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Nitrogen and carbon dynamics in prairie vegetation strips across topographical gradients in mixed Central Iowa agroecosystems

Marlín Pérez-Suárez[a,b], Michael J. Castellano[c], Randall Kolka[d], Heidi Asbjornsen[e,*], Matthew Helmers[f]

[a] Department of Natural Resource Ecology and Management, Iowa State University, 339 Science II, Ames, IA 50011, USA
[b] Instituto de Ciencias Agropecuarias y Rurales (ICAR), Universidad Autónoma del Estado de México, Carretera Toluca - Atlacomulco Km. 14.5, CP 50000 Toluca, Mexico
[c] Department of Agronomy, Iowa State University, Ames, IA 50011, USA
[d] USDA Forest Service, Northern Research Station, 1831 Hwy 169 East, Grand Rapids, MN 06514, USA
[e] Department of Natural Resources and the Environment, University of New Hampshire, Durham, NH, USA
[f] Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, IA 50011, USA

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ABSTRACT

Reductions of nitrogen (N) export from agricultural lands because of changes in specific N stocks and fluxes by incorporation of small amounts of prairie vegetation strips (PVS) are poorly understood. The primary objective of this study was to evaluate the effect of the presence and topographical position of PVS on soil and plant carbon (C) and N stocks relative to annual crop and native prairie vegetation. The study was implemented within three small adjacent watersheds, treated with one of the following cover types: (1) 100% row-crop agriculture (CROP); (2) 20% prairie vegetation (PVS) distributed along the contour across three topographical positions: upslope, sideslope and footslope position; and (3) 100% 17-year old reconstructed native prairie (RNP) as the control condition. Total soil organic C (SOC), total soil N (TN), inorganic N availability as indexed by ion exchange resins, N stocks in plant biomass and litter, and the ratio of C_3:C_4 plant species were measured during the 2010 growing season. Results showed that over five years of treatment, PVS footslope improved soil quality by increasing TN by almost 100% and SOC by 37%; while CROP footslope TN decreased by 31% and SOC decreased by 28%. Overall, N stocks in plant biomass and litter were higher in PVS compared with RNP, except in the footslope where the lower N plant stocks was associated with higher C_3 abundance in RNP. Nitrogen availability was higher in CROP (25.4 ± 1.4), followed by PVS (10.2 ± 1.3), and RNP (2.2 ± 1.4); with the highest values recorded in the upslope position for PVS and RNP, and the footslope for CROP. These findings are important for designing watersheds with PVS to reduce N accumulation in the footslope position and promote additional N retention in soil organic matter and plant biomass, thereby minimizing N losses to streams.

1. Introduction

In the Midwestern U.S., conversion of native tallgrass prairie to intensively managed row-crop agriculture with high inorganic nitrogen (N) fertilizer inputs has significantly altered the N cycle (Lauenroth et al., 1999; Robertson and Vitousek, 2009). One of the major consequences of this land use change is increased N export to groundwater, streams, and rivers (Robertson and Vitousek, 2009). These N losses contribute to reduced soil fertility (Lauenroth et al., 1999) and expansion of the seasonal hypoxic zone in the Gulf of Mexico (Alexander et al., 2008; Goolsby et al., 2001; Howarth et al., 2000).

Strategies to reduce N export from agricultural lands have included the establishment of riparian buffer systems (Dosskey et al., 2002; Lovell and Sullivan, 2006) and, more recently, the incorporation of small amounts of prairie vegetation strips (PVS) in strategic locations within crop fields (Asbjornsen et al., 2013; Helmers and Eisenhauer, 2006). Both riparian buffers and PVS function as physical barriers that reduce N losses by minimizing soil erosion (Dosskey, 2001; Dosskey et al., 2002; Helmers and Eisenhauer, 2006; Hernández-Santana et al., 2013; Zhou et al., 2010, 2014). Additionally, riparian buffers and PVS retain NO_3-N through biogeochemical transformations resulting from plant uptake and microbial processes. These transformations include NO_3-N transfer to above and belowground plant tissues, denitrification,

* Corresponding author.
E-mail addresses: heidi.asbjornsen@unh.edu, mperezs@uaemex.mx (H. Asbjornsen).

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immobilization by microorganisms, leaching (Barrett and Burke, 2000; Kaye et al., 2002).

In native tallgrass prairie ecosystems, plant species composition is an important factor that can influence N and C cycling and storage, particularly due to species-specific traits associated with the C_3 and C_4 plant functional groups that typically dominate these ecosystems (Eviner et al., 2006; Hobbie, 1992; Wedin and Tilman, 1990). For example, C_4 prairie grasses typically produce more biomass (both above- and below-ground) and have more recalcitrant tissue (i.e. higher C:N and lignin:N ratios) than C_3 grasses and forbs (Baer et al., 2002; Wedin and Tilman, 1990). Consequently, increasing dominance of C_4 species generally decreases N and C mineralization rates (Baer et al., 2002; Epstein et al., 1998; Mahaney et al., 2008). In contrast, C_3 forbs have deeper roots and take up more water and nutrients (Nippert and Knapp, 2007) and accumulate N and C deeper in the soil layers compared to C_4 grasses (Fornara and Tilman, 2008). Therefore, simultaneous presence of different plant functional groups with different functional traits may sustain multiple ecosystem services in grassland ecosystems as result of niche partitioning that allow the species to capture resources in ways that are complementary in space and time (Fornara et al., 2009; Fornara and Tilman, 2008; Nippert and Knapp, 2007). Therefore, incorporation of a C_3 and C_4 species mix within crop fields should increase plant functional complementarity in PVS promoting retention of N from agricultural watersheds. Studies in Minnesota USA indicate high-diversity mixtures of both C_3 and C_4 stored 500% and 600% more soil C and N than did monoculture plots of the same species (Fornara and Tilman, 2008). Thus, mixes of C_3 and C_4 species in PVS within crop fields should increase SOC stocks and the accompanying stoichiometric sink for N (Barrett and Burke, 2000; Fornara and Tilman, 2008; Mahaney et al., 2008; Ramundo et al., 1990) when C accumulates more rapidly than N. Additionally, management practices such as annual burning and mowing can affect prairie vegetation composition (ratio of C_3 to C_4 plant species) and influence N and C cycling in RNP and PVS (Collins et al., 1998). For example, although mowing and burning influencing the presence of forbs, burning declined plant richness (Carter et al., 2000). With respect to N cycling, Maron and Jefferies (2001) found substantially greater amounts of N in prairie soils with mowing, while fire reduced net N mineralization, N availability, and plant uptake, while promoting immobilization of existing N in the organic fraction of soil from turnover of organic matter of lower quality (low N content and high C:N ratio; Anderson et al., 2006; Blair, 1997; Turner et al., 1997).

Potential impacts of PVS on TN stocks and transformations in agricultural landscapes may also be influenced by landscape position. Research conducted in restored and native tallgrass prairie ecosystems showed that both N cycling and availability (Schimel et al., 1991; Turner et al., 1997), as well as plant N uptake and C storage (Knapp et al., 1993; Nippert et al., 2011; Turner et al., 1997) varied by slope position. However, knowledge about the specific mechanisms that control spatio-temporal fluxes of N and C within PVS located in different landscape positions and embedded within a matrix of annual crops is lacking (Lovell and Sullivan, 2006).

To advance understanding of the ecological functions and management of PVS with respect to N and C dynamics within agricultural landscapes, the objectives of this study were to: (1) evaluate changes in total soil organic C and N stocks under PVS compared to an annual rowcrop agricultural system (CROP) and a 17-year old reconstructed native prairie (RNP); (2) quantify the amount of N stored in plant aboveground biomass and assess the ratio of C_3:C_4 species within PVS and RNP; (3) determine the inorganic N availability under each of the three cover types; and (4) assess the influence of topographical position on each variable measured in #1–3 above. We hypothesized that (1) total SOC and TN stocks would be higher in PVS compared to CROP; (2) plant N stocks would be higher in PVS than RNP due to additional N supply from fertilizer applied in crop areas upslope the strips; (3) inorganic N availability would be higher in CROP compared PVS and RNP, with higher N availability in PVS than RNP because of fire management and lower C_3:C_4 ratios in RNP; and (4) topographical position would influence N availability and retention through redistribution of water and organic matter from upslope to downslope positions in the three covers.

2. Methods

2.1. Study area

The study was conducted at the Neal Smith National Wildlife Refuge (NSNWR), a 3000 ha area managed by the U.S. National Fish and Wildlife Service located in the Walnut Creek watershed in Jasper County, Iowa. The central mission of the NSNWR is to reconstruct the pre-settlement vegetation on the landscape, particularly native tallgrass prairie. Lands that have not yet undergone restoration activities are either maintained as pasture or leased to local farmers for production of corn and soybean using approved practices (e.g., no-till and restricted chemical inputs). Reconstructed prairies are maintained by prescribed fire, generally implemented in the spring every 1–2 years.

The NSNWR comprises part of the southern Iowa drift plain (Major Land Resource Area 108C) (USDA Natural Resources Conservation Service, 2006), which consists of steep rolling hills of Wisconsin-age loess on pre-Illinois a till (Prior, 1991). Dominant soils within the study area belong to the Ladoga series (Mollic Hapludalf), characterized as having 5–14% slopes and being highly erodible (Nestrud and Worster, 1979; Soil Survey Staff, 2003). Mean annual precipitation is 850 mm with the largest storms occurring between May and July (National Ocean and Atmospheric Administration Station at the NSNWR).

2.2. Experimental design

This study was implemented on three small adjacent watersheds (0.73, 3.0, and 0.60 ha), each of which was subjected to one of the following treatments: (1) 100% rotational row-crop agriculture of corn (*Zea mays*) and soybean (*Glycine max*; hereafter 'CROP'), (2) 20% perennial cover (distributed in three strips: upslope, sideslope and footslope position) (hereafter 'PVS'), and (3) 100% reconstructed 17-year old native prairie (hereafter 'RNP') as the control condition. In July 2007, areas receiving PVS treatment were tilled and broadcast seeded with native tallgrass prairie seed mix containing 32 species (Table 1) in a proportion of 26 C_3 species (3 grasses and 23 forbs) and 6 grasses C_4 (Hirsh, 2012). This mixture reflected the common mix of species used by the NSNWR staff in prairie reconstruction practices as in the RNP. The width of the PVS ranged from 27–41 m at the footslope to 5–10 m at the sideslope and upslope positions. The RNP was managed with prescribed burning in the spring every 1–2 years (April 2005, 2007, 2008, and 2010) following standard NSNWR practices. Due to logistical constraints that preclude management of PVS with fire, they were mowed annually to remove senesced vegetation. Prior to treatment, these two watersheds were dominated by perennial bromegrass (*Bromus* L.) for at least 10 years without fertilizer application. In August 2006, the crop areas in the watersheds and the areas to be planted to PVS were uniformly tilled with a mulch tiller. Starting in spring 2007, a 2-year no-till corn-soybean rotation (soybean in 2007) was implemented in the CROP and PVS treatments. During corn years, approximately 135 kg ha^{-1} of NH_3-N was injected to the soil before planting.