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SHORT COMMUNICATION

Soil nitrogen distribution and deposition on shortgrass prairie adjacent to a beef cattle feedyard

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Abstract Cattle feedyards can impact local environments through emission of ammonia and dust deposited on nearby land. Impacts range from beneficial fertilization of cropland to detrimental effects on sensitive ecosystems. Shortgrass prairie downwind from an adjacent feedyard on the southern High Plains of Texas, USA changed from perennial grasses to annual weeds. It was hypothesized that N enrichment from the feedyard initiated the cascade of negative ecological change. Objectives were to determine the distribution of soil nitrogen and estimate N loading to the pasture. Soil samples were collected from 119 locations across the pasture and soil total N (TN), nitrate-N and ammonium-N (AN) determined in the top 30 cm. Soil TN concentration decreased with distance downwind from the feedyard from 1.6±0.2 g kg^{-1} at 75 m to 1.2±0.05 g kg^{-1} at 582 m. Nitrate-N concentration decreased within 200 m of the feedyard and changed little at greater distances. Ammonium-N concentration decreased linearly ($P<0.001$) with increasing distance from the feedyard from 7.9±1.7 mg kg^{-1} within 75 m from the feedyard to 5.8±1.5 mg kg^{-1} at more than 550 m from the feedyard; however, distance only explained 12% of the variability in AN concentration. Maximum nitrogen loading, from 75 to 106 m from the feedyard, was 49 kg ha^{-1} year^{-1} over 34 years and decreased with distance from the feedyard. An estimate of net dry deposition of ammonia indicated that it contributed negligibly to N loading to the pasture. Nitrogen enrichment that potentially shifted vegetation from perennial grasses to annual weeds affected soil N up to 500 m from the feedyard; however, measured organic and inorganic N beyond that returned to typical and expected levels for undisturbed shortgrass prairie.

Keywords Nitrogen loading · Soil fertility change · Beef cattle · Feedyard

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Introduction

More than seven million fed beef cattle, about a fourth of those marketed in the US, are found in the southern High Plains region within 250 km from Amarillo, TX, USA. Most are fed in more than 100 open-lot feedyards with capacities greater than 5,000 head, with median capacity of 32,000 head. Regionally, ammonia emitted from feedyards, which can comprise half the nitrogen in the rations fed to cattle (Todd et al. 2007), can interact with other atmospheric constituents, travel long distances, and subsequently return to the earth. Nitrogen then cycles through terrestrial and aquatic ecosystems, with potential negative impacts such as overenrichment of N-sensitive ecosystems (Matson et al. 2002; Rabalais 2002). Locally, dust, odors, emission of ammonia, and particulate formation can create environmental problems ranging from nuisance issues to potential health and local ecosystem impacts (Todd et al. 2004).

Shortgrass prairie, the natural ecosystem of the southern High Plains, is sensitive to inputs of nitrogen. Shortgrass prairie after N fertilization showed increased productivity that was often accompanied by vegetative composition change from native perennial grasses to nitrophilic annual species (Rauzi 1978; Rauzi and Fairbourn 1983; Samuel

and Hart 1998; Paschke et al. 2000), with N rates as low as 22 kg ha^{-1} initiating changes in composition and productivity.

A 25,000-head feedyard began operation in 1970 adjacent and upwind to a shortgrass prairie pasture on the US Department of Agriculture, Agricultural Research Service (USDA-ARS) Conservation and Production Research Laboratory, Bushland, TX, USA. About 25 years after the feedyard was established, it was observed that pasture vegetation nearest the feedyard was changing from desirable native perennial grasses to weedy annual grasses and forbs. Todd et al. (2004) investigated the degradation of the pasture using historical reports and contemporary measurements and found that vegetation closest to the feedyard changed from dominant perennial grasses blue grama [*Bouteloua gracilis* (H.B.K.) Lag. ex Griffiths] and buffalo grass [*Buchloe dactyloides* (Nutt.) Engelm.] to weedy annuals kochia [*Kochia scoparia* (L.) Schrad.] and pigweeds (*Amaranthus spp*.) and the native annual grass little barley (*Hordeum pusillum* Nutt.). Soil phosphorus and manure dust deposition were greatest nearest the feedyard and decreased with increasing distance downwind from the feedyard. At more than 500 m downwind from the feedyard, vegetation and soil P were at values typical of undisturbed shortgrass prairie. Todd et al. (2004) concluded that the observed changes were consistent with N fertilization of shortgrass prairie and estimated that from 19 to 31 kg N ha^{-1} year^{-1} were deposited on the impacted area nearest the feedyard for 30 years. However, soil nitrogen in the pasture was not quantified. Our objectives in this study were to (1) determine the distribution of soil nitrogen across the pasture and (2) estimate N loading to the pasture based on soil nitrogen distribution.

Materials and methods

Experimental site and characteristics

Research was conducted at the USDA-ARS Conservation and Production Research Laboratory, Bushland, TX, USA (35° N, 102° W, elevation 1,170 m) in 2004 on a 13-ha portion (360×360 m) of a 18.5-ha native shortgrass pasture (see Todd et al. 2004 for details). The soil of the pasture is mostly a Pantex silty clay loam (fine, mixed, superactive, thermic Torrertic Paleustoll) with slope <1%, with Pullman soil found on the east margin of the study area. The two series differ primarily in depth to the calcic horizon. Prevailing winds are southerly to southwesterly, with 46% of mean hourly wind directions between 157° and 248°. The adjacent, upwind feedyard, with a one-time capacity of 25,000 head, was constructed and stocked in 1970. Feedyard pens covered about 22 ha and were located west and southwest of the native pasture.

Soil sampling and analysis

Soil cores (40-mm diameter) were collected at 119 locations on a 22.5 by 60-m grid at depths of 0–2, 2–4, 4–6, 6–15, and 15–30 cm in 2000 and repeated again at the same locations in 2004. At each sampling location, five cores were extracted within 1 m^2 and composited by depth increment. Soil samples were air dried, ground, and passed through a 2-mm sieve and cold-stored at −5°C until analysis. The distance of each soil sample location downwind from the feedyard was determined along a southwest to northeast line, corresponding to the direction of prevailing southwesterly winds; there were 17 distances with n=7 sample locations for each distance. Soil total nitrogen (TN) was determined by dry combustion and analysis of evolved gases (Variomax Carbon–Nitrogen Analyzer, Elementar America, Mt. Laurel, NJ, USA[1]) on samples collected in 2004. Nitrate-N (NN) and ammonium-N (AN) were determined in 2 M KCl soil extracts from samples collected in 2000 using ion-selective electrodes (Orion 95-12 for ammonia and Orion 93-07 for nitrate; Orion Research, Inc., Cambridge, MA, USA), read with an Orion 407A specific ion meter (Keeney and Nelson 1982; Mulvaney 1996). For AN determination, the sample solution was adjusted to pH>11 using NaOH + methanol to assure conversion of ammonium to ammonia. Ammonium-N and nitrate-N concentrations were estimated by comparison to prepared standard solutions of ammonium and nitrate in 2 M KCl. Means and standard deviations of TN, AN, and NN concentrations for the 30-cm profile were calculated for each distance. Nitrogen loading to the pasture was estimated by calculating the difference between TN in the 30-cm profile of each distance and TN at 582 m from the feedyard, which was assumed typical of unaffected soil, based on comparison with TN levels in similar soils. These differences were then divided by the 34 years of feedyard occupancy to derive a mean annual rate of N loading to the pasture.

Results and discussion

Soil nitrogen distribution

Soil TN concentration decreased with distance downwind from the feedyard, from 1.6±0.2 g kg^{-1} at 75 m to 1.2±0.05 g kg^{-1} at 582 m (Fig. 1a). Greatest variability was

[1] The mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the US Department of Agriculture.

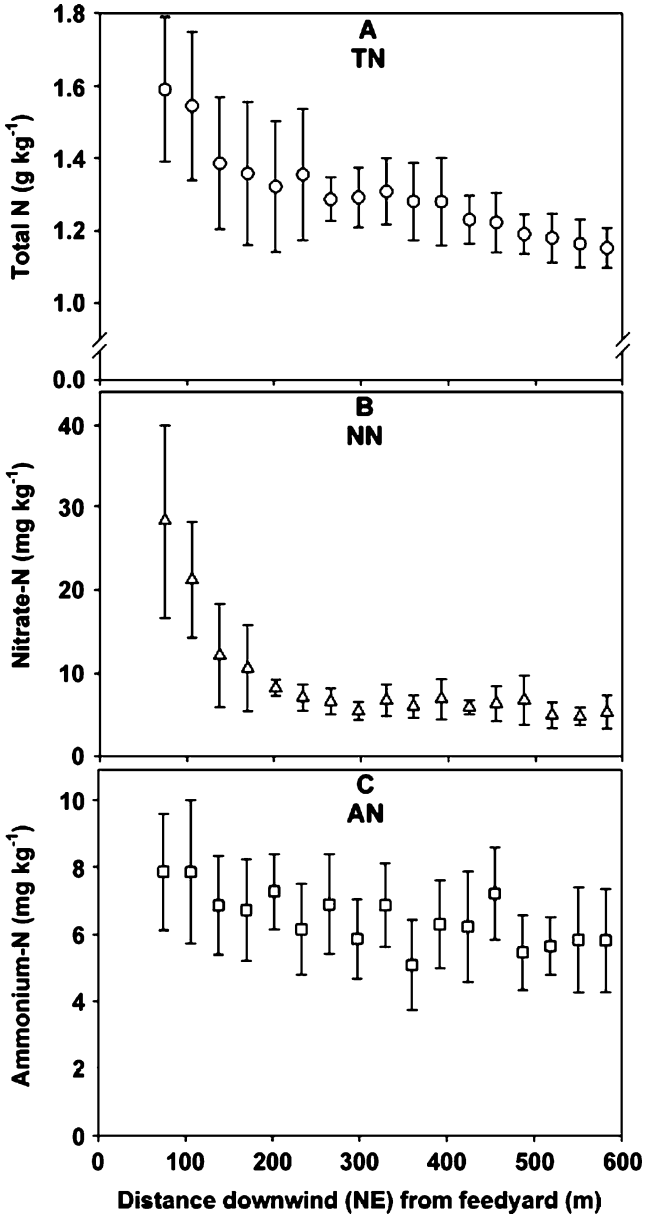

Fig. 1 **a–c** Soil total N (*TN*), nitrate-N (*NN*), and ammonium-N (*AN*) concentrations in the 30-cm profile with distance downwind (northeast) of the feedyard. *Error bars* indicate the standard deviation for each distance for n=7 observations

observed within 200 m of the feedyard, where coefficient of variation (CV) ranged from 12.6% to 14.5%. Variability decreased at greater distances, with CV ranging from 4.5% to 9.5%. Total N in the 0–30-cm profile decreased from 6,390 to 4,630 kg ha^{-1} with increasing distance from the feedyard.

Concentration of NN decreased from 28.3±11.7 to 10.6±5.2 mg kg^{-1} within 200 m of the feedyard, then changed little at greater distances, with NN concentration ranging from 5.3 to 8.2 mg kg^{-1} (Fig. 1b). Nitrate-N concentration showed greatest variability within 200 m of the feedyard, where CV ranged from 33% to 51%, compared with CV at greater distances, which ranged from 12% to 44%. Nitrate-N mass ranged from 114 kg ha^{-1} nearest the feedyard to 20 kg ha^{-1} at more than 500 m from the feedyard.

Constant variance of AN over distance values and random distribution of residuals allowed regression analysis of the relationship between AN and distance from the feedyard. Ammonium-N concentration decreased linearly with distance from the feedyard (slope=−0.0037 mg kg^{-1} m^{-1}, $p<0.001$) from 7.9±1.7 mg kg^{-1} within 75 m from the feedyard to 5.8±1.5 mg kg^{-1} at more than 550 m from the feedyard (Fig. 1c). However, distance only explained 12% of the variability in AN concentration (AN=7.7–0.0037D, r^2=0.12). Ammonium-N mass in the 30-cm profile ranged from 32 kg ha^{-1} nearest the feedyard (≤106 m) to 23 kg ha^{-1} at 582 m.

Soil TN on the west side of the pasture, nearest the feedyard, increased by 38%, compared with TN on the east side of the pasture at 582 m from the feedyard. Long-term application of manure to cropland generally increased soil nitrogen. Sanchez et al. (2004) applied 4 Mg ha^{-1} of composted dairy manure in 6 of 8 years (104 kg N ha^{-1} each year) to corn–corn–soybean–wheat rotations and increased N by 33%. Parham et al. (2002) examined changes in a soil cropped to continuous winter wheat that received 6,700 kg ha^{-1} of manure nitrogen over 100 years. Soil N increased about 30% in the top 30 cm compared with a check treatment. Increased soil TN reported in this study is consistent with long-term manure application, in this case, as dust and ammonia deposited from the upwind feedyard source.

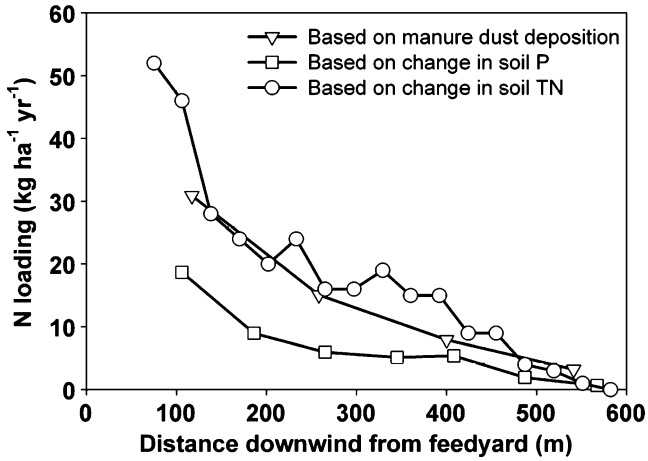

Fig. 2 Nitrogen loading to the pasture estimated from manure dust deposition or change in soil P taken from Todd et al. (2004), or estimated from change in soil total N (*TN*) with distance downwind (northeast) of the feedyard

Nitrogen loading estimates

We assumed that TN at 582 m downwind from the feedyard was at concentration typical of undisturbed grassland (1.15 g kg^{-1} in top 30 cm). Using this as baseline, we calculated the N loading to the rest of the pasture. Nitrogen loading over 34 years at 75 m from the feedyard was 52 kg ha^{-1} yr^{-1}, decreasing with increasing distance from the feedyard (Fig. 2).

Todd et al. (2004) estimated N loading to the pasture in two ways: (1) calculating annual manure dust deposition on the pasture; and (2) using soil P as a conservative proxy for manure additions to the pasture and calculating its change across the pasture from typical undisturbed concentration. They found that from 19 to 31 kg N ha^{-1} $year^{-1}$ was deposited nearest the feedyard over 30 years. Estimates based on the change in soil P or dust deposition differ from the estimate based on change in soil N. The former two changes estimate N loading due to manure dust. The latter change combines manure dust and dry deposition of ammonia. Dry deposition of ammonia would be expected greatest nearest the feedyard and could account for the 20–30 kg N ha^{-1} $year^{-1}$ difference between the N loading estimate based on soil N and that based on soil P or dust deposition. McGinn et al. (2003) calculated ammonia dry deposition downwind from beef feedyards in Canada. They found that, adjacent to feedyards, 57–209 kg N ha^{-1} $year^{-1}$ was deposited; at 200 m downwind, 35–50 kg N ha^{-1} $year^{-1}$ was deposited. Based on a mean N loading rate of 17.7 kg ha^{-1} yr^{-1} to the 13-ha pasture estimated in this study, 7,800 kg N was deposited over 34 years, which yields an average 0.63 kg N day^{-1} deposited. The pasture is directly downwind 1/4 of the time, so net deposition rate estimated during downwind days was 2.5 kg N day^{-1}. If half this amount is dust-borne N and half is dry-deposited ammonia-N, then net dry deposition of ammonia accounts for only 0.05% of the annualized NH_3–N daily emission rate (2,400 kg day^{-1}), based on the annualized per capita emission rate for beef cattle (96 g $head^{-1}$ day^{-1}) reported by Todd et al. (2007).

Nitrogen enrichment nearest the feedyard most likely caused the shift from native perennial grasses to annual weedy species as documented by Todd et al. (2004). Soil N more than 500 m from the feedyard remained at levels typical and expected for undisturbed shortgrass prairie on Pullman soil. Though fugitive nitrogen deposited on adjacent land from feedyards is a very small fraction of that emitted from feedyards as ammonia and dust, it can negatively impact a nitrogen-sensitive ecosystem like shortgrass prairie. The radius of potential impact is localized, however, with most effects within 500 m of the feedyard source.

References

Keeney DR, Nelson DW (1982) Nitrogen-inorganic forms. In: Page AL, Miller RH, Keeney DR (eds) Methods of soil analysis, part 2—chemical and microbiological properties, 2nd ed. Agronomy No. 9, ASA and SSSA, Madison, pp 643–698

Matson P, Lohse K, Hall SJ (2002) The globalization of nitrogen: consequences for terrestrial ecosystems. Ambio 31:113–119

McGinn SM, Janzen HH, Coates T (2003) Atmospheric ammonia, volatile fatty acids, and other odorants near beef feedlots. J Environ Qual 32:1173–1182

Mulvaney RL (1996) Improved diffusion methods for determination of inorganic nitrogen in soil extracts and water. Biol Fertil Soils 24:413–420

Parham JA, Deng SP, Raun WR, Johnson GV (2002) Long-term cattle manure application in soil. I. Effect on soil phosphorus levels, microbial biomass C, and dehydrogenase and phosphatase activities. Biol Fertil Soils 35:328–337

Paschke MW, McLendon T, Redente EF (2000) Nitrogen availability and old field succession in a shortgrass steppe. Ecosystems 6:144–158

Rabalais NN (2002) Nitrogen in aquatic ecosystems. Ambio 31:102–112

Rauzi F (1978) High rates of nitrogen change composition of shortgrass rangeland in southeastern Wyoming. J Range Manage 31:366–370

Rauzi F, Fairbourn ML (1983) Effects of annual applications of low N fertilizer rates on a mixed grass prairie. J Range Manage 36:359–362

Samuel MJ, Hart RH (1998) Nitrogen fertilization, botanical composition and biomass production on mixed grass rangeland. J Range Manage 51:408–416

Sanchez JE, Harwood RR, Wilson TC, Kizilkaya K, Smeenk J, Parker E, Paul EA, Knezek BD, Robertson GP (2004) Managing soil carbon and nitrogen for productivity and environmental quality. Agron J 96:769–775

Todd RW, Guo W, Stewart BA, Robinson C (2004) Vegetation, phosphorus, and dust gradients downwind from a cattle feedyard. J Range Manage 57:291–299

Todd RW, Cole NA, Clark RN (2007) Ammonia emissions from open lot beef cattle feedyards on the southern High Plains. In: Proc. 16th Annual International Emission Inventory Conference–Emission Inventories: Integration, Analysis, Communication, May 14–17, 2007, Raleigh, NC. http://www.epa.gov/ttn/chief/conference/ei16/session5/todd.pdf. Accessed 17 March 2008