Nitrogen

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Spatial Variability in Inorganic Soil Nitrogen Production in a Mixed-Vegetation Urban Landscape

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Abstract: Urban landscapes are not homogeneous, and small-scale variations in plant community or management inputs can give rise to a large range of environmental conditions. In this paper, we investigated the small-scale variability of soil nitrogen (N) properties in a single urban landscape that has distinctly different patches or types of cover. We specifically measured soil net N mineralization, nitrification, and exchangeable forms of inorganic N for patches with traditional turfgrass versus patches with common turfgrass alternatives such as ornamental grasses, groundcovers, and mulches. All soil N properties were variable among landscape patches, showing that soil N processing can vary on scales of a few meters. Notably, both mineralization and nitrification were the highest in a patch covered with perennial peanut, but exchangeable nitrate (NO_3^-) was low for the same soil, indicating that soils under perennial peanut may be producing high levels of inorganic N but that the produced N does not stay in the soil, possibly leaching to underlying groundwater. We recommend future studies on the mechanisms that drive the variable N properties seen under distinct urban landscape patches, with special emphasis on potential patterns in N losses for mixed-vegetation landscapes.

Keywords: nitrogen mineralization; nitrification; turfgrass; residential landscapes; landscape patches; urban soils; perennial peanut; urban landscapes

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1. Introduction

A well-managed, aesthetically pleasing landscape is associated with wellbeing in many residential landscapes, and the area of turfgrass in the United States is larger than that for any irrigated crop [1]. For many urban homeowners in the United States, turfgrass is the predominant lawn cover. To maintain a healthy, attractive turfgrass cover, regular fertilization, irrigation, and pest control management plan is often established [2]. Besides the associated economic implications, the fate and potential loss of nutrients (nitrogen and phosphorus) from fertilized turfgrass have important implications for aquatic ecosystems since nutrients mobilized by leaching and/or runoff may impair receiving waterbodies through eutrophication and algal proliferation [3–5].

While numerous studies have indicated that nutrient losses via leaching and runoff are minimal from healthy, properly maintained turfgrass and that turfgrass lawns are sinks of nitrogen (N) in urban watersheds [6–8], turfgrass fertilizers are increasingly targeted by management practices and policies aimed at reducing anthropogenic nutrient inputs to aquatic ecosystems [9]. For example, in Florida, more than 50 counties and municipalities have enacted fertilizer ordinances that often prohibit any application of N- and phosphorus (P)-bearing fertilizers to urban lawns during Florida's summer rainy season (June to September) each year [10,11]. The premise behind these bans is that summer rains may lead to increased leaching and runoff losses of N and P applied as fertilizer to lawns, in turn leading to increased anthropogenic nutrient loading to nearby waterbodies. To date, the efficacy of the fertilizer ban ordinances has not been demonstrated, and they remain controversial strategies for urban nutrient management [12,13].

To address urban nutrient management needs, we need not only more studies on the mechanisms and extent of nutrient mobilization from urban landscapes but also a better understanding of soil nutrient dynamics in these landscapes [14,15]. Nutrients associated with soil organic matter pools have been identified as one source of N and P that may be mobilized from urban lawns to stormwater runoff [5,16,17]. We also need research focused on a wider variety of potential urban landscape covers, such as mulches or ornamental plants other than turfgrass. Only a few studies have investigated differences in soil nutrient cycling between turfgrass monoculture lawns and lawns with a mix of species. In one such study, Erickson et al. [8] compared N leaching and runoff from a St. Augustine turfgrass monoculture versus a mixed-species lawn in Florida. For both lawn types, N losses via surface runoff were minimal, but leaching losses were substantial, especially for the mixed-species lawns, which lost up to 48.3 kg N ha^{-1} via leaching. By comparison, the turfgrass lawns in the study lost 4.1 kg N ha^{-1} via leaching, indicating that the turfgrass was more effective than mixed-species vegetation for preventing N leaching from lawns. In another study, Amador et al. [18], studied pore water nitrate (NO_3^-) concentrations at 60 cm soil depth under turfgrass versus various landscape covers, including flowers, shrubs, and unplanted mulched beds. In their study, flowers, managed turfgrass, and ornamental deciduous and evergreen trees represented a lower risk of NO_3^- loss from the soil than unplanted mulched areas, which the authors recommended should be used sparingly in urban landscapes because of the potential for NO_3^- leaching to groundwater. Amador et al. [18] suggested that these unplanted mulched areas were more susceptible to NO_3^- leaching because there was no plant sink for N produced by mineralization of soil organic N. That study also noted that unplanted mulched landscape beds lost via leaching nearly twice the NO_3^- input to the landscape through atmospheric deposition, making the unplanted mulched areas net sources of NO_3^- to the underlying groundwater.

The sparse studies on soil N dynamics in mixed-species urban landscapes are in line with the framework for urban soil ecology presented by Byrne [19], in which the heterogeneity commonly found in urban landscapes gives rise to a specific "habitat structure," or a unique composition of physical matter with consequent unique effects on local ecological variables. Variation in habitat structure gives rise to differences in soil pH, moisture content, microbial populations, temperature, and vegetation cover, which in turn may all cause variations in the N cycling processes within an urban landscape [15,20–22]. This means that distinct patches may emerge, creating a landscape mosaic where ecological variables can vary at scales of just a few meters or less. In this study, we selected a mixed-species urban landscape with this type of small-scale patchiness in vegetative cover and investigated the spatial variability of inorganic N production in soils. We hypothesized that differences in landscape cover at a spatial scale of meters would result in varying levels of soil inorganic N production, as measured by nitrification and net N mineralization rates. We tested this hypothesis by evaluating N cycling processes in soils under traditional turfgrass and several common ornamental alternatives to turfgrass.

This work is important because it helps constrain and fill knowledge gaps related to N cycling processes in urban soils by focusing on small-scale differences that are common in urban landscapes. While previous studies mentioned above [8,18] have focused solely on N leaching from mixed-vegetation landscapes, this work adds the body of knowledge by focusing on N cycling processes, namely mineralization, and nitrification. Typically, urban lawns and other green spaces are broadly categorized as "lawn" or "turfgrass," when in reality, they are seldom turfgrass monocultures but instead a mosaic of various vegetative types and ground covers. As we grapple with water quality degradation associated with excess nutrients from urban landscapes, research models may be used to predict the transformations and movement of N in urban soils—and accounting for the expected mosaic of variable N processing in urban soils can lead to improvements in those modeling efforts. For example, in Florida, the Nitrogen Source Inventory and Loading Tool (NSILT) is a model used to predict the fate of fertilizer N applied to urban landscapes. The model is based on the best available data on N inputs and N transformations in urban soils but is informed only by data on N cycling in turfgrass soils, without consideration for other land cover types (e.g., flower beds or mulched areas) [23]. In this work, we show how N cycling processes in a single urban landscape can be highly variable, and we argue that efforts to constrain the fate of urban nutrient sources can be improved by greater attention to mixed-vegetation landscape scenarios as well as data at finer spatial scales.

2. Materials and Methods

2.1. Study Site

The research was carried out at the University of Florida's Gulf Coast Research and Education Center (UF-GCREC) in Hillsborough County, Florida (27°45′39.2″ N 82°13′47.4″ W), which is part of the Tampa metropolitan area. The research center was constructed in 2005 on abandoned citrus farmland. Its main building was surrounded by a variety of ornamental vegetation cover that is typical of urban residential and commercial land uses in the Tampa, Florida area, including turfgrass, landscape trees, and flowering shrubs in mulched beds. The annual average precipitation of the site was 1325 mm, and the annual temperature ranged from 11–32 °C. The soils at the research center were mostly sandy spodosols of the Zolfo series (sandy, siliceous, hyperthermic oxyaquic Alorthods) [24].

2.2. Selection of Landscape Patches and Soil Sampling

We selected 6 distinct urban landscape patches surrounding UF-GCREC and 1 remnant agricultural (Agr) patch for soil sampling and analysis of inorganic N production (Table 1). The non-agricultural patches were turfgrass (TfGr) and potential turfgrass alternatives common for residential landscapes in Florida, which included 1 patch of perennial peanut (PP), a low-growing alternative ground cover; 2 patches with ornamental grasses and shrubs (OMx and OGa); and 2 patches consisting mostly of mulch with little or no other vegetation (MulP and MulC). Table 1 describes the vegetation and other characteristic features of each landscape patch.

Table 1. Description of landscape patches.

Landscape Patch	Image	Description and Management Practice
TfGr		• Bermuda turfgrass (*Cynodon dactylon*) • Rainfall supplemented with sprinkler irrigation to achieve at least 0.5 inches of water per week • Mowed to maintain a height of about 3–4 inches
PP		• Leguminous perennial peanut (*Arachis pintoi*) • Rainfall not supplemented with irrigation
OMx		• Beds of mixed ornamental vegetation, including spider plant (*Chlorophytum comosum*), white ginger plant (*Hedychium coronarium*), giant spider lily (*Crinum asiaticum*), and creeping lantana (*Lantana montevidensis*) • Rainfall supplemented with sprinkler irrigation to achieve at least 0.5 inches of water per week
OGa		• Beds of ornamental gamma grass (*Tripsacum dactyloides*) • Rainfall supplemented with sprinkler irrigation to achieve at least 0.5 inches of water per week

Table 1. *Cont.*

Landscape Patch	Image	Description and Management Practice
MulP		• Mulched with pine needles; no vegetation • Rainfall not supplemented with irrigation
MulC		• Mulched with pine bark nuggets; no vegetation • Rainfall not supplemented with irrigation
Agr		• Fallow agricultural pasture used 6 months earlier for strawberry production • Selected to provide a contrast comparison of N between residential landscapes and a remnant agricultural field

Soil sampling took place on each landscape patch in September 2018. We used a hand auger to take 5 cm-diameter cores from 4 random locations within each patch to a depth of approximately 52 cm. All 4 cores for each patch were then each divided into 3 subsamples by depth (0–15 cm, 15–30 cm, and 30–52 cm) to provide 4 field replicates for each depth per landscape patch. Subsamples of the soils were then air dried and sieved through a standard #10 (2 mm) sieve and analyzed for soil pH, total soil N, and total soil C. Soil pH was measured with a soil:water 1:2 (w/v) slurry. Total soil N and C were measured on a Thermo Flash 1112 A NC Soil Analyzer in the University of Florida Wetland Biogeochemistry Laboratory. Field moist sieved soils were used to analyze for soil gravimetric water content, percent organic matter, and exchangeable inorganic N. Percent organic matter was determined via the loss on ignition method. Exchangeable inorganic N (NOx and NH_4^+) was determined by extracting 10 g soil with 50 mL 2 M KCl for 1 h and analyzing for NO_3^- and NH_4^+ via a continuous segmented flow analyzer (AA3, SEAL Inc., Mequon, WI, USA) by EPA methods 353.2 and 350.1, respectively.

2.3. Inorganic Soil Nitrogen Production

We defined inorganic N production as the rates of production of NH_4-N (mineralization) and NO_3-N (nitrification). Mineralization is the microbial process whereby organic N is converted to mineral N, while nitrification is the process whereby ammonium N is converted to NO_3^-N by aerobic bacteria. Both soil net mineralization and nitrification rates were determined after methods described by Raciti et al. [15]. Briefly, 10 g field moist soil was incubated in Erlenmeyer flasks for 14 days with a 12:12 light/dark cycle and at lab ambient temperature (approximately 22 °C). Flasks were loosely covered with parafilm, and DI water (<2 mL) was periodically added to the soils as needed to maintain field capacity moisture conditions during the incubation. At the conclusion of the incubation period, soils were extracted with 50 mL 2 M KCl and analyzed for NO_3^- and NH_4^+ as above. A separate set of flasks and soils was likewise analyzed but without incubation and taken as the time zero, or initial, measurements. At the conclusion of the incubation period, net mineralization was calculated as the accumulation of total inorganic N (NH_4^+ + NO_3^-) and nitrification was calculated as the accumulation of NO_3^-. Results were expressed in mg N kg soil^{-1} day^{-1}, after using the initial gravimetric soil water content to base calculations on the equivalent dry mass of soil in each flask. Results were examined for each landscape patch by depth as well as on a whole-core basis [15].

2.4. Statistical Analysis

Descriptive statistics to relate mean, median, and standard errors for rates of inorganic N production were developed for each landscape patch with JMP v.15 software (SAS

Institute, Inc., Cary, NC, USA). Regression analysis was used to examine possible linear relationships between mineralization and nitrification rates for each landscape patch, also with JMP v.15 software.

3. Results and Discussion

3.1. Inorganic Soil Nitrogen Production

For all landscape patches, median whole core net mineralization and nitrification were highest in the Agr soils, with median rates of 1.1 mg and 0.7 mg N kg/d, respectively (Figure 1; Table S2, Supplementary Materials). Whole core net mineralization and nitrification were next highest in the PP soils (median 0.8 and 0.5 mg N kg/d, respectively). The relatively high inorganic N production rate results for the PP patch could be related to the ability of perennial peanut to fix atmospheric N in the soil in the presence of rhizobia bacteria [25]. In the process of N fixation, atmospheric dinitrogen is cleaved and enzymatically catalyzed to produce two molecules of ammonia, leading to subsidies of NH_4^+ to the soil. When soil NH_4^+ levels are initially low, net mineralization is slow because inorganic N is preferentially incorporated into microbial biomass [26]. On the other hand, increasing levels of soil NH_4^+ have been shown to increase N mineralization rates in soils [26]. In this way, it is likely that N fixation by the perennial peanut led to high initial levels of soil NH_4^+, which in turn promoted the high N mineralization rates seen in the PP soil. We are aware of no studies on the fate of fixed N when perennial peanut is used as a turfgrass alternative in urban landscapes. However, as discussed below, exchangeable NO_3^- was lower in the PP soils than all other landscape patches, indicating that even though the PP soils had high levels of NO_3^- production (nitrification), they were not maintaining high NO_3^- levels. Potential fates of the produced NO_3^- to explain its loss in the PP soils include denitrification, plant uptake, and leaching. The well-oxygenated and low organic matter conditions of our sandy soils make denitrification unlikely, since denitrification requires oxygen-limited environments and an organic carbon source [27]. We recommend future studies to investigate whether the inorganic N produced in soils under perennial peanut is readily lost via leaching, especially in sandy soils where NO_3^- mobility would be high. While perennial peanut offers water-saving advantages over traditional turfgrass [28], it may come with the tradeoff of greater inorganic N leaching potential, though this has not been studied yet for urban soils.

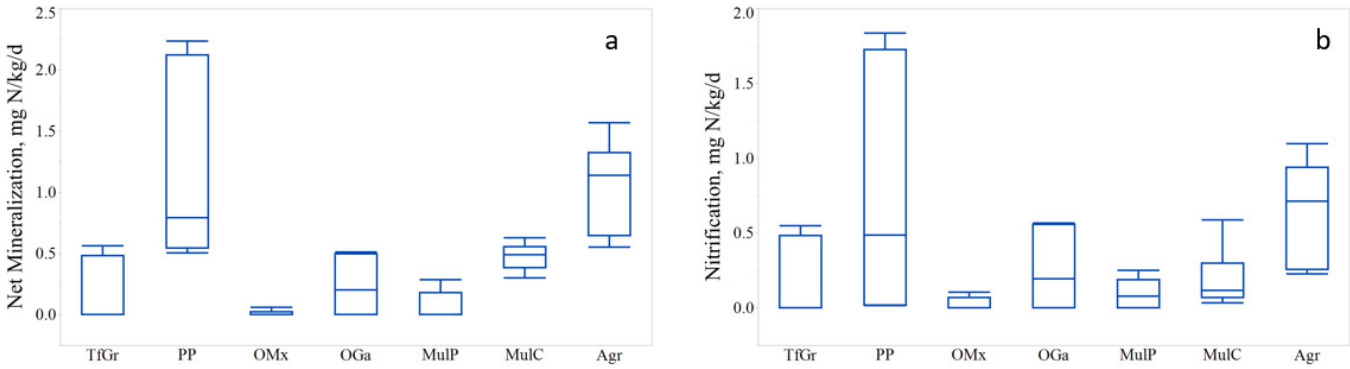

Figure 1. Net N mineralization (**a**) and nitrification (**b**) rates in landscape patches. Values based on whole-core basis. Agr; remnant agricultural field, TfGr; turfgrass, PP; perennial peanut, OMx; patches with a mixture of ornamental grasses, OGa; patch with gamma grass, MulP; patch with pine needle mulch, MulC; patch with pine bark nuggets.

After Agr and PP, the TfGr soils had the third highest median rates of net N mineralization and nitrification (Figure 1; Table S2). There were likely fertilizer subsidies of inorganic N in both the Agr and TfGr patches. As with the PP soils, relatively high initial levels of inorganic N for Agr and TfGr probably led to higher inorganic N production rates during the soil incubations when compared to non-perennial peanut turfgrass alternatives (OMx, Oga, MulP, and MulC patches) [26]. For all landscape patches except the mulched areas (MulP and MulC), regression analysis revealed a significant linear relationship between nitrification and net mineralization on a whole-core basis (Figure 2). This is not surprising since nitrifying bacteria need ammonia as an energy source thus that nitrification generally increases with increasing ammonia levels in soils [27]. Identifying the underlying mechanism responsible for the lack of this relationship under the mulched landscape areas was beyond the scope of this paper, but factors that may inhibit nitrification include soil C:N ratios above ~22, acid soil pH conditions, and low oxygen availability [15]. We observed that the MulP landscape patch had the highest C:N among all landscape types (~22–23, Table S1), possibly indicating suppressed nitrification and a relatively less active N cycling microbial community in the MulP soils.

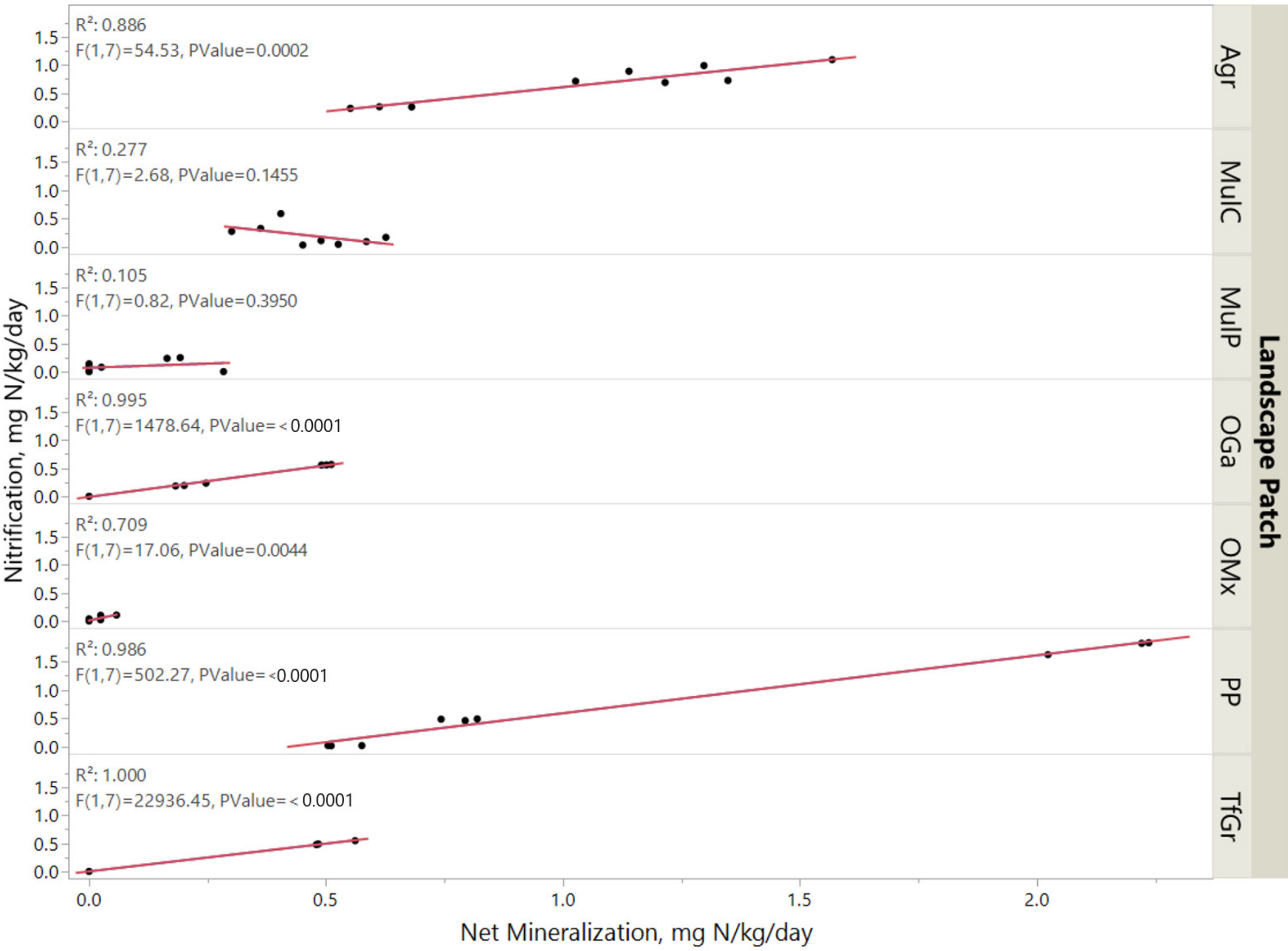

Figure 2. Regressions of nitrification against net N mineralization in the landscape patches, on a whole-core basis. Agr; remnant agricultural field, TfGr; turfgrass, PP; perennial peanut, OMx; patch with a mixture of ornamental grasses, OGa; patch with gamma grass, MulP; patch with pine needle mulch, MulC; patch with pine bark nuggets.

3.2. *Exchangeable Inorganic Soil Nitrogen*

Among the non-agricultural soils (all patches except Agr), the PP soils contained the highest median KCl-exchangeable NH_4^+ (1.4 mg/kg) but the lowest KCl-exchangeable NO_3^- (0.4 mg/kg) on a whole-core basis (Figure 3). As discussed above, this relatively low exchangeable NO_3^- pool for the PP soils indicates that N losses via leaching may be taking place. While the use of perennial peanut for urban landscapes has not been studied in terms of its potential for increased N leaching, several studies have looked at this for agricultural settings where perennial peanut is used for forage crops or as a cover crop.

Woodard et al. [29] observed that a forage system with perennial peanut leached more N than a comparable one with bermudagrass. In that study, the authors concluded that perennial peanut might pose threats to groundwater quality under agricultural systems because of its apparent role in subsidizing high NO_3^- levels in the soil.

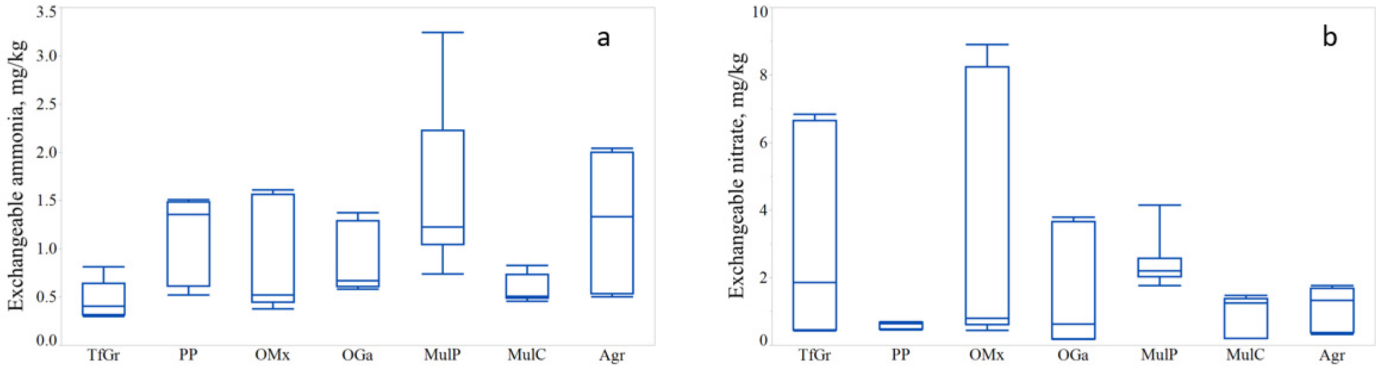

Figure 3. Exchangeable soil ammonium (**a**) and nitrate (**b**) in the landscape patches. Values are on a whole-core basis. Agr; remnant agricultural field, TfGr; turfgrass, PP; perennial peanut, OMx; patch with a mixture of ornamental grasses, OGa; patch with gamma grass, MulP; patches with pine needle mulch, MulC; patch with pine bark nuggets.

The mulched landscape patches (MulP and MulC), for which vegetation was absent, contained higher mean pools of exchangeable NH_4^+ and NO_3^- than the turfgrass and ornamental patches, though there was considerable spread in the data (Figure 3). It is likely that the mulched landscapes had higher mean exchangeable inorganic N due to the lack of a plant sink to remove inorganic N from the soils [18]. It is also likely that the mulches contained their own pools of N, which leached from the mulch and added to soil N pools [30]. In a study of several urban landscape alternatives, Loper et al. [30] observed that organic soil amendments such as composts could increase inorganic N leaching when compared to soils without amendments. In that study, the authors recommended that landowners did not apply nutrients to mulched areas and that landscape managers recognize that different patches of the same landscape may have different management needs.

In general, exchangeable NH_4^+ was highest in the surface 0–15 cm for all soils, while NO_3^- was generally higher with soil depth, perhaps indicating a tendency for NO_3^- to move downward in the soil profiles that are predominantly sand (Figure 4). At the 30–52 cm soil depth, exchangeable NO_3^- was higher in 4 out of 6 non-agricultural soils than it was in the Agr soil, indicating that the urban landscape patches may pose a greater threat of NO_3^- leaching than the agricultural soil (Figure 4). Turfgrass N fertilization has been found to contribute to the leaching of NO_3^- in Florida's sandy soils. For example, Shaddox and Surtain [31] found that applied N in Bermuda grass turf leached between 8% and 12% on a 10% slope. Notably, the NO_3^- concentrations in the 30–52 cm depth for the mixed ornamental (OMx) and the gamma grass patch (OGa) were in sharp contrast to each other, with much more NO_3^- at depth for the mixed ornamental patch than for the gamma grass patch. Gamma grass is one of the most deeply rooted ornamental grasses, with root depth up to 1.8 m [32], and its deep rooting may be contributing to N uptake deep in the soil profile.

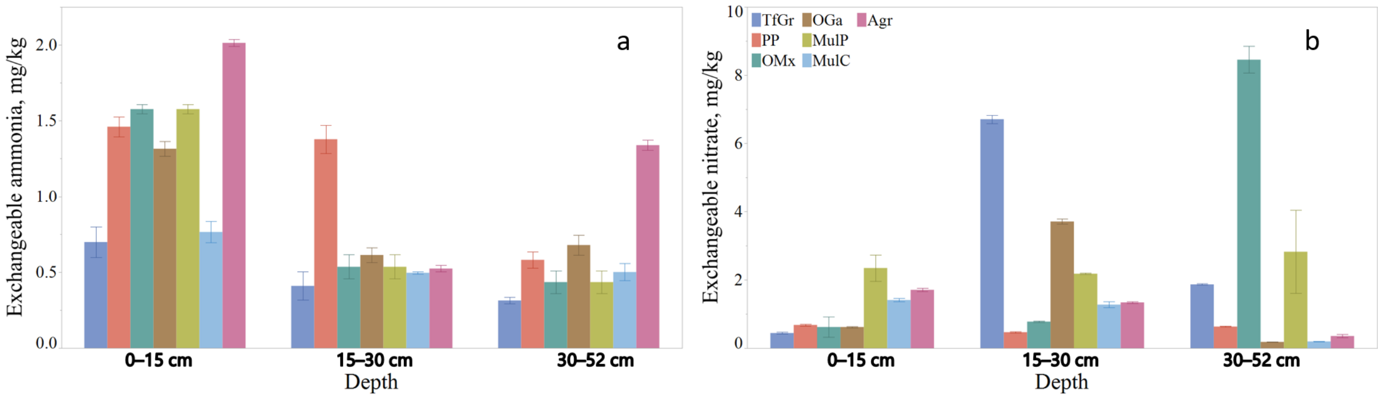

Figure 4. Exchangeable soil ammonium (**a**) and nitrate (**b**) in each landscape patch by soil depth. Agr; remnant agricultural field, TfGr; turfgrass, PP; perennial peanut, OMx; patch with a mixture of ornamental grasses, OGa; patches with gamma grass, MulP; patch with pine needle mulch, MulC; patch with pine bark nuggets.

4. Management Implications and Future Research Needs

It is beyond the scope of this paper to make recommendations about which landscape patch is preferable from a N availability or groundwater protection standpoint, as our main intent was to only investigate fine-scale variability in N production in a mixed-vegetation urban landscape. However, some key takeaways are manifest in our results. The first of these is that inorganic N availability and production were, in fact, highly variable among landscape patches at scales of a few meters, in support of our hypothesis. This finding supports the habitat structure framework of urban soil ecology presented by Bryne [19], who argued that the high spatial heterogeneity of human activities in urban landscapes leads to a large range of soil properties at often small scales. The presence of soil amendments such as mulches or plants such as perennial peanuts that can subsidize soil N pools is just two ways that humans influence urban soil properties. We have shown here that inorganic N production is variable in a single urban landscape and have presented some discussion as to why this may be the case for our specific landscape patch types. At a minimum, we argue that urban landscapes should not be broadly managed but that landscape managers should recognize that the nutrient needs of patches within a single landscape may be different and that the nutrient fates in soil under those patches may also be different. This has important implications for how urban soil properties are included in models that aim to predict nutrient transport from urban landscapes. Very likely, we need spatially finer-scale investigations of nutrient fate and transport in urban landscapes, especially those with mixed vegetation or heterogeneous human influences. Too often, urban landscapes are assumed to be covered with turfgrass only, and other possible land covers need to be more fully considered by those who aim to quantify the effects of urbanization on the environment.

A second key takeaway of this work is the implication related to potential N losses by leaching from certain landscape patches. The high nitrification potential of perennial peanut seen here suggests that this turfgrass alternative may produce NO_3^- that can be readily leached from sandy soils. However, our sample size was small, and similar work should be conducted in the future to expand the temporal and spatial scope of this work. In particular, we recommend studying N leaching under perennial peanut when it is used as an urban groundcover. We also recommend future work to better understand the mechanisms that drive the differences in potential N losses we observed among landscape patches. Some of the potential drivers include irrigation status, soil pH, moisture content, organic matter content, and variations in the soil microbial community. Finally, because urban landscapes are tied to human activities, we recognize that sociocultural variables may drive differences in soil properties as well [33,34]. These sociocultural variables may include the choice of plants that are used in ornamental beds. For example, we observed that the two ornamental patches had very different levels of inorganic N at the greatest soil depth, likely due to greater uptake of N at depth by the deeply rooted gamma grass. This human choice as to which plants to include in a landscape may therefore impact N losses by leaching through the soil profile.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/nitrogen3010009/s1, Table S1, Basic soil physical/chemical properties for landscape patches used in this study; Table S2, Raw data showing nitrification, mineralization, and exchangeable inorganic N for all landscape patches and soil depths.

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References

1. Milesi, C.; Running, S.W.; Elvidge, C.D.; Dietz, J.B.; Tuttle, B.T.; Nemani, R.R. Mapping and modeling the biogeochemical cycling of turf grasses in the United States. *Environ. Manag.* **2005**, *36*, 426–438. [CrossRef] [PubMed]
2. Stier, J.C.; Horgan, B.P.; Bonos, S.A. *Turfgrass: Biology, Use, and Management*; American Society of Agronomy Madison: Wisconsin, DC, USA, 2013.
3. Shuman, L. Phosphorus and nitrate nitrogen in runoff following fertilizer application to turfgrass. *J. Environ. Qual.* **2002**, *31*, 1710–1715. [CrossRef] [PubMed]
4. Bell, G.E.; Moss, J.Q.; Nett, M.; Carroll, M.; Horgan, B.; Martin Petrovic, A. (Eds.) Management practices that reduce runoff transport of nutrients and pesticides from turfgrass. In *The Fate of Nutrients and Pesticides in the Urban Environment*; ACS Symp Series; ACS Publications: Washington, DC, USA, 2008.
5. Krimsky, L.S.; Lusk, M.G.; Abeels, H.; Seals, L. Sources and concentrations of nutrients in surface runoff from waterfront homes with different landscape practices. *Sci. Total Environ.* **2021**, *750*, 142320. [CrossRef] [PubMed]
6. Easton, Z.M.; Petrovic, A.M. Determining nitrogen loading rates based on land use in an urban watershed. *Fate Nutr. Pestic. Urban Environ.* **2008**, *997*, 19–42.
7. Lusk, M.G.; Toor, G.S.; Inglett, P.W. Characterization of dissolved organic nitrogen in leachate from a newly established and fertilized turfgrass. *Water Res.* **2018**, *131*, 52–61. [CrossRef]
8. Erickson, J.; Cisar, J.; Volin, J.; Snyder, G. Comparing nitrogen runoff and leaching between newly established St. Augustinegrass turf and an alternative residential landscape. *Crop Sci.* **2001**, *41*, 1889–1895. [CrossRef]
9. Yang, Y.-Y.; Lusk, M.G. Nutrients in Urban Stormwater Runoff: Current State of the Science and Potential Mitigation Options. *Curr. Pollut. Rep.* **2018**, *4*, 112–127. [CrossRef]
10. Hartman, R. The Spread of Fertilizer Ordinances in Florida. *Sea Grant Law Policy J.* **2008**, *1*, 98.
11. Dukes, M.D.; Krimsky, L.; Lusk, M.G.; Trenholm, L.; Unruh, B.; Atkinson, M.; Mylavarapu, R. Urban Fertilizer Ordinances in the Context of Environmental Horticulture and Water Quality Extension Programs: Frequently Asked Questions. *EDIS* **2020**, *2020*. [CrossRef]
12. Hochmuth, G.; Nell, T.; Sartain, J.; Unruh, J.B.; Martinez, C.; Trenholm, L.; Cisar, J. Urban Water Quality and Fertilizer Ordinances: Avoiding Unintended Consequences: A Review of the Scientific Literature. *EDIS* **2009**, *2009*. [CrossRef]
13. Ryan, C.D.; Unruh, J.B.; Kenworthy, K.E.; Lamm, A.J.; Erickson, J.E.; Trenholm, L.E. Culture, Science, and Activism in Florida Lawn and Landscape Fertilizer Policy. *HortTechnology* **2019**, *29*, 854–865. [CrossRef]
14. Raciti, S.M.; Groffman, P.M.; Fahey, T.J. Nitrogen Retention in Urban Lawns and Forests. *Ecol. Appl.* **2008**, *18*, 1615–1626. [CrossRef] [PubMed]
15. Raciti, S.M.; Groffman, P.M.; Jenkins, J.C.; Pouyat, R.V.; Fahey, T.J.; Pickett, S.T.; Cadenasso, M.L. Nitrate production and availability in residential soils. *Ecol. Appl.* **2011**, *21*, 2357–2366. [CrossRef] [PubMed]
16. Yang, Y.-Y.; Toor, G.S. Sources and mechanisms of nitrate and orthophosphate transport in urban stormwater runoff from residential catchments. *Water Res.* **2017**, *112*, 176–184. [CrossRef]

17. Jani, J.; Yang, Y.-Y.; Lusk, M.G.; Toor, G.S. Composition of nitrogen in urban residential stormwater runoff: Concentrations, loads, and source characterization of nitrate and organic nitrogen. *PLoS ONE* **2020**, *15*, e0229715. [CrossRef]
18. Amador, J.A.; Hull, R.J.; Patenaude, E.L.; Bushoven, J.T.; Görres, J.H. Potential nitrate leaching under common landscaping plants. *Water Air Soil Pollut.* **2007**, *185*, 323–333. [CrossRef]
19. Byrne, L.B. Habitat structure: A fundamental concept and framework for urban soil ecology. *Urban Ecosyst.* **2007**, *10*, 255–274. [CrossRef]
20. Hope, D.; Zhu, W.; Gries, C.; Oleson, J.; Kaye, J.; Grimm, N.B.; Baker, L.A. Spatial variation in soil inorganic nitrogen across an arid urban ecosystem. *Urban Ecosyst.* **2005**, *8*, 251–273. [CrossRef]
21. Kaye, J.P.; McCulley, R.; Burke, I. Carbon fluxes, nitrogen cycling, and soil microbial communities in adjacent urban, native and agricultural ecosystems. *Glob. Chang. Biol.* **2005**, *11*, 575–587. [CrossRef]
22. Scharenbroch, B.C.; Lloyd, J.E.; Johnson-Maynard, J.L. Distinguishing urban soils with physical, chemical, and biological properties. *Pedobiologia* **2005**, *49*, 283–296. [CrossRef]
23. Katz, B.G.; Eller, K. The Nitrogen Source Inventory and Loading Tool (NSILT) and restoration of water-quality impaired springs. *Fla. Sci.* **2016**, *79*, 299–310.
24. Web Soil Survey. Natural Resources Conservation Service, US Department of Agriculture. Available online: https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm (accessed on 1 November 2018).
25. Miavitiz, E. (Ed.) Rhizomal perennial peanut in the urban landscape. In Proceedings of the Florida State Horticultural Society, Marco Island, FL, USA, 2–4 June 2002; Volume 115, pp. 136–138.
26. White, J.; Reddy, K. Influence of selected inorganic electron acceptors on organic nitrogen mineralization in Everglades soils. *Soil Sci. Soc. Am. J.* **2001**, *65*, 941–948. [CrossRef]
27. Reddy, K.R.; DeLaune, R.D. *Biogeochemistry of Wetlands: Science and Applications*; CRC Press: Boca Raton, FL, USA, 2008.
28. Rouse, R.E.; Miavitz, E.M.; Roka, F.M. Guide to using rhizomal perennial peanut in the urban landscape. *EDIS* **2004**, *2004*. [CrossRef]
29. Woodard, K.R.; French, E.C.; Sweat, L.A.; Graetz, D.A.; Sollenberger, L.E.; Macoon, B.; Portier, K.M.; Rymph, S.J.; Wade, B.L.; Prine, G.M. Nitrogen removal and nitrate leaching for two perennial, sod-based forage systems receiving dairy effluent. *J. Environ. Qual.* **2003**, *32*, 996–1007. [CrossRef]
30. Loper, S.J.; Shober, A.L.; Wiese, C.; Denny, G.C.; Stanley, C.D. Nutrient leaching during establishment of simulated residential landscapes. *J. Environ. Qual.* **2013**, *42*, 260–270. [CrossRef]
31. Shaddox, T.; Sartain, J. (Eds.) *Fate of Nitrogen During Grow-In of a Golf Course Fairway under Different Nitrogen Management Practices*; Soil and Crop Science Society of Florida: Tallahassee, FL, USA, 2001.
32. Brown, R.N.; Percivalle, C.; Narkiewicz, S.; DeCuollo, S. Relative rooting depths of native grasses and amenity grasses with potential for use on roadsides in New England. *Hortscience* **2010**, *45*, 393–400. [CrossRef]
33. Grimm, N.B.; Grove, J.G.; Pickett, S.T.; Redman, C.L. Integrated approaches to long-term studies of urban ecological systems: Urban ecological systems present multiple challenges to ecologists—Pervasive human impact and extreme heterogeneity of cities, and the need to integrate social and ecological approaches, concepts, and theory. *BioScience* **2000**, *50*, 571–584.
34. Law, N.; Band, L.; Grove, M. Nitrogen input from residential lawn care practices in suburban watersheds in Baltimore County, MD. *J. Environ. Plan. Manag.* **2004**, *47*, 737–755. [CrossRef]