NITRATE LEACHING IN FLORIDA

URBAN ENVIRONMENTS

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Non-Thesis Research Paper

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Introduction

Numerous counties within the State of Florida have proposed restrictions on the sale and application of fertilizer. Fertilizer nitrogen is a pollutant in Florida's shallow groundwater. Excessive nitrate-N in drinking water can cause low oxygen in infant's bloodstream (blue baby syndrome), spontaneous abortions, and non-Hodgkin's lymphoma. Average groundwater background nitrate concentrations are less than 2 mg/L. Nitrate concentrations above 4 mg/L can affect human activities and the United States Environmental Protection Agency has established 10 mg/L as the maximum contamination level (Nolan, 2001). Excessive nitrate-N in the Florida environment creates "red tide" fish kills and is a component of accelerated euthropication in the landscape when combined with excessive phosphorous applications.

State, county, and local officials are debating what the appropriate restrictions on nitrate-N fertilizers given the above negative consequences of excessive nitrate-N. Some debate has focused on banning fertilizer sales and applications in urban areas during the rainy summer months. The highly urbanized Pinellas and Hillsborough Counties had extensive debates in 2010 over this issue.

This literature review will examine the components of nitrate-N fertilizer debate concentrating on impacts to the urban environment. The review will begin by focusing on nitrate behavior in soils and the susceptibility of Florida soils to nitrate leaching. Then, the review will concentrate on nitrate sources and reactions specifically relating to urban environments. Within the discussion on nitrate-N in urban areas, content will include discussion on theories differentiating urban and non-urban environments and land use. Finally, this literature review will evaluate the need for fertilizer restrictions based on the evidence collected and offer a balanced solution to curb excessive nitrogen in Florida groundwater.

Background- Nitrate Behavior in Soil and Florida Groundwater Vulnerability

Nitrate (NO_3^-) is a mobile ion in most soil profiles given that most soils have negatively charged surfaces. Also, nitrate is soluble in water and can persist in groundwater for decades and, above concentrations of 10mg/L, nitrates are almost impossible to remediate in groundwater (Nolan, 2002). Taken together, nitrate-N has a great potential to leach from the soil surface to the groundwater through the soil profile. The soil nitrogen cycle is multi-faceted and deserves a detailed analysis for each part of the N-cycle. For this literature review, discussion will limited to nitrification and denitrification reactions with nitrogen compounds.

Organic or inorganic nitrogen can transform into different N-compounds upon entry into the soil. One major transformation results in the nitrification of organic-N compounds and ammonium. Nitrification of organic-N compounds involves several steps. Organic-N transformation begins with the mineralization process. The below equation is an example of the mineralization of the organic-N compound urea to ammonia (Eq. 1) and a secondary hydrolysis reaction changing ammonia to ammonium (Eq. 2).

$$\text{(Eq. 1) } NH_2CONH_2 + H_2O = 2NH_3 + CO_2$$
$$\text{(Eq. 2) } NH_3 + H_2O + CO_2 + NH_4^+ + HCO_3^-$$

In aerobic soil conditions, nitrification of ammonium is favorable reaction. The overall reaction is a two step process mediated by nitrifying bacteria that ubiquitous in the soil (Eq. 3) (Nolan, 1997).

(Eq. 3)

First Reaction: $NH_4^+ + ½\ O_2$ + nitrosomonas bacteria = $NO_2^- + 2H^+ + H_2O$

Second Reaction: $NO_2^- + ½\ O_2$ + nitrobacter bacteria = NO_3^-

The significance of the nitrification process relates to the amount of nitrate in the soil. Di and Cameron (2002) in their study of nitrate leaching noted that significant amounts of soil organic N are mineralized and there generally are low concentrations of ammonium ions in the soil. Organic and inorganic (non-nitrate) N-compound transformations into nitrate result in nitrate becoming the dominant ion in aerated soil conditions. This domination leads to more nitrate leaching even if the nitrogen input is not originally nitrate.

Most literature on nitrate leaching discusses the denitrification process as a major mechanism of nitrate removal in the environment. Denitrification is the process where nitrate is transformed into the nitrous gas compounds of nitrous oxide or dinitrogen. Denitrification is biologically mediated under anaerobic soil conditions using organic matter (CH_2O) decomposition by bacteria as the energy source for the reaction. (Nolan, 1997) Common anaerobic bacteria involved in denitrification are *Pseudomonas, Bacillus, Thiobacillus* and other bacterial genera. The simplified denitrification reaction chain in equation 4 shows how nitrate is transformed into the various nitrous gases. Equation 5 is a general reaction.

(Eq. 4) $4NO_3^- + 5CH_2O$ + anaerobic bacteria = $2N_2 + 5HCO_3^- + H^+ + 2H_2O$

Nitrate concentrations in the landscape environment can be mitigated by gaseous nitrogen loss to the atmosphere. Groffman (2009) notes that alteration of nitrogen cycle towards increasing denitrifying conditions can alleviate nitrate leaching but nitrous oxide destroys ozone in the atmosphere so increased nitrous oxide production from denitrification will lead to a decreased ozone layer.

As previously discussed, nitrate is mobile in the soil profile due to the repulsion of a negative ion within negatively charged soil and nitrate leaching into groundwater is common problem. Once in the soil, soil physics and hydrological and greatly influence the soil's vulnerability to leaching and the rate of nitrate infiltration.

Selection of dynamic factor models based on performance coefficients	
Variables	Coeff.
	0.819
WTE, GwFD, Prec.	0.780
WTE, GwFD, Prec, Irr.	0.790
Fert., WTE, GwFD, Prec., Irr.	0.813
WTE, GwFD	0.789
WTE, Prec.	0.793
WTE, Irr., Prec.	0.798
Prec.	0.736
WTE	0.764
GwFD, Prec.	0.736
WTE, GwFD, Irr.	0.769
Irr.	0.742
GwFD	0.746
GwFD, Irr., Prec.	0.743
WTE, Irr.	0.767
GwFD, Irr.	0.763
Fert.	0.740
WTE= Water Table Elevation, GwFD= Ground Flow Direction Prec.= Rainfall, Irr.= Irrigation, Fert.= Fertilizers	

Ritter (2007)

Ritter (2007) examined nitrate leaching and hydrology relating to agriculture production in South Florida. Agriculture land adjacent to potable water supply of the

Everglades and Biscayne National Parks is very vulnerable to nitrate leaching given its high permeability. Based on predictive and actual values, nitrate leaching was most affected by water table elevation, groundwater flow direction (movement of nitrates from source pollution to affecting areas farther away), and precipitation (*see above table)*. His analysis supports an intuitive hydrological notion that high water table require shorter distance to travel to the groundwater and higher precipitation rates will push nitrates down the soil profile more quickly.

Caccia (2005) study of water quality and nitrogen concentration in South Florida's Biscayne Bay support Ritter's evaluation on precipitation's effects on nitrogen leaching. Dissolved inorganic nitrogen concentrations (both nitrate and ammonium) in Biscayne Bay varied greatly between Florida's wet and dry season. Wet season nitrate concentrations (0.103 mg/L) far exceeded dry season concentrations (0.013 mg/L) and ammonium ion concentrations were three fold higher in the wet season.

Summary statistics for all observations for 1994-2003 broken out by season (mg/L)			
Variable	Overall Median	Wet Season Median	Dry Season Median
NO3-	0.007	0.013	0.005
NO2-	0.001	0.002	0.001
NH4+	0.011	0.016	0.009

Caccia (2005)

In conclusion, Florida soils are particularly vulnerable to nitrate leaching. First, nitrates are mobile ions and are prone to leaching especially with Florida's sandy soils. In addition, non-nitrate N sources are still prone to leaching with the nitrification process in aerated soils. Florida's high water table elevation, groundwater flow, and heavy precipitation will increase Florida's vulnerability to nitrate leaching. Given Florida's vulnerability, examination on nitrogen inputs particularly with urban fertilizer sources and non-urban sources must proceed to determine the most prudent means to reduce nitrate leaching.

Urban Ecology Defined

This literature review wants to focus on the urban factors of nitrate leaching but, before discussion, the definition of urban areas. McIntyre (2000) examined the definition of an urban ecosystems or ecology. Initial examinations of previous literature in "urban" environmental studies did not include exact definitions of urban. Most scientific studies have used urban and human dominated landscapes as equal and interchangeable names. Everyone could define New York City as a human dominated ecosystem. This definition loses strength in the following example. An oligiotrophic lake hundreds of miles away from an urban area receives excessive nitrogen and phosphorous from urban wastewaters. Its ecology changes to eutrophic and cattails now dominate solely from the wastewaters received from an urban area. The question now posited is that lake human dominated. McIntyre explains that

"Fundamentally, a landscape defined as urban shows some effects of human influence. Taken literally, this could mean that the most remote sites could be called urban simply because humans have influenced a portion of their area at some point in time…this description of urban is too broad to be very useful, and it confounds the differences between human-dominated and truly urban ecosystems (6)."

Therefore, the definition of urban ecosystems requires further attention and refinement.

McIntyre proposes investigation into this issue on two fronts using the urban definition previously used by ecologists and adding quantitative data used by social scientists to define urban areas. Previous ecologists have used land-use types, urban-natural areas, gradient analysis, monitoring single areas over time, and ecological footprints to determine human domination of landscapes. Social sciences have focused exclusively over human activities for many years and have developed quantitative structures to determine differences between urban and non-urban areas. Social sciences use demography, physical geography, ecological processes, and energy use to determine urban areas. One cited example used by McIntyre was "a political unit...more than 25,000 individuals" (12). McIntyre leaves the discussion with no definition of urban and non-urban areas but with a means for a better definition in the future.

The lack of precise urban and non-urban is also confronted by Bernard Nolan in his analysis of shallow groundwater vulnerability in the Southeastern United States (2000). As seen in McIntyre, land-use types have been a dominant mechanism to determine urban areas. On regional and national scales, vulnerable groundwater systems are difficult to analyze according to Nolan using land-use types. Evaluation of general biogeochemical factors in shallow groundwater is the preferred method. For example, reducing biogeochemical reactions positively affected water quality as organic matter presence and anoxic conditions led to nitrate losses in groundwater. Increased denitrification and the reduction of nitrification (both microbial mediated processes) decreased nitrate leaching. Therefore, nitrate-reducing ecosystems regardless of land-use types are more important to determine nitrate leaching potential.

But yet, Nolan's 2006 analysis of groundwater nitrate leaching vulnerability uses many parameters associated with land-use: farm fertilizer, population density, and cropland/pasture/fallow and others along with biogeochemical factors. This departure alters the above commentary about nitrate analysis based primarily on biogeochemical processes. Therefore, both McIntyre and Nolan do not provide a concise definition of urban areas.

Kaye (2006) postulates that the three potential research areas for urban biogeochemistry are urban engineering, human demographic trends, and household scale actions. The household scale area of future research is a primary interest to establishing nitrate leaching and loading within urban areas. In the absence of current research, this literature review will use a combination of land use types and biogeochemical processes to define urban areas and evaluate nitrate leaching in those urban areas.

Land Use and Urban Areas

Groffman (2004) explains the difficulty in examining nitrogen and urban ecosystems in the following statement. He makes similar statements to the previous statements made by McIntyre and Nolan.

> "The heterogeneity of urban ecosystems, with a mix of roads, buildings, grass, water infrastructure, agriculture, and natural and seminatural ecosystems, has made it difficult to evaluate basic ecosystem functions relevant to production, consumption, decomposition, and nutrient fluxes. The interaction of physical, ecological, and social drivers of urban ecosystems, structure and function has been a particular challenge to analysis of these ecosystems." (394)

Agriculture, water infrastructure, and seminatural ecosystems are mentioned in Groffman's analysis of urban heterogeneity. These areas can directly correspond to studies on nitrates in the particular land-use structures: agriculture, urban water discharge, and forested areas in the urban landscape. Based on his analysis of nitrogen fluxes, agriculture and urban/suburban areas had a higher mean nitrogen yield (6.7 kg N/ha) than forested areas (0.52 kg N/ha). With this data, both agriculture and urban land-uses have high concentrations of nitrogen.

Specifically, Caccia (2005) examined land-use patterns in the Biscayne Bay area in South Florida. All sections received excessive nitrogen inputs into Biscayne Bay from the South Dade agriculture areas (80,000 acres of winter vegetables) and urban waste especially from the Black Point Landfill and Sewage Treatment Plant. Caccia found the highest nitrogen concentrations near the shoreline in the Central and North Bay while the South Bay section consisting of undisturbed mangrove forests had the lowest concentrations of nitrogen in the entire region. In addition, Caccia's study showed total nitrogen in the North Bay (more urbanized) had more nitrates within total nitrogen than the South Bay. The South Bay section had more organic total nitrogen than the North Bay section leading to the implication that the mangrove forests in the South mitigate nitrate concentrations.

Other studies have concluded that agriculture and urban land-use contributed to nitrate leaching. Coulter (2004) studied nitrate concentrations in the Salmon River area of Kentucky also correlated elevated nitrate-N concentrations with agriculture and urban land-use. Wernick (1998) finds similar results in land-use in British Columbia, Canada. Given all of the above results, agriculture and urban land-use patterns had a direct correlation to high nitrate concentrations that result into groundwater leaching.

Nitrate leaching in agriculture and urban areas originates from excessive nitrogen loading from the activities associated with those land-uses. For this, nitrogen sources for agriculture and urban areas are different.

Nitrate inputs in agriculture primarily animal manure and chemical fertilizers. Wernick (1998) notes that European standards for animal stocking density range from 1.7

to 4.5 AU/ha depending on the particular country to combat excessive nitrogen entering the groundwater. Squillage (2002) used data from the National Water-Quality Assessment (NAWQA) Program of the Geological Survey in 1999 to make the correlation that agriculture land use was mostly associated anthropogenic nitrate. For all chemical combinations (400+ total chemicals tested), nitrate tested positive in 8 of the top 25 most frequently detected mixtures. Most nitrate combinations were found associated with pesticide commonly used in agriculture production like simazine.

Top 25 Most Frequently Detected Mixtures					
Compound 1	Compound 2	Compound 3	Compound 4	# sample of 1497	% mixture only
atrazine	demethylatrazine			284	5.6
deethylatrazine	nitrate			214	2.8
atrazine	nitrate			198	3.0
atrazine	demethylatrazine	nitrate		179	14.5
atrazine	simazine			138	4.3
deethylatrazine	simazine			127	0.0
atrazine	demethylatrazine	simazine		120	5.0
nitrate	simazine			111	4.5
atrazine	metachlor			103	0.0
deethylatrazine	metachlor			99	0.0
deethylatrazine	trichloromethane			97	4.1
atrazine	prometon			96	1.0
atrazine	demethylatrazine	metachlor		95	2.1
atrazine	nitrate	simazine		92	1.1
deethylatrazine	nitrate	simazine		92	1.1
deethylatrazine	prometon			90	0.0
atrazine	demethylatrazine	prometon		87	5.7
nitrate	trichloromethane			86	5.8
tetrachloroethene	trichloromethane			86	2.3
atrazine	demethylatrazine	nitrate	simazine	86	14.0
atrazine	trichloromethane			78	1.3
metochlor	nitrate			76	0.0
nitrate	prometon			73	4.1
deethylatrazine	metachlor	nitrate		71	0.0
atrazine	metachlor	nitrate		70	1.4

Squillage (2002)

For urban areas, Squillage asserts that NAWQA data shows a different scenario for anthropogenic nitrate. Urban land-use shows detection of volatile organic compounds

(VOC), pesticides, and many common chemical mixtures, but was not a source of anthropogenic nitrates. Coulter (2004) supports this notion by stating that nitrates were significantly lower in urban areas when compared to agricultural land-use. Interestingly, Coulter notes that ammonium-N was higher in urban land-use postulating that urban waterfowl was the source of nitrogen inputs.

Other studies contradict the assertion that nitrate loading is low in urban areas. Wernick (1998) and Gardner (2004) provide evidence of a strong correlation between increased population density and sewage with increased nitrate leaching. Wakida (2004) finds great vulnerability for nitrate contamination from septic tanks in unplanned and less regulated areas outside of urban areas along with leaking sewers inside urban areas.

As discussed previously, the heterogeneity of urban areas causes difficulties in assessing nitrate concentrations. A concise urban definition may include agricultural areas, septic tanks, and other point sources for nitrates. Urban fertilizer use is one component. The one unanswered question would be the level of impact by nitrogen fertilizer to the total nitrate load from urban sources. General biogeochemical fertilizer reactions are the same whether in urban or non-urban but the one constant from land use studies is that urban areas produce high amounts of nitrates that leach into the groundwater. Even without complete information, urban fertilizer nitrogen loading must be reduced as part of an overall nitrate reduction in urban areas.

Fertilizer Biogeochemistry in Urban Areas and Nitrate Reduction Strategies

Policy concerns with urban nitrate groundwater contamination have been concentrated on the sale and use of fertilizers. Wakida (2004) finds that the main sources of total nitrogen are sewage leaks and discharge, septic tanks, industrial spillages, landfills, fertilizer use in landscaping among many other sources. For this literature review, the fertilizer use in landscape and the biogeochemical reactions will be the sole discussion point henceforth.

Previous small scale research has shown the potential impacts of excessive nitrate leaching for landscaping fertilizer use. Wakida finds research in a rural area where home gardens accounted for 27% of the area's nitrate leaching but also accounted for 3% of the acreage. He notes that the probable cause is the application of soluble nitrogen at higher than recommended rates. Urban areas have a large amount of acreage set aside for landscaping and home gardens. For example, New York City has 1000 community gardens while Berlin, Germany has over 80,000 gardens. Groffman (2009) finds that there are more than 150,000 km^2 of urban grasslands to add to potential residential and commercial landscaping fertilizer applications. Given the high rates of nitrate leaching per area as seen in the above example, landscaping has a great potential to add excessive nitrates to the urban ecosystem.

Kaye (2006) analyzes the spatial dynamics of the urban landscape and how that affects the nitrogen loading of the landscape. Even though patchiness is common to all ecosystems, human interactions have continually divided the land into smaller and smaller parcels down to the single, small homeowner lawn. Within these small mosaic pieces, individual owners have introduced and supported exotic plant species. These exotic plants interrupt any ecological analysis of an urban ecosystem as the local biogeochemistry and productivity are altered including nitrogen cycling. For example, non-native plant species may require more water and nutrient inputs to maintain their aesthetic appeal to the individual owner.

The turfgrass portion of the urban landscape has the ability to capture large amounts of nitrate inputs before the nitrates move beyond the root zone. Turfgrass is grass species grown for the aesthetic appeal of the landscape and not for any agriculture (grazing, etc.) purposes. For turfgrass, Wakida found that golf courses and residential lawns are a source of nitrate leaching. Groffman (2009) adds that

> "Although urban grasslands can be heavily fertilized and can have high N losses, especially if over-fertilized and over-watered, they also have been shown to have considerable potential for N retention. This retention likely arises from the fact that urban landscapes have young, actively growing vegetation and an extended growing season relative to native and agriculture systems" (1845).

In fact, best management practices for agriculture swine farms have recommended the established of annual ryegrass and bermudagrass to reduce nitrates in runoff. In studies cited by Line (1998), nitrates were reduced by 47-100% in swine runoff. Based on both studies, the turfgrass component of urban landscapes does have the potential for large nitrate retention.

The above turfgrass nitrate retention system does not include the plant material only but the urban turfgrass ecosystem cycles and removes nitrates from the environment. Groffman (2009) finds that the urban grasslands have multiple sinks for nitrate retention including the thatch layer and root system along with denitrification. Other smaller variables in the grassland ecosystem were local site conditions and clippings management.

The thatch layer and root system of the turfgrass ecosystem have a great impact on nitrogen retention. Groffman notes that newly sodded turf without mature root structure and thatch layer can lead to a 20-50% increase in nitrate leaching over a mature stand of turfgrass. Nitrate retention is linked to the increase in carbon cycling and microbial immobilization. Groffman's research showed high rates of total soil respiration in mature stands of turfgrass. Total soil respiration is an index to measure soil carbon cycling and nitrogen demand by microbes. Without tree canopies, the temperature of the urban turfgrass ecosystem increases priming the microbes in the ecosystem to immobilize the nitrogen added as fertilizer. In fact, Groffman notes that residential grasslands have more prime productivity than native grasslands surrounding the urban areas. Therefore, the urban grassland system retains nitrates added to the ecosystem. The next unanswered question is that immobilization does not necessarily include nitrate removal from the ecosystem. The urban grasslands ecosystem is still retaining and cycling nitrogen. Research is required to nitrogen fate if mineralization occurs in the ecosystem and nitrate reintroduction is produced.

Groffman notes that denitrification as another component of nitrate retention in the urban grassland system. Unlike roots, thatch, plant uptake, and increased immobilization, denitrification is a part of the nitrogen cycle that removes nitrates from the soil out to the atmosphere. Groffman noted that the N_2O was emitted 10x more in urban turfgrass systems than native grasslands. The most important factor with the increase of denitrification in urban turfgrass was irrigation inputs. Increased water inputs reduced oxygen concentration in the soil profile leading to increased denitrification.

In addition, nitrate leaching from turfgrass fertilizer applications is considered to be highly manageable given proper techniques are involved. Wadika states that

"The leaching of nitrate from fertilizer applied to turfgrass depends highly on soil texture, N source, rate and timing, and irrigation/rainfall. The worst case scenario for nitrate leaching is an application of a soluble N source at a rate higher than the recommended rate, to a sandy site that is overirrigated" (7).

In a previous section Florida soils were determined to be particularly prone to nitrate leaching due to sandy soils and high summer precipitation rates. Even though turfgrass has the potential to retain large amounts of nitrogen inputs, Florida summer conditions (substituting over-irrigation for excessive summer precipitation) are the worst case scenario for nitrogen applications in the urban landscape.

Wadika states in the above citation that over-irrigation is one component of the worst case scenario for nitrate leaching. Other scientists have found an important correlation between nitrate leaching and irrigation practices. Gehl (2005) concurred that leaching potential is influenced by water flux down the soil profile and initial nitrate concentration. Gehl examined corn production in sandy soils and found that irrigation is an important factor. Nitrate leaching was prominent with high nitrate concentrations combined with irrigation moving the contaminants below crop root zones. According to the study's results, over-irrigation by 25% in sandy soils can increase the water flux and, thus, nitrate leaching by a 10x factor. Gehl relates close management of irrigation water as an important key to controlling agriculture nitrate losses to groundwater.

In conclusion, the Groffman (2009) research shows that sufficient irrigation will aid nitrate removal through denitrification and Gehl shows that over-irrigation can increase nitrate leaching in the urban grassland ecosystem. Therefore, water management is a key component in the urban landscape. Pinnelas County, Florida's regulations banning fertilizer use in residential landscapes in the summer months will help curb nitrate leaching given the above research on water regulation in nitrate retention in the urban ecosystem.

Beyond water management, Groffman noted two other factors that affect nitrate leaching: application rate and nitrogen source. Shuman (2000) research nitrate leaching specifically on golf course greens replicates Florida soils well as they are both sandy in texture and have high porosity and, therefore, prone to leaching. Shuman found that

"the efficacy of 'spoon feeding' to prevent nitrate-N leaching from porous media. For higher application rates, the percentage of added N leached from a soluble source was higher (313).

Also, Shuman discusses the recommendation for the use of slow release nitrogen source to lower nitrate leaching. A later research project from Shuman (2003) ranked ureaformaldehyde and isobutylenediurea as preferred nitrogen source for applications in sandy, porous media like Florida residential and commercial properties. Therefore, rate and nitrogen sources are important management practices to reduce nitrate leaching in urban ecosystems.

Conclusion

Numerous counties within the State of Florida have proposed restrictions on the sale and application of fertilizer to limit the amount of nitrates leached in Florida groundwater. The nitrate in fertilizer and within the nitrogen cycle is a pollutant that causes environmental damage through eutrophication and, above 10 ppm, can cause adverse health effects in humans. Florida is particularly vulnerable to nitrate leaching due to its sandy soils, high water table elevation, and high precipitation rates during the summer months.

State, county, and local officials are still debating over the appropriate means to reduce nitrate leaching and summer fertilizer sales and use is one part of that debate. Numerous studies link urban ecosystems to increased nitrate leaching. Recently, Pinellas County has banned all sales and use of fertilizers during the summer months and was not overturned by state officials. Also within the past few years, Broward County has required future fertilizer applicators to be licensed similar to pesticides before applying for a business. One enforcement section of the Broward County regulation is following Florida best management practices limiting fertilizer use during the summer months.

Urban grassland ecosystem grasslands are efficient in nitrate retention. Beyond plant uptake, the primary mechanism for retention is microbial immobilization from carbon cycling. Proper horticultural practices in regards to irrigation rates, low nitrogen rates per multiple applications, and slow release fertilizers reduce nitrate leaching and can remove nitrates through denitrification. Therefore, local and regional government agencies are correct in instituting these regulations intended the limit nitrate leaching. Urban nitrate leaching is a complex problem and these regulations are just to begin the process of lowering nitrate loading into Florida groundwater.

Issues and Concerns

This literature review examined many issues surrounding urban nitrate leaching and fertilizer use without a solid conclusion. The lack of research into this area was stated with numerous papers. The first major difficulty was the lack of development in defining an urban ecosystem. The heterogeneity of urban ecosystems makes this definition difficult as McIntyre suggests. Social sciences may be able to help narrow some parameters in the definition but, ultimately, ecologists must find an accepted, universal definition of urban ecosystems. Without defining urban, further research can be weakened by objections that the testing area is not considered an urban area.

The second major area of concern is the lack of research on how nutrients are cycled in small urban landscapes. Even though urban ecosystems are complex with various soils, plants, and local environments, general statements on nitrogen cycle and other nutrient mechanisms can be formed by extensive research. From there, local adaptations from general statements can be made like the urban nitrogen cycle pertaining to leaching. Currently, more research is needed to fully understand urban nitrate cycling and the relationship with fertilizers.

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