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Groundwater conditions under a reconstructed prairie chronosequence

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ABSTRACT

Chronosequences are useful to evaluate long-term changes in ecosystem services but assessing groundwater quality changes using this approach has rarely been done. In this study, groundwater level and quality comparisons were made in a watershed-scale reconstructed prairie chronosequence that extended back in time approximately 13 years at the Neal Smith National Wildlife Refuge (NSNWR) near Prairie City, Iowa. Our objectives were to determine whether groundwater conditions varied significantly across the chronosequence and quantify the rate of nitrate concentration reduction when row crop fields are replaced by prairie. We installed 19 groundwater wells at upland locations selected to provide similar soil type, landscape position and slope. Water samples were collected on five occasions in 2006 and 2007 and analyzed for field parameters, anions and NO_3-N, NH_4-N and PO_4-P. Significant groundwater changes were primarily associated with groundwater levels, and groundwater nitrate and chloride concentrations. The groundwater was deeper under the older prairie plantings but fluctuated similarly among all well sites. Groundwater nitrate and chloride concentrations decreased 0.58 and 0.52 mg/l per year over the 13-year chronosequence, respectively. Results are seen to provide some guidance to land managers regarding possible nitrate concentration reductions achievable from converting cropland to perennial land cover in similar geomorphic settings.

1. Introduction

Nitrate-nitrogen (nitrate) export from the Corn-Belt region of the United States has been identified as a major contributor to Mississippi River pollutant loads and development of hypoxic conditions in the Gulf of Mexico (Goolsby et al., 1999; Burkart and James, 1999). Traditional efforts to reduce nitrate losses from agricultural systems have considered a variety of in-field and edge-of-field management practices, including crop rotations, fertilizer applications, riparian buffers and conservation tillage (Dinnes et al., 2002). One common conservation practice in the U.S. Corn-Belt region is retiring marginal row croplands to grassland as part of the United States Department of Agriculture Conservation Reserve Program (CRP). Drainage water under CRP and alfalfa (*Medicago sativa*) land cover was found in one study to contain nitrate concentrations 35 times lower than drainage water from corn (*Zea mays* L.) and soybean (*Glysine max* L.) fields (Randall et al., 1997). Reconstructed tallgrass prairie was shown to offer similar water quality benefits as CRP, with significantly less drainage and nitrate leaching losses compared to managed corn systems (Brye et al., 2000, 2001). However, such efforts to study the benefits of perennial grasses on subsurface water quality have typically focused on side-by-side plot comparisons that rarely extend beyond a few years in duration.

Chronosequences are time series of sites of varying age with otherwise similar characteristics and they offer an approach useful in evaluating long-term trends in ecosystems without the difficulty of conducting research across many years. Few studies have attempted to quantify groundwater quality changes using a chronosequence, however, and such attempts are often confounded by uncontrolled variation in other characters among sites. Simpkins et al. (2004) used a buffer chronosequence to assess whether groundwater quality improved under a multi-species riparian buffer but they observed inconsistent buffer performance due to differences in age and composition of alluvial sediments. Recently, chronosequences were utilized effectively in evaluating the effects of afforestation on water recharge and nitrate leaching (Van der Salm et al., 2006; Hansen et al., 2007). In a study comparing two chronosequences of oak and spruce on former arable lands, water recharge was found to decrease as a power function from arable farm land through various plot ages in an 18-year oak stand and 14-year old spruce stand (Van der Salm et al., 2006). Nitrate leaching declined with age in the oak stand from 16 kg/ha per year at the youngest stand to 8 kg/ha per year at the 18-year old stand, but no change in nitrate leaching was observed in the spruce chronosequence. In another Danish study, nitrate

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leaching as measured in soil water under three afforestation chronosequences indicated that nitrate concentrations became almost negligible in forest stands of 5–20 years in age (Hansen et al., 2007). However, they noted that variations in nitrate leaching occurred within the chronosequence based on differences in soil texture and degree of canopy closure.

In this study, groundwater level and quality comparisons were made in a watershed-scale reconstructed prairie chronosequence in central Iowa that extended back in time approximately 13 years. Although a long-term monitoring project is currently following soil and water quality changes under a single reconstructed prairie field in the watershed (Schilling et al., 2007), results from this effort will take many years to achieve. Using the reconstructed prairie chronosequence in this study provided an alternative to long-term monitoring at a single site to detect groundwater quality changes occurring under reconstructed prairie.

The specific objectives of this study were to: (i) evaluate groundwater level and quality patterns beneath a reconstructed prairie chronosequence and a cropped field and (ii) estimate the rate by which nitrate concentrations in groundwater are reduced when row crop fields are planted in reconstructed prairie. To meet our objectives, site locations were selected to ensure uniform landscape position, soils and geology across the chronosequence so that variations in groundwater quality were due to vegetation management and not differences in site characteristics that have complicated other studies.

2. Materials and methods

2.1. Study area

The study was conducted at the NSNWR in the 5218 ha Walnut Creek watershed in Jasper County, Iowa (Fig. 1). The NSNWR is the site of an ambitious project implemented by the United States Fish and Wildlife Service to rebuild a portion of the tallgrass prairie ecosystem in the agricultural Midwest. From 1992 to 2005, an average of about 90 ha of prairie were planted each year, mostly in blocks ranging from 1 to 15 ha in size (Schilling and Spooner, 2006). As of 2005, 1224 ha of the Walnut Creek watershed were planted in native prairie, representing 23.5% of the watershed (Schilling and Spooner, 2006).

The Walnut Creek watershed is located in the Southern Iowa Drift Plain landscape region, an area characterized by steeply rolling hills and well-developed drainage (Prior, 1991). Soils within the Walnut watersheds fall primarily within four major soil associations: Tama-Killduff-Muscatine; Downs-Tama-Shelby; Otley-Mahaska and Ladoga-Gara (Nestrud and Worster, 1979). Most of the soils are silty clay loams, silt loams or clay loams formed in loess and till. The Walnut Creek watershed is in a humid, continental region with average annual precipitation of around 750 mm. Highest monthly rainfall totals typically occur in May and June, although large storms occurring throughout the summer can lead to rapid rises in discharge. Discharge tends to be flashy, displaying rapid responses to precipitation. Stream discharge at a stream gauge at the Walnut Creek outlet has ranged from a high of 56.276 m^3/h to a low of 2 m^3/h (Schilling et al., 2006).

2.2. Site selection protocol

All chronosequence sampling sites were located within the ownership boundary of the NSNWR (Fig. 1). Potential sampling sites were stratified by landscape position, soil type and slope to reduce variability among the chronosequence. All sites were located in an upland landscape position on either Tama or Otley silty clay loam soils. These soil map units are very similar and consist of well drained soils on convex ridge-tops and side slopes that formed in loess under tallgrass prairie vegetation (Nestrud and Worster, 1979). All sites were located on B slopes (2–5% slopes). The upland landscape positions were selected to ensure that the groundwater monitoring wells were installed in topographic high area typified by groundwater recharge (Freeze and Cherry, 1979). Sites were located in areas with very little topographic gradient to minimize runoff and ensure that precipitation infiltrated through chronosequence soils. Prior to land conversion to reconstructed prairie by the U.S. Fish and Wildlife Service, the sites were in row crop rotation of corn and soybeans.

A total of 19 wells were installed across the chronosequence plots, with three wells typically installed within each age class. A single well was installed in the 1998 and 2002 plots, and for the 1997 class, a single well was installed in two separate plots. Plot ages at the NSNWR ranged from 0 year (agricultural field) to 13-year old reconstructions.

In order to examine the nitrate-N levels beneath similar but older prairie reconstructions, four wells were installed at Grinnell College's Conard Environmental Research Area (CERA). This ~150 ha research area is approximately 25 miles northeast of the NSNWR in eastern Jasper County (Fig. 1). Two wells were installed in two separate reconstructions planted in 1974 (one well in each) and an additional two in two reconstructions planted in 1987. All four wells were sited on ridge-tops as above and were underlain by a Tama silt loam soil formed from loess under prairie. Prior to land conversion to reconstructed prairie the sites were in row crop rotation of corn and soybeans.

2.3. Field monitoring and analysis

All groundwater monitoring wells were installed to a depth of 6.1 m using a truck-mounted hydraulic probing unit. The wells were installed using a 3.05 m long, 25-mm diameter factory slotted PVC well screen and 3.05 m solid PVC riser. A silica sand filter pack was poured around the screen and bentonite pellets were added to provide a seal above the screen. In the upland landscape position, where a simple loess over till sequence was present, no detailed lithologic studies were conducted.

Monitoring wells at the NSNWR were sampled five times from June 2006 to November 2007, specifically on June 7, 2006, October 19, 2006, April 5, 2007, June 18, 2007 and November 13, 2007. These times provided samples from before, during and after the growing season. Water levels in the wells were monitored to 2 mm accuracy using an electronic water level probe. Water samples from wells were collected using a peristaltic pump and analyzed in the field for temperature, specific conductance (SC), pH, dissolved oxygen (DO) and reduction–oxidation (ORP) potential using a YSI water quality meter. Accuracy of the measurements was ±0.10 C for temperature, ±0.2 pH units for pH, ±0.1% for SC, ±0.2 mg l^{-1} for DO and ±20 mv for ORP. Due to equipment difficulties, water samples were not field analyzed in October 2006. Well water was slowly pumped to an enclosed sample cup where groundwater chemistry readings were taken with the multi-probe to minimize exposure to the atmosphere. Water samples for laboratory analysis were field filtered through a 0.45 μm glass fiber filter, transported on ice and analyzed within 12 h of collection. Ammonia-N and nitrate-N were determined by flow injection analysis (QuickChem 8000, Lachat Instruments) using the phenolate (NH_4-N) and cadmium reduction (NO_3-N) methods and soluble reactive phosphorus (PO_4-P) via the molybdenum blue ascorbic acid method. Water samples collected in 2007 were further analyzed for selected anions (Br, Cl, Fl and SO_4) via anion chromatography (Lachat Instruments).

In 2007, continuous water level monitoring was conducted in three wells, an old prairie (1994 reconstruction), a new prairie (2003 reconstruction) and an existing farm field planted in corn