URBAN LAWN NITROGEN DYNAMICS

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Abstract. The largest single crop in the United States happens to be turf grass; it covers 1.9% of the land area. Many lawn owners add fertilizers and pesticides to their yards in order to maintain appearance, which causes concern since nitrogen (N) laden fertilizers may be polluting our watersheds as nitrates (NO3-) or emitting nitrous oxide (N2O, a greenhouse gas) into the atmosphere. Lawns may actually provide ecological benefits and previous research suggests that they have a great ability to retain N; but we do not know exactly why they retain N. Which is why we asked if location (front yard vs. back) or age of neighborhoods controls variability in lawn nitrogen environmental performance. We also asked, what regulates nitrification (a process that produces NO3-) and N2O production, and why is there so much carbon (C) at depth in the soil profile? We expected higher amounts of nitrates and N2O in front yard lawns due to higher amounts of nitrogen fertilizer application. In lawns that have higher nitrification rates, we expected to see low amounts of roots. Also, we anticipated higher C amounts with high amounts of roots at depth. In order to test our hypotheses we collected soil samples to 1meter depth from residential lawns in three neighborhoods in Baltimore, MD. We quantified root biomass and soil carbon and NO3- levels and measured N2O production and potential net mineralization and nitrification rates. We found no significant differences in nitrification, N2O, or NO3- between front and back yards or in different neighborhoods. Nitrification was low everywhere, with no correlations between nitrification or NO3- and other variables. There was also no correlation between roots and carbon at depth, but there was a significant positive correlation between soil wetness and N2O. These results suggest that the high N retention observed in previous studies is widely distributed in the Baltimore area, likely due to active growth and N uptake by lawn grasses. Further research is needed to confirm the mechanisms behind this retention. The source of carbon at depth also remains uncertain, as roots do not appear to be the source of C at depth; leaching of dissolved organic carbon (DOC) from the surface might be important. The relationship between soil wetness and N2O suggests that overwatering might increase the flux of this greenhouse gas.

INTRODUCTION

Globally, humans are increasingly migrating to urban and suburban areas, thereby driving the rapid change to a service economy (Nilon et al. 2003) and modifying more open land for societal use (Kaye et al. 2005). Given the United States Census Bureau definition of “urban” as an area with a density of 1,600 people/km^2, urban land in America alone increased by 47% from 1982-1997 with only a population increase of 17% (Fulton et al. 2004). Even more startling are the statistics for the Delmarva area of U.S. East Coast. Current trends of urbanization indicate the Chesapeake Bay area of the U.S. will increase in urbanized land area by 80% by 2030 (Goetz et al. 2004).

Much of what is left of open land in urban areas is decorative rather than functional; that is, green spaces attached to houses rather than arable land for agriculture. Lawns, an important component of urban and suburban areas, cover 1.9% of the United States; they cover 10% of the state of Maryland (Milesi et al. 2005). Land owners often fertilize highly (Law et al. 2004), leading to concerns about the movement of fertilizers from lawns into receiving waters and the increasing instances of eutrophication (Cold et al. 1990; Boesch et al. 2001). In the Chesapeake Bay watershed, nitrate (NO_3), a by-product of fertilizer use is the prime cause of eutrophication (Nolan et al. 1997; Kemp et al. 2005). Nitrous oxide (N_2O), a crucial greenhouse gas that has a global warming potential 300 times greater than CO_2 (IPCC 2007), may be released due to lawn fertilizer use. Given the concentrated amount of lawn area and the commonplace use of nitrous fertilizers, we must consider how exactly lawns play into the nitrogen cycle.

The U.S. National Science foundation funded long-term ecological research (LTER) project; the Baltimore Ecosystem Study LTER (BES) has conducted extensive recent research on N-cycling in urban lawns. While other studies, especially those on irrigated areas of the western U.S., have found that fertilized lawns emit high amounts of nitrous oxide (N_2O) (Kaye et al. 2004; Bijoor et al. 2008; Hall et al. 2008; Townsend-Small et al. 2011), studies in BES have found that N_20 fluxes are much lower than the western studies, that N retention was surprisingly high, and that NO_3 leaching was surprisingly low (but still significant) in lawns relative to forests (Raciti et al. 2008, 201 la; Groffman 2009). With these limited studies, scientists have identified the need to determine the factors controlling the variation in lawn environmental performance between different studies and regions.

We hypothesized that variation in the environmental performance of lawns is related to several factors centering on the significant variation in human management of lawns (Law et at. 2004; Osmond et al. 2004) and that this variation is related to multiple socio-economic and local neighborhood factors (Zhou et al. 2009). A visually obvious source of variation is the difference between more highly managed front lawns, which may serve aesthetic purposes in a neighborhood context (Cook et al. 2011), and much more variably managed backyards. Natural factors such as soil type that control the growth and movement of roots and the accumulation of organic matter are also likely important controllers of lawn N dynamics (Petrovic 1990; Easton et al. 2007). Raciti et al. (2011b) observed surprisingly high levels of organic C and N, deep (to 1m) in the profile of lawn soils and suggested that accumulation of organic matter may play a role in the high N retention (Raciti et al. 2008), low nitrification (Raciti et al. 2011a), N_2O flux, and $N0_3$ leaching (Groffman et al 2009). However, the factors underlying the high organic matter levels and the role that this plays in regulating N losses are not clear. Researchers should have particular interest in the factors regulating nitrification, which is the key process regulating both hydrologic and gaseous losses from ecosystems (Aber et al. 1989; Galloway et al. 2003).

In this study we addressed several of the uncertainties that have emerged from recent research on N dynamics in lawns. We made measurements of soil NO_3, root biomass, rates of potential net N mineralization and nitrification, N_2O flux, and soil organic matter (SOM) levels in samples from the front and back yards of residential homes. The locations of the homes were in three different neighborhoods in the Baltimore metropolitan area. Our objectives were to determine whether: (1) N cycling differs between front and backyard lawns, (2) nitrification is regulated by root biomass and/or soil organic matter content, and (3) high root biomass explains high carbon (C) at depth in the soil profile. We anticipated higher amounts of NO_3 and N_2O in front yard lawns due to higher amounts of nitrogen fertilizer application. In lawns that have higher nitrification rates, we expected to see low amounts or roots and/or soil organic matter. Finally, we projected higher C amounts with high amounts of roots at depth.

METHODS AND MATERIALS

The BES research is focused on the Gwynns Falls watershed (76°30', 39°15' and ~170 km^2) which spans a rural to urban gradient in the Baltimore metropolitan area. Subwatersheds within the Gwynns Falls vary in land-use from agriculture to industry to residential. Forests and agricultural areas are dominant in the headwaters, but a higher density of residents and industries predominate downstream (Shields et al. 2008). A fraction of the watershed is natural forest dominated by tulip poplar (*Liriodendron tulipifera*); oaks, primarily chestnut (*Quercus prinus*), scarlet (*Quercus coccinea*) and white (*Quercus alba*) in the uplands; red maple (*Acer rubrum*); green ash (*Fraxinus pennsylvanica*); American elm (*Ulmus americana*); river birch (*Betula nigra*); and sycamore (*Platanus occidentalis*) in the lowlands (Brush et al.

1980). Urban lawns consist primarily Kentucky bluegrass (*Poa pratensis*), tall fescue (*Festuca arundinacea spp*.), fine fescue (*Festuca spp*.), and white clover (*Trifolium repens*.)

The Baltimore metropolitan area lies on two physiographic areas, the Piedmont and the Atlantic Coastal Plain. BES research is focused on Piedmont Plateau, in the northwest portion of the watershed. Igneous and metamorphic rocks are beneath the plateau, which cause variation in soil fertility (Froelich et al. 1980). High fertility soils (e.g., Legore series) are found over mafic rocks and weathered minerals from amphilbolite, diabase, or other basic igneous rocks (NRCS 1998). These high fertility soils have higher pH, better water retention capacity, and higher N availability (Groffman et al. 2006). Atmospheric N deposition in the Baltimore area is estimated 1.1 g N m^{-2} y^{-1} (Groffman et al. 2004).

We sampled in three watersheds within the Baltimore metropolitan area that provided a contrast in soil type and density. Glyndon (81 ha) and Dead Run 5 (192 ha) are subwatersheds of the Gwynns Falls dominated by small (0.1 ha) residential parcels with an average housing age of 25 years (Grove et. al. 2004). Soils in the Glyndon watershed are dominated by the low fertility Manor and Glenelg series while Dead Run 5 is characterized by the higher fertility Legore series soils. Cranberry Branch is an 850 ha watershed located in exurban Carroll County, MD. Housing age in this watershed is similar to Glyndon and Dead Run, but parcels are larger (0.4 ha). Soils in Cranberry Branch are dominated by the low fertility Glenelg series.

Residential parcels (five per watershed) were selected for sampling by walking through neighborhoods and requesting permission from homeowners who were home. Within each parcel, front and back yard sampling locations were randomly chosen from areas not within close proximity to underground power lines and pipes. Intact cores (1 m depth by 3.3cm diameter) were taken with an AMS sampler. Cores were enclosed in plastic sleeves with end caps and stored at 4^{o}C until processing (within 1 week). Cores were sliced in half so that soil profile characteristics would be visible and undisturbed, allowing for assessment of horizon depths and evidence of profile disturbance.

Soil cores were cut into 4 sections--0-10cm, 10-30cm, 30-70cm, and 70-100cm--and then hand sifted for 10 min to remove roots and rocks larger than 2mm. Roots were dried at 105°C then weighed. Soil moisture was determined by drying at 105°C , and soil organic matter content was determined by loss on ignition (450˚C for four hours). Bulk density was calculated by dividing the volume of each core section by the rock-free dry weight of the soil in each core section. Inorganic N (NH_4^+ and NO_3^-) was extracted using 2 M KCL and analyzed colormetrically using a flow injection analyzer.

Subsamples of homogenized soil were set aside to determine rates of N_2O production, potential net N mineralization, nitrification, and microbial respiration. 10g of homogenized soil were placed into 1L mason jars and sealed with lids with septa that allow for gas sampling. Jars were placed into boxes and stored in room temperature. After 10 days, gas samples were removed from the jars and transferred to evacuated glass vials via needle and syringe. Concentrations of N_2O and CO_2 were determined by electron capture and thermal conductivity gas chromatography respectively. Mason jars were then opened and inorganic N was extracted and analyzed as described above. Potential net N mineralization was calculated as the accumulation of inorganic N over the 10-day incubation. Potential net nitrification was calculated as the accumulation of NO_3^- over the 10-day incubation. Microbial respiration was calculated from the accumulation of CO_2 over the 10-day incubation.

Three-way analysis of variance (ANOVA) was used to evaluate the effects of lawn location (front and backyard), watershed (Cranberry, Glyndon, and Dead Run 5), and depth on the key response variables (bulk density, soil organic matter (SOM) content, extractable NO_3^-, potential net N mineralization and nitrification rates, microbial respiration, N_2O production, and root mass) (SAS 1988, release 6.03, SAS

Institute Cary, North Carolina). Regression analysis was used to test for relationships amongst measured variables.

RESULTS

Nearly all variables showed significant declines with depth (Table 1, Figures 1, 2 and 3) Bulk density (BD) and N_2O production were exceptions however, as these variables were not statistically different among the four depth intervals. Nitrate, root mass, potential net nitrification and potential net mineralization rates declined more sharply with depth than SOM.

Location (front versus back yard) had no effect on any variable. Bulk density, SOM, root mass, potential N mineralization and nitrification, NO_3^- pool size, microbial respiration and N_2O production were all quite similar in front and back yards (Table 2, Figure 2).

Watershed did not have a statistically significant effect ($p<0.05$) on lawn performance. Bulk density, SOM, root mass, potential N mineralization and nitrification, NO_3^- pool size, microbial respiration and N_2O production were all quite similar in the Glyndon, Dead Run 5 and Cranberry Branch watersheds (Table 3, Figure 3).

There were no significant relationships between nitrification (Figure 4) or N_2O (Figure 5) and SOM or root biomass. A significant correlation ($p=0.0013$) was found between N_2O production and soil moisture (Figure 6).

DISCUSSION

Surprisingly, front and backyards showed little differences across all watersheds. We expected front yards to yield higher nitrate levels, nitrification rates, and N_2O production due to the aesthetic role of front lawns, i.e. we expected inherent, or imposed (e.g., by a homeowner association) desires to have a neat, green front lawn to lead homeowners to apply higher rates of fertilizer to front years (Cook et al. 2012). We also expected backyards to have higher bulk density than front yards due to the recreational role of backyards, i.e. these areas get more foot and/or vehicle and/or pet traffic that might lead to soil compaction. But front yards may also be compacted due to parking, playing, and walking on the lawn.

The lack of differences in N cycling variables between front and back yards could be because our ideas about fertilizer differences between yards were wrong or because biological factors such as grass or microbial N uptake overcome differences in fertilizer input. Understanding the factors controlling fertilizer input is an active topic of research in BES and elsewhere (Law et al. 2004; Osmond et al. 2004; Cook et al. 2012). While we did not collect detailed data on long-term fertilization practices at our sites, we saw evidence for high biological N cycling in our sites. SOM was relatively high in all sites at 10cm (7%) compared to previous studies in the Baltimore area, e.g., 5.5% in Groffman and Pouyat (2009). Nitrification rates were relatively low in our sites relative to the Baltimore sites studied by Raciti et al. (2011), while our forest soils had similar net nitrification rates. These results suggest that even if front yards are more heavily fertilized than backyards, nitrate levels and N_2O production might not be elevated.

We expected differences between the Glyndon, Cranberry Branch and Dead Run 5 watersheds due to differences in soil type. Groffman et al. (2006) found that differences in the two main soil types in the Baltimore area affect forest soil nitrogen dynamics. Therefore, we expected lawns developed on the more nutrient rich soils that underlie the Dead Run 5 watershed to have higher rates of nitrification and N_2O production than lawns developed on the more nutrient poor soils in the Glyndon and Cranberry Branch watersheds. However, while the difference in soil type causes significant differences in soil N cycling in forests, these differences are not expressed in lawns. The vegetation change from forest to lawn clearly overwhelms the natural soil controls. The other watershed effect we expected to observe was between the large lots in Cranberry Branch and the smaller lots in Glyndon and Dead Run. Law et al. (2004) suggests that people manage small lots more intensively than large lots. But we see no evidence for that in these data.

Not surprisingly, most variables declined with depth, consistent with other lawn studies in Baltimore (Raciti et al. 2011). More surprising was the lack of relationship between roots and other variables. We hypothesized that high levels of organic matter at depth reported by Raciti et al. (2011) were driven by high root biomass. But root biomass declined very sharply with depth, much more sharply than SOM, so there does not appear to be a direct link between the two. High SOM at depth may be coming from leaching of dissolved organic carbon from the surface that gets adsorbed on soil particles at depth. Interestingly, much of the carbon at depth appears to be labile as microbial respiration declined with depth much less sharply than many other variables.

We also expected to find relationships between roots and nitrogen cycling, with negative correlations between roots and nitrification, nitrate and N_2O production. Mechanistically, root biomass could serve as an index of plant uptake capacity or of the supply of carbon to support microbial immobilization. However, we did not observe a relationship between roots and nitrogen cycling, likely because the rates of nitrification and N_2O production in our sites were quite low. Possibly the N cycle is so tightly controlled by plants and microbes in these lawns that it is not possible to see relationships between roots and specific processes.

We observed positive relationships between N_2O and soil moisture. N_2O is produced by denitrification and nitrification, both of which are stimulated by soil moisture, especially denitrification, which is an anaerobic process. These results suggest that naturally wet and/or irrigated lawns might produce substantial amounts of N_2O.

CONCLUSIONS

Our results suggest that there is a marked uniformity in nitrogen cycling in home lawns across the Baltimore metropolitan region. We observed similar rates of multiple processes in front and back years, across a wide range of soil and housing density conditions. These results should be extremely useful for assessments of nitrogen dynamics in urban ecosystems and landscapes in Baltimore and other metropolitan areas.

The results support previous research in the Baltimore area and elsewhere that suggests that lawns have surprisingly conservative nitrogen cycling. It is important to note that our study did not include any obviously over-fertilized or compacted sites that might function as hotspots of nitrogen export to water and air. Still our sites were representative of the vast majority of lawns in the region and our results suggest that these ecosystems have significant potential for nitrogen cycling and retention. Further work to elucidate the specific mechanisms of this retention, and to develop management practices to sustain and improve it, is clearly warranted.

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APPENDIX

TABLE 1. Soil profile analysis of 15 front and back yard lawns at four depths. Values are mean ± standard error of 15 front and 15 back yard samples taken in three different watersheds/neighborhoods, n=30. There were no statistically significant ($p < 0.05$) differences for any variable.

	0-10cm	**10-30cm**	**30-70cm**	**70-100cm**
Bulk density (g/cm^3)	0.79±0.03	1.26±0.12	1.25±0.02	0.79±0.04
Soil organic matter[1] (%)	7.0±0.0	5.0±0.01	4.0±0.01	3.0±0.00
NO_3^- (mg N/kg)	9.39±1.06	2.61±0.30	0.83±0.14	0.73±0.33
Potential net N mineralization (mg N/kg/d)	4.63±1.39	1.34±0.45	1.25±0.87	3.45±2.22
Potential net nitrification (mg N/kg/d)	0.31±0.04	0.09±0.02	0.03±0.02	0.03±0.03
Microbial Respiration (mg C/kg/d)	10.17±0.85	4.54±0.37	4.43±0.38	4.69±0.50
N_2O production (ng N/g/d)	1.79±0.04	1.74±0.05	1.81±0.02	1.78±0.05
Root mass (mg/kg)	49.79±11.43	3.03±1.13	1.01±0.50	0.29±0.08

[1] Differences in soil organic matter between 10 – 30 and 70 – 100 cm depths significant only at $p < 0.10$.

TABLE 2. Bulk density, soil organic matter, extractable NO_3^-, potential net M mineralization, potential net nitrification, microbial respiration, N_2O flux, and root mass in 15 front and back yard lawns. Values are mean ± standard error of 15 front and 15 back yard samples combined over four depths, n=60. There were no statistically significant ($p < 0.05$) differences for any variable.

	Back	**Front**
Bulk density(g/cm^3)	1.05 ±0.07	0.99 ±0.03
Soil organic matter (%)	0.04 ±0.00	0.05 ±0.01
Extractable NO_3^- (mg N/kg)	3.61 ±0.71	3.17 ±0.51
Potential net N mineralization (mg N/kg/d)	3.00 ±1.18	2.33 ±0.76
Potential net nitrification (mg N/kg/d)	0.09 ±0.02	0.14 ±0.03
Microbial respiration (mg C/kg/d)	5.77 ±0.49	6.14 ±0.52
N_2O production (ng N/g/d)	1.77 ±0.04	1.78 ±0.02
Root mass (mg/kg)	14.65 ±5.79	12.41 ±3.72

TABLE 3. Bulk density, soil organic matter, extractable NO_3^-, potential net M mineralization, potential net nitrification, microbial respiration, N_2O flux, and root mass in three different watersheds/neighborhoods. Values are mean ± standard error of 5 residential parcels in each neighborhood sampled in both the front and back yards, combined over four depths, n=40. There were no statistically significant ($p < 0.05$) differences for any variable.

	Cranberry Branch	**Dead Run 5**	**Glyndon**
Bulk density (g/cm^3)	1.02 ±0.04	0.95 ±0.04	1.10 ±0.10
Soil organic matter (%)	0.05 ±0.00	0.05 ±0.00	0.04 ±0.01
Extractable NO_3^- (mg N/kg)	3.58 ±0.90	2.97 ±0.50	3.62 ±0.81
Potential net N mineralization (mg N/kg/d)	2.22 ±0.88	1.51 ±0.49	4.27 ±1.84
Potential net nitrification (mg N/kg/d)	0.08 ±0.02	0.11 ±0.02	0.16 ±0.04
Microbial respiration (mg C/kg/d)	6.40 ±0.66	5.83 ±0.67	5.65 ±0.53
N_2O production (ng N/g/d)	1.80 ±0.01	1.78 ±0.05	1.75 ±0.04
Root mass (mg/kg)	14.40 ±5.04	19.73 ±8.70	6.46 ±2.03

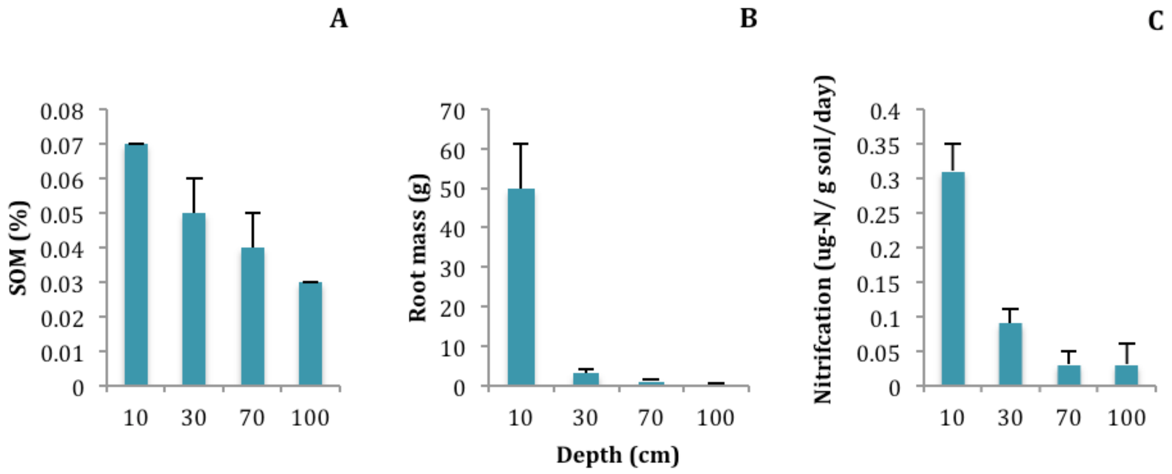

FIGURE 1. (A) Soil organic matter (SOM), (B) root mass, and (C) nitrification rate at 4 depth intervals (0-10cm, 10-30, 30-70 and 70-100). Values are mean ± standard error of 15 front year and 15 back year samples taken in three different watersheds, n=30. (See Table 3 for statistical analysis.)

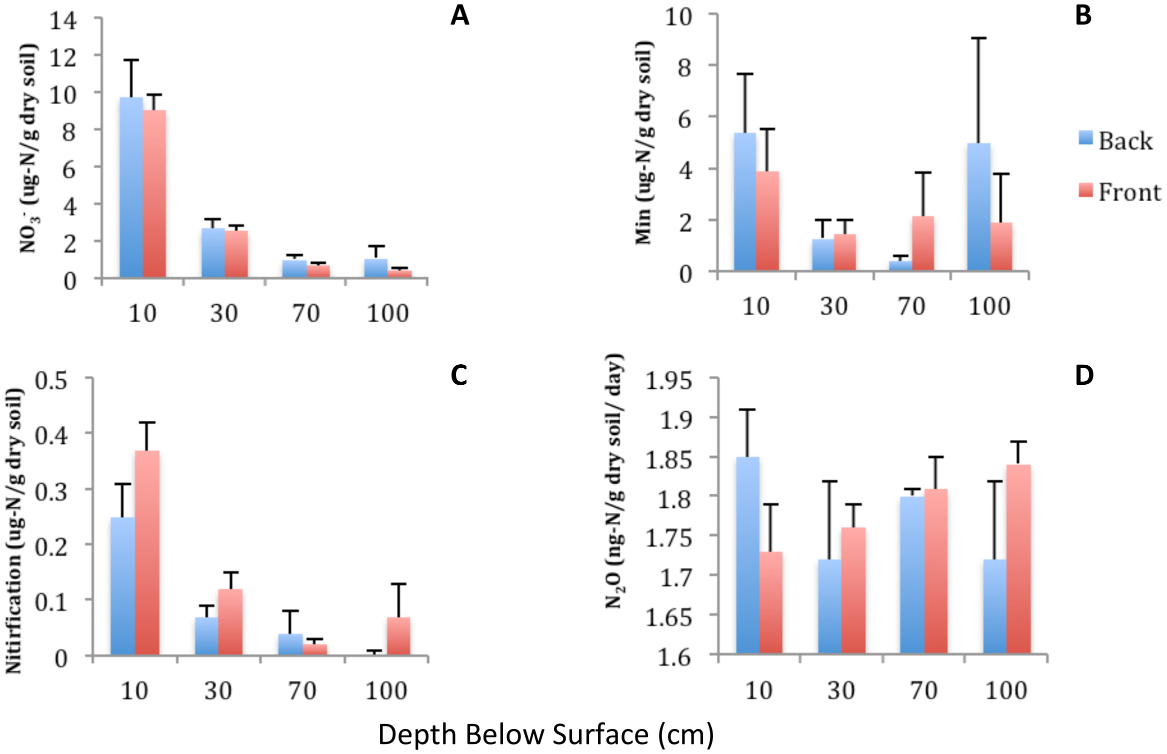

FIGURE 2. Extractable nitrate (A), potential net N mineralization (B), potential net nitrification (C) and N_2O production (D) in front and back yard samples at four depths. Values are mean ± standard error of 15 front and 15 back yard samples taken in three different neighborhoods, n=15. There were no significant differences between front and back yard samples at any depth for any variables.

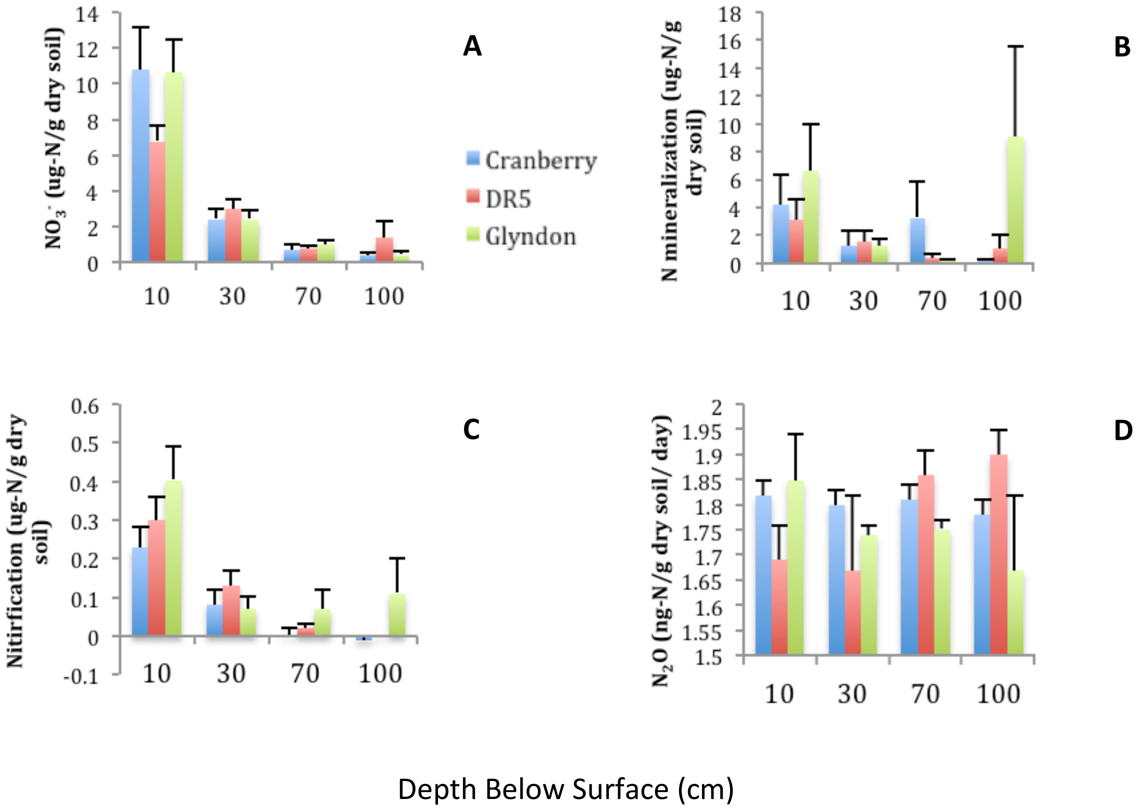

FIGURE 3. Extractable nitrate (A), potential net N mineralization (B), potential net nitrification (C) and N_2O production (D) in three different watersheds/ neighborhoods at four depths. Values are mean ± standard error of 5 front and 5 back yard samples taken in each neighborhoods, n=10. There were no significant differences between watersheds/neighborhoods at any depth for any variables.

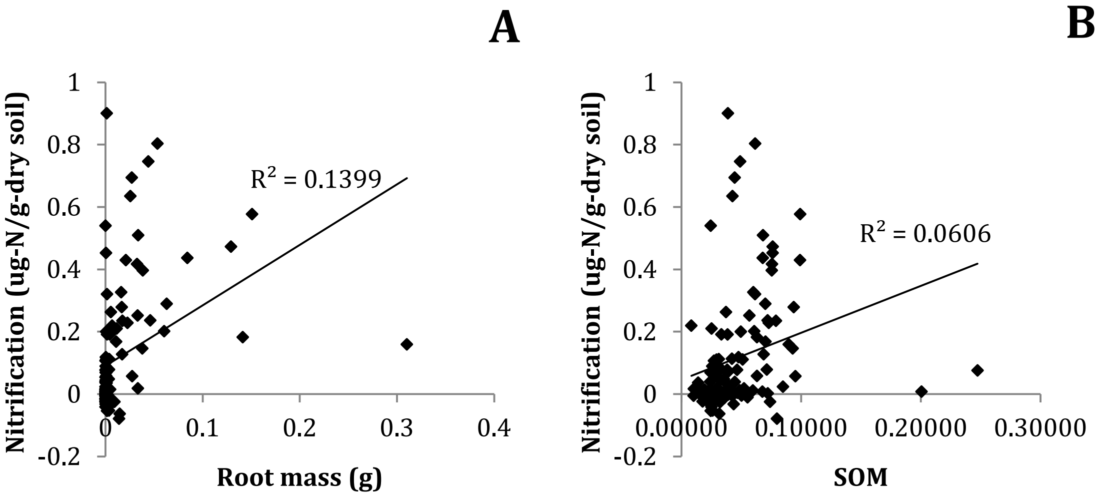

FIGURE 4. Potential net nitrification versus root mass (A) and soil organic matter (SOM, B) at 0 – 10 cm depth, n = 30.

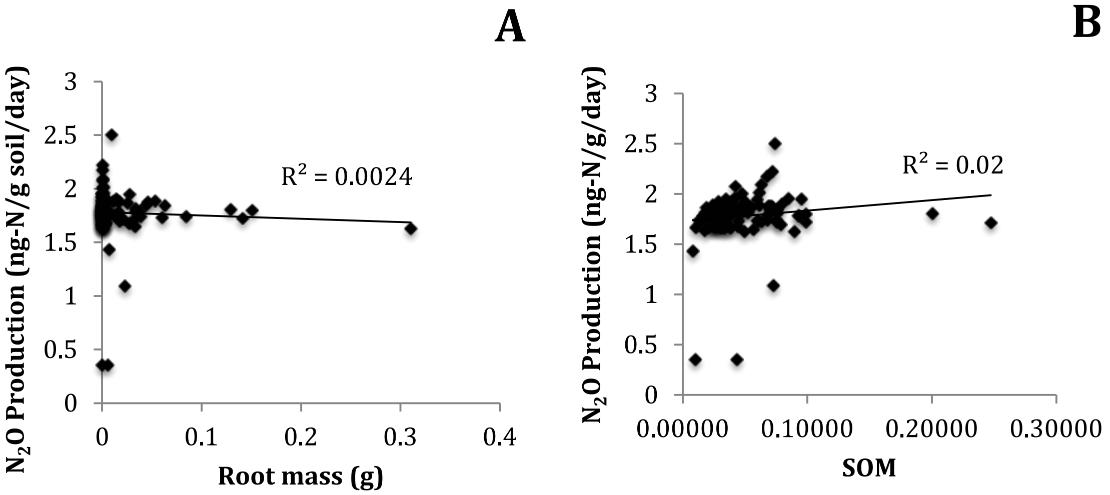

FIGURE 5. N_2O production versus root mass (A) and soil organic matter (SOM, B) at 0 – 10 cm depth, n = 30.

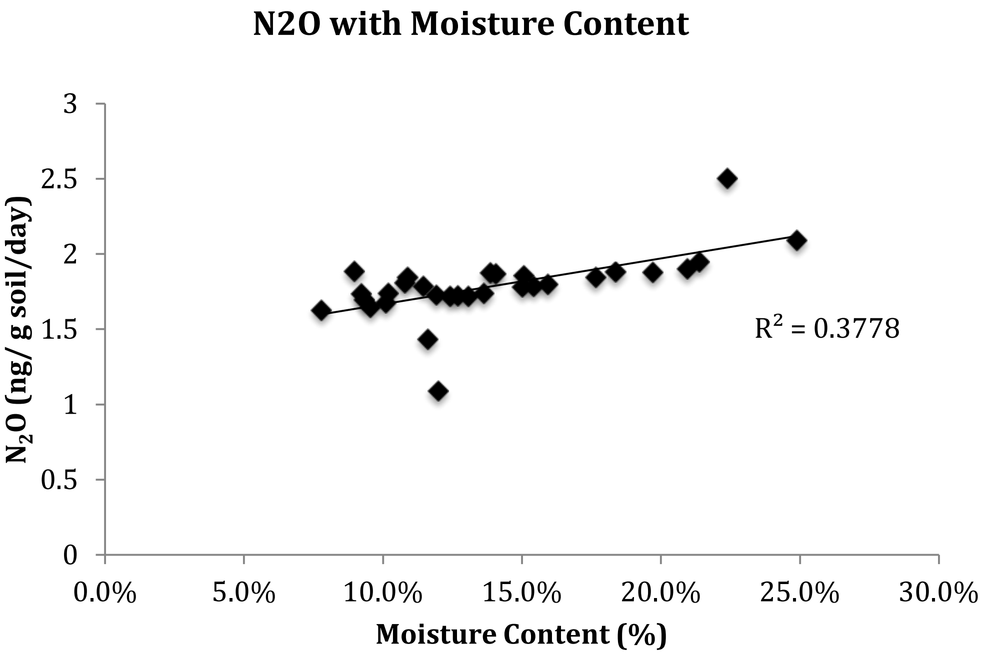

FIGURE 6. N_2O production versus soil moisture at 0-10cm core depth.