ratings, Hoelon applied at 1.33 and 2.66 pt/A to 2-leaf ryegrass resulted in 87% and 95% control, respectively. Delaying the application of Hoelon at these same rates until ryegrass reached the 4-leaf stage resulted in a slight reduction in control, however, differences were not significant compared with the 2-leaf treatments. Slight injury in the form of discolored plants was observed with the early applications, and appeared to decrease over time.

Maverick 75WG: Maverick contains the active ingredient sulfosulfuron. It is manufactured by Monsanto and is registered for preemergence and early postemergence control of grasses and broadleaf weeds. The one-year rotation restriction on the current label limits the opportunity for using Maverick in Kentucky□s crop rotations. Results of this research indicated that Maverick applied at 0.5 oz/A to 2-leaf ryegrass resulted in 60% control. Only 7% control was achieved when Maverick was applied to 4-leaf plants.

Control with Preharvest Applications in Wheat

Limited observations indicate that Italian ryegrass matures slightly later than wheat. If this observation holds true, the use of Roundup Ultra as a preharvest treatment after wheat seed are physiologically mature, but before maturity of Italian ryegrass, may help in long-term control by limiting viability of Italian Ryegrass seed. Roundup Ultra and many other glyphosate formulations are registered for use after the hard-dough stage of wheat grain (30% or less moisture) and at least 7 days before harvest.

An experiment was conducted in 1999 with the intent to search for options that would allow early applications, such as applying to high moisture wheat and using an early maturing wheat variety. Results of the experiment indicated that none on the preharvest treatments affected the germination of wheat seed. The germination results ranged from 85 to 90% for Clark and from 83 to 86% for Pioneer 2540. The germination of Italian ryegrass was 97% for seed collected from the non-treated check plots for both Clark and Pioneer 2540. The preharvest applications of Roundup Ultra at 2 pt/A did not appear to affect the germination of Italian ryegrass, even at the earliest application made to Clark on June 6. The percent germination of Italian ryegrass seed ranged from 91 to 97% for the Roundup Ultra preharvest treatments made during the period between June 6 through June 16, 1999.

One observation worth noting from this study was the impact that Italian ryegrass had on wheat growth. Fall wheat stands were uniform and averaged approximately 31.5 plants/ft^2 for both Clark and Pioneer 2540. The Italian ryegrass population was extremely dense in portions of the study and severely limited growth of wheat during late winter and spring. A rating of percent ground cover occupied by wheat on July 8 was used to reflect the affect Italian ryegrass had on biomass of wheat. The biomass ratings were highly variable and were not affected by the preharvest treatments. Although both varieties were affected by competition, there was a definite trend indicating that Pioneer had less biomass and may be more prone to competition from Italian ryegrass than Clark.

No-tillage Corn

Burndown Control in Corn

A three-year study compared several herbicide options for burndown control of Italian ryegrass. Gramoxone Extra applied at 1.5 pt/A alone provided 18 to 55% control of Italian ryegrass. Including atrazine 4L at 3 pt/A with Gramoxone Extra improved control over that achieved with Gramoxone Extra alone, however, the level of control was acceptable in only one out of three years. Corn yields tended to be a slightly greater when Gramoxone Extra was combined with atrazine than when Gramoxone Extra was applied alone.

Ryegrass control with a single application of Roundup Ultra at 2 pt/A combined with atrazine at 3 pt/A tended to be slightly better compared with control from Gramoxone Extra plus atrazine. However, control was more consistent when the Roundup Ultra rate was increased to 3 pt/A. Corn yield tended to be greater with Roundup treatments than with Gramoxone Extra.

Applying Gramoxone Extra at 1.5 pt/A as an early preplant treatment followed approximately two weeks later with Gramoxone Extra at 1.5 pt/A plus atrazine at 3 pt/A provided at least 93 % control of Italian ryegrass across all three years. Similar results were achieved when Roundup Ultra at 2 pt/A was applied as the early preplant treatment followed by Gramoxone Extra plus atrazine at planting.

Selective Control with Postemergence Herbicides in Corn

A number of technologies based on using herbicide-resistant corn hybrids were evaluated in 1997 for Italian ryegrass control. Some of the treatments showed favorable results, particularly where Roundup Ultra was utilized. A more extensive experiment was conducted in 2000 to compare the timing of application of postemergence herbicides. In all instances Gramoxone Extra at 1.5 pt/A plus atrazine at 3 pt/A was applied at planting for initial burndown control. The postemergence treatments were applied at 1, 2, 4, or 6 weeks after planting. The treatments included: 1) Roundup Ultra at 2 pt/A applied overtop Roundup Ready corn; 2) Lightning applied at 1.28 oz/A overtop Clearfield corn; 3) Liberty applied at 28 oz/A overtop Liberty Link corn; and 4) Accent at 0.67 oz/A applied overtop Clearfield corn. All postemergence herbicides provided similar level of Italian ryegrass control regardless of the timing of application. Italian ryegrass control ranged form 53 to 63 % for treatments at 1 week after application planting and 66 to 80 % for treatments at 2 weeks after planting. Delaying postemergence applications until 4 or 6 weeks after planting resulted in 93 to 100% control of Italian ryegrass.

Summary and Conclusions

Based on herbicides currently registered for use in wheat, Hoelon appears to offer the most consistent control of Italian ryegrass up to the 4-leaf stage of growth. Experimental herbicides such as Axiom or Everest may have the potential to control Italian ryegrass, however, further research is needed to evaluate crop tolerance and to define such parameters as rate and timing of application.

Although preharvest applications of Roundup Ultra appear to be relatively safe to wheat and offer some control of weeds present at wheat maturity, they do not reduce the viability of Italian ryegrass seed.

Effective burndown control of Italian ryegrass can be achieved with a single application of Roundup Ultra at 3 pt/A plus atrazine at 3 pt/A or with a sequential treatment of Gramoxone Extra applied early preplant followed approximately two weeks later with Gramoxone Extra at 1.5 pt/A plus atrazine at 3 pt/A. The sequential program involving Gramoxone Extra may be the preferred option for rapid burndown or destruction of any habitats that may harbor voles or other pests that reduce corn stands.

The use of postemergence herbicides as a sequential spray following a burndown program in no-till corn may offer some control or suppression of Italian ryegrass. Delaying the application until sufficient regrowth of ryegrass has occurred appears to be important to achieving optimum results with postemergence treatments. A number of options are available to growers including Roundup Ultra, or a similar glyphosate formulation, applied only to Roundup Ready corn; Lightning applied only to Clearfield corn, Liberty applied only to Liberty Link corn, or Accent applied to regular or herbicide-resistant corn hybrids.

FUSARIUM HEAD BLIGHT AND PLANT RESIDUE MANAGEMENT

Robert Todd, Edward Deibert, Robert Stack, John Enz
Departments of Soil Science & Plant Pathology
North Dakota State University
Fargo, North Dakota 58105-5638
Contact: Robert Todd 701-231-6362
Email: robert_todd@ndsu.nodak.edu

Introduction

Many factors appear related to the development of Fusarium Head Blight, including greater use of minimum tillage and rotations planted to susceptible host crops. Production techniques that maintain crop residues at or near the soil surface can be related to high incidents of scab outbreaks (Stack 1997). Miller et al. (1998) report conventional tillage markedly reduced the level of Fusarium Head Blight infection compared to no-till. Since corn is a host for the scab fungus, increasing corn acreage will result in the presence of infected corn residue on the soil surface (Windels and Kommedahl, 1984). An increase in conservation tillage with a concomitant increase in corn acreage may be contributing to recent scab epidemics (McMullen et al., 1997; Stack 1997). It is the consensus of many investigators that *Fusarium* control via residue management may provide one means to control this disease (Stack, 1997).

If *Fusarium graminearum* survival is related to residue decomposition, then residue management strategies which enhance displacement of *Fusarium* might be developed. Since residue decomposition is a microbial process, manipulation of the microorganisms might accelerate the loss of *Fusarium*. Management options might include "plowing down" residue or use of nitrogen fertilization to enhance the decomposition process.

The objectives of this research (funded by the U.S. Wheat and Barley Scab Initiative) are:

1. *Determine the decomposition rates of plant residue left on the surface of the soil and that which is "plowed" down.*
2. *Quantify the presence of Fusarium in the respective residues.*
3. *Develop strategies to accelerate the displacement of Fusarium by manipulation of the indigenous soil microbial populations.*

Methods

An investigation was began in September 1999 in which residue decomposition and fusarium survival are quantified when wheat, barley and corn residue was placed on and below the soil surface. Cover crop and nitrogen (N) fertilizer rates are included with monitoring parameters related to decomposition such as soil temperature and water, carbon to nitrogen ratio of the residue.

Wheat, barley, and corn residues, infested with *Fusarium graminearum*, were collected following the 1999 crop harvest. Prepared residue "litter bags" were placed in a field of wheat stubble that received a tandem disk and harrow operation. One-half of the replicated test plots were fertilized with nitrogen. Decomposition rates (weight loss) and *Fusarium* populations using quantitative plating techniques were determined for each residue treatment (Todd et al., 2000). In the spring of 2000 following standard crop rotation practices, a soybean cover crop was planted on one-half the plots to establish plant canopy and soil water variables. The twenty-four treatments include:

- Residue Type: Wheat, Barley and Corn
- Residue Placement: Surface and Buried at 3-4 inches.
- N Fertilizer: None and 120 lb. N/acre.
- Cover Crop: None and Soybean (planted in the spring of 2000)
- Replication: 3 reps of each treatment
- Sampling Intervals: 19

Results

Early results were summarized by Todd et al. (1999 and 2000). Representative data for the first 10 months of this investigation is presented in Table 1. Preliminary assessment indicates buried residue is decomposing at a faster rate than residue left on the surface. In the first year of field incubation, nearly all corn residue was decomposed while 20% of the barley and wheat residues were present in the buried bags. Thirty percent of the corn and wheat surface residues and 50% of the surface barley residue remained over the same time period. Nitrogen fertilizer slightly enhanced the decomposition rate. Fusarium populations appear consistent with the level of residue present.

Data collection will continue until the fall of 2001. Upon completion of the data collection phase, decomposition rates, fusarium survivability, soil water content, soil temperature and residue nutrient status will be correlated based on residue placement, N fertility and cover crop.

Table 1. Residue Decomposition and Fusarium Survivability (September 1999-August 2000)

Residue	Placement	Nitrogen (lbs/acre)	% Residue Remaining After 10 Months	% Residue Colonized by Fusarium
Corn	Surface	120	31	53
		0	32	92
	Buried	120	2	75
		0	3	95
Wheat	Surface	120	33	95
		0	26	95
	Buried	120	19	93
		0	17	73
Barley	Surface	120	52	96
		0	50	90
	Buried	120	20	54
		0	22	52

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EFFECT OF CONTINUOUS NO-TILLAGE IN A CORN-WHEAT-DOUBLE-CROP SOYBEAN ROTATION ON YIELDS AND SOIL PROPERTIES

L. Murdock, M. Díaz-Zorita, J. Herbek and J.H. Grove
Department of Agronomy, University of Kentucky
Contact: Lloyd Murdock (270 365 7541)
E-mail: lmurdock@ca.uky.edu

Introduction

The maintenance of continuous no-tillage (NT) systems has sometimes been thought to induce the development of negative soil conditions (higher soil compaction, lower soil temperatures, etc.) that can reduce the crop productivity, mainly for wheat, requiring the regular implementation of tillage practices to avoid this problem. No-till wheat has been grown in Kentucky for many years, presently 25 to 30 % of the wheat acreage in Kentucky is planted NT. The low acreage of NT wheat compared with other row crops is partially explained because many producers have not had the desired success with NT wheat and more information is required about production practices under continuous NT production systems.

The objective of this research is to determine the effects of the periodic tillage in continuous NT on the productivity of crops and its' effect on soil in a corn-wheat-double crop soybean rotation in western Kentucky.

Materials and Methods

The experiment was established in the fall of 1992 at the University of Kentucky Research and Education Center in Princeton (KY) on a Huntington silt loam soil (Fluventic Hapludoll) that it is moderately well-drained. The study was performed on a common crop rotation in Kentucky: corn-wheat-double crop soybean (2 years).

Two wheat-planting systems were compared: No-till wheat (NT) and tilled wheat (Till). NT wheat was planted directly into mechanically shredded corn stalks with a NT drill. Tilled wheat plots were chisel plowed and disked twice before planting. Corn and double crop soybean crops were planted under NT practices in both wheat planting systems (NT and tilled) so that, the only tillage difference between the two treatments was wheat-tillage. Each year, the three crops were planted at an optimum time (wheat: early to mid-October, corn: early April and double crop soybeans: mid-June). The crops' varieties changed from year to year. Soil pH, N, P and K were equally treated for both treatments (NT and tilled wheat).

Several soil and crop measurements were performed during the experiment since 1992. In this article we will present the yearly corn, wheat and soybean yields and some soil physical (bulk density and strength) and chemical (soil organic matter, total Nitrogen, pH in water and Mehlich III P and K) properties measured in the fall of 2000.

Results and Discussion

Only in 3 of the 8 years does tillage for wheat enhance grain yields with respect to continuous no-tillage (Fig. 1). When the NT wheat yielded considerably less than in the tilled treatments, freeze (1996 and 1998) and compaction (1993) were the observed problems. On average, the wheat yields in the continuous NT system were 4 % lower than in the treatments with tillage practices for wheat.

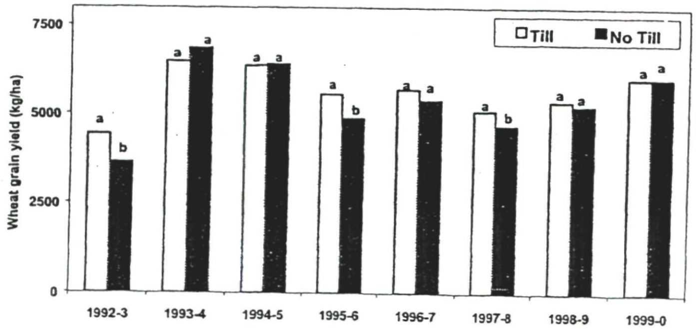


Fig. 1: Yearly effect of the tillage practices on wheat yields. Different letters on the top of each column indicate significant differences ($p<0.05$) between tillage practices in each season.

Continuous NT practices resulted in a 7% higher corn yield and a 3% higher double crop soybean yield (Fig. 2). The differences between the tillage systems were only significant for the corn crops.

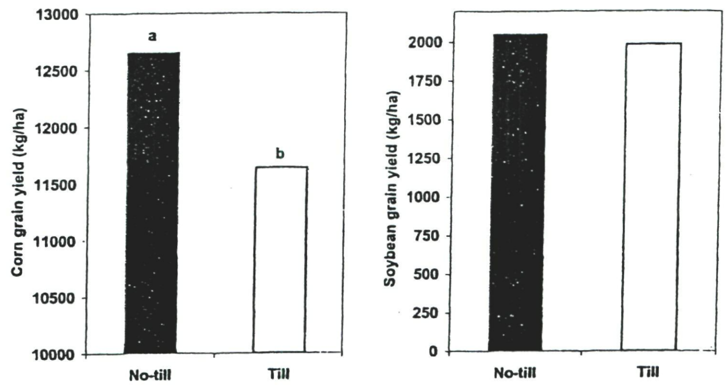


Fig. 2: Effect of tillage for wheat on the 8-year average corn and soybean yields. In each crop, different letters on the top of each column indicate significant differences ($p<0.05$) between tillage practices.

When the yearly yields are plotted as a function of the average yield for the season (Fig. 3), we can observe that the wheat tillage practices does not have any effect on the yields of the double crop soybean. The tillage for wheat was beneficial only in low yielding seasons but detrimental for the corn productivity. Generally, continuos NT systems allow higher corn yields than discontinuous systems.

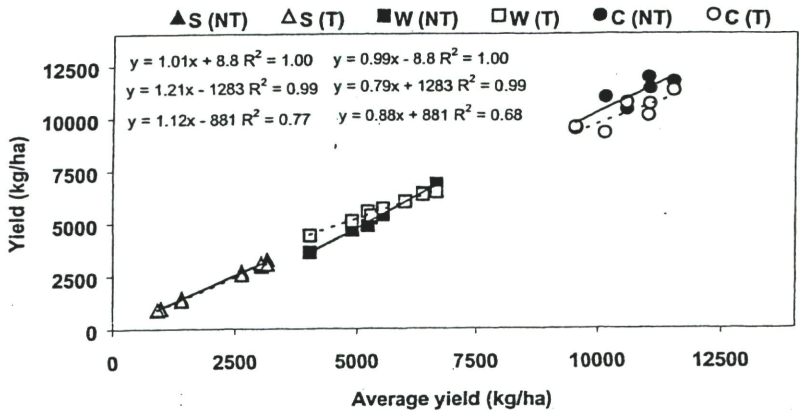


Fig. 3: Does benefit of tillage for wheat depend on seasonal productivity ? S = double crop soybean, W = wheat, C = corn, NT = no-tillage, T = tilled.

There were not significant differences in soil chemical and physical properties between the two tillage systems (Table 1). Although the continuous NT practices tend to present a stronger soil (higher penetration resistance values), the resistance of the soil for both systems was below 2 MPa, critical level for the normal root growth (Fig.4).

Table 1: Effect of tillage practices on the soil properties. Average of 0 to 10 and 10 to 20 cm depth. SOM = Soil organic matter, TN = total nitrogen and BD = bulk density.

		P	K	SOM	TN	BD
First year after tillage	pH	----------lb/acre----------		----------%----------		Mg/ha
No-Till	6.5	30	208	2.06	0.12	1.36
Till	6.2	30	212	2.12	0.12	1.32
Second year after tillage						
No- Till	5.8	30	192	1.99	0.10	1.37
Till	5.7	30	228	1.98	0.11	1.36

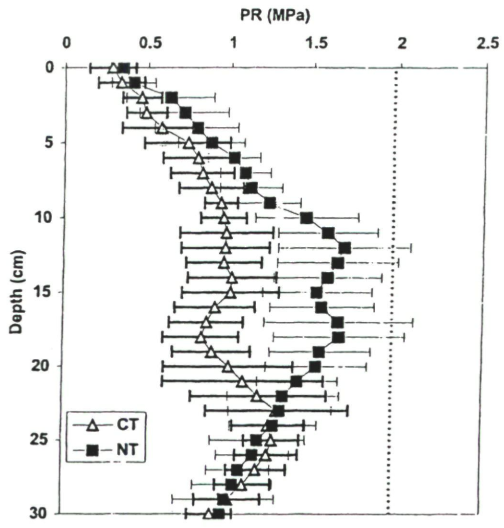


Fig. 4: Effect of tillage practices (CT = tilled, NT = no tillage) on the average soil penetration resistance (PR) values.

Results from other soil measurements characterizing the soil structure between both systems (data not presented) suggest that the disruption of NT systems with tillage before wheat seeding induces to changes in soil structure that remain for at least 2 seasons, affecting the yield of the succeeding summer crops.

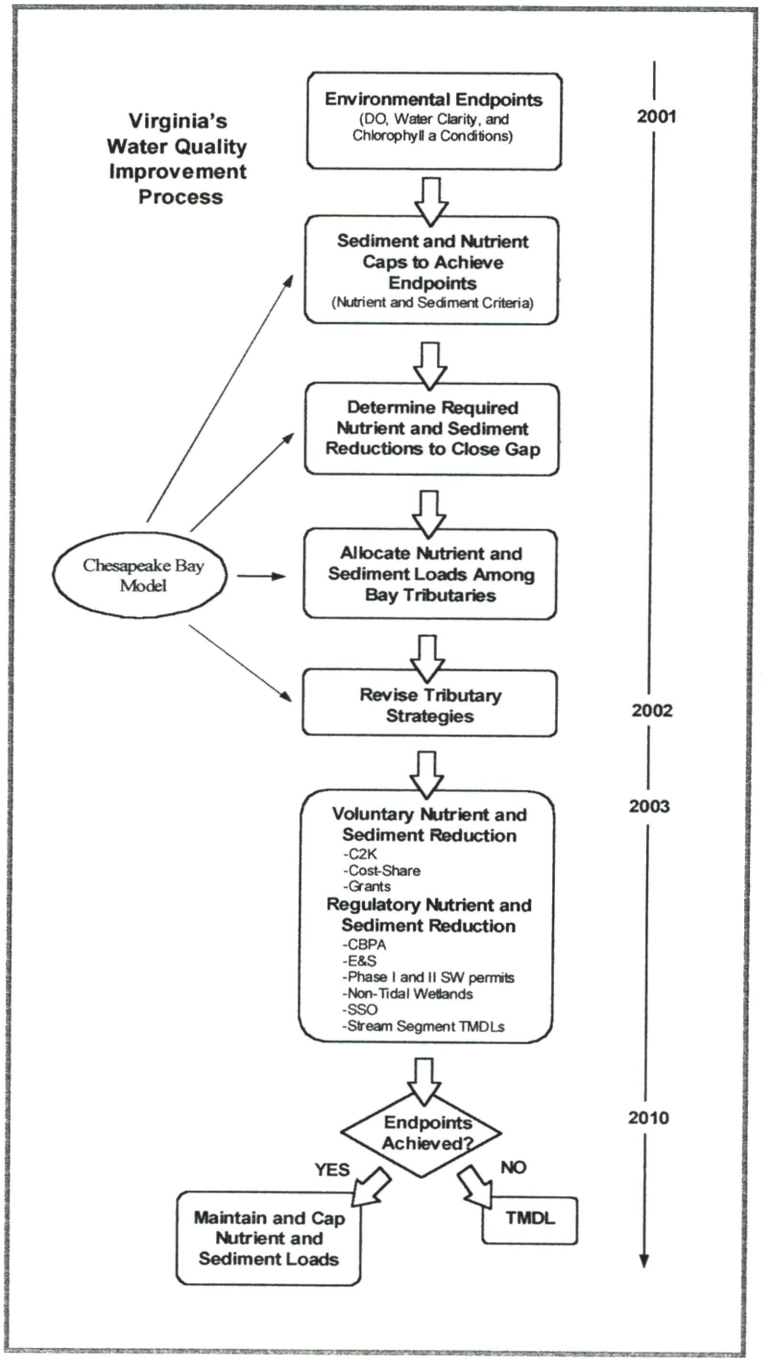
Conclusions

- No long-term differences in soil fertility parameters (pH, P, K), SOM, TN, BD and soil strength (PR) between tilled and NT wheat systems.
- The summer corn crop yields more in the NT wheat system.
- Only in low yielding seasons, tillage enhanced wheat yields.

Chesapeake Bay Program

And

Water Quality Information


Virginia's Water Quality Improvement Process
Environmental Endpoints
(DO, Water Clarity, and Chlorophyll a Conditions)
2001
Sediment and Nutrient Caps to Achieve Endpoints
(Nutrient and Sediment Criteria)
Determine Required Nutrient and Sediment Reductions to Close Gap
Chesapeake Bay Model
Allocate Nutrient and Sediment Loads Among Bay Tributaries
Revise Tributary Strategies
2002
2003
Voluntary Nutrient and Sediment Reduction
-C2K
-Cost-Share
-Grants
Regulatory Nutrient and Sediment Reduction
-CBPA
-E&S
-Phase I and II SW permits
-Non-Tidal Wetlands
-SSO
-Stream Segment TMDLs
2010
Endpoints Achieved?
YES
NO
Maintain and Cap Nutrient and Sediment Loads
TMDL

Virginia Chesapeake Bay Program

VIRGINIA'S TRIBUTARY STRATEGIES

A customized approach to reduce nutrient pollution in the rivers flowing into the Chesapeake Bay

February 1995

Virginia's need for tributary strategies

We need your input to identify balanced solutions, based on sound science and thorough economic impact analysis.

The 1983 Chesapeake Bay Agreement established a cooperative effort among Virginia, Maryland, Pennsylvania, the District of Columbia, the Chesapeake Bay Commission and the federal government to improve the condition of the Chesapeake Bay. In 1987 the agreement was expanded to include a goal of reducing the flow of nutrients into the bay 40 percent between the base year 1985 and 2000. That's why Virginia and the other bay states are developing tributary-specific strategies.

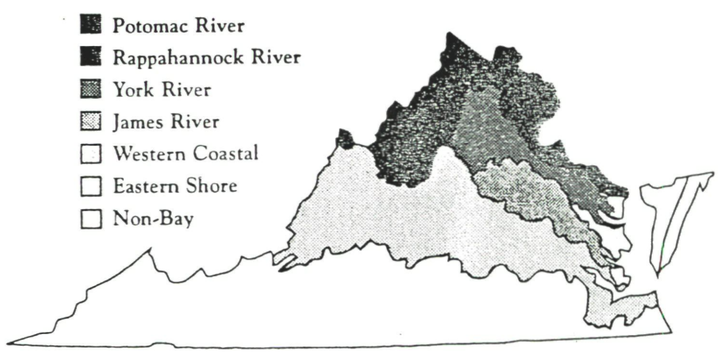
This general goal is intended to improve oxygen levels in the bay's waters. In turn this will help improve the habitats and health of living resources. The goal was reaffirmed following a reevaluation in 1992.

Nutrient sources are different in each of Virginia's major tributaries to the bay. Each tributary has different characteristics and circumstances and each requires a unique, site-specific, individualized response. Tributary strategies, as opposed to a *one-size-fits-all* prescription, permit bay states to address each of their tributaries separately.

In Virginia we have a two-pronged approach for our tributary strategies. This document focuses on the lower tributaries, where we have expanded monitoring and modeling programs to help determine appropriate nutrient reduction goals for each basin. We are also developing a strategy to reduce nutrients by 40 percent in Virginia's portion of the Potomac River Basin.

This document is also an example of how we in Virginia are committed to involving the citizens in the development of tributary strategies. We need your input to identify balanced solutions, based on sound science and thorough economic impact analysis. Through consensus building at the local level among diverse interests, Virginia can find ways to achieve greater reductions in nutrients. To that end, you are encouraged to consider the issues and options presented as we develop strategies, and raise others that may help improve nutrient reduction efforts. Voluntary public participation and citizen input are essential to cost-effective, feasible, equitable strategies. Virginians already have made significant strides to reduce pollution in the bay, and our tributary strategies will build on this progress.

Chesapeake Bay Watersheds in Virginia



Focus on nutrients

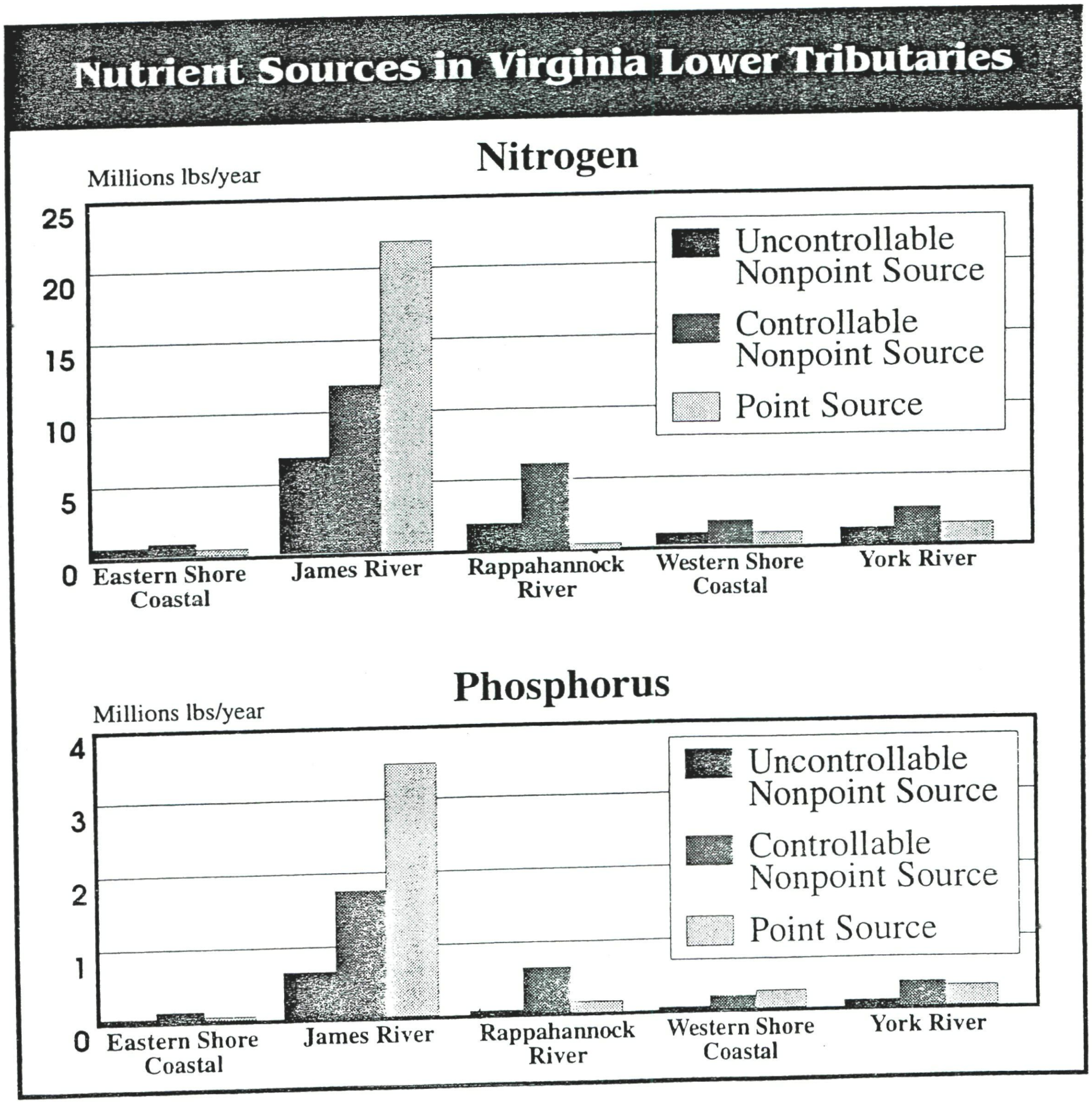
Nutrient enrichment - a surplus of phosphorus and nitrogen that washes off land, or is discharged from industrial or municipal sources - is one of the bay system's key problems.

The rivers and the bay support a wide variety of living resources, such as oysters, fish, crabs, waterfowl and many kinds of underwater plants. This aquatic life needs dissolved oxygen to survive. But excess nitrogen and phosphorus over-fertilize bay waters, causing an abundance of algae that prevents sunlight from reaching underwater plants. When the algae die, the process of decay robs the water of oxygen.

Nutrients occur naturally and would flow into bay waters even if people were not living around its shores. But *excess* amounts of nutrients come from sewage treatment plants, some industries, agricultural and lawn fertilizers, and a variety of other sources.

There are two main pathways nitrogen and phosphorus take to enter the bay and its rivers. One is point source (PS) pollution, which occurs primarily when sewage treatment plants and industrial facilities discharge treated wastewater into a river or stream. The other is nonpoint source (NPS) pollution, most of which is runoff from farm and pasture land, and from development in urban and suburban areas.

A mathematical computer model of the bay system has shown that each tributary has a different impact on nutrient-related problems of the main bay. Nutrients from the Potomac and more northern bay rivers are a major cause of these problems. Therefore the bay program partners have agreed that the upper bay tributaries, including the Potomac, have a 40 percent nutrient reduction goal.



However, because of their locations and movement of water within the bay, nutrients from the bay's more southern tributaries - those in Virginia - do not have the same effect on the main bay. As a result, we are focusing on restoring and enhancing water quality of the lower tributaries for their own sake.

We know their water quality can be affected by nutrient enrichment. But we lack enough tributary-specific information to determine appropriate nutrient reduction goals to enhance the health of the living resources and habitats within the tidal portions of these water bodies.

Developing strategies for Virginia's lower tributaries

Virginia has five lower tributary basins feeding the Chesapeake Bay. They include the Rappahannock, York and James rivers, and the smaller coastal basins on the Eastern Shore and the mainland.

We will be using mathematical water quality modeling to help determine nutrient reduction targets in the lower tributaries. However, the existing three-dimensional computer model of the bay does not adequately describe water quality within those tributaries. Therefore tributary-specific modeling is needed to further guide our nutrient reduction efforts. The new models will more accurately simulate the relationships among nutrients entering the rivers, nutrient enrichment, low dissolved oxygen, and critical habitat and living resource conditions in the tidal tributaries. Expanded data collection and monitoring are the first steps in developing successful models.

Expanded monitoring, enhanced models

The initial phase - the short term goal - requires enhanced monitoring in the tidal portions of the basins. Previous samples collected only in the main river channels may not accurately characterize water conditions near the shore, where most critical habitats and living resources exist.

With sampling at three points along a line that crosses the river, called a transect, additional data will be available to tell more about water quality. Recent enhancements to the monitoring network include the addition of four main channel sampling stations - one in the James River, two in the York River and one in the Rappahannock River - and transects across the rivers at eight locations and the river mouths. Each station is being sampled at least monthly for a full year. Data from this monitoring and other ongoing programs will then be used to develop the tributary models.

Expanded tributary monitoring began in January 1994 along with testing for additional water quality indicators. DEQ, with assistance from Old Dominion University and the Virginia Institute of Marine Science, is performing the monitoring.

The routine bay program monitoring, underway for almost nine years in the rivers, checks for typical physical and chemical parameters such as dissolved oxygen, pH, temperature, salinity, nutrients and suspended solids. The enhanced monitoring program adds tests for several nutrient forms not previously measured (particulate inorganic phosphorus, biogenic silica, particulate carbon). Permanent enhancements to the program include light attenuation measurements, field filtration of water samples, and lower detection limits for some analyses.

Besides the enhanced water quality monitoring program, other data collection efforts that will support model improvements are underway. One is quarterly sampling at significant municipal and industrial point sources in the tidal portions of the tributaries. These samplings better characterize nutrient inputs (total/dissolved nitrogen and phosphorus) from these discharges. Another study was done on the exchange of nutrients and oxygen between the river sediments and the water column. This is important to understand and quantify because the river sediments act as both a sink and a source of nutrients.

Virginia will continue collecting information to help in understanding the consequences of all control activities focused directly or indirectly on improving nutrient management. For example, a long-term study is underway to monitor and analyze the waters of a developing watershed in Caroline County to determine the extent that land-use regulations and policies associated with the Chesapeake Bay Preservation Act are protecting water quality from nonpoint source pollution. The study identifies water quality trends and detects possible pollution sources.

Other ongoing and planned activities that will improve our understanding of nutrients and their impacts on Virginia's lower tributaries include fall-line nutrient monitoring under normal flow and storm conditions, investigating groundwater inputs to the tributaries, determining the extent of nutrient loads from septic

more

systems, and learning how improved boating and marina sanitation can limit nutrient inputs. In addition, refinements are being made to the mathematical computer models used to simulate atmospheric deposition to the eastern United States. This will allow for better estimates of air pollution's impacts on the lands and waters of the bay region.

Development of the tributary models will build on this information and the Bay Program's three-dimensional main bay water quality model. We will use the tributary portions of that model as our starting point and we expect to have tributary-specific nutrient reduction goals by late 1997 or early 1998.

Each basin will have its own reduction number and each will have its own strategy. In the meantime, however, a 40 percent reduction from 1985 nutrient levels serves as an interim goal for each of the lower tributary basins.

Schedule

1994

- Conduct enhanced tributary monitoring from 1/94 - 12/94
- Initiate tributary-specific model code development

1995

- Continue tributary model development
- Develop comprehensive monitoring database

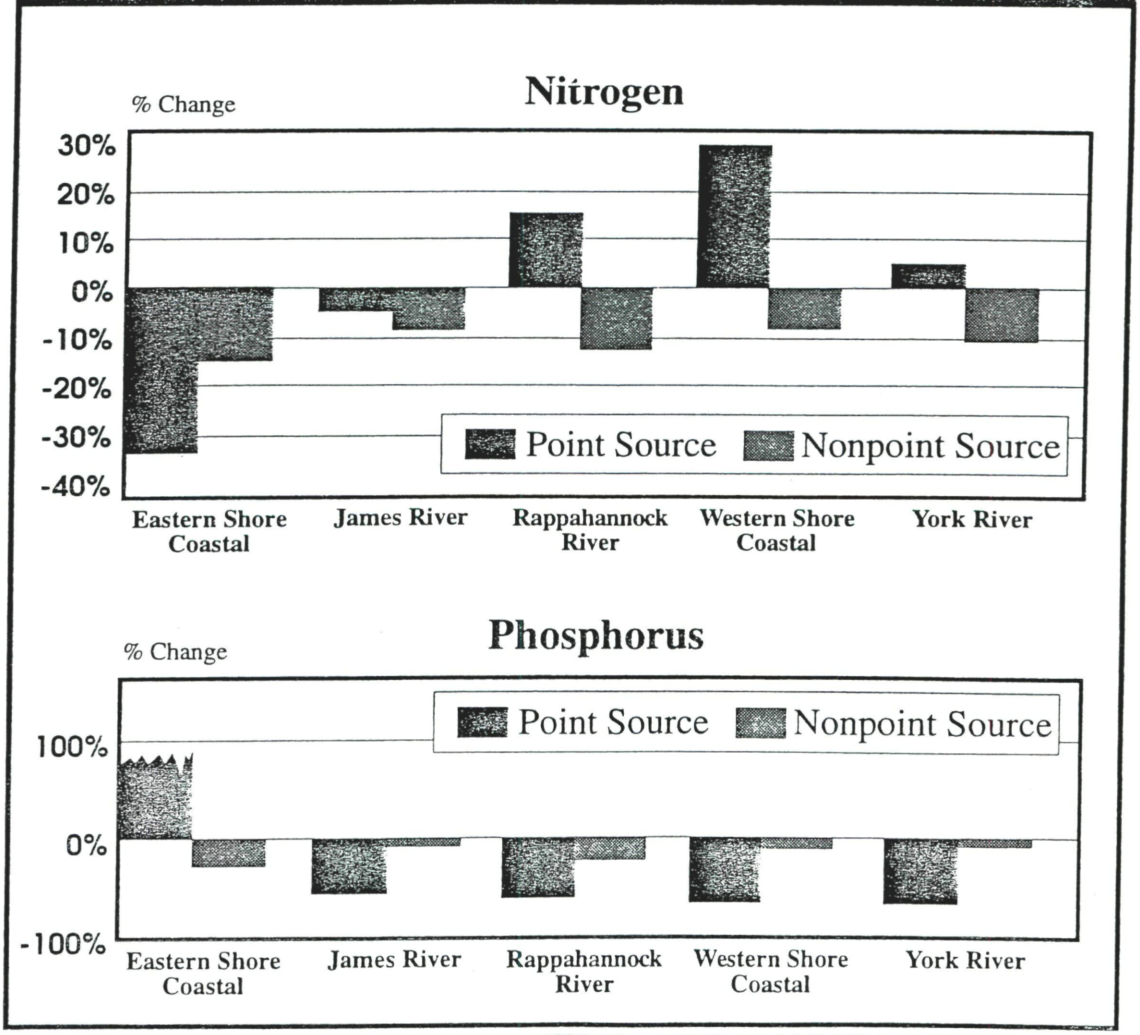
1996

- Complete tributary model calibration/verification
- Begin tributary model applications
- Begin linking model to requirements for living resources

1997

- Complete linking model to requirements for living resources
- Develop final tributary nutrient reduction goals

Percentage Change Nitrogen and Phosphorus, 1985-1993



The lower tributaries

As stated, Virginia's lower tributaries draining into the Chesapeake Bay include small coastal basins of the bay's eastern and western shores and the James, Rappahannock and York rivers. Here are brief descriptions of each.

The *Eastern Shore Coastal Basin*, mainly rural, had a population of 24,700 in 1990. Embayments there exhibit high nitrogen and phosphorus levels most likely attributable to agricultural activities. Waters there generally have adequate dissolved oxygen, although some areas occasionally experience levels low enough to threaten aquatic life.

The *Western Shore Coastal Basin* of the lower bay includes numerous rural watersheds as well as Hampton and highly urban areas of Virginia Beach. In particular, urban runoff contributes significantly to the high amount of suspended solids in the Lynnhaven Basin.

The *James River Basin*, the largest lower tributary watershed, is predominantly forested in the upper reaches yet heavily urban in tidal areas. The James' fall line phosphorus level regularly exceeds federal and state criteria, but its nitrogen levels, which are increasing in the middle and lower portions, are close to the state median. Despite the river's nutrient enriched condition, high fresh water flow and regular influxes of ocean water prevent it from experiencing the dissolved oxygen level problems of other bay rivers.

The *Rappahannock River Basin* is dominated by forests, pastures and other agricultural land uses. Phosphorus levels at the fall line are generally lower than the statewide median; nitrogen levels are generally higher. Both nutrients show distinctive seasonal changes, reflecting upstream nonpoint sources.

Lastly, the *York River Basin*, with about 161,000 residents, is the least densely populated lower tributary watershed. Phosphorus and nitrogen levels at the river's fall line are below the state median. Phosphorus levels are rising in the middle section, and nitrogen levels are rising throughout the tidal river.

Expected reductions by year 2000

Final nutrient reduction goals to restore living resources in the bay's lower tributaries will be set in late 1997 or early 1998. That's when needed data derived through increased monitoring and computer modeling will be available. Regardless of lower tributary goals, we have been and continue to undertake clean-up activities and explore future options. So where will current restoration efforts have us by the year 2000? And what options need to be considered?

First of all, *nonpoint source* pollution estimates are complicated by the diffuse nature of the sources. Some are mainly urban, some are predominantly rural. The size of the basin, the river flow and the absolute amount of nutrients they carry vary greatly. Estimates for NPS pollution loads presented in the following charts assume that current programs remain intact and that BMP installation continues at the current rate. Under these conditions, nonpoint source reductions will nearly double their 1993 values by the year 2000.

By the year 2000, assuming current program implementation, nitrogen reductions attributable to NPS efforts are expected to range from 14 to 34 percent. On the low end, both the James River and Western Coastal basins have estimated nitrogen reductions at about 14 percent. The York and Rappahannock basins are projected to have slightly greater NPS reductions, about 21 and 19 percent respectively. The Eastern Coastal Basin will see the greatest reduction, about 34 percent, by the year 2000.

Projected NPS phosphorus reductions follow a similar pattern. The James Basin is again at the low end with a near 18 percent reduction projected by the year 2000. With the next higher projected values, the York and Western Coastal basins come in at nearly the same reduction level, each about 24 percent. The Rappahannock River Basin is projected to have a greater than 32 percent phosphorus reduction, and the Eastern Coastal Basin again has the highest projected re-

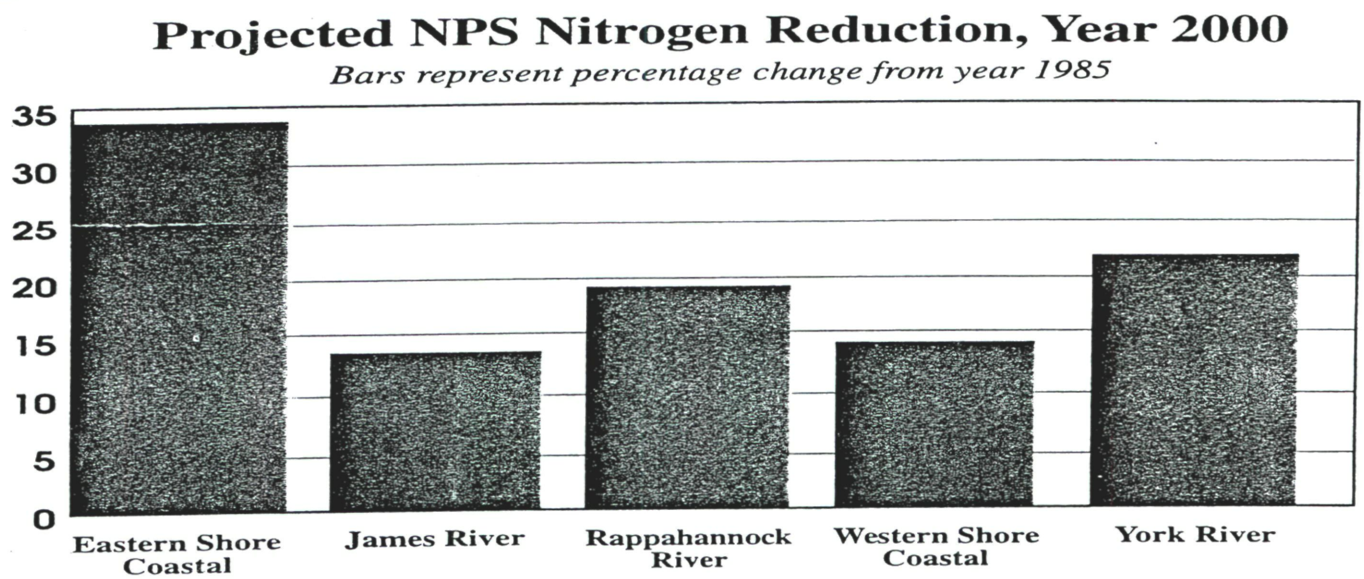
more

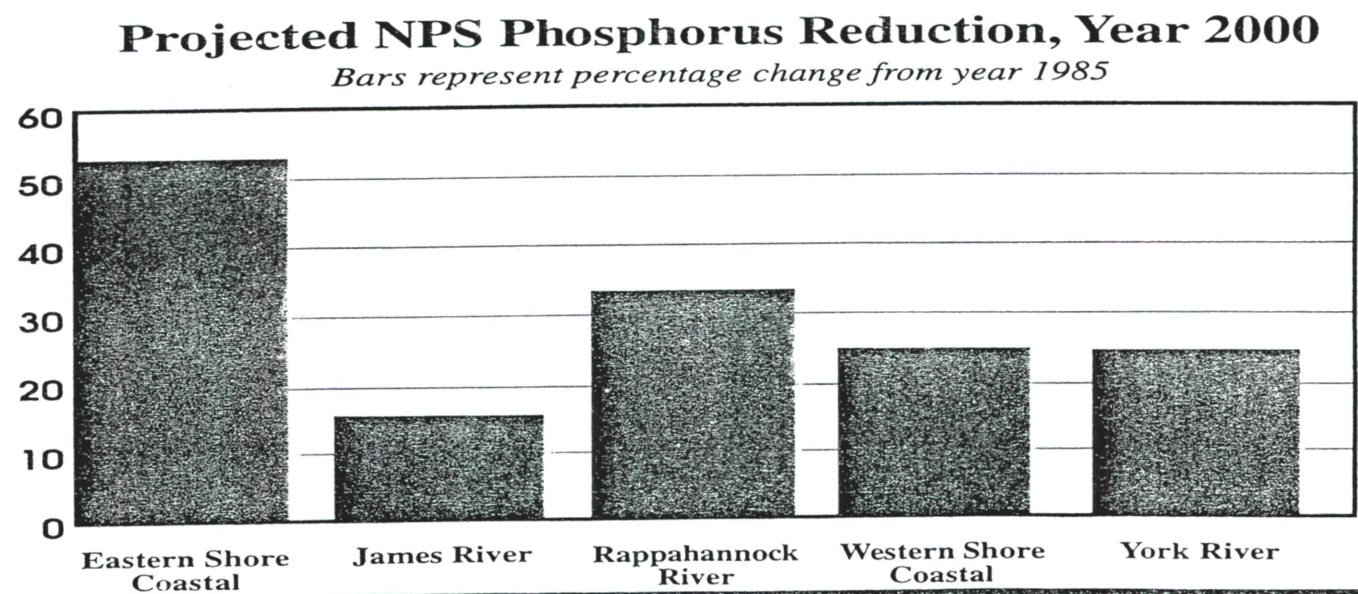
duction of about 52 percent. Implementation of NPS control best management practices would need to increase from current levels to achieve a 40 percent reduction goal.

Virginia will seek to reduce nutrients in *point source* discharges two ways. First, the state will fully implement the Virginia Water Control Board's Point Source Policy for Nutrient Enriched Waters, which limits phosphorus discharges to 2 mg/liter. Second, plant owners will be encouraged to install biological nutrient removal (BNR) systems when faced with ammonia effluent limits. This will reduce nitrogen levels at plants operating BNR systems.

Three basic options have been explored for estimating prospective nutrient load reductions attributable to point sources. The first is *seasonal BNR* (SBNR). BNR is an emerging wastewater treatment process which uses microorganisms to reduce nutrients beyond levels conventionally achieved. SBNR is generally most efficient during warmer periods of the year. The second option, *year-round BNR* (YRBNR), is the same basic system with modifications that allow for cold weather operation. The last option is *limit of technology* (LOT). This represents application of the best treatment processes available for nutrient reduction.

If we used all today's technology at the point sources, the greatest possible reductions would be achieved with LOT. For example, if LOT were used at the point sources in the York Basin, their nitrogen load would decrease 76 percent, and their phosphorus load would fall 98 percent. As LOT is the highest degree of treatment





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Options for Point Source Nitrogen Reduction, Year 2000

Figures represent percentage change from Year 1985

Basin/Scenario	SBNR	YRBNR	LOT
ES Coastal	-83	-90	-96
James	-41	-63	-81
Rappahannock	+73	+12	-51
WS Coastal	-34	-62	-84
York	-3	-43	-76

Options for Point Source Phosphorus Reduction, Year 2000

Figures represent percentage change from Year 1985

Basin/Scenario	SBNR	YRBNR	LOT
ES Coastal	-3	-3	-95
James	-57	-57	-97
Rappahannock	-36	-36	-97
WS Coastal	-71	-71	-99
York	-63	-63	-98

available, it carries the highest price tag. Using LOT at the York Basin's point sources would cost about $205 million to install. Capital construction costs for SBNR and YRBNR in the York have been estimated at $29 million and $49 million respectively.

A large poultry processing plant contributes most of the *Eastern Shore Coastal Basin's* point source nutrient load. The plant has significantly reduced nutrient discharge since 1985. Phosphorus controls needed to achieve a 40 percent reduction would exceed BNR technology but not approach LOT.

For the *James Basin*, sizable nitrogen reductions have already occurred. A basin-wide reduction of 40 percent could be achieved with any of the options listed for point source nitrogen control.

In the *Rappahannock Basin*, the phosphorus goal can nearly be met with seasonal BNR. Nitrogen loads, however, will increase mainly because of an expected threefold increase in flow. Only LOT would exceed a 40 percent reduction level.

Because the *Western Shore Coastal Basin* has few point sources of nutrients, any changes dominate analysis of the options. The level of treatment needed to reduce nitrogen 40 percent lies between seasonal and year-round BNR.

Finally, results for the *York Basin* reflect the few plants discharging a significant nutrient load. Year-round BNR would meet a 40 percent reduction for both nutrients.

Lower Chesapeake Bay tributary strategy public meetings

The public is invited to eight meetings on the lower tributary strategies. All begin at 7:30 p.m. Meeting dates and locations are:

Wednesday, February 15
Richmond - DEQ Innsbrook office, 4900 Cox Rd., Glen Allen
West Point - West Point High School, 2700 Mattaponi Ave., Rm. 121

Thursday, February 16
Charlottesville - Albemarle County Office Bldg., 401 McIntire Rd.
Hampton - City Hall Building, Hampton City Council Chambers (8th floor), 22 Lincoln Street

Tuesday, February 21
Culpeper - Culpeper County Middle School, 14300 Achievement Drive
Tappahannock - Essex County Office Complex, North Cross Street

Wednesday, February 22
Lynchburg - Lynchburg Public Library, 2315 Memorial Ave.
Accomac - Accomack County Courthouse, Courthouse Ave.

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VIRGINIA'S TRIBUTARY STRATEGIES

P.O. Box 10009
Richmond, VA
23240
(804)762-4570

Virginia Chesapeake Bay Program

VIRGINIA'S TRIBUTARY STRATEGIES

A customized approach to reduce nutrient pollution in the rivers flowing into the Chesapeake Bay

The James River Tributary Strategy

Voluntary public participation and citizen input are essential to cost-effective, feasible, equitable strategies.

Over the next year, the 10,102 square miles of the James River basin will be the subject of considerable study as efforts to develop a nutrient reduction tributary strategy for the basin intensify. The Rappahannock and York river basins are undergoing similar activities. This strategy development is part of an ongoing effort to improve the water quality of these Chesapeake Bay tributaries while reducing pollutants flowing into the Bay.

The 1983 Chesapeake Bay Agreement established a cooperative effort among Virginia, Maryland, Pennsylvania, the District of Columbia, the Chesapeake Bay Commission and the federal government to improve the condition of the Chesapeake Bay. In 1987, the agreement was expanded to include a goal of reducing the flow of nutrients into the Bay 40 percent between the base year 1985 and 2000. In 1992, the Bay Agreement was amended to include development of nutrient reduction strategies for each of the main rivers feeding the Chesapeake Bay.

The 40 percent nutrient reduction goal is intended to improve oxygen levels and water clarity in the Bay and tributaries. In turn this will help improve the habitats and health of living resources. Tributary strategies not only work to improve living resources in the Bay, they also work to improve habitat conditions for living resources in the individual rivers.

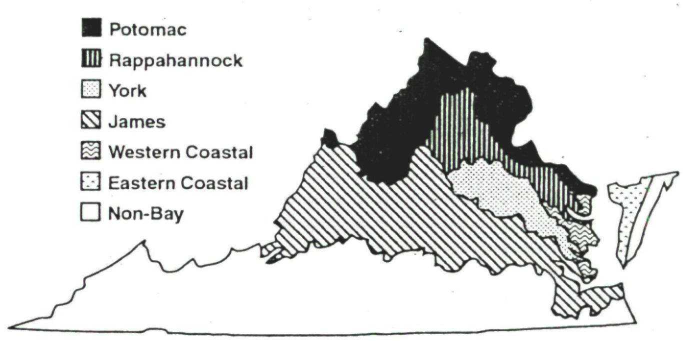
Nutrient sources are different in each of Virginia's major tributaries to the Bay. Each tributary has different characteristics and circumstances and each requires a unique, site-specific response. Tributary strategies, as opposed to a one-size-fits-all prescription, permit Bay states to address each of their tributaries individually.

The Virginia Approach

Virginia recently completed its first tributary strategy in support of reaching the 40 percent goal, ***The Shenandoah and Potomac River Basins Tributary Nutrient Reduction Strategy.*** The Shenandoah and Potomac strategy was driven by cooperative participation by local governments and other stakeholders in the river basins. The efforts for the James and other lower tributaries will rely on this same type of involvement.

While the strategy for each basin will differ, the development process and the principles behind that process will remain uniform. Agencies under Virginia's Secretary of Natural Resources will work closely with local govern-

Virginia's Chesapeake Bay Watersheds



ments, Planning District Commissions, Soil and Water Conservation Districts, sanitation and wastewater authorities, conservation and river-user groups, and other stakeholders to develop strategies that are practical, equitable and cost effective. Participation in the development and implementation of tributary strategies is strictly voluntary. Completed tributary strategies, however, are a prerequisite for localities, groups, or individuals in the Bay watershed receiving funding under the Virginia Water Quality Improvement Act for nutrient reduction and other related river restoration activities.

A major step - the assessment

Staff from the Virginia Department of Conservation and Recreation, Department of Environmental Quality, Chesapeake Bay Local Assistance Department and other natural resource agencies are working with localities and local interests to assess local conditions including ongoing pollution reduction activities. To more effectively work with the many local governments and stakeholders in the James River basin, it has been divided into four regions. Teams in the lower, middle, Piedmont and upper James are identifying existing nutrient loads, measuring reduction practices already in place, assessing how much nutrient reduction is practical in the particular region and identifying corrective measures.

This assessment process is crucial to the development of a workable and ultimately successful strategy. A first step in this assessment is a full inventory of all pollution reduction activities already playing a role in reducing nutrients. Future practical, equitable, and cost effective measures will build on these existing practices.

Setting the goal

As stated, the basin assessment and strategy development process used in the lower tributaries will be similar to the approach taken in the Shenandoah-Potomac basin. With different issues, physical conditions, interests, and constituents in each tributary, a similar process will still lead to individualized strategies. We are already assured that the strategy process for the James, Rappahannock and York will differ from the Shenandoah/Potomac in one key area – the nutrient reduction goal.

A state-of-the-art computer model of the Bay system has shown that each tributary has different impacts on the nutrient related problems of the main Bay. Nutrients from the Potomac and more northern Bay rivers are a major cause of these main Bay problems. Therefore the Bay Program partners have agreed on a 40 percent nutrient reduction goal for the upper Bay tributaries, including the Potomac.

However, because of their locations and the movement of water within the Bay, nutrients from the Bay's more southern tributaries, including the James, do not have the same effect on the main Bay. As a result, we are focusing on restoring and enhancing water quality within the lower tributaries for their own sake.

The nutrient reduction goal for the James River basin will be based on the needs of living resources found in the James River basin. We know water quality can be affected by nutrient enrichment. But, at this time, we still lack tributary-specific information needed to determine appropriate nutrient reduction goals to enhance the living resources and habitats within the basin.

For that reason, the state has been working with Chesapeake Bay Program modeling experts to develop tributary specific mathematical models to provide the data needed to develop nutrient reduction goals based on habitat and living resources needs. It is hoped that results from these model runs will be available for analysis early in 1998.

The Commonwealth of Virginia has the responsibility to set nutrient reduction goals for the James and each of its other southern tributaries. This will not, however, be done in a vacuum. It is imperative that the state receive input from stakeholders and that stakeholders understand the data and the rationale behind the setting of the goal. Two way communications will be vital as the state sets the nutrient reduction goal for the James River basin.

Focus on Nutrients

Nutrient enrichment – a surplus of phosphorus and nitrogen that washes off land, settles from the air, or is discharged from industrial or municipal sources – is one of the Bay system's key problems.

The rivers and the Bay support a wide variety of living resources, such as oysters, fish, crabs, waterfowl and many kinds of underwater plants. This aquatic life needs dissolved oxygen to survive. But excess nitrogen and phosphorus over-fertilize Bay waters, causing an abundance of algae that prevents sunlight from reaching underwater plants. When the algae die, the decay process robs the water of oxygen.

Nutrients occur naturally and would flow into Bay waters even if people were not living around its shores. But excess amounts of nutrients come from sewage treatment plants, some industries, agricultural and lawn fertilizers, and a variety of other sources.

There are two main pathways nitrogen and phosphorus take to enter the Bay and its rivers. One is point source (PS) pollution, which occurs primarily when sewage treatment plants and industrial facilities discharge treated wastewater into a river or stream. The other is nonpoint source (NPS) pollution, most of which is runoff from farm and pasture land, and from development in urban and suburban areas.

For point sources, Biological Nutrient Removal (BNR) technology is one key to success. BNR can eliminate between 60 and 85 percent of the nutrients that treatment plants discharge. The James River strategy may also look at alternatives to BNR, such as nutrient trading.

For nonpoint source pollution, best management practices (BMPs) are the key to reducing nutrient levels. Farmers, in particular, can and do reduce nonpoint source pollution by managing agricultural land differently. The core of the nonpoint portion of any tributary strategy will be the continuation of current programs and activities, such as farm plan implementation, conservation tillage, nutrient management, and management of animal wastes and highly erodible lands, plus additional focus on lawn care by homeowners. Stormwater management also is a key element to eventual success in nutrient reductions.

While monitoring and scientific studies have shown the impact of nutrient enriched waters on the Bay and tidal portions of Bay-feeding rivers, the positive effects of nutrient reduction efforts can be experienced from the mouth to the headwaters of the James and other rivers.

Excessive amounts of the fecal coliform bacteria, an indicator of human or animal waste, or other harmful biological elements can lead to health problems or other impairments in river segments. While not specifically written for fecal coliform or these other biological impairments, the stratgies will address their controllable sources. Likewise, turbidity or excessive sediments are a problem in sections of the James River. Looking primarily at NPS pollution and stormwater management, it is anticipated that a final James River strategy will address sediment control measures.

The James River

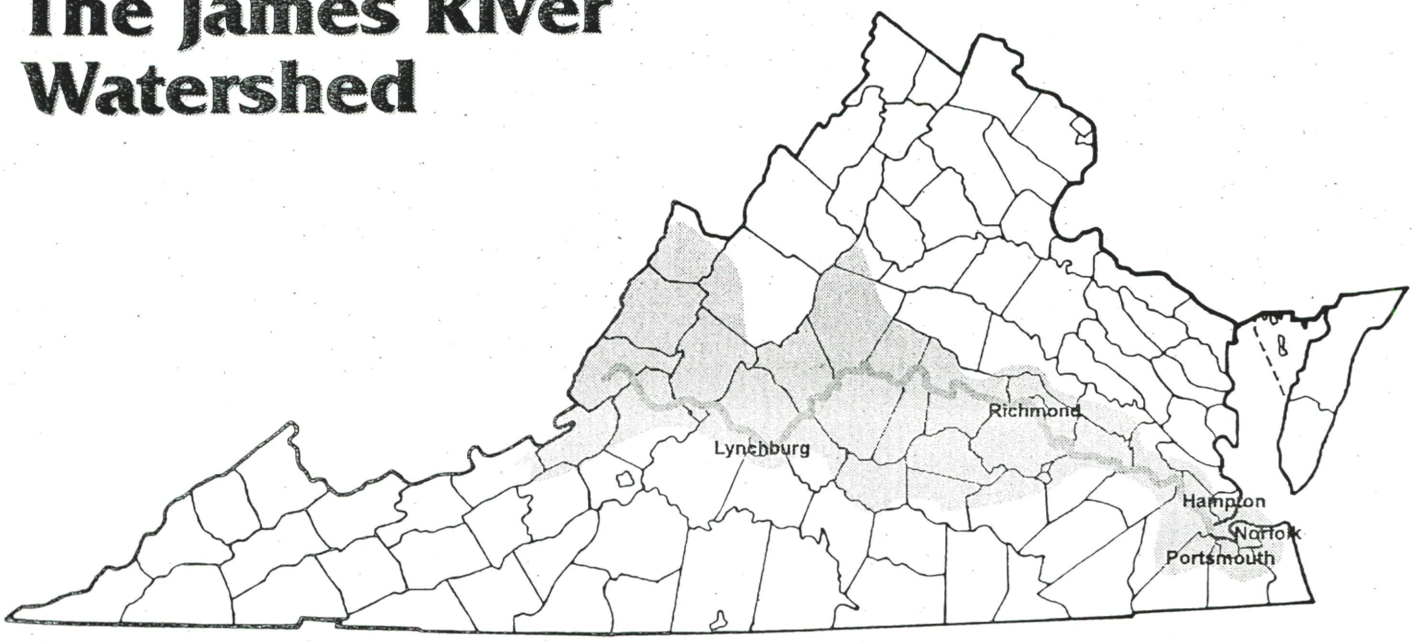
The James River basin's population in 1990 was nearly 2 million and it is expected to grow another 8 percent by the turn of the century. The basin's population comprises about 42 percent of Virginia's Chesapeake Bay watershed population and roughly one-third of the state's total.

Except for a small drainage area in West Virginia, the James' watershed is located almost entirely within Virginia. The river is 450 miles long and drains 10,102 square miles, one-fourth of the state's land base and 47 percent of Virginia's Bay basin. Land use in the river's basin varies considerably from its headwaters to its mouth. Overall, about 71 percent of the land is forested, 23 percent is agricultural, and 6 percent is urban. Major urban areas include the Hampton Roads complex and the Richmond metropolitan area.

The James is historic, scenic, and has unique recreational value. Williamsburg, Jamestown, more than a dozen colonial plantation sites and 75 other registered landmarks lie within the basin. The Virginia General Assembly has officially designated a stretch of the river from Charles City County to Surry County *historic*.

In a similar vein, the river's upper reaches and falls in Richmond have been designated *scenic*. Rapids in the heart of the city attract from around the nation those interested in

The James River Watershed



kayaking, whitewater rafting, canoeing and fishing. The fall line in Richmond enables inland shipping and transportation, and, of course, the James basin down river is home to the Hampton Roads complex. One of the East Coast's busiest seaports, the area is well known as a naval and shipbuilding center.

One of the state's premier bald eagle roosting areas lies within the basin, on Powell Creek in Prince George County. Up to 125 of the noble birds have been spotted there.

The river has been very productive historically. Over the past 50 years, more than 75 percent of all private leases for oyster seeding have been made for sites in James waters. Unfortunately, more than 53,000 acres of shellfish beds have been closed, and landings of shad, striped bass and oyster harvests have declined greatly.

The James receives the highest combined point and nonpoint nutrient inputs of any of the major Virginia Bay tributaries. About 53 percent of the controllable nitrogen and 58 percent of the phosphorus entering the river originate from point sources.

It is the only major river in Virginia where phosphorus levels at the fall line, located in Richmond, exceeded federal and state criteria. These fall line levels have decreased since a statewide ban on phosphorus detergent was implemented in 1989. Nitrogen levels at the fall line are close to the state median. Down river from Richmond, water clarity is decreasing in some of the river and is insufficient to support growth of aquatic vegetation throughout most of the tidal waters. Nitrogen levels in the tidal river are decreasing but remain quite high. The entire tidal portion of the river has been designated as *nutrient enriched* by the State Water Control Board. Levels of chlorophyll, an indicator of algae production, are decreasing in some of the tidal river but are still quite high. High freshwater flow and regular influxes of seawater prevent the James from experiencing the dissolved oxygen problems found in the York, Rappahannock and Potomac rivers.

Bay Modeling

Decisions regarding the restoration of the Bay and associated nutrient reduction goals are based on the results of water monitoring and a series of complex water quality computer models. The original goal, agreed to in 1987, of reducing controllable nutrient inputs by 40 percent by the year 2000 was, in fact, based on these ever-evolving models' results.

In 1994, DEQ, with the assistance of Old Dominion University and the Virginia Institute of Marine Science, expanded the Bay monitoring program that had been ongoing for nearly nine years. Previously, monitoring checked for typical physical and chemical parameters such as dissolved oxygen, pH, temperature, salinity, nutrients and suspended solids.

The enhanced monitoring program added tests for several nutrient forms not previously measured such as particulate inorganic phosphorus, biogenic silica and particulate carbon. Permanent enhancements to the program include light attenuation measurements, field filtration of water samples and lower detection limits for some analysis.

Better monitoring at the tributary's fall-line now enables more accurate estimates of nutrient loadings by the models. The setting of specific nutrient reduction goals for each tributary will be based on results of monitoring, tributary specific modeling and other on living resources and habitat information. The models have been further revised to focus on living resource responses in Virginia's lower tributaries.

In a nutshell, the models account for many sources of nutrients and predicts effects on the Bay and tributary water quality given various scenarios. The models, already 10 years in the making, are three distinct, complex models working together to provide program managers and decision-makers with reliable, useful information and guidance.

The first of these models, the *watershed model*, provides accurate estimates of nitrogen and phosphorus loa[ds] delivered to each Bay tributary. It also simulates nutrien[t] reduction strategies potentially undertaken on behalf of Bay restoration. The model breaks up the Bay's 64,000 square mile drainage basin into 90 segments, for each of which vast amounts of data have been derived and incorporated.

The second is the *airshed model*. The Bay's airshed is vast, reaching well into Ohio. This is a three-dimensional (3-D), 15-layer model made up of 22,000 cells whose layers reach more than 9 miles high. Its purpose is to account for airborne nutrients, a significant source of the nitrogen reaching the Bay.

The final piece of the modeling framework is called the *tributary water quality model,* a fully three-dimensional water quality model of the Bay and its tributaries. Chemical, physical, and biological dynamics of the Bay are calculated by a water quality model. It is coupled with a transport (or hydrodynamic) model represented by about 8,000 computational cells. The water quality model includes a sediment submodel simulating sources and sinks of nutrients to and from the bottom. In addition, biological enhancements include the addition of benthic animals (such as clams and worms), algae that grow from the enrichment of nutrients and the small primary consumers that eat the[m] and a submerged aquatic vegetation model. With these model enhancements, we hope to be able to link biological responses to nutrient load changes in different regions of each tributary.

Bay Tributary Strategy Development, Implementation

With the Shenandoah and Potomac River Basins tributary strategy process underway, the 1996 Virginia General Assembly passed legislation that provided a framework and time frame for the development of Virginia's tributary strategies. The language was amended in 1997 to reflect a more realistic time frame for development of lower tributary strategies considering the scheduled availability of modeling information. This legislation is now part of the Code of Virginia, § 2.1-51.12:1-3

The Shenandoah/Potomac River strategy was completed and submitted by the January 1, 1997 deadline called for by state law. The deadline for completion of the York and James River strategies is July 1, 1998, with the Rappahannock and eastern and western coastal basins to have strategies by January 1, 1999.

Under this new law, "The Secretary of Natural Resources shall coordinate the development of tributary plans designed to improve water quality and restore the living resources of the Chesapeake Bayand its tributaries. Such plans shall be tributary specific in nature..."

The Chesapeake Bay and the waterways feeding it are among the Commonwealth's most recognized and utilized natural resources. They touch citizens from all walks of life. Recognizing this, the law seeks to make the development of these strategies a very public process citing involvement by stakeholders "including but not limited to local government officials; wastewater treatment operators; seafood industry representatives; commercial and recreational fishing interests; developers; farmers; local, regional and statewide conservation and environmental interests..."

The law gives the framework for the strategies, calling for specific elements to be included. Those elements are:

- recommended specific strategies to meet nutrient reduction goals
- a progress report on the Bay Toxics Strategy
- a progress report on the Bay submerged aquatic vegetation restoration goals
- a progress report related to the Local Government Partnership Initiative

According to the law, the Secretary of Natural Resources will also annually submit a tributary strategy progress report by November 1.

While the law calls for plans to provide updates on a variety of water quality issues, the reduction of nutrients is clearly the main focus. In developing reduction strategies, the act calls for specific recommended state, local and private responsibilities, actions and timetables. It also calls for benchmarks for tracking and evaluating progress, estimated benefits, scientific documentation of recommended actions, analysis of how and when goals will be achieved, cost effectiveness and equity analysis and state funding commitments, and methods for considering alternative or additional funding mechanisms.

Virginia Water Quality Improvement Act of 1997

Motivated by the need to finance the completed Shenandoah-Potomac River nutrient reduction strategy and the lower basin strategies now being developed, Governor Allen introduced legislation to provide several funding sources for these Chesapeake Bay related nutrient reduction efforts. What ultimately resulted was the Virginia Water Quality Act of 1997 (§ 10.1-2117 through 2134). During the course of the legislative session, in consultation with stakeholders of all views and persuasions, the act took on statewide characteristics and will now fund water quality improvement activities in both tributaries with established strategies and in areas outside the Chesapeake Bay drainage area. Ultimately, the lower tributary strategies will also be funded through this act.

This new act recognizes that the quality of state waters is a responsibility shared among state and local governments, as well as individuals. Therefore it establishes cooperative programs related to nutrient reduction and other point and nonpoint sources of pollution.

The act directs the Department of Environmental Quality to assist local governments, businesses, and individuals in the control of point source pollution with technical and financial assistance made available through grants provided from the fund. Likewise, it directs the Department of Conservation and Recreation to provide similar assistance to local governments, Soil and Water Conservation Districts, other groups, and individuals in efforts to control nonpoint source pollution.

The initial appropriation to fund the act is $15 million. Ten million of this appropriation will go to point sources with the remaining $5 million going to nonpoint sources. The point source funds will finance at least 50 percent of design and implementation costs of nutrient reduction technologies at publicly owned treatment works until all tributary plans are developed and implemented. They may also provide for a 50 percent reimbursement for previously installed biological nutrient reduction technology upon execution of a grant agreement.

Half of the nonpoint source grants will go to projects outside the Bay watershed, with the remaining half going to implement existing tributary strategies. Nonpoint source initiatives eligible for funding may include the acquisition of conservation easements, nutrient management plan assistance, implementation of nutrient reduction practices, stormwater management, urban erosion and sediment control, and local government reimbursement for tax relief as an incentive for water quality improvement.

Conclusion

The development of a nutrient reduction strategy for the James River depends on the informed, active participation of local governments, interested and affected parties and the general public. We are working to establish a partnership that leads to the identification of balanced solutions to the restoration and enhancement of water quality and living resource habitat conditions in the James River basin – solutions that are based on sound science and a thorough understanding of the economic implications of alternative courses of action.

Through consensus building at the local level among diverse interests, Virginia can find ways to achieve greater reductions in nutrients. To that end, you are encouraged to consider the issues and options presented as we develop strategies, and raise others that may help improve nutrient reduction efforts. Voluntary public participation and citizen input are essential to cost-effective, feasible, equitable strategies.

You can become involved by calling the team leader in your area. They are Mark Bennett, basinwide coordinator and Upper James team leader (804/371-7485); Rick Hill, Piedmont James (804/786-7119); Shep Moon, Middle James (804/225-3440); and John Kennedy, Lower James (804/698-4312). For more information on strategy development, including meetings or activities in your area, write James River Tributary Strategy, Virginia Department of Conservation and Recreation, 203 Governor Street, Suite 213, Richmond, Virginia 23219 or call (804) 786-5045.

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VIRGINIA'S TRIBUTARY STRATEGIES

P.O. Box 10009
Richmond, VA
23240
(804) 762-4570

IV. Model Results

A primary purpose of water quality modeling is scenario analysis. Models are used to develop and test various management options or strategies aimed at improving water quality. This section of the report focuses on what scenarios were run in order to assess anticipated water quality and living resource responses in the James River below the fall line to various loading scenarios. All scenarios are based on a 10-year simulation period using the corresponding hydrology from the years 1985 to 1994.

Scenario Descriptions

The Chesapeake Bay estuary Model Package (CBEMP) framework provided projections of the expected water quality responses in the tidal James River under a variety of management options. Four reference scenarios provided a base for the analysis (Table 4.1). These scenarios were:

Table 4.1 Reference Scenarios:

SCENARIO	DESCRIPTION
Base Case	1985 land use, 1985 point source discharge & 1985 BMP levels throughout the entire watershed.
1996 Progress	1996 land use, 1996 point source discharge & 1996 BMP levels throughout the entire watershed.
Full Voluntary Program Implementation (FVPI)	Full voluntary program implementation throughout the entire watershed. Point source concentrations of 5.5 mg/L TN and 0.5 mg/L TP with flows projected to 2000. NPS-Ag @ 75% cropland conservation till, 25% conventional till, 10% forest buffers, BMPs to animal wastes (80%), streambank protection (15%), nutrient management (75%), & septic connections (50%).
Limit of Technology	*Limit of Technology* describes the maximum practical level of implementation given unlimited resources and 100% land application based on "do everything, everywhere" using current available technologies throughout the entire watershed. Point source conc. of 3.0 mg/L-TN and 0.075 mg/L-TP with flows projected to 2000. NPS-Ag @ 75% cropland conservation till, full forest buffers, 100% BMPs to animal wastes, streambank protection, nutrient management, & septic connections.

Table 3.1 – Nutrient and Sediment Loads
James River Basin: 1985

	Point Source	Nonpoint Source	Total	Units
Phosphorus	3.6	2.5	6.1	million lbs/yr
Nitrogen	22.1	19.1	41.2	million lbs/yr
Sediment	N/A	2.01	2.01	million tons/yr

Table 4.4. Tidal James and Western Shore Percent Improvements from 1985 Conditions for Four Key Water and Habitat Quality Measurements and Associated Cost Estimates.

Scenario	Percent Loading Reductions from 1985 Conditions			Percent Improvements of Water Quality and Living Resource from 1985 Conditions				Virginia Cost Estimates (Millions)		
	Total Nitrogen (%)	Total Phosph. (%)	Total Sediment (%)	Surface Chlorophyll Tidal Fresh (%)	Deep Waters <3 mg/l DO (%)	Bay Grass Area (%)	Bay Grass Density (%)	Point Source Capital Cost	Non-Point Sources	Total
1996 Progress	11	36	2	23	16	210	95	$ 55	$ 3	$ 58
1996 Progress/Trib. Strat. Above	11	36	2	23	23	210	95	55	3	58
Current Limit of Tech. Sediment/Trib. Strat. Above	11	36	17	23	23	277	189	55	380	435
Extreme Sediment Reduction/Trib. Strat. Above	11	36	40	22	23	489	789	55	-	-
James AFL BNR Equiv./Trib. Strat. Above	15	38	6	25	-	210	108	126	-	-
James TF BNR Equiv./Trib. Strat. Above	32	36	2	52	-	354	200	-	-	-
James TF BNR Equiv. For N Only/Trib. Strat. Above	32	39	7	52	-	354	221	164	-	-
BNR Equivalent/Trib. Strat. Above	42	40	7	52	44	354	217	383	51	434
Midpoint 1996-Full Volun. Imp	30	47	6	42	N/A	334	227	-	-	-
Interim Bay Agreement Goal/Trib. Strat. Above	29	35	3	28	41	242	90	197	19	216
Full Voluntary Imp./Trib. Strat. Above	50	58	9	61	51	486	410	1,430	132	1,562
Full Voluntary Implementation	50	58	9	62	61	486	411	1,430	132	1,562
Current Limit of Technology	61	69	17	72	68	741	1861	2,342	465	2,806

1. Western Shore James includes Lynnhaven to Hampton Roads.
2. Total sediment load does not include bank loads directly to tidal waters.
3. Deep water failing habitat criteria under 1985 conditions was 4% of the total deep hypoxic waters in VA.
4. Grass beds were very sparse. Under maximum nutrient reductions, bay grass density attains only 1.4 g C/m as compared to the Western and Eastern Shore that attain above 50-100 g C/m, respectively.
5. Point source cost calculations include the HRSD-Chesapeake/Elizabeth STP from the Western Shore. All point source cost estimates are planning level estimates which are normally expected to be accurate +50% to –30%.
6. Nonpoint source costs reflect total installation cost for both state portion and stakeholder match but do not reflect the technical assistance and maintanance cost of the best management practice.
7. AFL = Above Fall Line; BFL = Below Fall Line; TF = Tidal Fresh; BNR = Biological Nutrient Removal

Rainfall Simulation of a total 3.38 inches (2-5 yr. return storm) (mowed corn stalk residue) on a 7.5% slope/Pamunkey fine sandy loam. Clean till small grain seedbed vs. 10-year continuous No-Till corn, small grain and double crop soybean rotation (3-crops/2 yrs.). Surface applied poultry litter @ 3t/ac vs. Broadcast 10-10-10 @ 1500 lb./ac (treatments A, D, & E) vs. Control @ 0 lb./ac treatment C at corn planting.

Table 2. 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 (99.8)	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

Chesapeake Bay Watershed Model – Va. Sediment Loading Data Base

USGS- Hydrology & VDCR Landuse = (VIRGIS) Potential Stream Sediment Loadings = Annual Erosion Rate in Tons/Acre/Year (USLE Estimate) multiplied by the delivery ratio, which is a function that includes the influence of ground cover, steepness and length of flowpath to a receiving stream. Sediment loading was only calculated for agricultural land.

Range

Low Potential =	**1-4 tons/acre/yr.**
Medium Potential =	**5-16 tons/acre/yr.**
High Potential =	**17 & up tons/acre/yr.**

Tidal York and Western Shore[1] Percent Improvement From 1985 Conditions For Three Key Water and Habitat Quality Measurements And Associated Cost Estimates

Scenario	Percent Loading Reductions from 1985 Conditions			Percent Improvements of Water Quality and Living Resource from 1985 Conditions			Virginia Cost Estimates (Millions)		
	Total Nitrogen (%)	Total Phosph. (%)	Total Sediment (%)[2]	Anoxia < 1 mg/L (%)[3]	Bay Grasses Area (%)	Bay Grass Density (%)[4]	Point Sources Capital Cost[5]	Non-Point Sources[6]	Total
96 Progress Whole Bay	2	36	16	13	1	22	$ 0.00	$ 0.84	$ 0.
A 1996 Progress/Trib. Strat. Above	2	36	16	34	3	31	$ 0.00	$ 0.84	$ 0.
NR+Equivalent/Trib. Strat. Above	28	41	15	44	4	36	$ 19.65	$ 21.08	$ 40.
idpoint 1996-Full Volun. Imp. /Trib. Strat. Above	20	47	16	46	4	38	-	-	-
A Interim Bay Agreement/Trib. Strat. Above	45	29	11	44	4	35	$ 19.65	$ 35.52	$ 55
A West Shore Full Voluntary Imp./Trib. Strat. Above	5	36	16	38	3	33			
A Full Voluntary Implementation /Trib. Strat. Above	38	56	21	49	7	41	$ 134.37	$ 35.52	$ 169
ull Voluntary Implementation Whole Bay	38	56	21	72	7	49	$ 134.37	$ 35.52	$ 169
urrent Limit of Technology Whole Bay	48	68	32	80	9	54	$ 249.09	$ 99.21	$ 348

Note: Trib. Strat. Above means that the loads from the Potomac River and above were held constant at agreed upon tributary strategy levels.
Draft: March 17, 1999

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[1] Western Shore York includes Poquoson to Middle Peninsula with Mobjack Bay and Piankatank River.

[2] Total Sediment load did not include bank loads to tidal waters.

[3] Anoxic water for the Tidal York under 1985 conditions was <1% of the total anoxic waters in Virginia.

[4] Under maximum nutrient reductions, bay grass density attains 60 g C/m^2 as compared to 50 - 100 g C/m^2 for the Western and Eastern Shores.

[5] Point source cost calculations include the Gloucester STP and Mathews Courthouse STP from the Western Shore. All point source cost estimates are planning level estimates which are normally expected to be accurate within +50% to -30%.

[6] Non-point source costs reflects total installation cost for both state portion and stakeholder match but do not reflect the technical assistance and maintenance cost of the best management practice.

CHESAPEAKE BAY WATERSHED MODEL APPLICATION AND CALCULATION OF NUTRIENT AND SEDIMENT LOADINGS

Appendix H: Tracking Best Management Practice Nutrient Reductions in the Chesapeake Bay Program

A Report of the
Chesapeake Bay Program
Modeling Subcommittee
Annapolis, MD

August 1998

Chesapeake Bay Program

Printed by the U.S. Environmental Protection Agency for the Chesapeake Bay Program

Table H.1.14 BMP Practices resulting in a Land Use Change

BMP Type	Land Use Change
Conservation Reserve Program (CRP)	cropland to pasture
forest conservation	pervious urban to forest
forest/grass buffers	cropland to forest/pasture
tree planting	cropland/pasture to forest
conventional tillage/conservation tillage	conventional tillage to conservation tillage

Land use Conversions from Conventional Tillage to Conservation Tillage

In the Phase IV Watershed Model, conservation tillage is tracked on an annual basis to reflect increases or decreases that occur in tillage management. Acreage in conservation tillage for each of the six Chesapeake Bay basin states was obtained through the Conservation Technology Information Center (CTIC). CTIC provides annual data sets for each state showing the acres of cropland planted using conservation tillage.

CTIC collects these data in an annual survey conducted on a county-by-county basis by USDA Natural Resources Conservation Service offices, and soil and water conservation districts to track tillage systems used on annually planted crops. The acreage for "Total Cropland Planted" and "Total Cropland Planted Using Conservation Tillage" major data categories is tracked by the CTIC surveys and used by the Chesapeake Bay Program. Within this CTIC data set, conservation tillage is further broken down into the following major data subcategories; "15-30 Percent Residue Tillage," "Under 15 Percent Residue Tillage," "Mulch Tillage," and "No-Till Tillage." Tillage methods and acreage for the following crop types are estimated by the annual surveys: corn full season and double cropped; small grain fall and spring seeded; soybeans full season and double cropped; cotton; grain sorghum full season and double cropped; forage crops; and other crops.

Once the Chesapeake Bay Program obtains these data, a CTIC software program (CEDAR) is used to organize the data into a new data set that includes "Total Tillage" (all acres planted, including those planted by conservation tillage) and "Conservation Tillage" (all acres planted using conservation tillage) for each county. This data set includes the following crops: corn full season; small grain fall and spring seeded; soybeans full season; cotton; grain sorghum full season; forage crops; and other crops. To eliminate double counting of acres, the double cropped acres are not included in this data set. Forage is included, since at the planting stage it responds more like tilled cropland in the first season of growth.

This data set is normalized to the cropland areas represented in the Phase IV Watershed Model by adding all acres of the above crops for both "Total Tillage" and "Conservation Tillage," and then dividing "Conservation Tillage" by "Total Tillage" to get "Percent Conservation Tillage" for each county. This percent value is then used to adjust conservation and conventional tillage within each county of the Chesapeake Bay Program Land Use data set. This adjustment is made within the data set by multiplying the "Percent Conservation Tillage" by the total cropland (less hayland) for each county to get the acres of conservation tillage in each county. The difference between total cropland (less hayland) and conservation tillage is the conventional tillage acres. Both conservation and conventional tillage acres are multiplied by the percent of county in each Phase IV Watershed Model segment. These county values are added to obtain both conservation and conventional tilled acres within each model segment.

Figure H.1.3 shows the amount of conservation tillage compared to the amount of conventional tillage as modeled by the Phase IV Watershed Model. The Chesapeake Bay Watershed, in 1985 had more conservation tillage than conventional. By the year 2000, it is projected that conservation tillage will have been implemented on even more acres. The trend of decreasing conventional tillage and increasing conservation tillage practice is also evident in Figure H.1.4 on a national basis.

Definitions

Crop Residue Management (CRM)

CRM is a year-round conservation tillage management system beginning with the selection of crops that produce sufficient quantities of residue. The system may include the use of cover crops after low residue producing crops. CRM includes all field operations that affect residue amounts, orientation and distribution throughout the period requiring protection. Site-specific residue cover is usually expressed in "percent residue" but may also be expressed as "pounds of residue."

"Crop Residue Management is a year-round tillage management system."

Conservation Tillage

Conservation tillage is any tillage and planting system with 30% or more residue remaining on the soil surface after planting to reduce soil erosion by water. Where soil erosion by wind is the primary concern, conservation tillage is any system that maintains at least 1,000 pounds per acre of flat, small grain residue equivalent on the surface throughout the critical wind erosion period.

"Conservation tillage includes no-till, ridge-till and mulch-till ... any system with 30% residue remaining after planting."

Conservation tillage includes:

No-till and Strip-till - The soil is left undisturbed from harvest to planting except strips up to 1/3 of the row width (strips may involve only residue disturbance or may include soil disturbance). Planting or drilling is accomplished using disc openers, coulter(s), row cleaners, in-row chisels or roto-tillers. Weed control is accomplished primarily with crop protection products. Cultivation may be used for emergency weed control. Other common terms used to describe No-till include direct seeding, slot planting, zero-till, row-till and slot-till.

Ridge-till - The soil is left undisturbed from harvest to planting except for strips up to 1/3 of the row width. Planting is completed on the ridge and usually involves the removal of the top of the ridge. Planting is completed with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is accomplished with crop protection products (frequently banded) and/or cultivation. Ridges are rebuilt during cultivation.

Definitions: Conservation tillage includes no-till/strip-till, ridge-till & mulch-till.
Conservation tillage, 30% residue. Reduced tillage, 15-30% residue.
Intensive/conventional tillage, 15% residue.

Mulch-till - Full width tillage which disturbs all of the soil surface is preformed prior to and/or during planting. Tillage tools such as chisels, field cultivators, disks, sweeps or blades are used. Weed control is accomplished with crop protection products and/or cultivation.

More Tillage Definitions

Reduced-till - Tillage types that leave 15-30% residue cover after planting or 500 to 1,000 pounds per acre of small grain residue equivalent throughout the critical erosion period.

Intensive-till or Conventional-till - Tillage types that leave less than 15% residue cover after planting or less than 500 pounds per acre of small grain residue equivalent throughout the critical erosion period. Generally involves plowing or intensive (numerous) tillage trips.

Stale Seedbed

Stale seedbed is *not* an official category. The residue level after planting dictates the category (mulch-till, reduced-till, or intensive-till). Fields are tilled full-width soon after harvest. The seedbed 'settles' until planting is performed in the undisturbed (settled) seedbed or in re-formed beds (minimum disturbance). Weeds and/or cover crops are managed with crop protection product(s) and/or cultivation.

Other Terms

Non-cropped acres - Includes newly established permanent pasture, fallow, annual conservation use, and the Conservation Reserve Program (CRP)

Highly Erodible Land (HEL) - USDA Natural Resources Conservation Service (NRCS) has determined which fields meet the HEL criteria based on conservation compliance requirements. Both HEL and HEL Adequately Treated are reported in acres.

Total Planted Acres - Includes newly seeded alfalfa and other rotational forage crops ... only the year they are planted. Acres reported may exceed the cropland base due to double cropping. Does not include newly established permanent pastures, fallow, annual conservation use and Conservation Reserve Program (CRP) acres.

Small Grains - Includes wheat, oats, barley, rye, rice, etc. 1997 fall-seeded and 1998 spring-seeded crops ... both harvested in 1998 ... are included in this report. Rice is considered a spring-seeded small grain.

Forage Crops - Grasses or legumes planted as part of a crop rotation.

Permanent Pastures - Includes land planted to grasses or legumes.

Other Crops - Crops not specifically listed, such as vegetable and truck crops, peanuts, tobacco, etc.

Fallow - Cropland idled or "fallowed" the entire growing season.

Conservation Reserve Program (CRP) - Long-term land retirement program. Land recorded in the 1998 survey includes acres through the 17th sign-up that are remaining under contract.

Annual Conservation Use - Discontinued in 1997, this category included cropland idled for government cropland diversion programs.

"Reduced-till has between 15% and 30% residue cover on the soil's surface after planting. Intensive-till has less than 15% cover."

Definitions: Conservation tillage includes no-till/strip-till, ridge-till & mulch-till.
Conservation tillage, 30% residue. Reduced tillage, 15-30% residue.
Intensive/conventional tillage, 15% residue.

Name of Practice: Continuous No-till System

DCR Specifications for No. SL-15A

A. Description

Implement Continuous No-till system and nutrient management technologies resulting in the reduction of non-point source pollution to state waters from nutrients and sediments.

B. Purpose

To increase bio mass/soil quality and recognize nutrient management indicators to manage the movement of nitrogen, phosphorus, sediments and runoff with the use of no-till planting.

C. Policies

1. Only double crop cash grain or cotton rotations that include at least two crops of small grain in five years are eligible. All required small grain crops must be harvested for grain. Straw must remain on the field.

2. If the planting of a cover crop is needed to maintain Bio Mass, producer is eligible to plant cover under SL-8B or WQ-4.

3. Producer must have and follow a current nutrient management plan prepared by a Virginia Certified Nutrient Management Planner to be eligible for cost-share.

4. The system must be maintained for a minimum of five years. By accepting payment for this practice the recipient agrees to update his conservation plan.

5. All crops must be planted using no-till methods.

6. All eligible fields must have a cropping history two out of the past five years.

7. State cost-share will be provided only one time per field.

D. Specifications

1. This practice is subject to the specifications of NRCS Standards 329A Residue Management, 340 Cover and Green Manure Crop No-till and Strip Till, 344 Residue Management, 590 Nutrient Management, and 595 Pest Management.

2. Bio Mass Requirements for cash grain, oilseed, cotton and small grain rotations must maintain a minimum of 80% residue cover on a minimum 80% of enrolled acres and must be maintained for the lifespan of the practice.

E. Rate

The state cost-share rate is a one time incentive payment of $100 per acre.

F. Technical Responsibility

Technical responsibility is assigned to NRCS in consultation with Virginia Certified Nutrient Management Planner and agricultural extension agent due to the standards listed above. Any individual with appropriate NRCS job approval authority can allow authorization. All component practices used in the installation of this BMP must be entered into the NRCS reporting system and are subject to spot check procedures and any other quality control measures.

Revised March 2001

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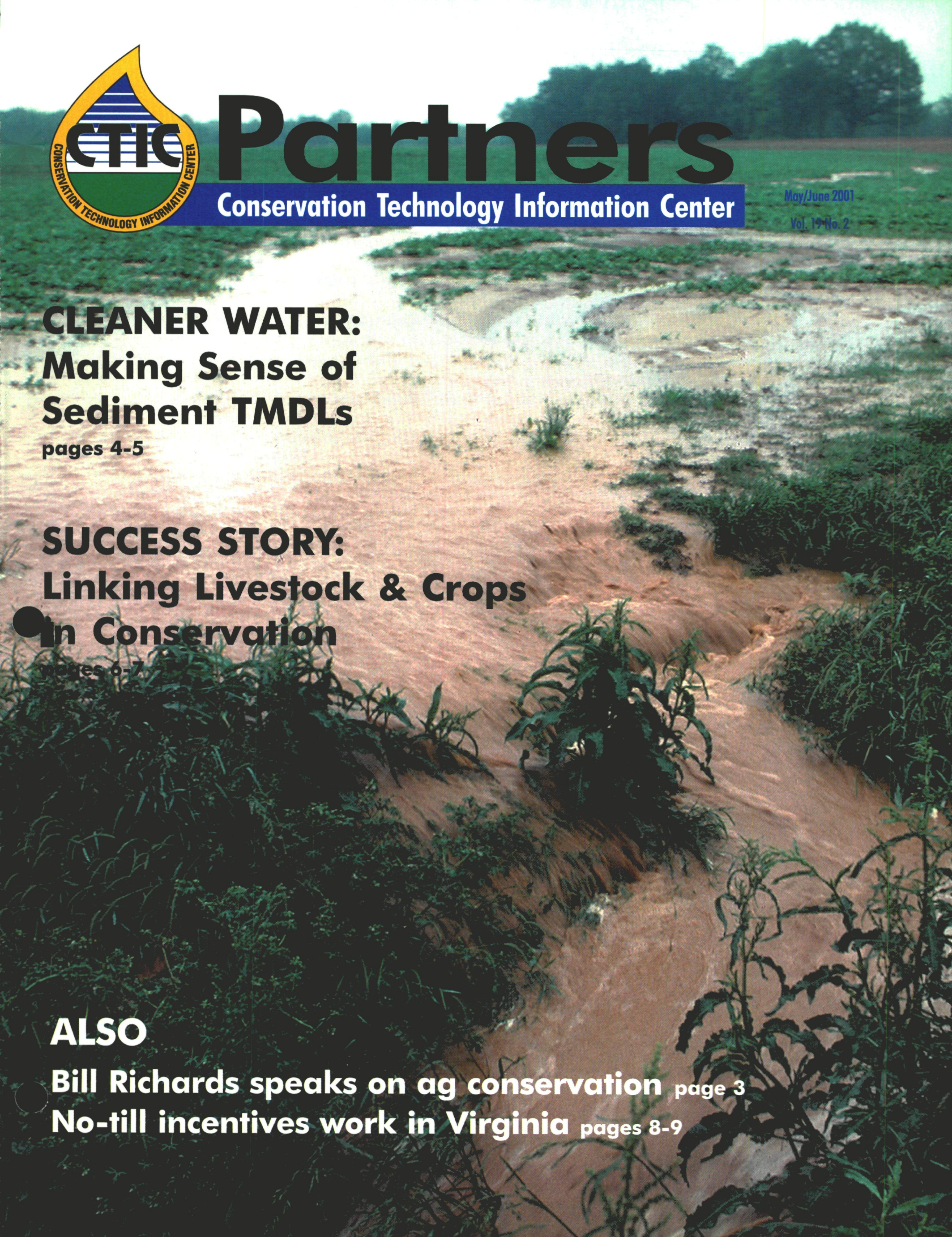

CLEANER WATER: Making Sense of Sediment TMDLs

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SUCCESS STORY: Linking Livestock & Crops in Conservation

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ALSO

Bill Richards speaks on ag conservation page 3

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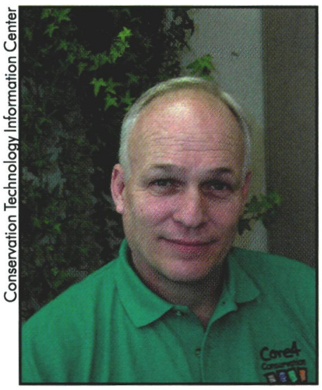
Keeping it Simple

Common sense for conservation solutions

Sometimes I get confused and I'm not sure why. If information is given to me in straightforward, everyday language, I should be able to understand it. Unfortunately in the business of conservation, we too frequently must work with perplexing concepts that befuddle the mind. Take, for example, Total Maximum Daily Loads or TMDLs. The name alone is confusing, and the explanation can be even more so.



Conservation Technology Information Center

John A. Hassell, CTIC executive director

But, TMDLs aren't the only mind-boggling issue. Add to that list Comprehensive Nutrient Management Plans, Hypoxia, Section 319 of the Clean Water Act, Source Water Protection, the Coastal Zone Management Program, or many of the other current federal programs.

It doesn't have to be this way. Someone once said, "Keep it simple stupid." I have to agree that simple is better.

One of the environmental tragedies of the 20th century occurred with the dust storms of the 1930s. Action had to be taken quickly, and it had to occur with little hindrance. There were no environmental impact statements to write, no work plans, no quarterly progress reports, no annual report or final report. The problem was identified, the practices were recommended and implementation proceeded. It took local, state and federal governments working together with local landowners to address this challenge. The partnership worked and the environmental tragedy turned into the dawn of a new conservation movement across the country. Common sense and the common good prevailed to protect our nation's resources and our citizen's livelihoods.

So why don't we use the same common sense approach to today's environmental issues? A partnership of government, industry and citizens works together to identify the most pressing resource issues, determine the management necessary to protect the resource, outline required actions for the next 12, 36 and 60 months and then work cooperatively to implement the plan. This simple process is possible, and it works. This process is Core 4 Conservation.

Core 4 Conservation's innovative approach promotes Better Soils, Cleaner Water, Greater Profits and a Brighter Future for the future of American agriculture. It's a proactive approach that promotes conservation while addressing farm profits. It requires the full involvement of a committed public/private partnership. Core 4 Conservation is flexible, locally led and site specific so that producers realize short-term benefits and long-term sustainability. CTIC is uniquely qualified to build effective public/private partnerships and support their efforts to spread the Core 4 Conservation message. CTIC can provide training, offer technical guidance and help generate national recognition for partnership efforts.

If you're tired of being confused and want a simple but effective approach to natural resource protection, then you need Core 4 Conservation. It's the common sense approach that works.

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CTIC leads the development of public-private partnerships that promote soil and water quality by equipping agriculture with affordable, integrated management solutions.

Staff
John A. Hassell, Executive Director
Ed Frye, Project Manager
Lyn Kirschner, NRCS/EPA Water Quality Specialist
Karen A. Scanlon, Communications Director
Dawn Sinclair, Receptionist
Tammy Taylor, Office Manager
Dan Towery, NRCS Natural Resources Specialist
Jessica Woods, Accounting Specialist

Intern
Brad Ramsay

Consultants
Angie Fletcher
Mick Haberzetle

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Conservation Technology Information Center (CTIC)
1220 Potter Drive, Room 170
West Lafayette, Indiana 47906-1383
Tel: (765) 494-9555 Fax: (765) 494-5969
E-mail: ctic@ctic.purdue.edu
Web: www.ctic.purdue.edu

On the Cover
Sediment-laden runoff floods drainage ditches following a brief storm in Tennessee. Photo by NRCS.

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Ag for Today and Tomorrow

A conversation with Bill Richards, farmer and former chief of NRCS

Bill Richards, current CTIC board member and former chief of the Soil Conservation Service (now Natural Resources Conservation Service), helps his family work 3,000 acres of corn and soybeans on their farm, Richards Farms, Inc. They haven't used a plow on the south central Ohio farm's riverbottom soils in 40 years and have farmed completely no-till for the last 15 years. *Partners* asked Richards to comment about agricultural conservation in the Midwest and about the future of conservation programs.

What are three major agricultural conservation issues that Midwest farmers face today?

Erosion still tops the list. If you lose the soil you lose organic matter and you lose land value and damage the environment. Number two is water management, which includes quantity and quality. Farmers in this region deal with too much or not enough water. The third issue would be nutrient management, and that includes manure management for many Midwest producers.

How are these issues addressed?

We know that conservation tillage increases organic matter and biological activity in the soil. In the early 1990s, government and private sector efforts to promote Crop Residue Management helped to significantly reduce erosion. In recent years, however, erosion rates leveled off because conservation tillage adoption leveled off.

Farmers can do more to store water where it falls and better manage water on their fields. With residue-covered fields, for example, a farmer can increase infiltration while minimizing runoff. Sensible drainage also is necessary to take excess water off productive fields. Accounting for wetlands is part of conservation management as well.

Farmers must use the best technology available in their operations. For example, geographic information systems (GIS) and global positioning systems (GPS) can assist with precision nutrient management. Farmers can address all of these issues by developing a conservation plan for every acre they farm and working toward the Core 4 Conservation principles of better soil, cleaner water, greater profits and a brighter future.

What can Midwest farmers do this year to improve their profit margin?

First, they must stop maximizing yields and start maximizing profits. By switching from conventional tillage to no-till, a farmer will reduce fuel and labor costs. Our competitors all over the world are making the switch and reducing costs. Second, farmers should cooperate with neighbors for better purchasing power and marketing. Other advice would include spreading management talent, capital and machinery over as many acres as possible to lower the per unit costs.

Farmers react to incentives. We need a government-sponsored stewardship program that links incentives with conservation.

What can farmers expect with the new administration and new USDA leadership?

We'll see more farmers in leadership positions, bringing the customer perspective to the agency. We'll move from regulatory to more voluntary programs as well as shift to local and state programs over federal ones.

I think we'll see better cooperation between agencies and a greater emphasis on private sector involvement in technology transfer. Farmers demand more and better technology, and I'm concerned whether our current system can deliver that technology. The private sector will have to step up.

NRCS

Bill Richards at his family farm in Ohio.

What should farmers do to prepare for the reauthorization of the Farm Bill?

We need to broaden the Farm Bill debate to look at long-term programs that involve all sectors of agriculture and that include conservation provisions. The American public will demand those provisions if they know they'll be getting something – conservation of resources – for their tax dollars.

Farmers need an open mind and need to get involved. The more farmers rely on commodity payments, the more protective they become about conservation policy matters. Farmers must be ready for change. If passed, the conservation stewardship bill (proposed by Sen. Tom Harkin, D-Iowa) will move money to the countryside, provide an incentive to get conservation on the land and ensure better conservation management for all crops.

Today, farmers should think about implementing a conservation plan so they can qualify for incentives. Do it now, because once a new bill is passed, the system will be swamped.

Agriculture, Sediment and TMDLs

Keep soil on fields and out of streams with Core 4 Conservation

The acronym TMDL (Total Maximum Daily Load) has been around since its introduction in the 1972 Clean Water Act. Questions about TMDLs have been around just as long. Why should agriculture care about TMDLs? How does one determine a Total Maximum Daily Load? New research continues to address these questions and attempt to provide methods for unraveling the mystery of TMDLs.

A TMDL is the level of pollution a waterbody can tolerate and still meet water quality standards. TMDLs consider pollution from point sources, such as industries, cities and certain confined animal feeding operations, and nonpoint sources, which include cropland agriculture. They also consider natural background levels and add a margin of safety for the protection of the waterbody. Through the TMDL process, states and tribes focus on impaired watersheds. The process is unclear, however, about how TMDLs may affect individual farms and fields. Voluntary management of potential pollution sources can significantly improve watershed health and potentially reduce the need for TMDLs.

NRCS

Rainwater flowing over unprotected farm fields can carry valuable soil, fertilizers and other potential pollutants to nearby waterways.

Agriculture is, according to several published reports, a significant contributor of nonpoint source pollutants to assessed rivers and streams. Sediment and nutrients from cropland are the primary pollutants attributed to agriculture.

The 1998 National Water Quality Inventory rated siltation as the number one cause of poor water quality in the rivers and lakes assessed for that study. According to a 1998 Osterkamp et. al. study, "Economic Considerations of Continental Sediment Monitoring Program," approximately $16 billion is lost annually to damages caused by the excessive erosion, transport and deposition of sediment in North American surface waters.

Too much is a bad thing

Eroded soils from cropland or other land can be transported to waterways through runoff. The consequences of cropland erosion include: decreased productivity of the eroded cropland; physical, chemical and hydrological changes to the site where the soil settles; and transfer of nutrients and pesticides, which are attached to the sediment, to waterways.

Excessive sediment that reaches water bodies can cause several changes, such as making streams shallower and wider, changing the diversity of fish and other communities, increasing flooding and many others. Also, such quantities of sediment can lower the stream's ability to handle other types of pollutants common to agriculture, says Dan Butler, biologist with the Oklahoma Conservation Commission.

Wider streams have warmer water, which holds less oxygen and allows more aglal growth. Such streams can lose populations of large predatory fish and, consequently, gain large minnow populations. The minnows devour most of the algae-eating invertebrates, allowing algae to accumulate.

"In other words," says Butler, "a landowner who pollutes a stream or lake with sediment can significantly increase the effect of oxygen-demanding material and nutrients in that system. This is because a wide, shallow, sunny stream can't handle as much of these pollutants as a narrow deep shady stream."

Such a stream may require a TMDL to address the nutrient or oxygen deficiency problems, says Tom Davenport, U.S. EPA national nonpoint source expert. The farmer, his community and downstream neighbors would then work together in the TMDL process to ensure an equitable outcome.

Predicting exactly what effect sediment will have on a stream requires answering several questions. First, does the sediment contain other pollutants, or is it "clean" sediment? Is the quantity of sediment the primary concern? What was the "natural" condition of the stream or lake before the addition of sediment-laden runoff? Unfortunately, baseline conditions for the wide variety of streams and land uses of the U.S. are poorly understood.

Much attention has been given to conventional pollutants found in runoff while relatively few studies have addressed problems associated with the amount, or load, of clean sediment in streams. Other factors, including changing land use in the surrounding area, alterations of the stream channel, and the type and timing of precipitation events, make prediction of sediment loads difficult.

These factors and more must be considered in any TMDL

NRCS

This Iowa field had no protection against soil erosion and, after heavy rains, sediment was lost through severe sheet and rill erosion. Conservation tillage would have kept the soil in place.

investigation that determines the link between excess sediment and a measurable impairment to the water body's designated use, such as fish and wildlife propagation or irrigation. Sound scientific procedures are needed for developing TMDLs for clean sediment in lakes, streams and rivers in the U.S.

"The TMDL process is only as strong as its weakest component, and it must be based on sound science," says Davenport.

New tools to use

Sedimentation issues and TMDLs took center stage at the Seventh Federal Interagency Sedimentation Conference, held March 25-29, in Reno, Nev. A technical paper submitted by Roger A. Kuhnle, research hydraulic engineer, and Andrew Simon, research geologist with USDA-Agricultural Research Service in Oxford, Miss., presented a new method for evaluating streams impaired by sediment. Entitled "Evaluation of Sediment Transport Data for Clean Sediment TMDLs," their paper describes a technique for determining optimal values, or acceptable levels, of clean sediment in streams and rivers.

"This study provides us with a technique we can use to determine if a stream or river is impaired by sediment. Together with other methods proposed and under development, states and tribes will have a wide range of tools to assist with clean sediment TMDLs," adds Davenport.

The Kuhnle and Simon method assumes clean sediment can be identified as a problem for a stream. That identification is based on the relationship between the amounts of sediment and water in the stream. Implementing this technique requires careful measurement of the stream's capacity to receive and move sediment without suffering damage to itself or the flora and fauna that depend on it. All streams have the ability to handle some sediment without being damaged; the trick is estimating that amount. Estimates can be made by measuring sediment load in similar streams and how their stream life responds to additional sediment. As the amount of sediment in the stream goes down, there will be a certain level, below which the quality of the stream life does not improve.

"This is the stream's capacity for sediment," says Butler. "Subtract natural background and some more for a margin of safety, and you have the amount that can be transported safely in a stream."

Streams that receive too much sediment may require a TMDL. In that case, farmers and other land owners in the stream's watershed should work together to reduce sediment-related impacts, says Davenport.

The Kuhnle and Simon method offers one way to link stream capacity for sediment with land use and, therefore, assist with determining TMDLs. "With this technique, states and tribes can improve their efforts to determine if a stream or river has been impacted by too much sediment," says Davenport.

The establishment of clean sediment TMDLs will likely have a significant impact on the way farming is done all across the country. Farmers must consider not only cropland management but also stream bank erosion. In some agricultural areas, stream bank erosion contributes more sediment to streams than does cropland erosion.

A system that works

Core 4 Conservation provides a voluntary approach for addressing this and other water quality issues. A system of conservation practices can keep soil on cropland, reduce polluted runoff from fields and protect nearby water ways.

For example, a Core 4 Conservation system that includes no-till can reduce cropland erosion by up to 90 percent. Conservation tillage also can increase organic matter, improve infiltration and filter runoff. Conservation buffers add a second line of defense by slowing runoff from fields and, in doing so, decreasing its ability to transport sediment. Buffers also stabilize stream banks and edge-of-field drainage ditches. Nutrient and pest management reduce the amount of agrichemicals transported with sediment.

A site-specific Core 4 Conservation plan that includes conservation tillage and buffers, along with nutrient and pest management and other practices, would not only reduce polluted runoff from cropland, but help the farmer minimize input costs and increase profits as well.

America's farmers know the value of their soil. In this era of TMDLs, it's important to take steps to reduce soil erosion and sediment loss from fields and stream banks. With a site-specific Core 4 Conservation system, farmers can do that and, at the same time, improve soil quality and increase farm profitability.

For more about TMDLs, go to www.ctic.purdue.edu/KYW or www.epa.gov/owow.tmdl. For the Kuhnle and Simon study, go to www.sedlab.olemiss.edu/cwp_unit/NSLReport17.pdf .

Making the System Work

Manure management yields sweet smell of success in Indiana

By Steve Werblow

This is not a time when one might expect to see a hog and grain operation investing big bucks in new infrastructure or convincing landlords to improve their land and charge higher rent. After all, commodity prices have been soft and it hasn't been long since the nightmarish shakeout of the hog industry.

But the Mann family of Cloverdale, Ind., has spent the past few years constructing new buildings for its 1,000-sow farrow-to-finish operation and laying in new drainage systems on much of the 6,000 acres of cropland it farms. The Manns have even convinced landlords to allow them to upgrade rented land and lease it for higher rates.

All of the investment is guided by the ethics of Core 4 Conservation – better soil, cleaner water, greater on-farm profits and a brighter future. "It's the most profitable way for us to farm," says Chris Mann, who oversees agronomics and engineering for the family operation, White Oak Farms. "Not only does it protect our environment, but it makes our land yield better, too."

Indiana Farm Bureau

Core 4 Conservation principles help ensure a brighter future for the Mann family – Jennifer, Chris, Hannah and Josiah – which farms with Chris's brothers and father in Cloverdale, Ind.

Mann notes that his father, Fred, has been an avid no-tiller for 15 years, and he has seen yields increase 20 percent in that time.

"Yes, we have improved genetics," says Chris, "but when you pull up a soil sample, you can see that we've built up the soil. We have 3 to 4 percent organic matter on soils that typically run 1.5 percent. That pays off in improved aggregate stability, cation exchange capacity to hold nutrients and water-holding capacity."

Size right

Fred, Chris and Chris' three brothers each have a specific area of responsibility in White Oak Farms, linked together by the family's partnership. Much the same way, every aspect of the operation is sized and designed to function well while fitting into the overall plan. That's the key to the farm's conservation success and its economic stability, notes Chris, whose responsibilities in the field and on the design table put his B.S. in ag engineering and M.S. in agronomy to use.

White Oak Farms' manure management – driven by crop needs, not by the hog side of the business – is the lynchpin in the strategy. Last year, the family built a new farrow barn and five finishing barns, each situated over 10-foot-deep pits that provide a year's worth of manure storage. "That gives us real flexibility to apply our manure on an agronomic basis," says Mann, who designed the buildings. "The real problems with manure often happen when guys run out of storage and they have their backs up against the wall."

Going underground

While many livestock operations see manure as a liability, the Manns treat it as a valuable asset.

Indiana Farm Bureau

Chris Mann and his daughter, Hannah, take a soil sample. Assessing soil fertility, crop needs and manure nutrient analysis help the Manns set appropriate manure application rates and timing.

They agitate the manure in the pits with a chopper pump to homogenize it, helping ensure that nutrients are evenly distributed. Then they test the manure for nutrient analysis and use it to meet the agronomic needs of the family's corn crop – 150 units of nitrogen and 100 each for P and K, based on 180-bushel yield goals. About 600 acres of corn will utilize the hog operation's manure output.

Using a Magnum plow – a no-till shank that lifts soil and puts it back in place, leaving just a narrow slice through the soil surface – Mann injects the manure

8 to 10 inches deep. Though he prefers to apply in the spring, Mann will also knife in manure during the late fall, but only after soil temperatures have fallen so denitrification won't occur.

Placing the nutrients below the surface is particularly helpful in dry weather, when roots in the top couple of inches of the soil profile often wither and die, Mann notes. Conditions 10 inches below the surface – where soil is still damp – tend to be more conducive to good uptake, he says. To give the crop a boost before roots reach that deep, Mann applies 28-percent UAN as a starter through the planter, placing 35 units of actual nitrogen two inches below and two inches to the side of the seed.

When the corn reaches the V-4 (four-leaf) stage, Mann takes to the field with a chlorophyll meter and a Cardy meter, which measures nitrate mineralization in the soil. His goal is to make sure that the nitrogen is going to the crop, not into the water or air. It's an important way to fine-tune fertilizer rates, he says.

Grass strips stop the sediment

Running through the Manns' fields – and alongside them – are thousands of feet of grass buffer strips and waterways. Ranging in width from 40 to 66 feet, the grass strips are situated wherever water erosion is or can be a problem. That's easy to see in no-till, Mann points out, because there's no annual disking to erase rills.

The Manns seed their strips with 50 pounds per acre of tall fescue or perennial ryegrass. True to their philosophy of feeding one part of the operation with another, they protect new seedings by unrolling large bales of wheat straw cut before fields are double-cropped with no-till soybeans.

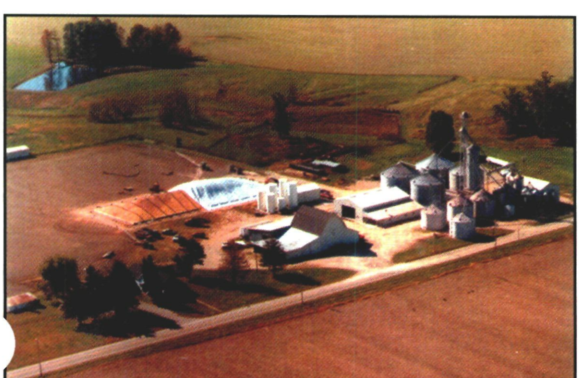
Drainage lengthens growing season

Grassed waterways tend to stay wet longer than well-drained no-till fields, notes Mann, so they can be prone to ruts when the farmable ground is ready to plant or harvest. To minimize damage to the waterways by improving drainage, the Manns often run a tile main down the center, about three feet below the surface.

White Oak Farms has invested heavily in tile on their own land and on rented land. It's a sound investment in central Indiana, where slow-draining soils and wet spring weather can delay planting, especially in no-till fields, says Mann. "We can plant earlier and create a longer growing season," he says. "We're willing to pay higher rent for well-tiled land because we can be so much more productive on it."

To improve their drainage systems, the Manns are replacing above-ground drainage pipes from old Water and Sediment Control Basins (WASCOBs) with buried french drains, a tactic Chris Mann learned from an NRCS conservationist while visiting farms in Minnesota. Large-perforated sock tile takes in high volumes of water that has shed suspended soil particles by percolating through three feet of pea gravel. The result: cleaner outflow into local streams. "You cut down how much soil is in the water," Mann notes, "and you don't have to farm around a riser."

White Oak Farms



Investing in new drainage systems, big manure pits and grassed waterways yields environmental and economic benefits for White Oak Farms' crop and hog operation.

Improving Rented Ground

Chris Mann, his father Fred, and his brothers Mike, Rob and Joe are serious about conservation. What's more, they're willing to put their money where their mouths are – not only on their ground, but on rented land, too.

"We've tried to get our landlords involved in conservation," says Chris. "We've done a lot of work trying to show them the benefits, we've showed them on paper all the things it can improve."

It's a win-win situation, notes Mann, even though improvements generally result in higher lease costs. "If a field's washing away, it's not going to be worth much," he points out. "And because tiling, grass waterways and no-till can make a field more productive, conservation has made these farms more valuable to us, too."

Big investments, big payoffs

In all, Mann figures White Oak Farms has invested $100 to $350 per acre over the past 10 years in soil and water protection measures that reflect Core 4 Conservation priorities. He believes it's money well-spent. "On land we own, we know the paybacks are going to be there," he says. "For long-term environmental sustainability, you protect the productive capacity of the field – and you leave it for future generations as well."

Steve Werblow is a free-lance writer based in Ashland, Oregon.

No-till Pays Bills in Virginia

Incentive program pays farmers to not till for five years

In Virginia's New Kent and Charles City counties, farmers can get paid to raise their plows, stop tilling the soil and protect soil and water quality. Through the Innovative Cropping Systems (ICS) program, no-till producers receive annual payments as well as the long-term support necessary to be successful.

"The main goal of the ICS incentive program is to provide a financial service that will convert producers to a continuous no-till system," says Brian Noyes, conservation specialist and district coordinator for the Colonial Soil and Water Conservation District. "In addition, many local resource conservation issues can be addressed through ICS."

Pay to stop and save

Producers willing to switch to no-till and adopt nutrient management technologies submit an application to the District, which coordinates the program with funds from the State of Virginia. Qualified producers who agree to practice no-till for five years can receive $65 per acre payments or five $13 per acre annual payments.

The initial response was overwhelming, says Noyes. When the program started six years ago, applications were submitted for 5,500 acres. With enough money to fund only 1,600 acres, ICS gave priority to applications with highly erodible and leachable soils.

Colonial Soil and Water Conservation District

At last year's Ag-Expo in Virginia, Brian Noyes (on left) and Paul Davis (with microphone) discuss ICS during a demonstration of the rainfall simulator.

Proof is out there

The results of ICS are impressive, says Paul Davis of the New Kent Cooperative Extension, a supporter of the program. In 1997 only 400 total acres used continuous no-till in New Kent and Charles City counties, but that figure has increased to more than 10,000 acres today.

David Black, owner of Heritage Farms, LLC, in Charles City, is one ICS participant that knows the value of no-till. More than 11 years ago, he made the switch from conventional tillage to save time working with corn, soybeans and wheat rotation on highly erodible lands. As he continued with no-till, along with nutrient and pest management, the benefits grew to include saving money and saving soil.

Colonial Soil and Water Conservation District

David Black and his father, George, earned the Clean Water Farm Award from the Colonial Soil and Water Conservation District in 1999. Black's Heritage Farms integrates a system of practices, including no-till, to improve soil and protect water quality.

For example, in the first four years of a no-till system, Black watched organic matter in the top eight inches of soil increase from 1 percent to 5 percent.

"We are still amazed at what happens to our soil," says Black. "According to NRCS formulas, I should be losing 44 tons of soil per acre per year. But, I'm not. I'm making that much or more soil."

Last fall, Black adds, he planted 250 acres of wheat using only 110 gallons of diesel fuel. With a conventional system, he would have burned at least 500 gallons. Plus, his no-till field is ready to plant earlier than conventional fields. So, he has more time off the field. " My wife says we have more free time than we need," he adds.

Black spends some of that free time working with Noyes and other partners to promote the ICS program. In fact, the economic and environmental benefits of no-till demonstrated by Black and other no-till farmers convinced Noyes to start the ICS program. Today they work together convincing farmers to