# The Relationship of Nitrate Concentrations in Streams to Row Crop Land Use in Iowa

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## ABSTRACT

**The relationship between row crop land use and nitrate N concentrations in surface water was evaluated for 15 Iowa watersheds ranging from 1002 to 2774 km² and 10 smaller watersheds ranging from 47 to 775 km² for the period 1996 to 1998. The percentage of land in row crop varied from 24 to >87% in the 15 large watersheds, and mean annual $NO_3$–N concentrations ranged from 0.5 to 10.8 mg/L. In the small watersheds, row crop percentage varied from 28 to 87% and mean annual $NO_3$–N concentrations ranged from 3.0 to 10.5 mg/L. In both cases, nitrate N concentrations were directly related to the percentage of row crop in the watershed ($p < 0.0003$). Linear regression showed similar slope for both sets of watersheds (0.11) suggesting that average annual surface water nitrate concentrations in Iowa, and possibly similar agricultural areas in the midwestern USA, can be approximated by multiplying a watershed's row crop percentage by 0.1. Comparing the Iowa watershed data with similar data collected at a subwatershed scale in Iowa (0.1 to 8.1 km²) and a larger midcontinent scale (7300 to 237 100 km²) suggests that watershed scale affects the relationship of nitrate concentration and land use. The slope of nitrate concentration versus row crop percentage decreases with increasing watershed size.**

Nitrate nitrogen (nitrate) is a common dissolved constituent found in surface waters throughout the midwestern USA, including Iowa (Hallberg and Keeney, 1993; Puckett, 1994; Goolsby et al., 1999). While nitrate originates from many sources, the primary nonpoint source in Iowa is agriculture, specifically the widespread use of nitrogen fertilizers, application of livestock manure, legumes, and mineralization of soil nitrogen (Hallberg, 1987; Goolsby et al., 1999). Nitrate is typically leached from cropped fields and moves as shallow ground water to streams. Ground water discharge as baseflow, and discharge of ground water by tile drainage, provide the main source of nitrate to Iowa's streams (Hallberg, 1987, 1989).

Drinking water supplies that use surface water or shallow ground water are particularly vulnerable to nitrate contamination. A statewide inventory of private wells in Iowa found that 18.3% of the wells sampled in 1988–1989 contained nitrate concentrations greater than the USEPA standard of 10 mg/L as N (Kross et al., 1990). Nitrate and other nutrients also contribute to stream eutrophication and other environmental concerns. Recently, nitrate and phosporous loads in the Mississippi River have been linked to hypoxic conditions in the Gulf of Mexico (Rabalais et al., 1996; Goolsby et al., 1999). The average annual export of nitrate nitrogen from Iowa in surface water has been estimated to range from approximately 204 075 to 222 215 Mg (225 000 to 245 000 U.S. tons), or about 25% of the nitrate that the Mississippi River delivers to the Gulf of Mexico, despite Iowa occupying less than 5% of its drainage basin (Libra, 1998).

Though previous studies have noted the relationship of agricultural land use and nitrogen concentrations in streams in other parts of North America (Hill, 1978; Mason et al., 1990; Jorden et al., 1997a,b), this relationship has not been investigated in Iowa, despite Iowa's agricultural prominence and land use history. The objective of this study was to examine the relationship of nitrate concentrations in surface water to row crop land use in 25 Iowa watersheds, ranging in size from 47 to nearly 2800 km². The nitrate–land use relationships presented in this study are then compared with smaller and larger watershed data to evaluate how this relationship changes according to watershed scale.

## MATERIALS AND METHODS

Mean nitrate concentrations and row crop land use were summarized for 15 watersheds ranging from 1002 to 2774 km² and 10 smaller watersheds ranging from 47 to 775 km² (Tables 1 and 2, respectively). Watershed size was classified to be largely consistent with standard U.S. Geological Survey (USGS) hydrologic unit codes (HUCs) (United States Geological Survey, 1974). Table 1 includes watersheds that generally fall into standard eight-digit HUC classification (1012 to 5058 km² or 390.6 to 1953 mi²) and Table 2 includes watersheds that fall into 11-digit HUC (162 to 1012 km² or 62.5 to 390.6 mi²) and 14-digit HUC classification (40 to 162 km² or 15.6 to 62.5 mi²). For ease of reference in this paper, watersheds shown in Table 1 are considered "large" and those in Table 2 are considered "small". Locations of large watersheds are shown in Fig. 1 and small watersheds in Fig. 2.

Watershed characteristics and nitrate concentration data were summarized from a variety of sources. Water quality information for the 15 large watersheds was collected from Iowa's fixed-station surface water monitoring network (Fig. 1). Iowa Department of Natural Resources (IDNR) representatives have collected water samples from the monitoring network on a monthly basis since the mid-1980s. Water quality data that was stored in the USEPA's STORET database was retrieved in 1999. STORET is a national computerized database for the storage (*STO*) and retrieval (*RET*) of water quality data maintained by the USEPA at the USEPA National Computer Center in Research Triangle Park, NC. Data from the small watersheds was compiled from specific water quality projects, including three Iowa Department of Natural Resources-Geological Survey Bureau (IDNR-GSB) water-

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**Abbreviations:** HUC, hydrologic unit code.

Table 1. Summary of watershed data for large watersheds (eight-digit hydrologic unit codes [HUCs]).

| No. | Watershed | Drainage area | Drainage area | Percent row crop | Mean $NO_3$–N concentration† |
|---|---|---|---|---|---|
| | | km² | mi² | % | mg/L |
| 1 | North River | 1002 | 387 | 51 | 4.2 |
| 2 | Volga River | 1044 | 403 | 45 | 5.5 |
| 3 | Soldier River | 1054 | 407 | 61 | 5.4 |
| 4 | Cedar Creek | 1373 | 530 | 53 | 3.6 |
| 5 | South Skunk River | 1515 | 585 | 81 | 8.4 |
| 6 | N. Maquoketa River | 1533 | 592 | 47 | 6.1 |
| 7 | Chariton River | 1642 | 634 | 24 | 0.5 |
| 8 | English River | 1647 | 636 | 54 | 3.8 |
| 9 | N. Raccoon River | 1847 | 713 | 88 | 10.1 |
| 10 | Upper Iowa River | 1994 | 770 | 31 | 4.3 |
| 11 | W. Fork Cedar River | 2191 | 846 | 75 | 5.3 |
| 12 | Floyd River | 2284 | 882 | 80 | 10.8 |
| 13 | E. Fork Des Moines River | 2569 | 992 | 85 | 7.1 |
| 14 | E. Nishnabotna River | 2639 | 1019 | 66 | 5.4 |
| 15 | Cedar River | 2774 | 1071 | 70 | 5.4 |

† Unpublished water quality data from the USEPAs STORET database.

shed projects, a U.S. Department of Agriculture management systems evaluation area (MSEA) project, and a USGS National Water Quality Assessment (NAWQA) project in eastern Iowa (Table 2). All water samples for nitrate analysis were collected and analyzed in a consistent and reliable manner following USEPA-approved quality assurance–quality control procedures. For both data sets, nitrate concentrations were averaged for the period of 1996 to 1998 in order to provide a consistent time period for comparison. Although some water quality data have longer periods of record, most of the project-specific data were limited to the last several years. Nitrate concentrations were normally distributed over the period of record so annual mean nitrate concentrations typically coincided with annual median values.

Watershed boundaries were delineated for the area above each surface water sampling point. Percent row crop in watersheds was determined by intersecting the watershed boundaries with a recently published land cover map of Iowa (Giglierano, 1999) using ArcView Geographic Information System (GIS) software (Environmental Systems Research Institute, 1999). Land cover data was interpreted from Landsat satellite imagery from 1992, although some imagery from 1990, 1991, or 1993 was used to in some areas due to 1992 cloud cover (Giglierano, 1999). At the scale of watershed comparisons used in this study, land use remained relatively constant between 1992 and the period 1996 to 1998. The relationship between percent row crop in watersheds and mean nitrate concentrations was determined using the Excel 97 (Microsoft, 1997) spreadsheet linear regression program. The land cover map indicated that 60% of the state is covered by row crops, 30% by grassland (pasture, hay, prairie, and wetlands), 7% by forest lands, and 1% each by urban areas and water bodies (Giglierano, 1999). Row crop and non-row crop areas are shown on Fig. 3 for simplification. The average percentage of row crop land use in the large and small watersheds evaluated in this study was similar to the statewide average (61 and 67%, respectively).

# RESULTS AND DISCUSSION

## Iowa Watersheds

The percentage of land in row crop in large watersheds varied from 24 and 31% in the Chariton and Upper Iowa watersheds, respectively, to more than 80% in the Floyd, East Des Moines, and North Raccoon watersheds (Table 1). Mean nitrate concentrations ranged from 0.5 mg/L to 10.8 mg/L. In the small watersheds, row crop percentage varied from 28 to 87% and mean nitrate concentrations ranged from 3.0 to 10.5 mg/L (Table 2). In both cases, nitrate concentrations were higher in watersheds that were more intensely row cropped. Linear regression of mean nitrate concentration and percent row crop was highly significant ($p <$ 0.0003) for both sets of watershed data and showed similar slopes of 0.11 (Fig. 4 and 5). The stronger correlation in the small-watershed data probably reflects the smaller data set and the lack of statewide diversity (i.e., soils, geology, landscape, topography, etc.) provided by the large-watershed data. Both data sets suggest that mean annual surface water nitrate concentrations in Iowa, and possibly similar agricultural areas in the mid-

Table 2. Summary of watershed data for small watersheds (11- and 14-digit hydrologic unit codes [HUCs]).

| No. | Watershed† | Drainage area | Drainage area | Percent row crop | Mean $NO_3$–N concentration |
|---|---|---|---|---|---|
| | | km² | mi² | % | mg/L |
| 1 | Squaw Creek[1] | 47.1 | 18.2 | 72.6 | 8.2 |
| 2 | Walnut Creek (Story Co.)[2] | 51.3 | 19.8 | 82.7 | 10.5 |
| 3 | Walnut Creek (Jasper Co.)[1] | 52.1 | 20.1 | 76.2 | 8.0 |
| 4 | Sny Magill[3] | 73.3 | 28.3 | 28.0 | 3.0 |
| 5 | Bloody Run[3] | 89.6 | 34.6 | 41.9 | 5.4 |
| 6 | Roberts Creek[4] | 183.1 | 70.7 | 57.4 | 7.1 |
| 7 | Flood Creek[5] | 321.2 | 124.0 | 81.7 | 9.2 |
| 8 | Old Mans Creek[5] | 521.6 | 201.4 | 56.1 | 6.0 |
| 9 | South Fork Iowa R.[5] | 580.4 | 224.1 | 86.7 | 9.2 |
| 10 | Wolf Creek[5] | 775.2 | 299.3 | 82.5 | 9.7 |

† Source of data: [1]Schilling and Thompson (1999) and unpublished data from IDNR-GSB; [2]Hatfield et al. (1999) and M.R. Burkhart, personal communication; [3]Seigley et al. (1994) and unpublished data from IDNR-GSB; [4]Rowden et al. (1995) and unpublished data from IDNR-GSB; [5]Becker et al. (2000).

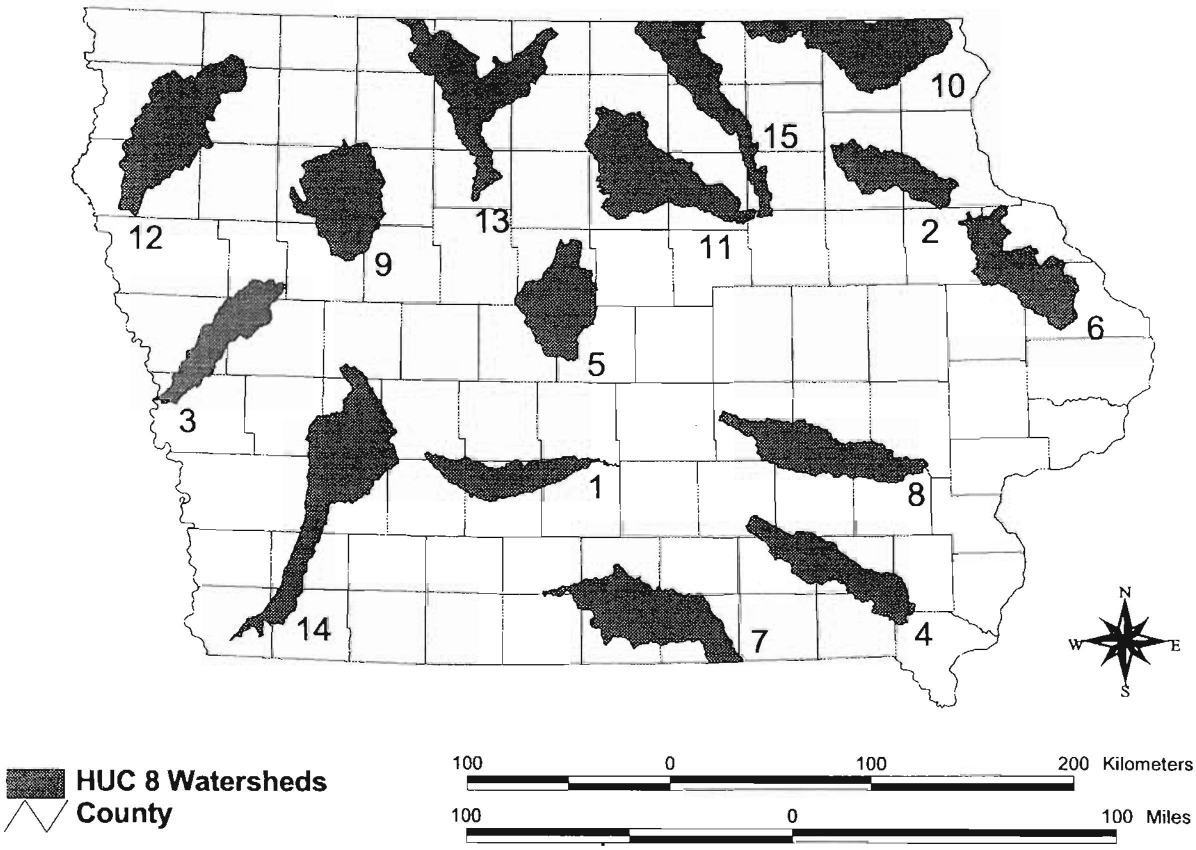


**Fig. 1. Locations of large watersheds (eight-digit hydrologic unit codes [HUCs]) identified in Table 1.**

western USA, can be approximated by simply multiplying the watershed's percent row crop by 0.1.

The low mean concentration of 0.5 mg/L for the Chariton River (Table 1) appears to be an anomaly, even considering the relatively small amount of row crop in the watershed (Fig. 3). This is at least partially due to the fact that the surface water sampling location is below a large reservoir (Rathbun Lake). Rathbun Lake is probably acting as a nitrate sink, reducing nitrate concentrations at the downstream sampling point. Eliminating this point from Fig. 4 reduces the slope of nitrate concentration versus percent row crop (0.095) as well as the correlation coefficient ($r^2$ = 0.5297).

Nitrate concentrations in three northeast Iowa watersheds (Upper Iowa, Volga, and North Maquoketa Rivers) plot higher than might be expected given their row crop percentage (Fig. 4). These three watershed are located in an area of Iowa underlain by shallow, highly permeable carbonate bedrock where stream discharge is dominated by baseflow and springs rather than runoff (Prior, 1991; Horick, 1989). Higher nitrate concentrations in these watersheds probably reflect more efficient delivery of nitrate from cropped fields to streams. In contrast, other large Iowa watersheds evaluated in this study are underlain by low-permeability glacial materials. In these watersheds, streamflow is more variable and dominated by higher proportions of surface runoff and tile discharge. Annual streamflow in these watersheds is often much lower per unit area than in the fractured-rock-dominated watersheds. For example, a fractured-rock watershed like the Upper Iowa has nearly twice as much streamflow per unit area compared with a glacial-till-dominated watershed like the Floyd River (northwest Iowa) (May et al., 1999).

## Effects of Watershed Scale

The effects of watershed scale on the nitrate–land use relationship were investigated by comparing the large and small Iowa watershed data with a similar relationship established for a single Iowa watershed (Schilling and Wolter, unpublished data, 2000) and a study of 42 interior U.S. basins (Goolsby et al., 1999). Recently, Schilling and Wolter (unpublished data, 2000) sampled 46 subwatersheds, ranging from 0.1 to 8.1 km$^2$, within the Walnut Creek watershed in Jasper County (see Fig. 2) to determine the source of nitrate loading in streams. The one-time sampling event was conducted over a 2-d period in May 1999 during baseflow. The Walnut Creek watershed is unique in Iowa in that it is the subject of a large restoration project involving conversion of row crop lands to native prairie (Schilling and Thompson, 1999). Because of the land conversion activities taking place, there is a wide range of row crop land use in subwatersheds within a single watershed. The percentage of row crop within Walnut Creek subwatersheds varied from 4.1 to 95.3% (Schilling and Wolter, unpublished data, 2000). The relationship of nitrate concentrations in surface water ($C$) was found to be a linear function of the percentage of row crop (RC%) in the

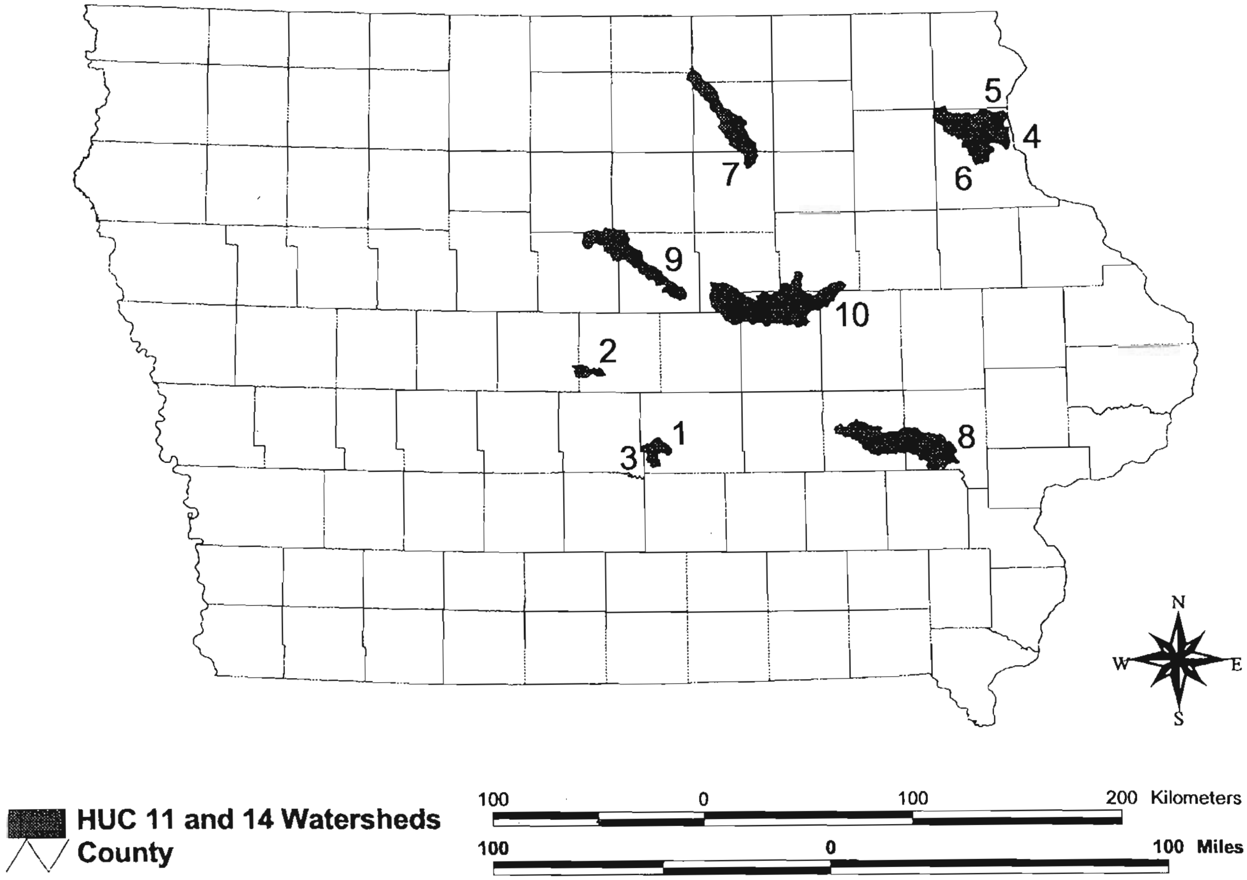


**Fig. 2. Locations of small watersheds (11- and 14-digit hydrologic unit codes [HUCs]) identified in Table 2.**

watershed ($C$ in mg/L = 0.14 RC% + 0.95; $r^2$ = 0.5142). The regression line for the Walnut Creek subwatersheds is plotted in Fig. 6.

Goolsby et al. (1999) examined many years of discharge, water quality, and land use data from 42 interior basins within the midcontinent of the USA to estimate nutrient flux to the Gulf of Mexico. The basins ranged in size from 7300 to 237 100 km$^2$ and percent cropland within the basins ranged from <0.1 to 73.9% (Goolsby et al., 1999). They found a strong linear relationship between nitrate concentrations and percent cropland ($C$ in mg/L = 0.065 RC% + 0.066; $r^2$ = 0.8158). The regression line for the interior basins is plotted on Fig. 6.

The data from this and other studies suggests that watershed scale affects the relationship of nitrate concentrations in surface water to percent row crop in watersheds (Fig. 6). The slope of the regression line is steepest for the small Walnut Creek subwatersheds (0.14), followed by slopes from small and large Iowa watersheds (0.11), and the interior basins (0.07) (Fig. 6). If the suspected anomalous point derived from the Chariton River watershed is removed from the data set, the slope of large Iowa watersheds decreased from 0.11 to 0.095, resulting in a steady progression of decreasing slope from smallest to largest watershed scale. Although the data combines many time scales, ranging from a single sampling event in the case of the Walnut Creek subwatersheds to more than 15 yr of record for the interior basin study, the scale relationship appears to be valid. It is hypothesized that nitrate concentrations are highest in surface water nearest the primary source (row crop fields) where row crop intensity is more constant and there is rapid delivery of nitrate from fields to streams. As one moves to larger and larger watersheds, the relationship of nitrate concentrations to percent row crop land use is dampened by many factors including in-stream nitrogen transformations (especially important in small streams; Isenhart and Crumpton, 1989; Alexander et al., 2000), variable baseflow and tile discharge from row crop and non-row crop areas, dilution of nitrate concentrations from non-row crop agricultural and urban lands, and variable precipitation and runoff events occurring over large geographical areas. Larger watersheds that include more urban areas would balance the effects of increased runoff from paved areas (resulting in nitrogen dilution) with additional inputs of nitrogen from point sources. Many factors, including those described above, probably contribute to the decreasing slope of nitrate concentration with increasing watershed size.

## CONCLUSIONS

In Iowa, nitrate concentrations in surface water show a strong linear relationship to watershed row crop intensity. In watersheds ranging from 47 to 2774 km$^2$, mean nitrate concentrations in surface water were approximately 11% of the watershed row crop percentage. As

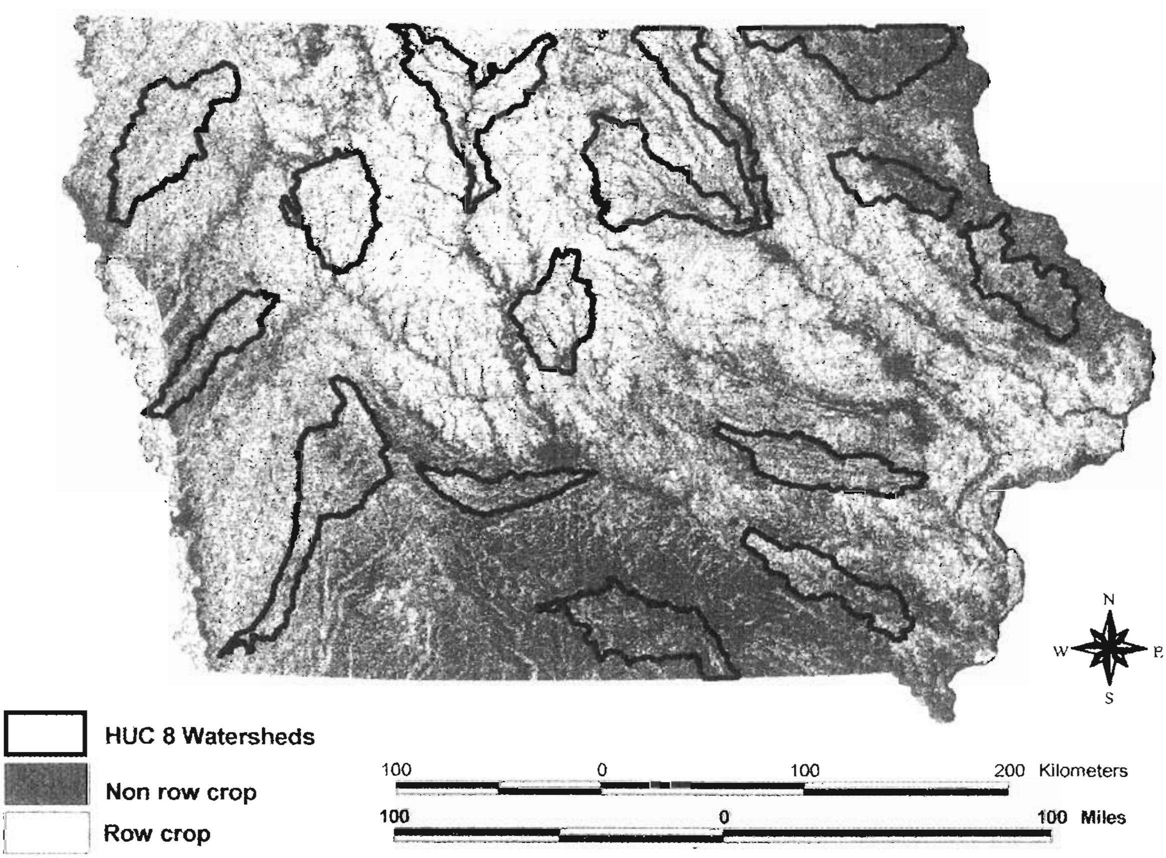


**Fig. 3. Land cover map of Iowa showing row crop and non-row crop areas (modified from Giglierano, 1999).**

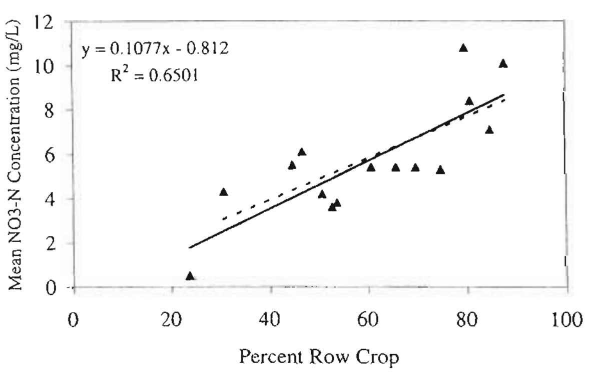


**Fig. 4. Linear regression of mean nitrate concentrations and percent row crop in large Iowa watersheds. Dashed line is regression without using Chariton River data point.**

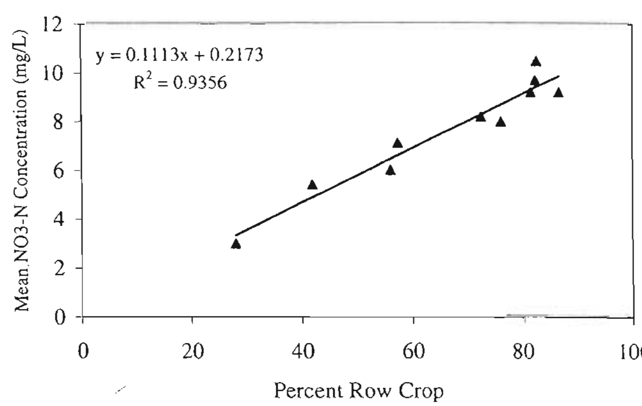


**Fig. 5. Linear regression of mean nitrate concentrations and percent row crop in small Iowa watersheds.**

a general rule of thumb, annual mean surface water nitrate concentrations in Iowa, and possibly similar agricultural areas in the midwestern USA, can be approximated by multiplying the watershed's percent row crop by 0.1. At watershed scales ranging from 0.1 to 237 000 km$^2$, the slope of nitrate concentration versus row crop percentage appears to decrease with increasing watershed size.

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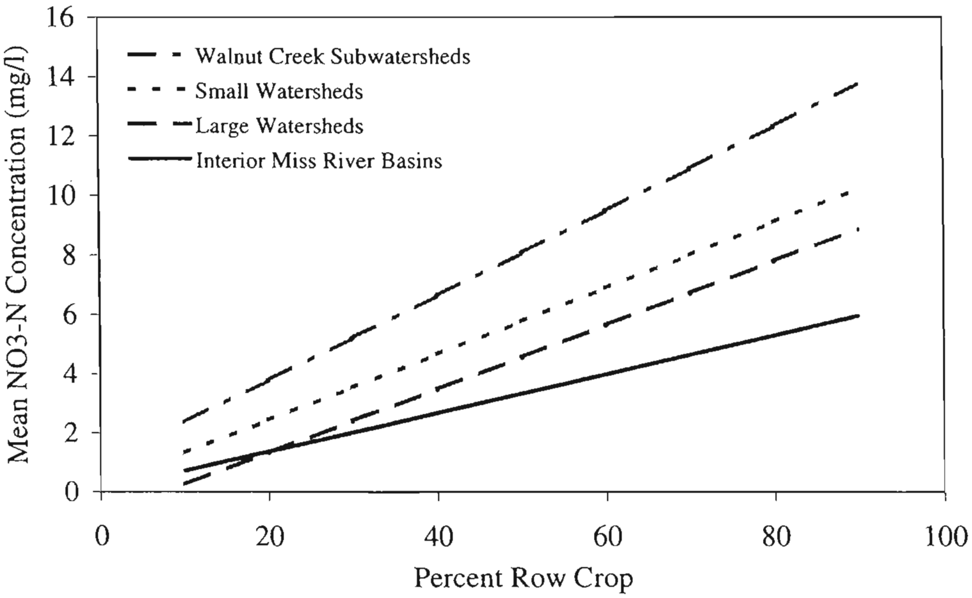


**Fig. 6. Regression lines for various watershed scales.**


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