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Impact of Farming Practices on Water Quality in Iowa

**Report of the Iowa
Management Systems Evaluation Areas Project
(MSEA)**

A cooperative project of
**USDA-Agricultural Research Service
USDA-Cooperative State Research Education and Extension Service
USDA-Natural Resource Conservation Service
Iowa Agricultural Experiment Station
Iowa Cooperative Extension Service
United States Geological Survey
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Executive Summary

The Iowa Management Systems Evaluation Area (MSEA) project team conducted research at four sites in Iowa to evaluate the impact of farming practices on surface and ground water quality. Current farming practices as well as modifications were studied at sites that were chosen on the basis of ongoing experiments and a history of herbicide and nitrogen monitoring. The four sites, Till Hydrology, Deep Loess Research Station (Treynor), Nashua, and Walnut Creek, represent a range of soil, geology, topography, and climate typical of Iowa. The fourth site on the 5600 ha Walnut Creek watershed south of Ames provided the project with a watershed including production scale fields in the corn belt.

Surface soils in three sites are derived from glacial till and one site from loess soil. While geology varies among sites, surface hydrology varies with topography. These sites represent approximately 35 percent of the soils farmed in Iowa. Tile drainage is extensive at all the sites except the site with the loess soil, and moves leached compounds from the bottom of the root zone into surface water. Surface runoff is a major transport process only for the loess soil and represents less than 5 percent of the water movement at the other sites. Water balance estimates in Walnut Creek show that about 48 percent of the precipitation is used in evapotranspiration, 48 percent to tile drainage, and the remaining 4 percent to ground water recharge. These numbers vary depending on year, tillage method, and crop selection.

Observations of nitrate-N, atrazine, alachlor, metribuzin, and metolachlor in surface runoff, stream flow, tile drainage, and shallow ground water reveal different characteristics among sites. Walnut Creek, Till Hydrology, and Nashua sites have significant tile drainage, and nitrate-N concentrations range between 15 and 20 mg/ℓ during spring and early summer. Rainfall patterns and the amount of preferential soil water movement into tile lines influence nitrate-N concentrations. An increase in water flow decreases nitrate-N concentrations in tile drains, but herbicide concentrations tend to increase. Preferential flow is a dominant feature of glacial till soils, and modifications to management practices need to take that into account. Annual nitrate-N loss from Walnut Creek ranged from 40 to 150 percent of fertilizer applied, depending on rainfall conditions. This loss was dramatic in the wet year, 1993, and a reduction was seen in 1994 of both concentrations and loads. Similar results were also observed at Nashua. While other herbicides showed very little loss, annual atrazine loss from Walnut Creek ranged from less than 1 percent to almost 7 percent in 1993.

The primary transport process for the Deep Loess site soils was surface runoff and leaching through the soil profile into the seepage from the stream bank. Atrazine and nitrate-N move rapidly in loess soils, often to depths of 30 m. In the glacial till soils there is much less downward movement and the rate depends upon the geological units. There were few detections of atrazine and even less of the other herbicides in the 152 wells installed in Walnut Creek. Observations from 47 domestic drinking water wells showed no quantifiable amounts of herbicides, and nitrate-N concentrations of less than 1 mg/ℓ. At the Nashua site on the Iowan surface, there is movement in the upper depths but few detectable amounts of herbicides below 10 m. The glacial till units show a significant potential for denitrification of nitrate-N and slow transport of herbicides. Also, drinking water from aquifers in Walnut Creek and Nashua is too old to be affected by modern agricultural activities.

Concentrations of nitrate-N, which is the primary chemical lost, can be reduced by improved management practices. Nitrogen placement and application with improved equipment in ridge tillage show significant reductions in nitrate-N leaching. Placing the nitrogen in the crop row rather than between rows reduces the movement because of preferential flow. Use of nitrate-N testing procedures and placement provides better use of split application during the season and more realistic nitrogen rates. Studies are being conducted on a Localized Compaction Doming (LCD) unit that places liquid nitrogen fertilizer in an area protected from preferential flow paths. Preliminary results show an increased nitrate-N concentration near the roots coupled with reduced leaching. Nitrogen management strategies can be implemented to enhance surface and ground water quality.

Although herbicide loss as a percent of applied basis is insignificant from the current farming practices, surface runoff events can cause the concentration to exceed the Maximum Contaminant Limit (MCL) for short periods. Adoption of conservation tillage practices reduces the likelihood of surface runoff and offsite movement, while increasing the water available to the crop. The increased water storage in the profile may increase leaching, but this effect has not been found in the field studies. At Nashua there was increased leaching under conservation tillage, but the concentrations of herbicide were reduced and nitrate-N were generally below 10 mg/ℓ. Postemergence herbicides like imazethapyr and nicosulfuron may be highly mobile in the soil water and the degradates of these compounds may indicate patterns in movement.

Distribution of weed populations depend on soil type, species, and management. Spatial distributions within fields are relatively stable over time. Weed management strategies need to be developed to better understand the spatial distribution within fields and the influences upon these distributions. Weed populations change with different tillage practices and will result in different herbicide use patterns and response to cultivation. Smother crops may be a viable control mechanism for weed control in the corn-soybean system.

Offsite impact of nitrate-N movement can be mitigated through the use of wetlands. Simulation models applied to Walnut Creek demonstrated that wetlands covering 1 percent of the land area could remove 45 percent of the nitrate-N load, and bring the nitrate-N concentration in the stream water to less than 10 mg/ℓ. Vegetative filter strips is another landscape management practice that reduces offsite impact of herbicide movement. Filter strips placed along the edge of fields and in combination with conservation tillage practices further reduce the risk of offsite movement.

Adoption of changes in farming practices and landscape management can easily reduce the impact of agricultural practices on water quality. There is also the need to develop criteria for the assessment of both fields and landscapes and their vulnerability to different management practices. These evaluations need to be conducted on a watershed scale in the Midwest to provide decision tools for farmers and policymakers.

Background

The multi-agency and multi-site Management Systems Evaluation Areas (MSEA) project was initiated as part of the Water Quality Initiative in response to extensive reports in Iowa and the Midwest of water contamination related to farming practices. These reports demonstrate a need to better understand the role of current farming practices on surface and ground water quality, and to develop strategies that could minimize the risk from farming systems. MSEA project investigators have conducted several studies based on these needs, and details are provided in several reports. A list of these reports and related material is provided in the last section.

Questions

Observations of water quality throughout Iowa prompted a number of questions about the effect of agricultural management systems on ground and surface water quality. The following four questions were asked in studies at three separate areas of the state to address these concerns:

1) What are the physical, chemical, and biological factors affecting the transport and fate of agricultural chemicals?
2) What are the integrated effects of crop, tillage, and chemical management practices on the quality of surface runoff, subsurface drainage, and ground water recharge?
3) How can the results from understanding the transport and management practices be combined with pedologic, atmospheric, geologic, and hydrologic processes to assess water quality?
4) What are the socioeconomic concerns regarding current and newly developed management practices?

Report Structure

This report blends the research from these questions to provide an analysis of the response of observed water quality parameters to different farming practices. The report also suggests modifications in agricultural and landscape practices based on an understanding of the processes affecting water quality.

Research Locations

Four sites were selected within Iowa to study specific farming practices and their relationship to water quality. The Deep Loess site at Treynor is on the loess hills in western Iowa, and the site at Nashua is on the Iowan surface in northeast Iowa. The Till Hydrology site is on the Des Moines Lobe near Ames located near the Walnut Creek watershed. The 5,600 ha Walnut Creek watershed, on the Des Moines Lobe, is linked with the Skunk River alluvium studies and provides an assessment of field and watershed scale response to agricultural practices. The characteristics of these sites have been described in several previous reports.

Investigators

A multi-agency and multi-disciplinary team was organized to address the questions within the Iowa MSEA Project and the goal of the MSEA program. Investigators and cooperating agencies are given below:

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Walnut Creek watershed and Des Moines Lobe responses

Setting and monitoring activities: Walnut Creek watershed is one of the major MSEA research sites. It is a 5,600 ha watershed dominated by row crop cultivation with over 85 percent of the land area in a corn-soybean rotation. Most of the soils are from the Clarion-Nicollet-Webster association and are formed on late Wisconsin drift. Similar drift covers an area known as the Des Moines Lobe over north central Iowa and south central Minnesota. Most soils in the watershed allow relatively rapid vertical drainage, and horizontal drainage is limited to local depressions under natural conditions. Crop yield potential for these soils is high because of deep soil profiles, high water holding capacity, and high fertility levels. Consequently, this watershed represents some of the most ideal crop production land in the corn and soybean region of the Midwest.

Four aspects of the hydrologic system are actively studied in the watershed, and include natural ground water contributions to streams, runoff, artificial subsurface drainage, and stream recharge to an alluvial aquifer. Transport of herbicides and nitrates is the primary focus of the hydrologic research. A study of the hydrologic setting of the watershed and its farming practices allows the observation of a complex set of interactions between ground and surface water, and the resulting effects on nitrogen and herbicide contamination. Walnut Creek watershed has been monitored since 1990 with weekly stream samples, and since 1991 with automated stream gages, tile drainage sites, surface runoff flumes, and shallow wells.

Water quality in streams and shallow ground water: Four years of intensive data show that relatively little atrazine and metolachlor, and negligible amounts of alachlor and metribuzin are lost from the watershed. Annual loads and application amounts of these chemicals are shown in Table 1.

Table 1. Annual applications and loads (kg) lost from Walnut Creek watershed for nitrate-N, atrazine, alachlor, metribuzin, and metolachlor. (Application amounts are not yet available for 1994.)

	Nitrate-N		Atrazine		Alachlor		Metribuzin		Metolachlor	
Year	Appl.	Load	Appl.	Load	Appl.	Load	Appl.	Load	Appl.	Load
1991	237300	98200	740	17.89	665	3.65	65	9.15	2549	31.93
1992	284860	143200	850	5.68	363	0.04	16	0.01	2369	8.47
1993	227040	337100	526	38.99	391	0.88	105	0.13	1648	34.52
1994		19800		1.25		0.01		0.01		1.10

Concentrations of nitrate-N at the confluence of Walnut Creek and Skunk River are often above 10 mg/ℓ, and decrease with an increase in stream flow. Hydrologic events during the study period also contributed to a decrease in nitrate-N concentrations (Fig. 1).
Nitrate-N loads from the watershed range from 40 to 150 percent of the total fertilizer applied (Table 1). There is a seasonal pattern of these losses related to the distribution of rainfall throughout the year, and 1992 and 1993 are shown as examples (Fig. 2). Although the typical herbicide losses are 2 percent, 1993 had losses up to 7 percent. Rainfall and resulting

stream flow influence concentrations to exceed the quantitation limit.

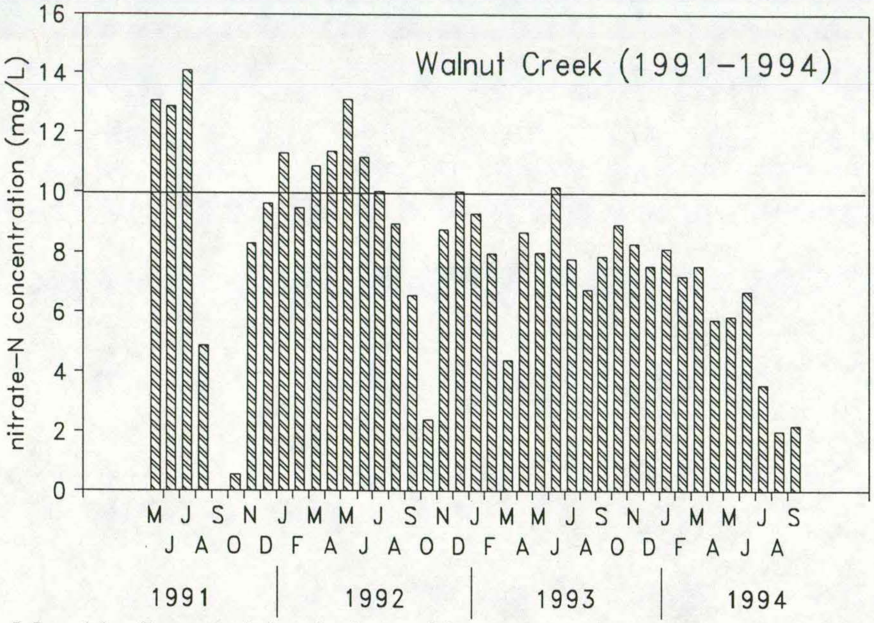


Figure 1. Monthly flow-weighted nitrate-N concentrations at the confluence of Walnut Creek watershed for 1991-1994.

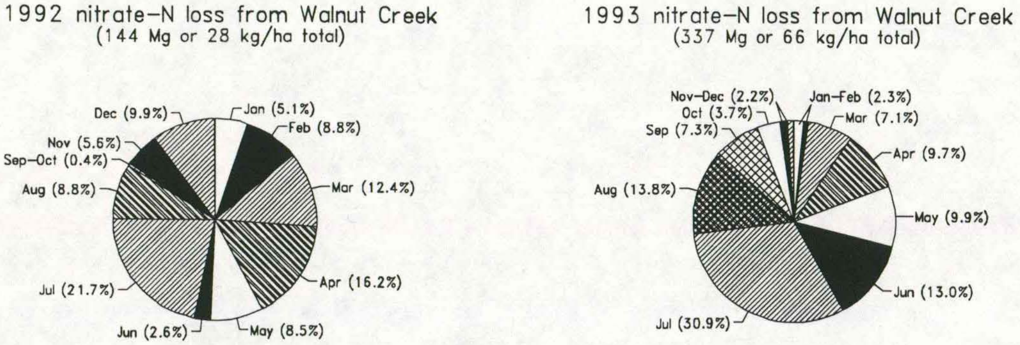


Figure 2. Monthly distributions of nitrate-N loss for 1992 and 1993 at the confluence of Walnut Creek watershed and Skunk River.

Shallow ground water quality shows little nitrate-N moving below 3 m, and concentrations observed in the wells deeper than 4.6 m averages 2.1 mg/ℓ (Table 2). Samples exceeding the 10 mg/ℓ MCL for nitrate-N in drinking water decrease with depth from 75 percent at 0 - 0.9 m to only 4 percent at greater than 4.6 m and the percentage of samples exceeding the 1 mg/ℓ quantitation limit decreased from 100 percent at 0 - 0.9 m to 67 percent at greater than 4.6 m. Little herbicide is found at any depth. Mean concentrations are below 0.1 μg/ℓ (Table 2).

Table 2. Nitrate-N, atrazine, alachlor, metribuzin, and metolachlor observations in nested piezometers within Walnut Creek watershed since 1991.

	depth increment (m)				
Nitrate-N	0-0.9	0.9-1.5	1.5-3	3-4.6	4.6+
total # observations	4	59	742	363	486
mean (mg/ℓ)	15.5	6.5	10.9	4.5	2.1
median (mg/ℓ)	13.6	3.2	9.3	2.0	1.3
maximum (mg/ℓ)	31.8	45.7	47.3	31.8	23.9
% > 1 mg/ℓ	100	95	93	75	67
% > 10 mg/ℓ	75	24	48	17	4
Atrazine					
total # observations	4	58	734	362	490
mean (μg/ℓ)	0.0	0.043	0.065	0.012	0.012
median (μg/ℓ)	0.0	0.0	0.0	0.0	0.0
maximum (μg/ℓ)	0.0	0.9	3.8	0.8	1.2
% > 0.2 μg/ℓ	0	10	15	2	2
# > 3.0 μg/ℓ	0	0	1	0	0
Alachlor					
# of observations	4	58	733	362	489
mean (μg/ℓ)	0.0	0.009	0.006	0.028	0.013
median (μg/ℓ)	0.0	0.0	0.0	0.0	0.0
maximum (μg/ℓ)	0.0	0.3	1.6	1.9	1.6
% > 0.2 μg/ℓ	0	3	1	3	1
# > 2.0 μg/ℓ	0	0	0	0	0
Metribuzin					
# of observations	4	58	733	362	490
mean (μg/ℓ)	0.0	0.007	0.009	0.004	0.006
median (μg/ℓ)	0.0	0.0	0.0	0.0	0.0
maximum (μg/ℓ)	0.0	0.4	1.4	0.5	0.5
% > 0.2 μg/ℓ	0	2	2	1	2
# > 3.0 μg/ℓ	0	0	0	0	0
Metolachlor					
# of observations	4	58	734	362	489
mean (μg/ℓ)	0.0	0.029	0.022	0.020	0.016
median (μg/ℓ)	0.0	0.0	0.0	0.0	0.0
maximum (μg/ℓ)	0.0	0.4	5.8	2.9	1.2
% > 0.2 μg/ℓ	0	1	3	2	3
# > 3 μg/ℓ	0	0	1	0	0

Most samples did not contain herbicides above the quantitation limit of 0.2 $\mu g/\ell$. One observation of atrazine above 3 $\mu g/\ell$ was made in a well 1.5 - 3 m deep. In computing these results zero concentration was assigned when no nitrate-N or herbicide above the quantitation limit was found. Unlike nitrate-N, no trend was found for herbicides except atrazine in either mean concentrations or frequency of detection. Atrazine was detected more frequently at depths of 0.9 to 1.5 m and at 1.5 to 3 m increments. Only two of more than 1,700 water samples exceeded the level of 3 $\mu g/\ell$, once for atrazine and once for metolachlor (the health advisory limit, HAL, for metolachlor is 100 $\mu g/\ell$. Overall, despite the intensive use of nitrogen fertilizers and herbicides (atrazine and metolachlor in particular), fertilizers and chemicals are not found in concentrations above the quantitation limit in the shallow groundwater system, 5 m. The same nitrate-N change with depth has been observed in the piezometers at the Till-Hydrology site. At that site there is a rapid decrease in nitrate-N concentrations with depth, and concentrations below 4 m are less than 2 mg/ℓ. There is no seasonal variation in the concentration profiles.

Stream flow and agricultural chemical observations in subbasins: Intensive tile drainage throughout the western portion of the watershed allows separate evaluation of the effect of runoff and drainage from streamflow and runoff. Three different sites are shown in Fig. 3 and represent total streamflow from a 2,550 ha basin (site 310), a 366 ha subbasin separated into tile drainage (site 220), and surface runoff (site 223). Comparison of the flow and chemical plots for site 310 indicates the differences in transport behavior among nitrate-N, atrazine, and metolachlor (Fig. 3). Daily and cumulative nitrate-N yield plots are similar to the corresponding flow plots.

Surface runoff and tile flow are significant transport mechanisms for atrazine and metolachlor. Surface runoff transports relatively large herbicide loads during short periods when storm flow is large. The nature of the cumulative flow and yield plots for surface runoff and stream flow during July 1993 demonstrates this point (Fig. 3). Tile flow transports herbicides as indicated by the larger cumulative yields compared to surface flow. Cumulative yields in stream flow are not influenced by increases in cumulative tile flow compared to increases in surface flow (Fig. 3). Surface inlets in the 220/223 basin allow surface runoff and standing water from potholes to drain directly into the tile system. Herbicide loads from May-June 1991 may be a result of surface runoff considering the increase in cumulative yield plots and the short time from chemical application to increased stream flow.

Observations of nitrate-N, atrazine, and flow in tile drainage from an individual 10 ha field without a tile inlet showed different patterns for herbicides and nitrate-N (Fig. 4a and b). As flow increased, nitrate-N concentrations decreased (Fig. 4a) and atrazine increased (Fig. 4b). Responsiveness of individual tile drains suggests a strong relationship between precipitation events and tile flow. Trends in nitrate-N concentrations suggest an initial dilution because of rapid water movement to the tile drain. Increases in atrazine concentration can be linked to water movement through preferential flow channels in the soil that have atrazine concentrations higher than the bulk soil.

Surface runoff from fields constitutes a relatively small portion of the water balance. Surface runoff occurs primarily in the early spring or late winter when snow melts on frozen soil. In 1991, rainfall runoff events caused atrazine concentrations in the stream to rise to 25 $\mu g/\ell$ and metolachlor to 80 $\mu g/\ell$, but only for a short time. Similar runoff events in 1992 happened later in the season and there were no detectable increases in the atrazine or metolachlor concentrations in the stream. Surface runoff events represent less than 1 percent of the stream discharge in a typical year.

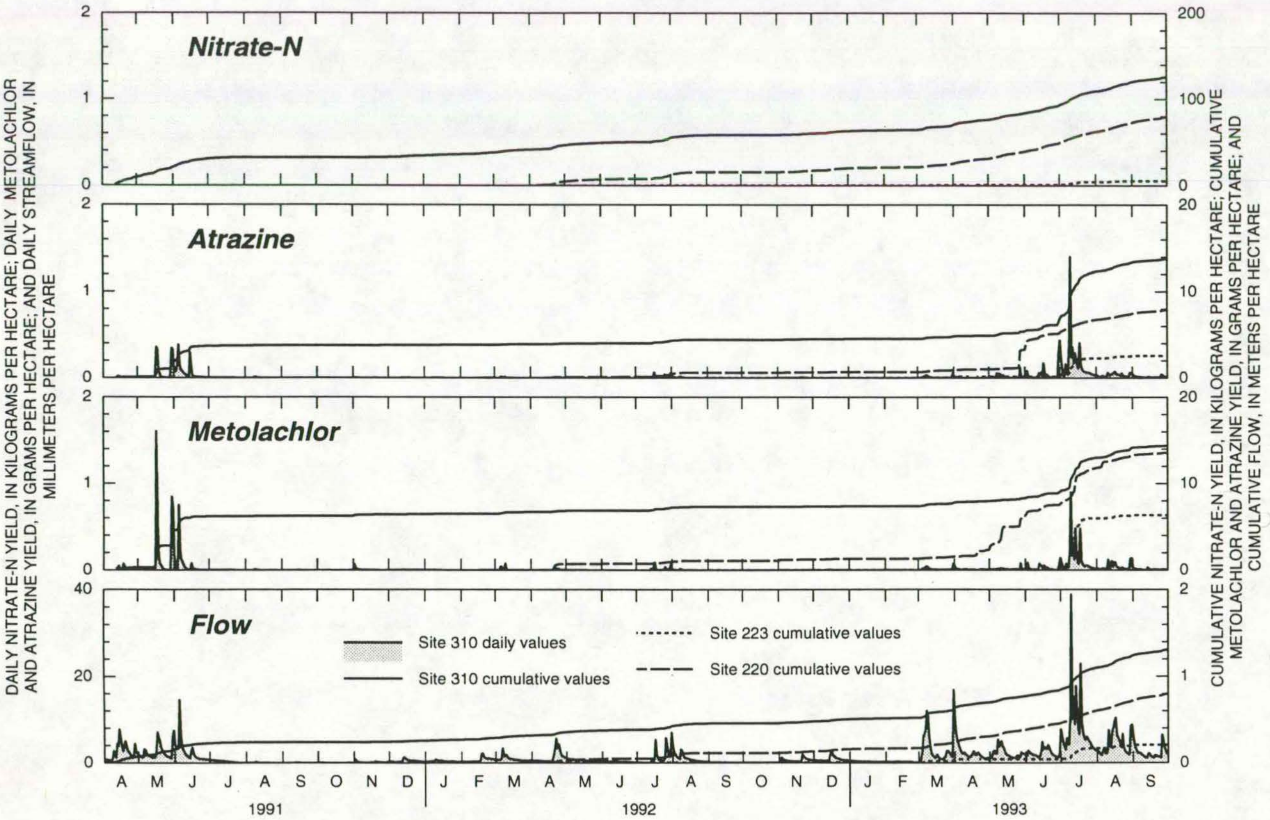


Figure 3. Daily and cumulative chemical yields and flow for three sites in the upper portion of Walnut Creek watershed for 1991-1993.

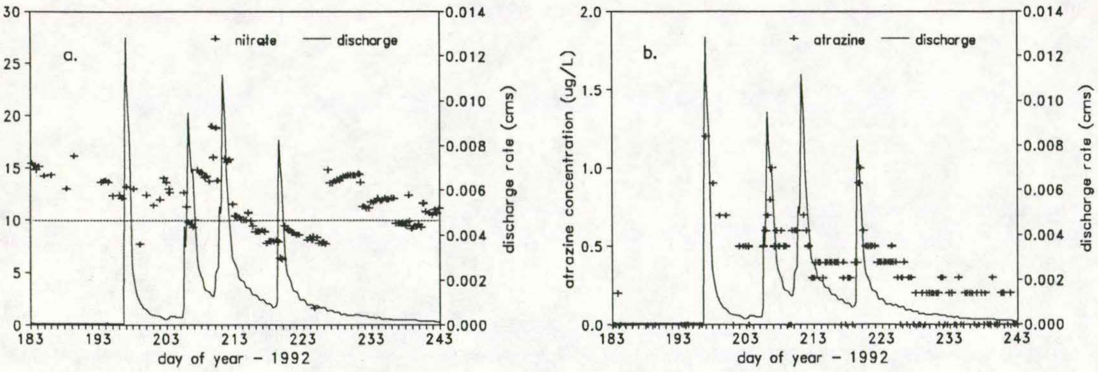


Figure 4. Hydrograph of tile flow and nitrate-N concentrations (a) and atrazine concentrations (b) in a single field drain tile from a 10 ha field in Walnut Creek watershed during July and August, 1992.

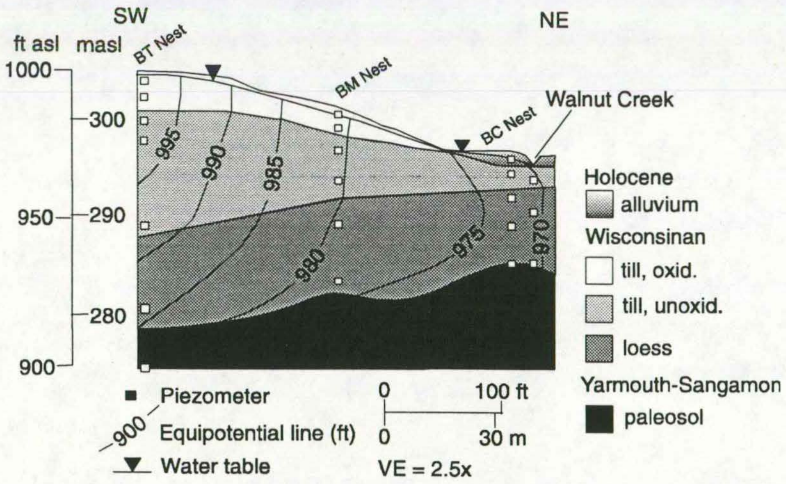
Geological attributes of the Des Moines Lobe: Observations of negligible concentrations of nitrate-N and herbicides in shallow piezometers prompted an evaluation of the geological attributes of Walnut Creek. Forty-seven private wells were sampled in Walnut Creek to evaluate the quality of drinking water. These wells are located in Pre-Illinoian bedrock valley (26), Pennsylvanian sandstone (10), and Mississippian limestone (11) aquifers in the watershed. These were sampled for nitrate-N, atrazine, alachlor, metolachlor, and metribuzin. Concentrations were below the quantitation limits. Ground water showed no modern tritium values, suggesting that ground water was recharged before 1950. Ground water in aquifers, determined by ^{14}C analysis, ranges from about 10,000 to more than 40,000 years old.

Two sites were selected to examine the quantity and quality of ground water discharge to Walnut Creek. Both sites were located immediately down gradient from actively farmed fields. At the transect located in the central portion of the watershed, ground water flows to the creek through both oxidized and unoxidized zones of the late Wisconsinan till (Fig. 5a). When the water table is high, most of the water flows through this zone and emerges as springs at the toe of the slope. Lateral flow occurs in these units and moves water into the creek (Fig. 5a). Recharge to unoxidized till and loess must occur at the ground water divide. A thick (10 m) oxidized zone composed of both oxidized late Wisconsinan till and oxidized Pre-Illinoian till appears to conduct most of the ground water flow towards the creek at the Animal Resources site located in the eastern portion of the watershed (Fig. 5b). However, there may be a small discharge from the unoxidized till into the creek (Fig. 5b). Fractured zones are common in the Pre-Illinoian till and appear as gray zones 1 to 2 cm wide and outline polygons that are about 5 cm across.

Geological units at the two transects are characterized by significantly different particulate organic carbon (POC) and high concentrations of dissolved organic carbon (DOC). POC values approach 1 percent in the late Wisconsinan till (Dows Formation) and Wisconsinan loess units. Values in oxidized late Wisconsinan and Pre-Illinoian till range from near 0 to 0.5 percent. Highest amounts close to 1.5 percent are found in the unoxidized Pre-Illinoian till. Values at the central transect are nearly ten times greater than those at the eastern transect. DOC concentrations in oxidized zones average 4.4 mg/ℓ and are within the normal range for ground water. DOC concentrations in unoxidized till and loess can approach 88 mg/ℓ. This amount of organic carbon provides an unlimited source of energy for microorganisms, which ultimately control the redox hydrogeochemistry. Because all electron acceptors have been exhausted in the sediment at depth, CH_4 is produced and is ubiquitous as a dissolved gas in ground water. CH_4 concentrations in ground water range from less than 1 μg/ℓ in the near surface piezometers to a maximum of 43 mg/ℓ in the loess. The CH_4 is exclusively microbial in origin. The age of the CH_4 in the ground water is estimated to be between 14,093+96 and 16,015+152 years Before Present (B.P.). Sand units in the formation showed a CH_4 production rate of 340 nmol CH_4/kg/d. Rates of CH_4 production in unoxidized Wisconsinan loess ranged from 62.4 to 226 nmol CH_4/kg/d. Highest rates of CH_4 production (2,040 nmol CH_4/kg/d) were associated with wood fragments within the loess.

Glacial stratigraphic units appear to control water quality variations. There is strong evidence of denitrification in the saturated zone at both transects. The depth of nitrate-N penetration depends on site stratigraphy, i.e., nitrate-N is found at greater depth (but at lower concentrations) at the eastern transect than at the central transect. This process may occur preferentially along fracture surfaces in the till and not necessarily in the general till matrix. The highest potential for denitrification lies in the Wisconsinan loess, which has the potential to denitrify 7,760 kg-N/ha/yr. The structure of the underlying units is the primary cause for the low nitrate-N and herbicide concentrations in the deeper wells.

a) Walnut Creek - Central Transect



b) Walnut Creek - Eastern Transect

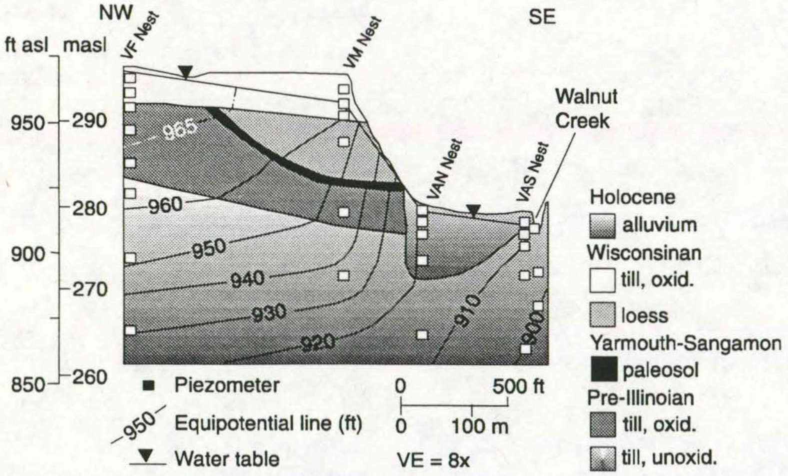


Figure 5. Transect of geologic units at the central (a) and eastern (b) locations in the Walnut Creek watershed.

Nitrogen distributions in selected fields: Nitrate-N concentrations in the tile drainage lines are consistently above 10 mg/ℓ for a large portion of the year. Nitrate-N concentrations within the soil profile are of concern because soil profile levels must be adequate for plant growth. Concentrations decreased over time since 1991 and with depth when the data are averaged across fields and sampling dates for a given year (Fig. 6). Nitrate-N concentrations were generally higher than 10 mg/ℓ in 1991 and 1992 but decreased to less than 10 mg/ℓ in 1993 for the upper 15 cm. Soil nitrate-N concentrations below 15 cm were consistently lower than 10 mg/ℓ for all three years.

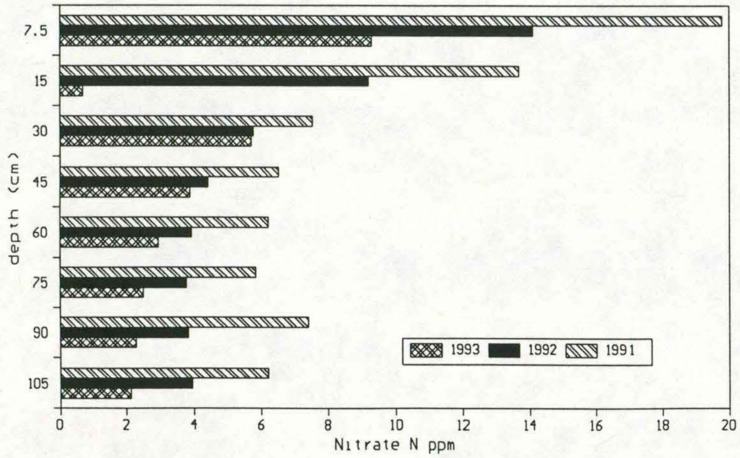


Figure 6. Nitrate-N concentrations observed in soil profiles collected throughout Walnut Creek watershed for 1991, 1992, and 1993.

Concentrations of nitrate-N were always highest in the upper 15 cm under corn or soybean. Nitrate-N concentrations in the upper 30 cm are higher under corn than soybean. Concentrations are also high in late spring and early summer because of fertilizer application. Nitrate-N concentrations are the same under corn and soybean at depths more than 30 cm and relatively constant with depth for the growing season. Nitrate-N concentrations at all depths under corn were lowest in August and increased significantly after harvest. Nitrate-N concentrations at all depths under soybean were lowest in the fall after harvest and almost equal for all other times during the year.

Pothole nitrate-N summary: A field with an isolated pothole within Walnut Creek was investigated extensively to evaluate the movement of herbicides and nitrate-N through the soil into a tile drain, and to evaluate the spatial variation of soil nitrogen and herbicide adsorption. This field was cropped to corn in 1992 and soybean in 1993. Nitrate-N in the soil profile early in the 1992 season was relatively low and similar for Canisteo, Clarion, and Okoboji soils (Fig. 7). Shallow ground water nitrate-N concentrations were found to be significantly higher under Clarion soils compared to the other two soil types for this field. Leaching may be the predominant route of nitrate-N loss in the Clarion soils whereas denitrification may dominate in the poorly drained Okoboji soils. Denitrification rates averaged 8 ng N/g/day in the Clarion soil and 70 ng N/g/day in the Okoboji soil. Nitrate-N amounts were lowest in mid-August for all three soil types because of rapid uptake of N by the corn plants from June to mid-August. After harvest in early November, soil nitrate-N levels increase over that observed in August because of mineralization of surface, below ground residue, and soil organic N. Over the winter, Canisteo soil lost the largest amount of nitrate-N (67 kg/ha), followed by Clarion soils (47 kg/ha) and Okoboji soils (19 kg/ha) (Figs. 7 and 8). This reduction in nitrate-N was probably the result of leaching in the early spring. Okoboji soils appear to have the least potential for leaching loss in the early spring. Tile drain water losses of nitrate-N for this field were greater in 1993 under soybean (62 kg/ha) than in 1992 under corn (33 kg/ha).

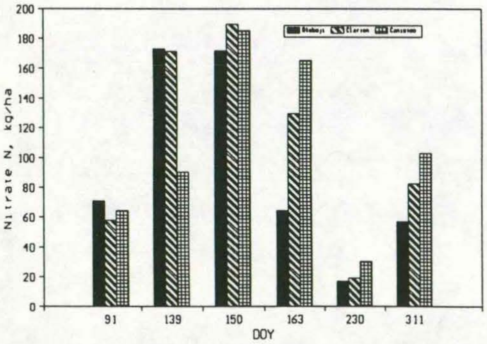


Figure 7. Nitrate-N concentrations observed over the growing season for three soils in the pothole field of Walnut Creek watershed for 1992.

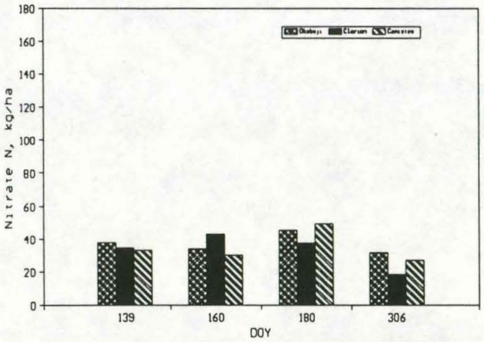


Figure 8. Nitrate-N concentrations observed over the growing season for three soils in the pothole field of Walnut Creek watershed for 1993.

<u>**Herbicide movement and loss in glacial till soils:**</u> Herbicide leaching through the soils in Walnut Creek is controlled by the timing of application relative to rainfall and infiltration, the high sorptive capacity of the surface soils, and the relative rates of degradation of different herbicides. Atrazine degradation results from biological and non-biological processes. Microbial degradation forms dealkylated metabolites, deethylatrazine (DEA) and deisopropylatrazine (DIA), which are found in drain water from tiles. DEA is produced in greater quantities than DIA in most soils. Ring cleavage results in the production of CO_2 (mineralization) and utilization of ammonia (NH_3) by the bacterial cells. Individual microorganisms were able to completely degrade solutions of 40 to 50 mg/ℓ of atrazine within 3 or 4 days, but ammonium-nitrate or organic N sources inhibited degradation. In soil, these reactions may be carried out by individual microorganisms or by a consortia of species.

Hydroxyatrazine was the most persistent of the four compounds in surface and subsurface Clarion and Nicollet-Webster soils. Atrazine, DEA, and DIA are sorbed to a lesser extent than hydroxyatrazine. DIA was mineralized to a greater extent than the other compounds. Saturated conditions enhanced degradation of atrazine, DIA, and DEA. Persistence of DEA was positively correlated with clay content and negatively correlated with organic matter. In soils with a history of atrazine use, DEA undergoes enhanced microbial degradation.

Metolachlor was also more persistent in subsurface soils than in surface soils. Rates of metolachlor mineralization were very low, indicating that cometabolic pathways of degradation were predominant in both surface and subsurface soils. The half life of metolachlor under unsaturated, aerobic conditions was 78 days in surface soil and 246 days in subsurface soil. Under saturated conditions, the half life was 47 days in surface soil and 79 days in subsurface soil. Dissipation of atrazine and metolachlor residues in surface soils (0-7.5 cm depth) is generally biphasic with rapid initial declines after application, followed by a second slow phase of dissipation. Atrazine is consistently detected in the top 15 cm of soil in concentrations of 15 to 80 μg/kg over one year following application in the surface soils (Fig. 9). This long-term persistence probably reflects the unavailability of adsorbed atrazine to the soil microorganisms. The frequency of atrazine detection in subsurface soils is greater in fields following atrazine application, but atrazine is also present in the subsurface in years when atrazine is not applied. The mean concentrations of atrazine (excluding non-detects) generally ranged from 5 to 25 μg/kg soil. The frequency of detection may reflect the influence of preferential flow process, such as leaching through worm burrows or fractures. Atrazine may be present in a greater frequency of samples at concentrations below the 5 μg/kg soil detection limit.

Field topography influenced herbicide movement in the watershed. Spatial soil sampling of the 8.5 ha pothole field site revealed that atrazine sorption was greatest in the potholes and surrounding areas (Table 3). The greater sorption of atrazine by these soils slows herbicide movement into the tile drain, thereby allowing more time for degradation. Sorption decreases in the subsurface soils, which enhanced the mobility of any herbicides reaching these depths.

The increased transport of water and atrazine in runoff into pothole areas appears to contribute to the greater degree of leaching, despite the greater adsorption of atrazine by pothole soils. Atrazine was detected at frequencies of 23 to 31 percent in the 1.5 and 2.6 m depth piezometers at the pothole field. The frequency of atrazine detection in piezometers from the pothole area (Harps and Okoboji soils) of the field was 38 percent compared to 13 percent in the summit and shoulder slope areas (Clarion soils). Less than 4 percent of the piezometer samples contained atrazine at concentrations exceeding 3 μg/ℓ.

Volatilization is a means of herbicide loss from the soil. Data from 1992, 1993, and 1994 indicate that metolachlor volatilization losses to the atmosphere were significant and were related to soil water conditions and the surface microclimate. It is estimated that between 5 and 20 percent of metolachlor movement from the field can be attributed to volatilization losses. Volatilization rates varied among years in response to climatic and soil water conditions. Peak volatilization rates were associated with increased surface soil water content from light precipitation events immediately following application. In 1993 volatilization losses were the lowest of the three years because of heavy precipitation events following application, which resulted in metolachlor transport below the soil surface. In 1994,

Table 3. Adsorption of atrazine by soils at the Pothole Field site.

Landscape Position	Depth (cm)	Organic C (%)	Sorption, K_d[1] (ℓ/kg)
Shoulder	0-7.5	1.7	2.5
(Clarion soils)	40-110	0.26	0.5
	140-210	0.06	0.3
Backslope	0-7.5	2.4	4.2
(Canisteo soils)	40-110	0.38	0.6
	140-210	0.09	0.4
Pothole	0-7.5	4.5	7.7
(Harps, Okoboji soils)	40-110	1.3	3.2

[1] K_d is the ratio of soil-adsorbed atrazine to solution concentrations, determined by batch equilibration methods.

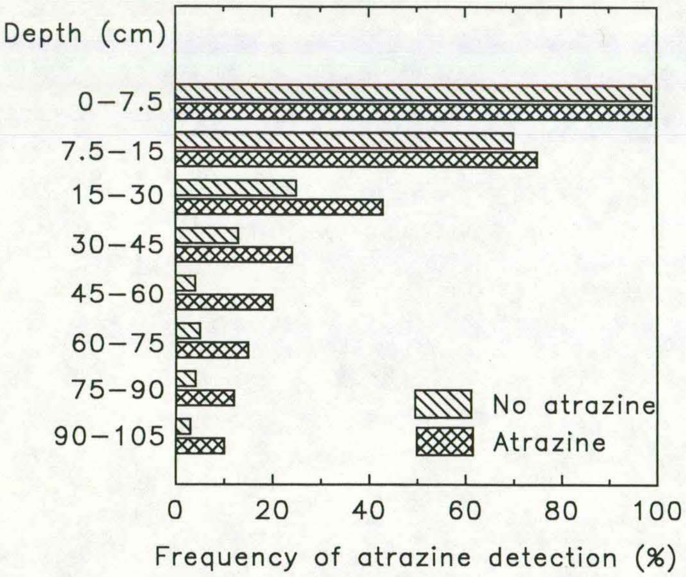


Figure 9. Frequency of atrazine detection in soils from the western part of Walnut Creek watershed. Atrazine was extracted from soil core segments from three field sites sampled in 1992 and 1993. Frequencies are shown for fields for years with and without atrazine application.

measurements made over a ridge till field showed greater volatilization losses than conventional tillage fields. Better understanding of these processes will result in management practices that can reduce off-site movement of pesticides into the atmosphere.

Water movement and water balance in glacial till soils: Precipitation can be intercepted by canopy, pond on the soil surface leading to runoff, infiltrate the soil matrix, or preferentially flow through macropores. Evaporation from canopy and soils occurs, and infiltrated water redistributes within the soil. Subsurface soil water moves vertically as well as laterally down slopes. Water movement occurs in the pore space, and pore structure is complex and three-dimensional. As the canopy and root system develop, much of the infiltrated water is intercepted by roots and transpired.

Subsurface lateral water flow patterns have been observed in the pothole field. Bromide moved downhill to 6 m, and over 70 percent moved vertically to 90 cm beneath the applied transect. The remainder of the bromide moved overland or through seepage planes. Preferential flow in 1994 was apparent during storms in April, September, and October of 1994. However, preferential flow or deep matrix drainage did not occur from June through August because infiltrating precipitation rarely penetrated more than 50 or 60 cm during the growing season. Water flow patterns over the landscape could result in accumulation of chemicals at lower landscape positions where they become subject to tile drainage. Accumulated nitrate-N could be subject to denitrification at lower landscape positions. Transpiration reduces leaching potential during the growing season except for large precipitation events. Spring and fall are the most susceptible times for preferential leaching.

Different hydraulic properties exist for different management zones resulting in preferential water flow. Wheel tracks decrease the hydraulic conductivity compared to within the row and untracked areas between rows. Preferential water flow can occur under wet conditions that approach saturation. Water movement patterns vary across a field depending upon the management practices.

Studies conducted on the field scale water balance for selected fields within Walnut Creek showed differences in water use rates among tillage practices. These differences are caused by crop residue and tillage practices. The period of May until early July was dry in 1992 and no-till and ridge-till fields used more water than chisel plowed fields. This was a reversal of early season trends when no-till and ridge-till had lower soil water evaporation rates. These results were the same for 1994 when the early spring was dry. Conservation tillage practices lead to an increase in the soil water storage within the soil profile and can lead to increased soil water availability when soil water is limited by rainfall. There has not been a year drier than normal in this study to determine if there are differences among these tillage practices. Conservation tillage practices could contribute to increased tile drainage flow in the early season. In evaluating the water balance for glacial till soils, about 48 percent of precipitation is used for evapotranspiration, 48 percent for tile drainage, and the remaining 4 percent contributes to ground water recharge. A change in the soil water balance in glacial till soils may have an impact on water movement into the tile drainage lines more than ground water recharge.

Nashua site tillage and water quality responses

The Nashua site is located on the Iowan Surface and overlies the Devonian Aquifer. Various experiments at Nashua have been conducted since 1976 on the same tillage, crop rotation, and chemical application procedures. These experiments allowed the observation of practices that are in equilibrium balance with the soil and climate.

Geological variation of the Iowan Surface at the Nashua site: Pre-Illinoian till lays over the Cedar Valley limestone of Devonian Age at the Nashua site (Fig. 10). This limestone aquifer is the same one used for the research farm well and is the major confined aquifer for all wells in the region. The Eagle Center Member is not a major aquifer in the region. Particle size analyses of the unoxidized Pre-Illinoian till at the site shows 37 percent sand (< 2mm), 43 percent silt, and 20 percent clay.

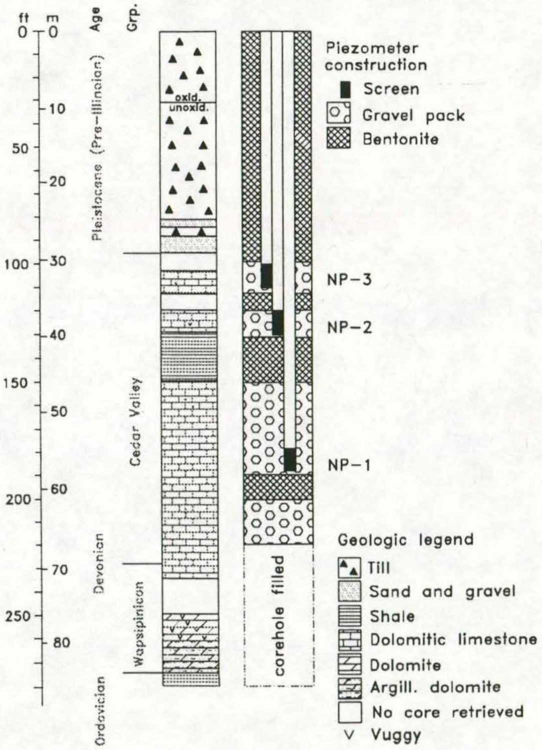


Figure 10. Geological unit cross-section for the Iowan Erosion Surface at Nashua, Iowa.

Hydraulic heads were nearly equal in the upper 10 m of the Pre-Illinoian till, which coincides with the thickness of the oxidized zone. This relationship suggests a strong lateral flow of water and chemicals towards lower spots on the landscape and also to the Cedar River (to the east). The oxidized zone shows a high density of fractures that could increase ground water velocities and presumably control contaminant transport. In contrast to the oxidized part of the till, the vertical hydraulic gradient steepens in the unoxidized Pre-Illinoian till. Piezometers completed in this zone alternately blow and suck air in relation to the prevailing surface barometric pressure. Even the abnormally high precipitation in 1993 failed to produce saturated conditions in this zone. A water table also exists in the Pre-Illinoian till near the land surface. Hydrologic situations such as this could be common in this region.

Hydraulic head data indicated a potential for vertical flow (downward) across the Chickasaw shale, although a potential for upward flow across the shale developed during 1993. Hydraulic heads show some relationship to the Cedar River and the aquifer probably discharges there. Ground water recharge to the deeper bedrock aquifer occurs faster (perhaps through sinkholes) than to the shallow bedrock aquifer. Recharge to the upper part of the bedrock aquifer above the shale probably occurs vertically through the Pre-Illinoian till.

Water quality observations at the Nashua site: Water quality tests from deep bedrock (Devonian Cedar Valley aquifer) showed no pesticide detections in any of the bedrock piezometers or in the research farm well. Nitrate-N concentrations were below quantitation limits of 1 mg/ℓ in the upper layer of the Cedar Valley unit (NP-2 on Fig. 10), but averaged about 6 mg/ℓ in the lower part of the Cedar Valley unit (NP-1 in Fig. 10). Nitrous oxide (N_2O) concentrations of 0.8 μmol/ℓ were detected in ground water from NP-1; thus, denitrification could be lowering an otherwise high nitrate-N concentration in this aquifer. Tritium analyses of water in NP-2 showed values <0.8 tritium units (TU). This value suggests that the ground water is probably more than 50 years old and perhaps explains why nitrate-N or pesticides were not detected. Ground water in NP-1 showed tritium activities of 20 TU, suggesting that this water was recharged in the 1980s or later. The age data, in addition to the fluctuation of hydraulic heads at the site, suggest that recharge to the deeper aquifer enters quickly through nearby outcrops, sinkholes, or agricultural drainage wells. Thus, the Cedar Valley limestone aquifer below the Chickasaw shale has the greatest potential for contamination by agricultural activities in the region.

Evidence of nitrate-N and chloride (Cl) to depths of nearly 10 m in the oxidized till proves that the shallow aquitard (Pre-Illinoian till) below the tile drain depth is contaminated. The high concentrations of Cl suggest a significant input from fertilizer. Nitrate-N is accompanied by concentrations of dissolved oxygen (O_2) similar to those seen in Des Moines Lobe till units. Concentrations of Cl despite the disappearance of nitrate-N and dissolved O_2 with depth in ground water suggest that denitrification occurs in ground water. Preliminary laboratory microcosm experiments show evidence of denitrification potential in at least the upper 3 meters of oxidized till.

Impact of tillage and crop rotations on shallow ground water quality: Weather patterns resulted in differences in nitrate-N and herbicide leaching losses to the ground water. Dry weather in 1988 and 1989 resulted in almost no subsurface drain flows. Most of the nitrate-N and herbicide will not move to the shallow ground water system in dry years. Average yearly subsurface drain flows and nitrate-N leaching losses with subsurface drain water were monitored for continuous corn and corn-soybean rotations under all tillage systems. Data showed continuous corn production system had the largest nitrate-N concentrations in the drain water (Table 4). Increased nitrate-N leaching losses under no-till and chisel plow are the result of larger volumes of drain flows because of preferential flow. Overall results indicate that the continuous corn production system receives higher N applications and results in higher NO_3-N leaching losses to ground water.

Herbicide losses with subsurface drainage water were somewhat higher under the no-till and ridge tillage systems when compared with chisel and moldboard plow systems. Also, the atrazine losses to drain water (or shallow ground water) were highest under no-till and lowest under moldboard plow system. This indicates a larger contribution of the preferential flow system under no-tillage conditions.

Table 4. Average yearly subsurface drain flows, nitrate-N concentrations in drain water, and losses with subsurface drain water for three years in relation to tillage and crop rotation.

Parameter	Rotation	Chisel plow	Moldboard plow	Ridge tillage	No-tillage
Drain flow, mm	Continuous corn	190ba	123b	203ab	245a
	Corn-soybean	173a	127b	139ba	130ba
Nitrate-N conc, mg/ℓ	Continuous corn	30.6ab	35.8a	21.8c	22.2bc
	Corn-soybean	18.5ba	19.0a	13.9ba	13.4b
Nitrate-N loss, kg/ha	Continuous corn	64.3a	45.8a	50.6a	61.2a
	Corn-soybean	32.1a	27.5a	23.7a	23.9a

Same letter in the same row indicates data are not significantly different at 0.05 level.

Modified N-management systems and their impact on shallow ground water quality: Cropping systems were modified at Nashua in 1993 to provide a comparison of different tillage, crop rotations, fertilizer rates and timing, and source of nitrogen on the nitrate-N loss to shallow ground water in the Iowan surface. Nitrogen management is the primary variable with comparisons of differential nitrogen rates of either commercial fertilizer or swine manure based on the Late Spring Nitrate Test or single fertilizer application rates of either 112 or 135 kg/ha. Nitrogen is applied to continuous corn, corn-soybean, or a narrow strip cropping system of corn-soybean-oats with berseem clover. Alfalfa is also evaluated for its production of nitrogen for row crops. These treatments are grown in either no-till or chisel-plow tillage systems.

Alternative N management practices showed significant potential to reduce ground water contamination. Corn plots under no-till that used the Late Spring Nitrate Test to determine N applications had 9.8 and 7.3 mg/ℓ in the tile drainage. Strip cropping and alfalfa treatments showed the lowest drainage water nitrate-N concentrations of all practices evaluated at this site. The values averaged 7 and 6 mg/ℓ in 1993 and 2.8 and 2.7 mg/ℓ in 1994, respectively. In 1994, plots under no-till and chisel plow that used the Late Spring Nitrate Test had 7.3 and 9.7 mg/ℓ nitrate-N, respectively.

Swine manure used as fertilizer may have more potential to leach soluble organic N (DON) compounds to tile drain water. In the spring of 1993, tile drain DON concentrations were about 10 mg/ℓ, similar to tile nitrate-N concentrations. As rainfall increased in June and July, tile drain DON concentrations increased dramatically to a maximum of about 60-70 mg/ℓ while tile nitrate-N concentrations remained at 10 mg/ℓ. Control plots that received no swine manure and were cropped to soybean, or plots fertilized with 135 kg/ha of commercial fertilizer and cropped continuously to corn also showed similar increases in the tile drain DON concentrations. This indicates that the potential for DON leaching can be high under N management strategies other than swine manure application. Tile drain DON concentrations were less than 10 mg/ℓ for all plots during 1994.

Nitrogen with the potential to mineralize decreased from 250 kg/ha in May 1993 to less than 100 kg/ha by late June 1993. This happened at the same time as large increases in tile drain DON concentrations were observed in 1993. Potentially mineralizable N remained low for the rest of 1993 and was less than 100 kg/ha during most of 1994. There was a slight increase in mineralization potential in the fall of 1994, indicating a recovery of the soil from the flushing during the summer of 1993. These data strongly suggest that a portion of the potentially mineralizable N pool in the soil may be vulnerable to leaching if the conditions are appropriate, as they were in 1993.

Deep loess watershed experiments

Since 1992, MSEA project researchers have monitored a watershed at the Deep Loess Research Station near Treynor, Iowa. This site is planted to continuous corn in a ridge tillage system. Deep loess soils provide a matrix for relatively rapid water flow through the root zone into the vadose zone. After 20 years of cultivated corn production, analysis of saturated-zone ground water from a domestic well in the glacial till revealed no detectable herbicide, and a nitrate-N level less than 5 mg/ℓ. However, shallower ground water samples from depths above the till and within the loess revealed concentrations of two herbicides and one metabolite in concentrations ranging from 0.1-2 μg/ℓ. Total atrazine load detected in the unsaturated zone exceeded the MCL for atrazine in June and July. Thus, triazine herbicides and their degradates leach through the soil and are capable of downward movement to depths of 30 m.

Surface runoff from the watershed showed presence of atrazine, metolachlor, and two atrazine metabolites, DEA and DIA. Changes in herbicide concentration are consistent with the shape of the surface runoff hydrograph. The surface runoff hydrograph and the surface runoff herbicide concentrations are shown together (Fig. 11). The surface runoff graph illustrates how a portion of the stored chemical mass is released rapidly (within two hours) following an intense rainfall.

There are differences in behavior among these chemicals. Herbicides are released more slowly because their mobility depends on water solubility and specific soil affinity or adsorption coefficient. A correlation of the surface runoff hydrograph with concentration data shows the presence of nitrate-N in surface runoff. Nitrate-N concentrations continue to increase until the surface runoff peaks, at which point concentrations decrease because of dilution.

Effect of ridge-tillage on herbicide movement: Loess soils degrade and rapidly distribute herbicide when cultivated. Deep loess soils respond more rapidly than glacial till soils to changes, especially agricultural chemical inputs. In addition, landscape features define hydrologic boundaries for most fields, which makes it possible to predict both surface and subsurface water movement patterns. Field responses to inputs are therefore assumed to represent those of a small agricultural watershed.

Ridge tillage enhances infiltration and increases the leaching of herbicides into the shallow ground water system. Ground water quality can be measured directly because water in the unsaturated zone within the loess emerges as surface flow at down gradient incised-channels. Thus, shallow ground water becomes the surface water carrying the agricultural chemicals off-site and into water resources. Furthermore, about 90 percent of the discharged water is subsurface flow. Ridge-tillage corn was started in 1972 with an average N fertilizer input of 168 kg/ha/yr, and the nitrogen stored in the loess soil profile has since increased steadily.

The cumulative effect of this nitrogen buildup combined with the slow release of nitrate-N mostly through subsurface flow is shown by comparison of the nitrate-N concentration in drainage. In 1972, measured values were <3 mg/ℓ; in 1994 they were >23 mg/ℓ. Management decisions can have a long term impact on leaching and surface runoff on the water resources in vulnerable soils.

Water quality concept for the Deep Loess soils: A conceptual model is being developed to assess both the on-site and off-site impact of agricultural chemical usage. The "water-quality profile" delineates the distribution of fertilizer and herbicide-derived chemicals and how that distribution changes throughout the subsurface over time. A 40-ha field has been equipped for collection of rainwater, surface runoff, soil-pore water, and both unsaturated-zone and saturated-zone ground water. In addition, four-foot continuous-core soil samples are taken at each defining landscape position at preapplication, postapplication, mid-growing season, and harvest. Data from the measurement of fertilizers and agricultural chemicals can lead to definitive statements on the impact that a given management practice in an area with defined drainage boundaries can have on water quality.

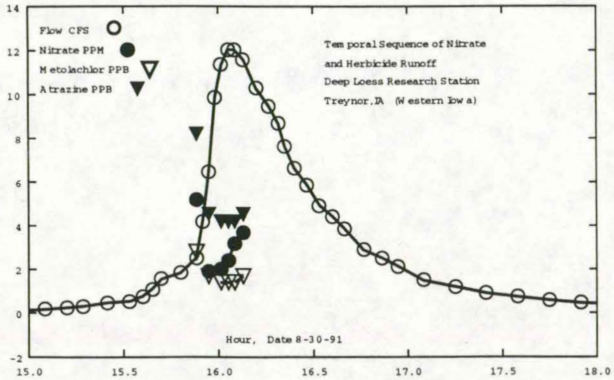


Figure 11. Surface runoff, nitrate-N, metolachlor, and atrazine concentrations for a storm event on August 30, 1991, at the Deep Loess Research Station.

Practices that potentially impact water quality

Farming practices

The MSEA project research team has identified several practices with the potential to improve water quality, and these could be adopted within the state and region.

Nitrogen placement with Localized Compaction and Doming (LCD): Preferential movement in glacial till soils rapidly carries water and nutrients through large cracks, root holes, or macropores. Knife injection of anhydrous ammonia fertilizer opens a small furrow, which can become a low resistance pathway for water. This furrow allows water to pass directly into and through the soil region with the highest fertilizer concentrations. Water flow through these furrows and nearby macropores must be reduced to decrease the potential for nitrate-N leaching. The approach is quite simple: disrupt and close the macropores near the fertilizer band, and close the knife slit to reduce infiltration through the band. Some preliminary testing has been conducted on an implement that can close macropores at the base of the knife slit, pack soil into the furrow, and mound the soil into a dome over the fertilizer band. Preliminary field tests of this operation reduced water flow through the fertilizer band and subsequent nitrate-N leaching. A comparison of field data at the end of the 1993 growing season showed that 19 percent more applied nitrate-N remained in the upper 80 cm of soil in plots treated with the LCD applicator than in plots treated with a conventional knife applicator, in spite of the abnormally high rainfall in 1993 (Fig. 12). Local compaction and doming can be particularly useful on preferential flow soils typical of the glacial till soils of the Midwest.

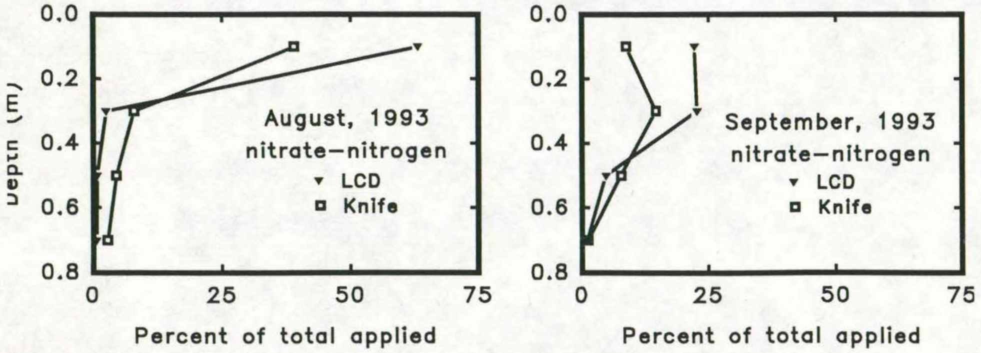


Figure 12. Distributions of nitrate-N in the upper 80 cm of soil when applied with a localized compaction and doming tool compared to knife injection.

Placement of N fertilizer in ridge-tillage: In fields with a long history of ridge tillage, tracers (used to simulate nitrate-N movement) showed greater vertical and lateral movement of nitrate-N under interrow furrows than under ridges. Wheel traffic reduced tracer movement under interrows. Placement of fertilizer in the ridge showed reduced movement beyond the root zone compared to placement between the rows. There is a concurrent pattern of water movement from the interrow into the row. Ridge tillage with fertilizer placement can improve nitrogen use efficiency and reduce leaching.

Split applications of nitrogen: Split N application (at a rate of 125 kg-N/ha) improves ground water quality and decreases the loss of NO_3-N to ground water. Highest NO_3-N concentrations in tile drainage were observed in the moldboard plots with a single N application rate of 175 kg/ha while the lowest NO_3-N concentrations were observed in tile drainage from no-till plots with split N applications. In both tillage systems, NO_3-N losses were greatest for the single N application practice. Overall averages of NO_3-N concentrations in drainage water under single and split applications were 24.7 and 14.9 mg/ℓ for the moldboard system and 16.9 and 9.9 mg/ℓ for the no-till system, respectively. These results indicate that split N applications at a lower rate of 125 kg/ha have the potential to reduce leaching without affecting yield. Corn yields for the study period (1984-1991) showed that yields were not affected by tillage (except for 1987) or by the fertilizer management scheme.

Herbicide banding: Herbicide banding, where only the crop-row area is treated, can decrease herbicide leaching compared to broadcast applications, where the whole area is treated. Banding also offers economic savings as typically only half (or less) of the amount of herbicide is used. The first detection of atrazine in tile drainage was within a month of application (Table 5). In 1987, atrazine was detected in 33 percent of the tile drain samples while metolachlor was detected in only 13 percent of the samples. Concentrations over the years varied depending upon rainfall. Both 1988 and 1989 were below normal in rainfall and data were not available. Banding also reduces the concentration of atrazine in the tile drainage under both moldboard plow and no-till practices (Table 5).

Table 5. Average atrazine concentrations (μg/ℓ) in tile drainage under broadcast and banded applications from 1987 to 1991.

	Moldboard plow		No-till	
Year	Broadcast	Banded	Broadcast	Banded
		(μg/ℓ)		
1987[1]	0.13	0.01	0.20	0.07
1988	na[2]	na	na	na
1989	na	na	0.15	nd[3]
1990[1]	5.50[4]	1.18	2.70	0.32
1991	0.35	0.22	0.53	1.30

[1] Atrazine applied at 2.24 kg/ha in 1987 and 1990.
[2] na means no samples were collected.
[3] nd means below quantitation limit.
[4] Maximum value detected was 19.0 μg/ℓ.

Herbicide incorporation: No-till practices provide surface residue, but also can lead to higher concentrations of atrazine, metolachlor, and cyanazine in runoff. New tillage tools that incorporate herbicides and allow for surface residue at the same time have the potential to both control erosion and reduce herbicide loss.

Weed management with innovative practices: Effective, economical, and environmentally sound weed management in different tillage systems over the long-term requires an integration of new information with established weed management principles. There is a need for technology that can deal with the altered ecosystems created by conservation tillage production systems. Current research indicates that weed species react differently to reduced or no-till systems. These differences must be considered in developing economically and environmentally sound weed management systems. It is also essential that crop producers and pest managers consider the idiosyncrasies of the biological interactions among weeds, crops, residues, and environment as they develop weed management plans for conservation tillage systems.

Field scale spatial distribution of weeds: Spatial aggregation of weed populations within fields is not well understood, but appears to be the result of many interacting factors. Characteristics such as soil pH, organic matter content, texture, structure, microbial activity, water holding capacity, and slope vary not only within fields, but also in how well herbicides can control different weed populations. In addition, misapplication of herbicides allows patches of weeds to escape control and leads to aggregation that cannot be attributed to biological variation. Scattering of seed from weeds that escape herbicide application also increases aggregation.

Post-emergence herbicides: Different herbicides with complex chemical properties have been introduced since the mid-1980s to control weeds in no-till and conservation tillage. Most prominent are the sulfonylureas (corn) and the imidazolinones (soybean). New analytical methods to determine parent and degradates identified the most probable degradate compounds by examining the likeliest soil-mediated breakdown chemistry. All analytes are detected at sub-ppb concentrations in ground water. The polyfunctional, amphoteric, and hydrophilic nature of these two herbicide families (water solubility range of 14-22 ppth) suggests a high degree of mobility through the soil volume with the potential for rapid leaching to ground water.

Smother plants for weed control: Smother plants are specialized cover crops with an ability to suppress weeds, and may prove to be an alternative to herbicides. An effective smother plant provides weed control without herbicide use, reduces soil erosion, and improves soil quality. Spring-seeded smother plants may avoid the problems associated with previously tested living mulch systems. Competition from spring-seeded smother plants may be easier to manage than winter annual and perennial species because planting patterns and rates can be chosen at the time of planting in response to environment and other factors. In addition, herbicide will not be necessary to eliminate the smother plant if its life cycle is of appropriate length.

In 1994, a short-cycle brassica and four varieties of annual medic were evaluated as spring-seeded smother plants for weed control in corn and soybean near Ames, Iowa. Smother plant seed were planted in a 25-cm band over the row at the time of planting at two planting dates for each crop. Interrow weeds were controlled with cultivation. Results of this experiment varied by crop and planting date. The most encouraging results were obtained with corn and smother plants planted on April 25. Moist soil conditions following planting resulted in excellent establishment of the smother plant, resulting in up to 90 percent weed suppression (Table 6). Short-cycle brassica and Sava medic were particularly effective in suppressing both annual grass and broadleaf weeds. Both medics and short-cycle brassica suppressed weeds without herbicide use. However, allowing these plants to reach maturity subjected the corn to excessive competition and reduced yield. The duration and/or intensity of competition from the smother plants must be reduced by mechanical removal, staggering planting times, selection of short-cycle plants, or herbicide application.

Table 6. Effect of smother plants on weed densities and corn yield at Ames, Iowa in 1994.

Smother plant	Weed density Annual grass	 Annual broadleaf	 Total	Corn Yield
	---------- plants per m of row ----------			kg/ha
Brassica	1	0	1	7550
Sava medic	2	1	3	8580
Santiago medic	4	5	9	8450
Caliph medic	18	4	22	8080
Paraggio medic	19	6	25	8440
Check	17	11	28	9700

Field mapping to aid in precision farming: Precision farming technologies that allow spatial application of nitrogen and herbicides across a field require accurate field maps of the soil characteristics affecting yield. Unfortunately, generation of these maps is expensive since intensive soil sampling and analysis are required. Non-contacting electromagnetic induction surveys can be used to reduce the cost and time required to prepare maps needed for precision farming for some chemicals.

Electromagnetic induction (EM) instruments when held near the soil surface measure soil properties by generating an alternating magnetic field within the soil. This alternating field then produces secondary magnetic fields that are linearly proportional to the soil's electrical conductivity. As the soil electrical conductivity is determined in most cases by a soil properties such as water, salt, or clay content, once this property is identified, an EM survey can be used to map this soil attribute and other related attributes quickly and cheaply.

EM measurements (Fig. 13) were used as a surrogate measure of organic carbon percentage in the top 15 cm of the soil. On the left figure is the distribution of soil organic carbon measured by collecting and analyzing 121 soil samples. On the right is the predicted soil organic carbon estimated from an EM survey, and measurements of soil organic carbon made at only two locations, one with low EM values and the other with high EM values. The predicted soil organic carbon distribution shows the same spatial patterns as the measured distribution, although the high levels in the northeast corner of the field were underestimated. This soil organic carbon distribution map could be used to fine tune herbicide applications since soil organic carbon affects both the efficacy and retention of herbicide.

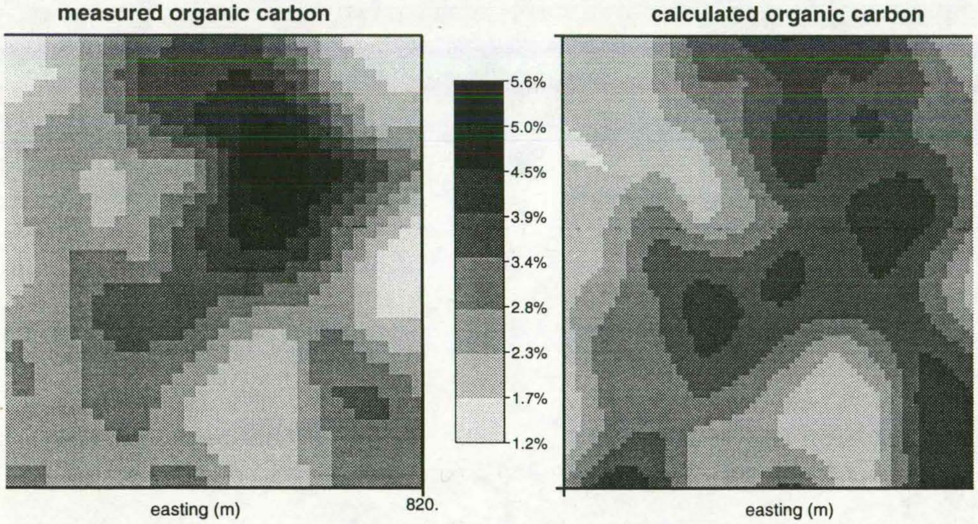


Figure 13. Map showing percentage of organic carbon in the upper 15 cm based on 121 soil core measurements (left) and the percentage calculated using an EM survey and only 2 soil core measurements (right).

Strip intercropping: Strip intercropping is the practice of growing relatively narrow (4 to 8 rows wide) crop strips contiguously in a field, and this practice reduces surface runoff and sediment concentration. Runoff samples from a strip intercropped area had 13 to 28 percent of sediment concentration in runoff compared to an untilled soybean field. Nitrate-N concentrations in tile drainage under the strips were lower than those observed under any of eight other cropping systems containing corn and soybean. The average nitrate-N concentration in the strips was 7 mg/ℓ. The other systems averaged between 7.1 and 10.2 mg/ℓ nitrate-N in the tile drainage.

Landscape practices that affect water quality

Vegetative filter strips: Vegetative filter strips, which are placed along the edge of fields or in waterways, effectively reduce the offsite transport of herbicides in surface runoff from fields. Studies conducted in Iowa show that these strips can remove up to 40 percent of the atrazine, cyanazine, and metolachlor. Vegetative filter strips remove filter contaminants through a combination of water infiltration into the upper soil layer and adsorption to the highly enriched organic matter layer. Filter strips are most effective when there is rapid water infiltration promoted by increasing the length of time the flowing water moves around and through the plant crowns and by a rough soil surface. Placed along the edge of fields, filter strips can remove sufficient quantities of sediment and herbicides from surface runoff to help protect stream water quality.

Wetlands and streams as off-site sinks for agricultural chemicals: Streams and wetlands are areas of intense biological activity, and dissolved fertilizers and pesticides can be lost or transformed as drainage water moves through these systems. However, stream and wetland ecosystems vary in their efficiency as contaminant sinks, and estimates of contaminant removal must integrate process dynamics, hydrology, and contaminant transport. Rates of nitrate-N and herbicide loss in Iowa streams and wetlands are determined primarily by the rate of chemical flux to benthic sites of transformation and uptake. Stream and wetland sediments are typically anaerobic within a few mm of the sediment-water interface, and rapid denitrification even in sediments underlying highly aerated stream waters is possible. The rate of nitrate-N loss varies with sediment type and characteristics. Type of sediment affects the length of the nitrate-N diffusion path through the sediment, which is a function of water movement, sediment oxygen distribution, and sediment porosity.

Models of nitrate-N and pesticide flux based on hydrologic and nitrate-N loading data for Walnut Creek were used to estimate the potential importance of stream and wetland ecosystems to the overall amount of nitrate-N exported from Walnut Creek watershed. Submodels of nitrate-N fate for streams and wetlands were combined with simple hydrologic models to estimate nitrate-N loading and loss in Walnut Creek. Model coefficients were estimated from experimental studies of nitrate-N loss in stream and wetland microcosms.

Two sets of model simulations are illustrated in Fig. 14. The first simulation represented current conditions in the watershed (the complete absence of wetlands), and thus demonstrated in-stream loss of nitrate-N but no loss because of wetlands. The second simulation represented a hypothetical situation with restored wetlands occupying an area equivalent to 1 percent of the watershed area and intercepting flows from subsurface drainage tile flows equivalent to 70 percent of total stream flow. Wetland outflows were then modeled as discharges to Walnut Creek. The stream is predicted to have sufficient capacity for nitrate-N removal to result in measurable declines in nitrate-N concentrations with distance downstream under low flow conditions in summer and early fall (Fig. 14). Under high flow conditions, in-stream loss continues but is overwhelmed by the high nitrate-N loads, and as a result, nitrate-N concentrations are predicted to change little with distance downstream during periods of high flow. The stream is predicted to remove only about 4 percent of the total nitrate-N load received on an annual basis. Based on the second simulation, the wetlands are predicted to have significantly greater nitrate-N removal capacity with measurable effects on nitrate-N exports even under high flow conditions. The model predicts that wetlands covering 1 percent of the watershed would remove approximately 45 percent of the annual nitrate-N load exported from the watershed. More importantly, the wetlands are predicted to result in substantially reduced concentrations of nitrate-N in water exiting the watershed compared to input concentrations. As shown in Fig. 14, with wetlands added to the system, nitrate-N nitrogen concentrations are predicted to average about 4 mg/ℓ, well below the drinking water standard of 10 mg/ℓ. There are opportunities for wetland restoration throughout the watershed.

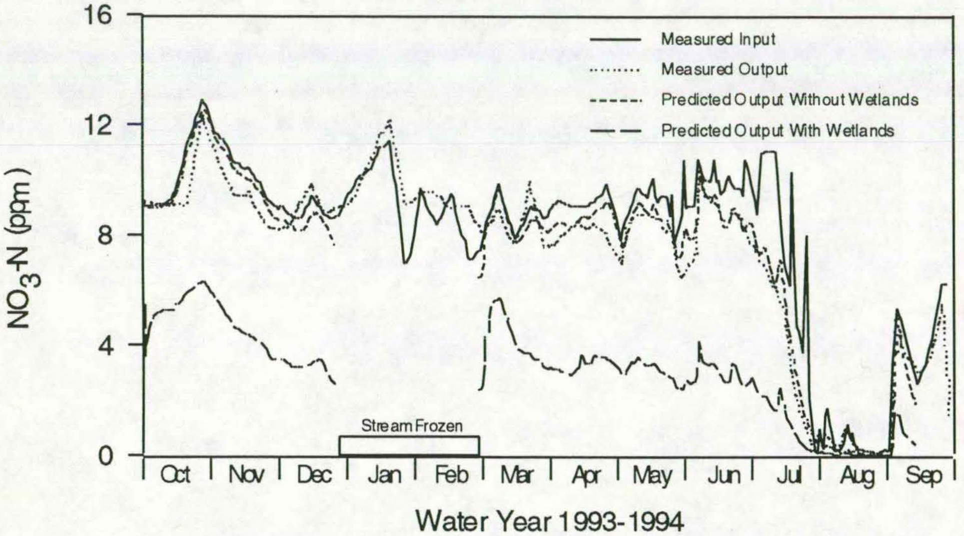


Figure 14. Comparison of the measured input of nitrate-N at the headwaters, the measured output at the confluence, and predicted concentrations exiting the watershed with and without wetlands for Walnut Creek watershed.

Farmers and acceptance of practices and technologies -- a sociological evaluation

Agricultural technologies, especially ones with environmental benefits, are not always readily adopted by farmers for various reasons. Some common reasons include a design problem in the technology, unreliable performance, managerial demands, unsafe operation, additional economic risk, or too expensive. An understanding of these barriers is necessary to guide research and to formulate new methods.

MSEA project researchers identified two practices and evaluated them for their efficiency in managing water quality and soil erosion. Despite favorable research results, the two practices are not widely adopted.

Ridge tillage, which was one of the practices, was chosen because it was as profitable as no till, and more profitable than reduced tillage systems. Ridge tillage also was very effective in reducing pesticide use and erosion or sediment transport. Iowa has a 5 percent acceptance of ridge tillage.

The second practice involved the use of permanent vegetative strips, filter strips, and contour buffer strips to reduce sediment transport to waterways. Although modeling and field studies showed these practices to be very effective, adoption rates are very low.

A comparison of the two technologies offers an interesting contrast. Ridge tillage is a profitable system that requires significant changes in farming practices, skills, and machinery investment. Permanent vegetative strips require little change in management, but the lack of profits, in the form of foregone crop production, is significant. The two practices, however, appear to be equally unpopular with farmers.

In an effort to better understand the reasons behind the low acceptance rate of these practices, six focus groups were conducted in 1994 in sites corresponding to six distinctive soil associations in Iowa. These sites and the corresponding soil associations were: Story, Clarion-Nicollet-Webster; Floyd, Kenyon-Floyd-Clyde; Plymouth, Galva-Primghar-Sac;

Shelby, Marshall; Lucas, Adair-Grundy-Haig; and Winneshiek, Fayette-Downs. Ten to fifteen commercial farmers who had not adopted either practice were recruited for each focus group. Participants were shown short video tapes that described each practice, defined terms, and presented research results on their economic and environmental performance. Farmers were then asked to discuss the technologies in a relatively free or open format and the group discussions were videotaped. Participants were also asked to complete a questionnaire providing information on their farm business, attitudes about conservation, and their estimate on the monetary value including the costs and benefits of each practice in their own farm business. These results are being summarized at the present time.

Outreach, education, and technology transfer activities

Goals and objectives:

An educational component of the MSEA project has developed educational materials related to water quality that would increase the awareness of farmers and other agricultural professionals about cropping practices and their effects on water quality. In addition, the project has demonstrated cropping practices with positive environmental effects, and identified constraints to adoption of these practices.

The following were the specific objectives for outreach education and technology transfer:

1. Develop new educational materials related to water quality for use in Iowa.
2. Increase awareness of MSEA research activities and water quality information for farmers, Extension agriculturalists and field crop specialists, Natural Resource Conservation Service personnel, and agribusiness personnel.
3. Evaluate and demonstrate alternative crop management strategies for farmers.
4. Work with sociologists and economists to assess the reluctance shown by farmers in adopting crop management practices that have a positive effect on water quality.
5. Document changes in cropping practices in the Walnut Creek watershed.

Accomplishments:

Educational materials including printed materials, slide sets, brochures, and videos have been prepared from this project, and several more are in different stages of production. Information about water runoff and infiltration, tillage, nitrogen management, weed management, crop development, soil factors affecting chemical movement, use of permanent vegetation, and intercropping were presented at various learning opportunities. Targeted audiences were primarily people who advise and provide service to farmers. Farmers were a secondary target addressed primarily at field tours and winter extension training sessions.

Nineteen field tours were conducted at MSEA research sites and on-farm satellite trial/demonstration sites from October 1991 through September 1994. Six hundred people attended these tours.

Information was presented at 16 winter meetings and short courses. Water quality topics included manure management effects on water, pesticide movement to surface water, and tillage effects on water quality. Audiences included 500 farmers and farm advisors. Information on soil water movement, soil compaction, and soil tilth and quality with implications for water quality was presented at 12 laboratory sessions conducted from 1992 to 1994. Nine hundred and twenty-five commercial agricultural advisors attended these sessions.

MSEA research updates were presented to 47 crops and agricultural engineering Extension area field specialists in 1992 and 1993.

Information on herbicide properties and movement to water resources was presented to a total of 2,256 participants at private and commercial pesticide applicator training.

Field trials for the 1992 cropping season were completed with a variable rate N fertilizer applicator (Soil Doctor^{R}). Variable rates were compared to rates determined using the Late Spring Nitrate Test and to typical N fertilizer rates in 2 trials. Although a second year of testing and additional sites were needed for a thorough evaluation, trials could not be conducted because of excessive rainfall and late corn planting in 1993.

During the 1993 and 1994 cropping seasons, ten on-farm satellite trials were conducted with farmers near the MSEA research sites. Six trials tested use of the Late Spring Nitrate Test to determine N fertilizer rates for corn compared to conventional rates. An additional four trials evaluated full vs. reduced herbicide rates or banding vs. broadcasting. Field tours were conducted at each of the trial/demonstration sites.

A GIS database now has crop and farm information for approximately 5,600 ha for the 1991 and 1992 crop years. The information was collected through personal surveys of farmers, crop history forms, mail-in surveys, and individual follow-up with farmers.

In addition, a $11,400 Integrated Pest Management Grant from USDA in 1992 made possible a detailed documentation on weed species in 500 ha of corn, soybean, and alfalfa. Entomologists also compared different trap types for European corn borer and corn rootworms.

Plans for the future

Emerging Problems and Issues: Research indicates that nitrate-N leaching and surface runoff of herbicides on sloping land are the two main concerns in Iowa. Although the percentage load of herbicides is quite minimal, concentrations often exceed the MCL or health advisory levels for drinking water. However, when a limited number of fields with a particular herbicide applied contribute to stream flow, concentrations are diluted.

Quantitative assessment of a field's vulnerability to herbicide and nitrate-N loss, and designs of landscape features and practices that can reduce losses are needed to better maintain water quality.

Development of nitrogen management practices together with conservation tillage practices that reduce surface runoff requires field studies that incorporate field and landscape variation into the decision-making process. Farming practices will be adopted only after they prove to be environmentally sound and without a negative impact on farm profit. Technology transfer programs developed with the research program can accomplish this need. Research that can lead to improved production efficiency and reduced onsite and offsite impacts at the same time is needed.

Project Infrastructure: Project infrastructure is already in place with the current MSEA project and could be adopted for a future project. Project infrastructure will be developed around existing staff. This includes staff in the National Soil Tilth Laboratory, Iowa State University, and Cooperative Extension. Interdisciplinary teams can be developed to address specific research objectives, develop and implement research plans, and develop technology transfer activities. Research teams also can develop project milestones and expected products for the future project. A number of existing projects within the National Soil Tilth Laboratory could easily become part of the MSEA research objectives.

Project Objectives: The following are objectives based on application on the landscape, evaluation of offsite impacts, and assessment of the vulnerability of fields and management practices.

1. Evaluation of the environmental and economic impact on the surface and ground water resources of adopting improved nitrogen and herbicide practices within farming systems of the Midwest.
2. Development and evaluation of techniques that can be used to assess the vulnerability of specific farming practices and fields on the offsite movement of nitrate-N and herbicides.
3. Development of procedures for the evaluation of offsite impacts from specific fields and landscapes, and application of landscape management practices, like filter strips or wetlands, to mitigate the offsite impacts on the water resources of different soils, geology, and climatic regimes of the Midwest.

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