Fertilizer Nitrogen Practices and Nitrate Levels in Surface Water within an Illinois Watershed

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ABSTRACT Proper nitrogen (N) management as it relates to crop yield has become a critical concern due to the environmental impacts of excessive N fertilizer application. This study monitored 36 sites within the Lake Bloomington, Illinois, watershed on a weekly basis to determine nitrate-N concentrations from various surface water sources. Average nitrate-N concentrations for the period 1993 to 2002 revealed the following: agricultural production drainage tiles, 17.0 mg/L; creek water (Money Creek tributary), 12.0 mg/L; organic agriculture drainage tiles, 11.4 mg/L; surface water runoff, 6.6 mg/L; wooded pasture drainage tiles, 1.6 mg/L; and rainwater, 1.2 mg/L. In addition, as creek water passed through a small municipality ("urban effect"), its concentration of nitrate-N dropped by an average of 0.6 mg/L. An initial watershed resident survey and an annual N fertilizer use survey were conducted to ascertain common N management practices of agricultural producers within the watershed. The mean expected corn grain yield was 9845 kg/ha and the median N fertilizer application rate was between 169 and 202 kg N/ha. On average, 54.5% of the N fertilizer in the watershed was applied in the fall, 32.5% was applied in the spring before planting, and 12.7% was applied after planting. Within the watershed, 64% nonfarming residents perceived agricultural crop production as having the greatest negative impact on water quality compared with only 15.6% of those actively engaged in farming. Knowledge from this study can be used to develop recommendations for sound N management practices within sensitive watershed regions.

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Lake Bloomington is a major source of drinking water for Central Illinois residents of Bloomington, IL, and has a history of nitrate (NO_3–N) concentrations that exceed 10 mg/L. Lake Bloomington was created in 1929 with surface area of 231 ha and depends primarily on surface water from two tributaries (Money Creek and Hickory Creek) and rainwater to maintain water volume. The Lake Bloomington watershed consists of approximately 18,807 ha, of which 93.2% is used for agricultural purposes [primarily corn, *Zea mays* L., and soybean, *Glycine max* (L.) Merr., production], 2.5% is urbanized, 2.5% is wetlands, and 1.8% is forested or contains surface water. The total population within the watershed is 4600 residents. The McLean County Extension Service, McLean County Soil and Water Conservation District, the Natural Resource Conservation Service of McLean County, Illinois State University, and the city of Bloomington, IL, formed a cooperative work group to address the nitrate water quality problems of Lake Bloomington.

Because Lake Bloomington has had a history of elevated nitrate concentrations exceeding 10 mg/L, local residents have become concerned over their drinking water quality. Drinking water contaminated with nitrate concentrations exceeding the maximum contaminant level (MCL) established by the USEPA can cause health effects in humans and animals with the most significant disorder known as methemoglobinemia. Certain individuals, including pregnant women and people exposed to antioxidant medications or chemicals, may also suffer health effects from higher levels of nitrate in the range of 100 to 200 mg/L (Self and Waskom, 1992). Gastric problems in both humans and animals have been reported from prolonged exposure to high levels of nitrate due to the formation of nitrosamines, which have also been linked to cancer in some animal studies (Shuval and Gruener, 1972).

Nitrate-N is a form of nitrogen (N) that is naturally occurring in most soils. Nitrogen fertilizers added to the soil for the purpose of crop production can also add to the concentration of nitrate within the soil. If these amounts become excessive, it has been shown to have profound effects on groundwater quality (Schepers et al., 1991). The proper management of N in watershed areas supplying water reservoirs is of critical importance from both environmental and human health viewpoints. The application of N fertilizers (both synthetic and organic) in the production of row crops (especially corn on tile-drained land) can result in relatively high concentrations of nitrate in the surrounding surface waters (Keeney and DeLuca, 1993). Schilling and Libra (2000) found a direct linear relationship between nitrate concentration in surface waters and the percentage of land devoted to row crop agriculture within the watershed. Non-agricultural sources of nitrate leaching can include natural mineralization occurring primarily in

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Abbreviations: AF, residents actively engaged in farming; DAP, diammonium phosphate; Dep, departure from long-term average; MAP, monoammonium phosphate; MCL, maximum contaminant limit; NF, residents not actively engaged in farming; Prec, precipitation; UAN, urea ammonium nitrate.

the spring due to organic matter breakdown and also from urban land use effluent via septic emissions (Gold et al., 1990).

Previous studies have indicated that the rate of N fertilizer was the primary determinant of the potential for nitrate leaching into groundwater when used in corn production (Patni and Culley, 1989); however, other determinants governing leaching include weather conditions, soil types, and crop management systems (Andraski et al., 2000). Work done by Baker and Johnson (1981) revealed that by controlling the amount, application timing, and type of N fertilizer used can reduce overall nitrate concentration in tile drainage water. Methods of reducing the potential for N loss from intensive agricultural production systems, such as utilizing winter cover crops and lowering fertilizer rates, have been previously investigated by researchers (Staver and Brinsfield, 1990; Hubbard et al., 1991).

Intensive agricultural practices in Central Illinois, which attempt to maintain relatively high corn yields (8–10 Mg/ha) are dependent upon maximum N fertilizer applications. Local producers within this watershed region may risk substantial economic loss from lowered productivity and grain yields without N fertilizer application (Roberts and Lighthall, 1991). Established agricultural production practices in this region have resulted in excessive nitrate leaching by tile drainage into shallow groundwater supplies and eventually into tributaries feeding Lake Bloomington. Nitrogen fertilizer rates greater than 130 kg/ha can easily be transported through clay loam soils (common to this region) under various precipitation amounts (Wagner et al., 1976). Hubbard et al. (1991) has shown that the majority of nitrate leaches beneath the root zone within 1.5 months after application if rainfall amounts to 20 cm in this time span. Seasonal patterns have also been observed to affect nitrate leaching with more significant amounts occurring in the winter and spring periods when there is minimal plant utilization (Owens et al., 2000).

Therefore, a management practice that might reduce potential nitrate leaching would be to delay N fertilizer application until crops can effectively utilize the N. Although this practice has been shown to be effective in reducing nitrate leaching (Andraski et al., 2000; Baker and Johnson, 1981; Owens et al., 2000; Smiciklas and Moore, 1997), post-emergence N fertilizer application involves greater risk for the producer due to possible time delays caused by weather variability during this critical stage of crop development. Thus, a typical N fertilization practice is to apply fall N to minimize the risk of wet soils delaying N application after planting.

The main objectives of this study were to quantify the sources of nitrate entering the surface water of Lake Bloomington and to document N management practices of producers within the watershed. It is hoped that information from this study will help create recommendations for dealing with N fertility management practices within sensitive watershed regions devoted extensively to agricultural row crop production of corn and soybean.

Methods and Materials

Initial Survey of Watershed Residents

An initial questionnaire was administered to all known households, landowners, and operators within the Lake Bloomington watershed (n = 941). The questionnaire characterized the perceptions that watershed residents and landowners held regarding the negative impact that activities within the watershed had upon water quality (Table 1). Perceptions held by individuals actively engaged in farming (AF) were compared with those not actively involved in farming (NF). A 36% response rate resulted in valid data from 334 respondents (AF, n = 105; NF, n = 229).

Annual Fertilizer Nitrogen Survey

A survey to ascertain N management practices of agricultural producers within in the Lake Bloomington watershed was conducted on annual basis. Questionnaires were mailed to all known landowners and tenants who were actively engaged in farming within the watershed each spring from 1993 through 1998. The average response rate over the 6-year period was 35%; approximately 100 surveys were returned out of the 285 that were mailed each year. Respondents provided information regarding corn yield, typical rate (kg/ha) of N fertilizer, and timing of the majority of their N applications during the previous growing season (i.e., fall, pre-plant spring, and after planting via sidedressing). In addition, respondents were asked to indicate if they split their applications of N fertilizer during the previous growing season, and the sources consulted in the determination of fertilizer N rates. From the returned surveys, the mean expected corn yield and N fertilizer application rates were determined. Precipitation information for this region of Central Illinois during these time periods was also recorded so that any anomalies in weather events would be noted (Table 2).

Table 1. Watershed residents and landowner perceptions of activities that have a perceived negative impact upon Lake Bloomington water quality (listed in rank order).

Residents actively engaged in farming (AF)		Residents not actively engaged in farming (NF)	
1.	Faulty septic systems (23.3%)	1.	Agricultural crop production (64.0%)
2.	Naturally occurring (18.9%)	2.	Faulty septic systems (9.5%)
3.	Urban development (18.9%)	3.	Urban development (9.0%)
4.	Agricultural crop production (15.6%)	4.	Naturally occurring (6.0%)
5.	Lawn applications (12.2%)	5.	Lawn applications (3.5%)
6.	Recreational use (4.4%)	6.	Other (3.5%)
7.	Household wastewater (3.3%)	7.	Livestock (2.0%)
8.	Other (2.2%)	8.	Recreational use (1.5%)
9.	Livestock (1.1%)	9.	Household wastewater (1.0%)

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Sources of Nitrate Survey

Within the Lake Bloomington watershed, various sites were monitored for nitrate concentration on a weekly basis beginning in 1993 and ending in 2002. These sample sites were chosen to be representative of various water sources originating in the watershed and draining into the Lake Bloomington. The sampling sites were categorized as follows:

1. Tile that drained native woodland/pasture—an interceptor riser pipe was connected to allow sampling access to the tile water effluent as it exited the pasture.
2. Tiles that drained row crop agricultural fields—tile water effluent was collected as the water exited the tile into surface drainage ditches.
3. Tile that drained an organic production field—an interceptor riser pipe was connected to allow sampling access to the tile water effluent as it exited the organic field.
4. Rainwater—a sample was collected after several significant rainfall events.
5. Surface water runoff—a sample was collected from grass waterways immediately after several significant rainfall events.
6. Creek water—samples were taken in approximately 3-km increments along the Money Creek tributary.
7. Small artesian well—a sample was taken from the surface.
8. Small surface water pond—a sample was taken from the surface.
9. "Urban effect"—creek water was sampled before it entered a small municipality, and after it had flowed through the municipality. This was done to determine if leaking septic systems or urban water use added or contributed nitrate to surface water supplies. A negative number indicates lower nitrate concentration as the water exits the municipality.

All water samples were analyzed for nitrate concentration (in mg/L) by personnel in the city of Bloomington, IL, water quality laboratory, using a commercially available calibrated nitrate probe.

Results and Discussion

Initial Survey of Watershed Residents

For watershed residents, initial perceptions differed greatly between AF and NF regarding the negative impact of various activities upon water quality within the watershed (Table 1). Sixty-four percent of NF perceived agricultural crop production as having the greatest negative impact on water quality compared with only 15.6% of AF. These apparent discrepancies helped to shape future educational programs aimed at increasing problem-recognition and the ability to improve water quality through N fertilizer management.

Annual Fertilizer Nitrogen Survey

During the 6-year period, the mean expected corn yield reported by agricultural producers was 9845 kg/ha. The self-reported median N fertilizer application rate during this time ranged between 169 to 202 kg N/ha, which was within University of Illinois N rate recommendations. Expected yield (75.3%) was the most often cited factor used by producers to determine fertilizer N rates. In addition, producers indicated that they made use of information and/or recommendations from fertilizer dealers (50.7%), soil test-

Table 2. Precipitation events by month for Central Illinois† from 1993 to 1998.‡

	1993		1994		1995		1996		1997		1998	
Month	Prec.§	Dep.	Prec.	Dep.	Prec.	Dep.	Prec.	Dep.	Prec.	Dep.	Prec.	Dep.
January	9.7	5.7	3.4	−0.6	8.1	4.1	4.0	0.0	5.1	1.1	7.2	3.3
February	5.3	1.4	4.0	0.2	1.4	−2.4	2.1	−1.8	11.4	7.5	6.4	2.8
March	8.4	0.6	2.6	−5.2	6.0	−1.8	4.5	−3.4	5.8	−2.0	12.0	4.2
April	12.6	3.0	11.5	2.0	12.4	2.9	7.3	−2.2	5.7	−3.9	11.2	1.7
May	6.2	−3.9	6.1	−4.0	26.5	16.4	19.1	8.9	8.1	−2.0	14.1	4.0
June	17.2	7.5	7.4	−2.3	7.3	−2.4	7.2	−2.5	6.9	−2.8	18.4	8.7
July	22.1	12.0	6.1	−3.9	6.5	−3.5	12.0	1.9	5.7	−4.3	6.2	−3.8
August	15.1	6.4	9.6	0.8	9.4	0.6	3.6	−5.2	16.7	8.0	9.1	0.3
September	19.9	10.4	5.3	−4.3	3.7	−5.8	5.2	−4.3	8.0	−1.5	3.8	−5.8
October	7.3	0.4	6.0	−0.9	9.7	2.7	5.7	−1.2	4.6	−2.3	9.3	2.4
November	7.1	0.1	11.7	4.7	5.7	−1.3	7.0	−0.1	7.1	0.1	4.7	−2.4
December	3.3	−3.5	6.0	−0.8	1.7	−5.1	3.2	−3.6	4.3	−2.5	3.5	−3.3
Annual	134.2	40.1	79.7	−14.3	98.4	4.4	80.9	−13.5	89.4	−4.6	105.9	12.1

† The Central Illinois region includes DeWitt, Logan, Macon, Mason, McLean, Menard, Piatt, Tazewell, and Woodford counties; the Lake Bloomington watershed is located in McLean County, Illinois.

‡ Information supplied by the Illinois Department of Agriculture Agricultural Statistics Annual Summaries from 1994 to 1999.

§ Average amount of precipitation in cm (Prec.) and departures in cm from long-term averages (Dep.)

Table 3. Most popular forms of nitrogen fertilizer used in Lake Bloomington watershed from 1993 to 1998 growing seasons. Some producers may use more than one form of nitrogen, thus the values will not tally to 100%.

Fertilizer nitrogen form	1993	1994	1995	1996	1997	1998	Avg.
				%			
Anhydrous ammonia	62.2	59.2	57.7	56.3	57.3	46.9	56.6
Anhydrous ammonia + N-Serve	41.8	48.0	43.7	48.1	53.7	54.2	48.3
Liquid N (28% N or UAN)	44.9	33.7	38.7	28.9	30.5	34.4	35.2
Liquid N + N-Serve	5.1	4.1	2.1	2.2	2.4	0.0	2.7
Urea	4.1	5.1	3.5	3.7	2.4	2.1	3.5
Ammonium nitrate	2.0	4.1	0.7	5.2	2.4	2.1	2.8
Ammonium phosphate	14.3	14.3	12.0	13.3	22.0	21.9	16.3
Ammonium sulfate	5.1	12.2	8.5	10.4	8.5	13.5	9.7
Manure	11.2	8.2	5.6	12.6	6.1	9.4	8.9
Green manure/organic N	0.0	2.0	2.1	1.5	0.0	1.0	1.1
Other	2.0	1.0	4.3	2.2	3.7	0.0	2.2

Table 4. Timing of nitrogen fertilizer application in Lake Bloomington watershed from 1993 to 1998 growing seasons.

Timing	1993	1994	1995	1996	1997	1998	Avg.
				%			
Spring (before planting)	45.7	36.2	32.6	31.1	29.1	20.0	32.5
After planting (sidedressing)	25.5	9.6	17.4	13.6	2.5	7.8	12.7
Fall	28.7	54.2	50.0	53.3	68.4	72.2	54.5

ing (41.5%), rates from previous years (36.4%), extension recommendations (14.4%), and private consultants (13.2%). The soil testing response is curious; the fertilizer N rate system developed at the University of Illinois did not utilize any soil test values for N. The most popular form of N fertilizer used by producers was anhydrous ammonia (Table 3), either alone or with combination with N-Serve (nitrapyrin; a commercial nitrification inhibitor). Other forms of fertilizer N used included liquid urea ammonium nitrate (UAN or 28% N) and diammonium or monoammonium phosphates (DAP and MAP). One must keep in mind that manure was not a major source of N for this watershed (Table 3), due to the small numbers of livestock within the watershed.

In addition to N rate and form, the timing of N fertilizer application has been shown to have a significant impact on nitrate leaching within the Lake Bloomington watershed (Smiciklas and Moore, 2007). Agricultural producers within the Lake Bloomington watershed who responded to our survey indicated that they applied the majority of their N fertilizer in the fall (Table 4). Specifically, 54.5% of fertilizer N was applied in the fall, 32.5% in the spring before planting, and 12.7% after planting in the spring. Slightly less than one-fourth (23.5%) of respondents reported that they split applications of N fertilizer. The amount of fall precipitation (Table 2) vastly influenced the timing of N application. Wet fall periods typically delayed fertilizer N application until the spring period (Tables 2 and 4). For example, the growing season with the greatest amount of fall-applied N was 1998 (72.2%), with a deficit of 5.8 cm of precipitation during the months of September, October, and November. In addition, the cost of fertilizer N in the fall is usually cheaper than purchasing the same fertilizer in the following spring. For these reasons, producers in the Lake Bloomington watershed prefer to apply the majority of fertilizer N in the fall.

Table 5. Influence of water source upon average nitrate concentration as sampled weekly beginning in 1993 to 2002 within Lake Bloomington watershed.

Surface water source	Avg. nitrate-N conc. ± standard error
	mg/L
Tile water—row crop ag production fields	17.0 ± 1.0
Surface water runoff—ag production fields	6.6 ± 1.4
Tile water—organic agriculture field	11.4 ± 1.8
Small artesian well	1.0 ± 0.2
Rain water	1.2 ± 0.2
Tile water—pasture/wooded field	1.6 ± 0.2
Creek water—the “urban” effect (enters town–leaves town)	–0.6 ± 1.0
Small pond within watershed	1.5 ± 0.2
Creek water—avg. value for Money Creek	12.0 ± 1.0

Sources of Nitrate Survey

To ascertain the sources of nitrate in the Lake Bloomington watershed, several water sources were sampled on a weekly basis for 10 years, starting in 1993, and concluding in 2002 (Table 5). The data gathered demonstrates that row crop and organic agricultural practices within the watershed may be responsible for releasing excessive nitrate into the tile drainage, which subsequently enters the Money Creek tributary and Lake Bloomington. As noted in Table 5, based on comparisons with pasture tile drainage water having an average nitrate concentration of 1.6 mg/L, the tile drainage water taken from row crop production

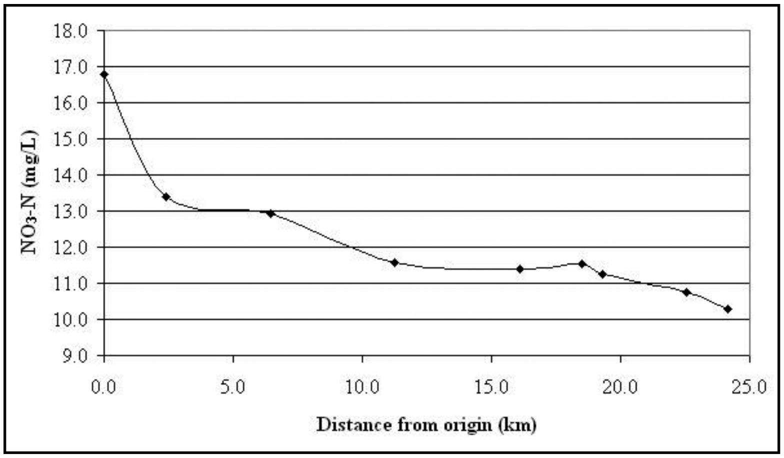

Fig. 1. Average nitrate-N concentrations from 1993 to 2002 of Money Creek water in Lake Bloomington watershed as affected by sampling location. Money Creek empties into Lake Bloomington 25 km from the origin.

fields and organic production had considerably elevated concentrations (17.0 and 11.4 mg/L, respectively). Thus, it appears that a major source of nitrate within the watershed is tile drainage from agricultural production fields.

In addition, the Money Creek tributary was sampled for nitrate concentration on a weekly basis at several sites (Fig. 1). This sampling was done to see the effect of location upon nitrate concentration in Money Creek water. At the origin, the level of nitrate concentration exceeds federal health standard of 10 mg/L (Fig. 1), and the nitrate concentrations decline as Money Creek approaches Lake Bloomington. Possible explanations for this decline would include:

1. In vivo processing of N would decrease the concentration of nitrate in Money Creek as it approaches Lake Bloomington (Ensign et al., 2006).

2. Nonagricultural land usage increases as Money Creek approaches Lake Bloomington, including sites such as woodlots and households (including municipalities and rural subdivisions).

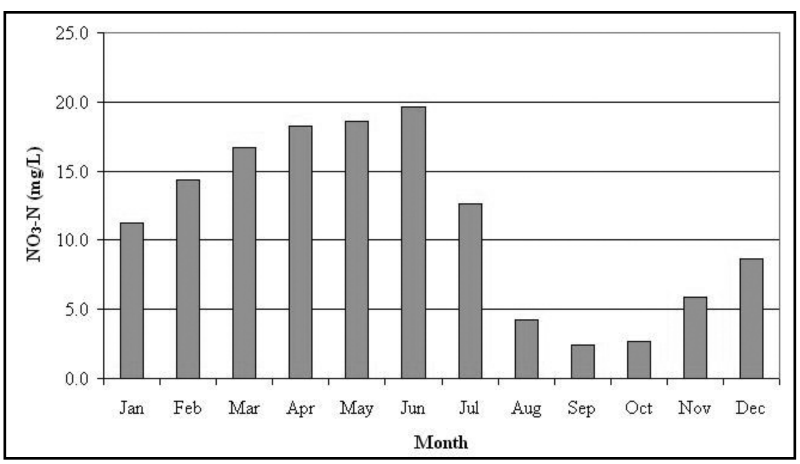

Fig. 2. Average nitrate-N concentrations from 1993 to 2002 of Money Creek water in Lake Bloomington watershed as affected by sampling date.

Our study was not designed to distinguish between these two possibilities, or other possibilities. Instead, we were interested in confirming or debunking the perception of AF residents that "faulty septic systems" was the number one source of nitrate to water entering Lake Bloomington (Table 1). To confirm or debunk the "urban" effect on nitrate concentration in creek water, a small tributary was sampled immediately before and after entering a small municipality (Towanda, IL). This was done to see if the older septic systems of houses within Towanda, IL, would leak nitrate into surface water supplies. The results of 10 years of weekly sampling indicated a higher concentration of nitrate as the tributary enters Towanda, IL, and a lower concentration of nitrate as the tributary exits Towanda, IL (Table 5; –0.6 mg/L). Thus, urban areas and wooded pastures do not contribute the excessive nitrate found in surface waters of Lake Bloomington watershed.

Thus, row crop agriculture of both conventional and organic methods may play a major role in the release of nitrate into Lake Bloomington watershed via tile drainage systems. Producers within the watershed are not over-applying fertilizer N, based on 6 years of survey data (see previous discussion). Data from the survey in regard to the timing of N fertilizer application demonstrated that 54.5% of the producers utilize fall-applied N (Table 4). What is problematic with fall N applications is that untimely weather events have been found to be a major, if not primary determinant influencing nitrate leaching, especially so in the spring before plant emergence (Hubbard et al., 1991; Gentry et al., 2000; Sogbedji et al., 2000). Our sampling data indicated also that the greatest amounts of nitrate leaching into Lake Bloomington occurred between mid-winter (January) to mid-summer (June), before the corn plants could effectively utilize the N fertilizer (Fig. 2). This information indicates that fall and pre-plant spring applications of N fertilizer may be primarily responsible for the elevated nitrate concentration in the tile drainage water. This data does suggest that management strategies can be developed and adopted through cooperative effort, which can better protect the quality of water in Lake Bloomington. Specifically, one management practice that may be effective in reducing the concentrations of nitrate in the surface waters entering Lake Bloomington is to encourage the spring and sidedress applications of N fertilizer. Pre-plant spring applications have been shown to produce similar grain yields and therefore should not be economically burdensome. Susceptibility to unusual spring weather events in this region may also pose problems with pre-plant spring N fertilizer applications. Recent studies have shown computer simulations to be effective in predicting N losses related to weather phenomena (Zhao et al., 2000). Based on the nitrate concentrations reflected in Money Creek, sidedressing of fertilizer N would be least susceptible to nitrate leaching in tile drainage lines, although this practice is not very common within the watershed (Table 4).

In conclusion, average nitrate concentrations for the period 1993 to 2002 revealed that row crop agriculture (both conventional and organic) release nitrate in tile drainage systems that feed Lake Bloomington, IL. The mean expected corn grain yield was 9845 kg/ha and the median N fertilizer application rate was between 169 to 202 kg N/ha for the watershed. On average, 54.5% of the N fertilizer in the watershed was applied in the fall, 32.5% was applied in the spring before planting, and 12.7% was applied after planting. Knowledge from this study can be used to develop recommendations for sound N management practices within sensitive watershed regions such as those surrounding the Lake Bloomington watershed.

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