Agric. Environ. Lett. Accepted Paper, posted 01/03/2019. doi:10.2134/ael2018.10.0055

Deep soil cores reveal large end-of-season residual mineral nitrogen pool

Sarah M. Hirsh* and Ray R. Weil

Department of Environmental Science and Technology, University of Maryland, College Park, MD 20742

*Corresponding author (shirsh@umd.edu)

Core Ideas:

- Residual mineral N in 0-210 cm deep soil following summer crops was evaluated
- Soils contained a mean of 253 kg ha^{-1} mineral N, 115 kg ha^{-1} as NO_3-N
- 55% of mineral N was 90-210 cm deep, where it is most at risk for leaching loss
- More residual NO_3-N remained after soybean than after corn
- Awareness of residual deep N levels is essential to develop N conservation practices

Agric. Environ. Lett. Accepted Paper, posted 01/03/2019. doi:10.2134/ael2018.10.0055

Abstract

The amount of mineral N remaining after cash crops informs agronomic and conservation practices. Few studies investigate mineral N below 30 cm, yet deeper N is more at risk for leaching to groundwater. We found, on average, 253 kg ha^{-1} of mineral N, 115 kg ha^{-1} in the NO_3-N form, remaining after summer cash crop growth in the mid-Atlantic region. Of this residual mineral N, 55% was 90-210 cm deep. More residual NO_3-N remained after soybean than after corn. These substantial pools of mineral N remaining deep in the soil profile after productive cash crops, even unfertilized soybean, suggest that practices should be designed to scavenge residual N from deep soil layers in the fall, before it is lost over winter.

Nitrogen (N) loading to water bodies in humid temperate regions occurs primarily by leaching during the non-growing season when evapotranspiration is minimal (Meisinger and Delgado, 2002). In the Mid-Atlantic USA, where corn (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.) are the main annual crops (USDA NASS, 2012), NO_3-N commonly leaches >1 m between fall and spring (Angle, 1990; Forrestal, et al., 2014; Meisinger and Delgado, 2002). Here, corn typically ceases N uptake by early-September when maturity is approached (Ciampitti, et al., 2013; Hanway, 1963). Excessive N contributes to eutrophication and hypoxia in the Chesapeake Bay (Ator and Denver, 2015; Phillips and Caughron, 2014), motivating the Maryland legislature to mandate nutrient management plans (Parker, 2000) which regulate N application to crops (Maryland Department of Agriculture, 2014). However, even with mandated efforts, N leaching continues to be a concern in Maryland (USEPA, 2017).

Spatiotemporal patterns of soil N influence the accessibility of N to growing crops and its susceptibility to leaching. End of growing season residual N, especially in deeper soil layers, is at risk of leaching below the root zone of subsequent crops and eventually into groundwater (Thorup-Kristensen, 1994). Even when crops are fertilized at recommended rates, substantial mineral N (N_{min}) remains in the soil at the end of the growing season. In Pennsylvania, following corn fertilized at economic optimum rates, 74 and 94 kg NO_3-N ha^{-1} remained in the upper 120 cm of non-manured and manured soils, respectively (Roth and Fox, 1990). Furthermore, fall uptake of 80 to 220 kg N ha^{-1} by early-planted cover crops (Dean and Weil, 2009; Wang and Weil, 2018) suggests that substantial soil N remains following even high yields of cash crops.

Data on the amounts and depth distribution of residual N_{min} in fall could assist in optimizing N conservation practices, such as cover cropping.

Materials and Methods

Twenty-nine row-crop fields were sampled across the Piedmont, Ridge and Valley, and Coastal Plain regions of Maryland and southeast Pennsylvania between 2014 and 2016. Fields were selected from farm operations that responded to our request via Extension educators and agronomy news outlets. The area has a temperate humid climate with 11°C mean annual temperature and 1044 mm mean annual precipitation uniformly distributed among all months (Maryland Department of State Planning, 1973; Polsky, et al., 2000). Soil infiltration rates are typically 6-15 cm h^{-1} in the Piedmont and 13-28 cm h^{-1} in the Coastal Plain (Markewich, et al., 1990). The crop grown prior to sampling was corn on 20 fields, soybean on four, perennial grasses on two, fertilized winter wheat on two, and tobacco on one. Most fields were managed with no-tillage or other conservation tillage and practiced winter cover cropping. Fields included a range of dairy or poultry manure histories: 11 with no manure, 11 with regular manure applications, and seven with occasional manure (one to two applications in past 10 years, or history of regular manure applications but none applied in the past three years). The 23 fields in Maryland applied N according to N-based nutrient management plans. The fields were grouped by their soil parent materials: Coastal Plain sediments, acidic rocks, and calcareous rocks.

To evaluate effects of previous crop on residual N, four pairs of adjacent corn and soybean fields were sampled in 2016. Three pairs had Coastal Plain sediments (Coastal Plain region) and one pair had acidic rock (Piedmont region) parent materials. The cropping histories included corn, soybean, small grain, and hay (see Figure 1). Paired-fields were sampled on the same day and had the same soil series, manure and tillage history.

Soil sampling and analysis

Soil cores 210 cm deep were collected using hand-driven probes (Dean and Weil, 2009; Veihmeyer, 1929) from 14 fields between 20-Aug and 20-Sep in 2014, from seven fields between 17-Aug and 25-Sep in 2015, and from eight fields between 24-Sep and 29-Oct in 2016. In 2014 and 2016 two soil cores were collected at five points along a straight transect; in 2015 three soil cores were collected at four points within the field. Points were 20 to 50 m apart, depending on the size and shape of the field; cores at a point were less than 1 m apart. In 2014 and 2016, soil was divided into 15 cm increments and two soil cores taken from each point along the transect were composited for each depth increment. In 2015, soil was divided into 30 cm increments, and the values of the three cores per point were averaged after soil analysis.

The soil was dried, sieved to 2 mm, and NO_3-N and NH_4-N was extracted (2 g soil in 20 mL solution) with 0.5 *M* potassium sulfate (K_2SO_4) and filtered. A Lachat QuikChem 8500 Automated Ion Analyzer (Hach Company, Loveland, CO) was used to analyze the filtrate for NH_4–N (salicylate method) and for NO_2-N + NO_3-N (cadmium reduction method). Stocks of NO_3-N and NH_4-N (kg ha^{-1}) were calculated from concentrations of NO_3-N and NH_4-N using soil bulk density values (core method). Soil particle size analysis was performed by the modified pipette method (Gavlak, et al., 2005).

Statistical analysis

All analyses were performed using SAS version 9.4 (SAS Institute, 2012). The level of probability considered significant was $p < 0.05$, unless otherwise stated. All ANOVA tests were performed using Proc Mixed. An ANOVA was performed to compare the NO_3-N or NH_4-N amounts among parent material groups for 0-210 cm, 0-30 cm, 30-90 cm, 90-150 cm, and 150-210 cm depth increments, with parent material group as the fixed effect and field as a random effect. A Pearson product-moment correlation was performed using Proc Corr to relate the soil NO_3-N and NH_4-N to soil percentages of sand and clay by depth. Proc Means was used to calculate the coefficient of variation (CV) among the four to five points in the field (each point averaging two to three cores) of the total 0-210 cm NO_3-N and NH_4-N for 19 of the fields. To compare pools of inorganic N following corn versus soybean, for the paired fields, an ANOVA was performed for each 30 cm increment soil depth on the stocks of NO_3-N and NH_4-N, with crop type (corn or soybean) as the fixed effect and field as a random effect.

Results

Following summer crop senescence, on average 253 kg ha^{-1} of N_{min} remained in the upper 210 cm of soil, with 22% located at 0-30 cm, 23% at 30-90 cm, 27% at 90-150 cm, and 28% at 150-210 cm depth. Across the 29 fields, 115 kg ha^{-1} of the total N_{min} was NO_3-N and 138 kg ha^{-1} was NH_4-N. Nitrate-N levels for Coastal Plain sediments fields were lower than acidic rock fields in the 90-150 cm depth and than calcareous rock fields in the 150-210 cm depth ($p < 0.10$; Table 1).

Across the 29 fields, sand percentage was negatively correlated with NO_3-N concentration ($p < 0.10$) at 0-30 cm, 90-150 cm, and 150-210 cm depths, but neither sand nor clay percentage was correlated with NH_4-N concentration. Within-field CV of 0-210 cm total stock of NO_3-N was on average 35% (standard error (SE) = 5.1, N = 19) and of NH_4-N was on average 44% (SE = 5.0, N = 19). The CVs for the two N species were uncorrelated.

Based on the four pairs of adjacent corn and soybean fields sampled in 2016, there was significantly more soil NO_3-N following soybean than corn at 30-60 cm, 120-150 cm, 150-180 cm, and 180-210 cm. Levels of soil NH_4-N differed between corn or soybean only at 180-210 cm (Fig. 1).

Discussion

Why so much residual N?

The large pools of residual N represent both fertilizer N unused by summer crops (Wang and Weil, 2018) and N mineralized from soil and plant organic matter (Dahnke and Johnson, 1990; Weil and Brady, 2017). Residual soil N is often assumed to be a result of N fertilizer over-application, or low N uptake during drought years (Forrestal, et al., 2012); hence, N management and policies to reduce N loading primarily focus on N fertilized fields (Maryland Department of Agriculture, 2014). However, we believe that large pools of residual N_{min} are more universal. Our data, in agreement with previous studies (Gentry, et al., 2001; Jaynes, et al., 2001; Kessavalou and Walters, 1999; Pantoja, et al., 2016; Rembon and MacKenzie, 1997) indicates soybeans without N fertilizer can leave even more residual nitrate in the soil profile than corn receiving fertilizer. Compared to corn, soybean creates a high N environment with less (and lower C/N ratio) residues, and therefore less N is immobilized (Angle, 1990; Gentry, et al., 2001; Green and Blackmer, 1995).

While stocks of NO_3-N and NH_4-N in the soil profiles were similar, our results suggest that NO_3-N is more transient, leaching through the soil, whereas NH_4-N is accumulating through cation exchange sorption. For example, crop (corn versus soybean) affected NO_3-N levels much more than NH_4-N levels. Similar results were found in Wisconsin (Bundy, et al., 1993) for the upper 90 cm of soil in spring. Kristensen and Thorup-Kristensen (2004) and Bergström (1986) also found that crop species affected residual NO_3-N more than residual NH_4-N. The negative correlation between sand and soil NO_3-N concentration (but not NH_4-N concentration) supports the expected faster NO_3-N leaching in sandier soils. The lack of correlation between clay and NH_4-N concentration is not surprising as the NH_4-N ions measured would occupy only a small fraction of the cation exchange sites on any of the soils.

Importance of vertical location of N

Many studies report how soil N is affected by cover crops (Chu, et al., 2017; Ebelhar, et al., 1984; Kuo and Jellum, 2002; Ladoni, et al., 2015; Ruffo, et al., 2004; Sainju, et al., 2006) or other cropping practices (Anderson and Peterson, 1973; Poudel, et al., 2002; Rice, et al., 1986; Scalise, et al., 2015) after sampling only 15 to 30 cm of soil. However, it is the deeper N (1-2 meters deep) that is most at-risk for leaching to groundwater before plants can take it up. Across all our fields, 57% (65 kg N ha^{-1}) of NO_3-N and 55% (138 kg N ha^{-1}) of total N_{min} to 210 cm was at 90-210 cm.

Land management implications

In regions, such as the mid-Atlantic, with year-long rainfall, favorable mineralization conditions during much of the “off-season” and permeable soil types, scavenging residual N as soon as possible after crop harvest will be important to prevent N from leaching beyond rooting depth. We suggest that early-planted, deep-rooted cover crops could be a tool to accomplish such N conservation.

Acknowledgments

The authors thank collaborating farmers and student technicians. This research was funded by Northeast Sustainable Agriculture Research and Education program (Project No. LNE14-338) and Maryland Soybean Board. Partial funding from USDA NIFA, Hatch project 1014496.

References

Anderson, F.N., and G.A. Peterson. 1973. Effects of continuous corn (*Zea mays* L.), manuring, and nitrogen fertilization on yield and protein content of the grain and on the soil nitrogen conten. Agron. J. 65:697-700.

Angle, J.S. 1990. Nitrate leaching losses from soybeans (*Glycine max* L. Merr.). Agric., Ecosyst. Environ. 31:91-97.

Ator, S.W., and J.M. Denver. 2015. Understanding nutrients in the Chesapeake Bay watershed and implications for management and restoration—the Eastern Shore (ver. 1.2, June 2015). USGS Circular 1406. http://dx.doi.org/10.3133/cir1406.

Bergström, L. 1986. Distribution and temporal changes of mineral nitrogen in soils supporting annual and perennial crops. Swed. J. Agric. Res. 16:105-112.

Bundy, L.G., T.W. Andraski, and R.P. Wolkowski. 1993. Nitrogen credits in soybean-corn crop sequences on three soils. Agron. J. 85:1061-1067.

Chu, M., S. Jagadamma, F.R. Walker, N.S. Eash, M.J. Buschermohle, and L.A. Duncan. 2017. Effect of multispecies cover crop mixture on soil properties and crop yield. Agric. Environ. Lett. 2:170030. doi:10.2134/ael2017.09.0030.

Ciampitti, I.A., J.J. Camberato, S.T. Murrell, and T.J. Vyn. 2013. Maize nutrient accumulation and partitioning in response to plant density and nitrogen rate: I. Macronutrients. Agron. J. 105:783-795.

Dahnke, W.C., and G.V. Johnson. 1990. Testing soils for available nitrogen. In: R.L. Westerman, editor, Soil testing and plant analysis. SSSA Book Ser. 3. SSSA, Madison, WI.

Agric. Environ. Lett. Accepted Paper, posted 01/03/2019. doi:10.2134/ael2018.10.0055

Dean, J.E., and R.R. Weil. 2009. Brassica cover crops for nitrogen retention in the Mid-Atlantic Coastal Plain. J. Environ. Qual. 38:520-528.

Ebelhar, S.A., W.W. Frye, and R.L. Blevins. 1984. Nitrogen from legume cover crops for no-tillage corn. Agron. J. 76:51-55.

Forrestal, P.J., R.J. Kratochvil, and J.J. Meisinger. 2012. Late-season corn measurements to assess soil residual nitrate and nitrogen management. Agron. J. 104:148-157.

Forrestal, P., J. Meisinger, and R. Kratochvil. 2014. Winter wheat starter nitrogen management: a preplant soil nitrate test and site-specific nitrogen loss potential. Soil Sci. Soc. Am. J. 78:1021-1034.

Gavlak, R., D. Horneck, and R.O. Miller. 2005. Soil, plant and water reference methods for the western region. 3rd ed. 125. WREP.

Gentry, L.E., F.E. Below, M.B. David, and J.A. Bergerou. 2001. Source of the soybean N credit in maize production. Plant Soil 236:175-184.

Green, C.J., and A.M. Blackmer. 1995. Residue decomposition effects on nitrogen availability to corn following corn or soybean. Soil Sci. Soc. Am. J. 59:1065-1070.

Hanway, J.J. 1963. Growth Stages of Corn (*Zea mays*, L.). Agron. J. 55:487-492.

Jaynes, D.B., T.S. Colvin, D.L. Karlen, C.A. Cambardella, and D.W. Meek. 2001. Nitrate loss in subsurface drainage as affected by nitrogen fertilizer rate. J. Environ. Qual. 30:1305-1314.

Kessavalou, A. and D.T. Walters. 1999. Winter rye cover crop following soybean under conservation tillage: Residual soil nitrate. Agron. J. 91:643-649.

Kristensen, H.L. and K. Thorup-Kristensen. 2004. Uptake of ^{15}N labeled nitrate by root systems of sweet corn, carrot and white cabbage from 0.2–2.5 meters depth. Plant Soil 265:93-100.

Kuo, S., and E.J. Jellum. 2002. Influence of winter cover crop and residue management on soil nitrogen availability and corn. Agron. J. 94:501-508.

Ladoni, M., A.N. Kravchenko, and G.P. Robertson. 2015. Topography mediates the influence of cover crops on soil nitrate levels in row crop agricultural systems. PloS One 10: e0143358. doi:10.1371/ journal.pone.0143358

Markewich, H.W., M.J. Pavich, and G.R. Buell. 1990. Contrasting soils and landscapes of the Piedmont and Coastal Plain, eastern United States. Geomorphology 3: 417-447.

Maryland Department of Agriculture. 2014. AgBrief nutrient management program. Maryland Department of Agriculture, Office of Resource Conservation. http://mda.maryland.gov/Documents/ag_brief/AgBrief_NM.pdf (accessed 16 Sep. 2018).

Maryland Department of State Planning. 1973. Natural soil groups of Maryland, technical series generalized land use plan. Publication 199. Baltimore, MD.

Meisinger, J.J., and J.A. Delgado. 2002. Principles for managing nitrogen leaching. J. Soil Water Conserv. 57:485-498.

Pantoja, J.L., K.P. Woli, J.E. Sawyer, and D.W. Barker. 2016. Winter rye cover crop biomass production, degradation, and nitrogen recycling. Agron. J. 108:841-853.

Parker, D. 2000. Controlling agricultural nonpoint water pollution: costs of implementing the Maryland Water Quality Improvement Act of 1998. Agricultural Economics 24:23-31.

Phillips, S., and B. Caughron. 2014. Overview of the U.S. Geological Survey Chesapeake Bay Ecosystem Program. USGS Fact Sheet 124-97. https://pubs.usgs.gov/fs/fs12497/.

Agric. Environ. Lett. Accepted Paper, posted 01/03/2019. doi:10.2134/ael2018.10.0055

Polsky, C., J. Allard, N. Currit, R. Crane, and B. Yarnal. 2000. The Mid-Atlantic Region and its climate: past, present, and future. Climate Research 14: 161-173.

Poudel, D.D., W.R. Horwath, W.T. Lanini, S.R. Temple, and A.H.C. van Bruggen. 2002. Comparison of soil N availability and leaching potential, crop yields and weeds in organic, low-input and conventional farming systems in northern California. Agric., Ecosyst. Environ. 90:125-137.

Rembon, F.S., and A.F. MacKenzie. 1997. Soybean nitrogen contribution to corn and residual nitrate under conventional tillage and no-till. Can. J. Soil Sci. 77:543-551.

Rice, C.W., M.S. Smith, and R.L. Blevins. 1986. Soil nitrogen availability after long-term continuous no-tillage and conventional tillage corn production. Soil Sci. Soc. Am. J. 50:1206-1210.

Roth, G.W., and R.H. Fox. 1990. Soil nitrate accumulations following nitrogen-fertilized corn in Pennsylvania. J. Environ. Qual. 19:243-248.

Ruffo, M.L., D.G. Bullock, and G.A. Bollero. 2004. Soybean yield as affected by biomass and nitrogen uptake of cereal rye in winter cover crop rotations. Agron. J. 96:800-805.

Sainju, U.M., W.F. Whitehead, B.P. Singh, and S. Wang. 2006. Tillage, cover crops, and nitrogen fertilization effects on soil nitrogen and cotton and sorghum yields. Eur. J. Agron. 25:372-382.

SAS Institute. 2012. The SAS system for Winows. Release 9.4. SAS Inst., Cary, NC.

Scalise, A., D. Tortorella, A. Pristeri, B. Petrovičová, A. Gelsomino et al. 2015. Legume–barley intercropping stimulates soil N supply and crop yield in the succeeding durum wheat in a rotation under rainfed conditions. Soil Biol. Biochem. 89:150-161.

Thorup-Kristensen, K. 1994. The effect of nitrogen catch crop species on the nitrogen nutrition of succeeding crops. Fertilizer Research 37:227-234.

USDA NASS. 2012. Census of Agriculture, Ag Census Web Maps. https://www.agcensus.usda.gov/Publications/2012/Online_Resources/Ag_Census_Web_Maps/Overview/ (accessed 16 Sep. 2018).

USEPA. 2017. Interim Evaluation of Maryland's 2016-2017 Milestones Progress. US EPA. https://www.epa.gov/sites/production/files/2017-06/documents/md_interim_2016_2017_milestone_eval_20170630_0.pdf (accessed 16 Sep. 2018).

Veihmeyer, F.J. 1929. An improved soil-sampling tube. Soil Sci. 27: 147-152.

Wang, F., and R.R. Weil. 2018. The form and vertical distribution of soil nitrogen as affected by forage radish cover crop and residual side-dressed N fertilizer. Soil Sci. 183:22-33.

Weil, R.R., and N.C. Brady. 2017. The nature and properties of soils. 15th ed.Pearson, Columbus, OH.

Table 1. Soil NO_3-N, NH_4-N, and mineral N (N_{min}) (kg N ha^{-1}) for 0-30 cm, 30-90 cm, 90-150 cm, 150-210 cm, and 0-210 cm. Values are means with standard error (SE) in parenthesis for all fields (N=29), Coastal Plain sediments fields (N=14), calcareous rock fields (N=6), and acidic rock fields (N=9). Within a mineral N type and depth increment, values followed by the same letter do not differ significantly among Coastal Plain sediments, acidic rock, and calcareous rock fields. The symbols * and † indicate $p < 0.05$ and 0.1, respectively.

Soil parent material	Depth increment	NO_3-N	NH_4-N	N_{min}
	-------- cm --------	---------------- kg N ha^{-1} (SE) ----------------		
All fields	0-210	115 (12.5)	138 (15.6)	253 (23.5)
	0-30	24.9 (3.83)	31.3 (2.74)	56.3 (5.43)
	30-90	25.2 (3.27)	33.6 (3.90)	58.7 (5.89)
	90-150	30.8 (3.66)	37.0 (4.70)	67.7 (7.16)
	150-210	33.9 (5.61)	36.0 (4.94)	69.9 (8.27)
Coastal Plain sediments	0-210	88.4 (17.8) a	137 (24.6) a	226 (37.8) a
	0-30	23.9 (5.08) a	30.0 (3.86) a	53.9 (8.22) a
	30-90	23.8 (6.11) a	33.5 (5.98) a	57.3 (10.4) a
	90-150	20.0 (3.55) a*	35.7 (6.63) a	55.7 (9.43) a
	150-210	20.7 (4.27) a†	38.1 (8.61) a	58.8 (11.5) a
Acidic rocks	0-210	136 (45.4) a	153 (51.0) a	289 (96.5) a
	0-30	24.1 (8.03) a	35.9 (12.0) a	60.0 (20.0) a
	30-90	25.2 (8.41) a	36.2 (12.1) a	61.4 (20.5) a
	90-150	44.5 (14.8) b*	43.0 (14.3) a	87.5 (29.2) a
	150-210	42.4 (14.1) ab†	38.1 (12.7) a	80.5 (26.8) a
Calcareous rocks	0-210	144 (58.8) a	117 (47.6) a	261 (106) a
	0-30	28.5 (11.6) a	27.8 (11.4) a	56.3 (23.0) a
	30-90	28.1 (11.5) a	29.9 (12.2) a	58.0 (23.7) a
	90-150	35.3 (14.4) ab*	30.9 (12.6) a	66.3 (27.1) a
	150-210	52.2 (21.3) b†	28.0 (11.4) a	80.2 (32.7) a

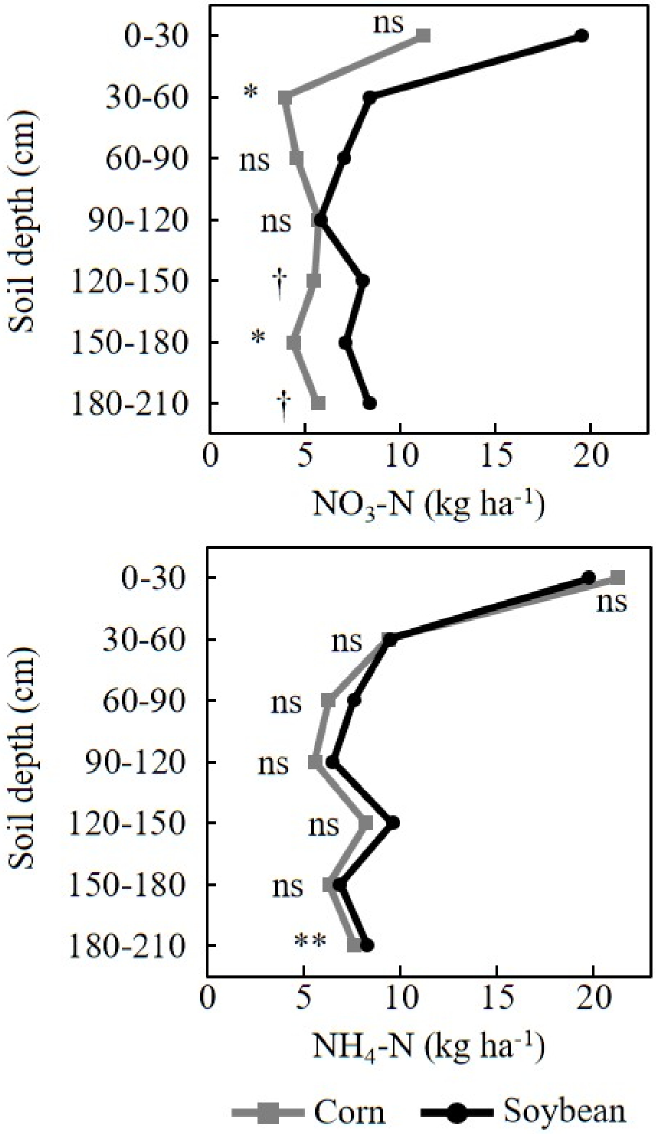

Figure 1. NO_3-N and NH_4-N (kg N soil layer^{-1} ha^{-1}) in four pairs of adjacent corn and soybean fields. Crop history of fields included: Field 1A 2016 corn, 2013-2015 Timothy hay; Field 1B 2016 soybean, 2015 corn silage, 2014 corn, 2013 sorghum; Field 2A 2016 corn, 2015 wheat/soybean, 2014 corn, 2013 wheat/soybean; Field 2B 2016 soybean, 2015 wheat/soybean, 2014 soybean, 2013 wheat/soybean; Field 3A 2016 corn, 2015 wheat/soybean, 2014 soybean, 2013 soybean; Field 3B 2016 soybean, 2015 wheat/soybean, 2014 soybean, 2013 corn; Field 4A 2016 corn, 2015 soybean, 2014 corn, 2013 soybean; Field 4B 2016 soybean, 2015 soybean, 2014 soybean, 2013 corn. Corn and wheat received 123-168, and hay received 73 kg N ha^{-1}. All fields had winter cover crops or small grains for the previous five years. No-till was practiced for five years on three pairs, and two years on one pair. Three pairs had no manure applied; one pair had one to two applications of dairy manure in the past 10 years. The symbols **, *, †, ns indicate $p < 0.01$, 0.05, 0.1, and not significant, respectively.

82x141mm (150 x 150 DPI)