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Agricultural conversion of floodplain ecosystems: Implications for groundwater quality

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A B S T R A C T

With current trends of converting grasslands to row crop agriculture in vulnerable areas, there is a critical need to evaluate the effects of land use on groundwater quality in large river floodplain systems. In this study, groundwater hydrology and nutrient dynamics associated with three land cover types (grassland, floodplain forest and cropland) were assessed at the Cedar River floodplain in southeastern Iowa. The cropland site consisted of newly-converted grassland, done specifically for our study. Our objectives were to evaluate spatial and temporal variations in groundwater hydrology and quality, and quantify changes in groundwater quality following land conversion from grassland to row crop in a floodplain. We installed five shallow and one deep monitoring wells in each of the three land cover types and recorded water levels and quality over a three year period. Crop rotations included soybeans in year 1, corn in year 2 and fallow with cover crops during year 3 due to river flooding. Water table levels behaved nearly identically among the sites but during the second and third years of our study, NO_3–N concentrations in shallow floodplain groundwater beneath the cropped site increased from 0.5 mg/l to more than 25 mg/l (maximum of 70 mg/l). The increase in concentration was primarily associated with application of liquid N during June of the second year (corn rotation), although site flooding may have exacerbated NO_3–N leaching. Geophysical investigation revealed differences in ground conductivity among the land cover sites that related significantly to variations in groundwater quality. Study results provide much-needed information on the effects of different land covers on floodplain groundwater and point to challenges ahead for meeting nutrient reduction goals if row crop land use expands into floodplains.

1. Introduction

Floodplains provide an abundance of ecosystem services to society (Opperman et al., 2010), including conservation of biodiversity (Tockner and Stanford, 2002), floodplain fisheries (Costanza et al., 1997; Bayley, 1991), floodwater storage (Opperman et al., 2009), water supply enhancements (Fleckenstein et al., 2004), recreation (Golet et al., 2006) and nutrient retention (Vidon and Hill, 2004; Van Der Lee et al., 2004; Krause et al., 2008; Natho et al., 2013). Denitrification is considered the main process associated with N losses in floodplains (e.g., Pinay et al., 2007; Saunders and Kalff, 2001), whereas sedimentation is a dominant process for phosphorus retention (Van Der Lee et al., 2004). Despite the services they provide, floodplains are among the most threatened ecosystems in the world (Tockner and Stanford, 2002). River regulation (e.g., levees) and intensive agricultural use have disconnected the interactions of rivers with their floodplains and homogenized floodplain environments (Schilling and Jacobson, 2011; Antheunisse et al., 2006; Hohensinner et al., 2004).

Encroachment of row crop land use into perennially-vegetated floodplains is occurring throughout the U.S. Midwest as demands from the biofuel industry are driving expansion of corn and soybean production into marginal areas (Secchi et al., 2011), and perennial grasslands, forest and pastures are increasingly being converted to row crops (Schilling et al., 2010). Approximately one-half of the corn grown in the US is now used for ethanol production and there is economic pressure for still more production (Mehaffrey et al., 2012). Effects of this expansion on hydrology (Xu

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et al., 2013) and nutrient delivery to receiving waters (Jha et al., 2010; Donner and Kucharik, 2008) are being increasingly recognized. Fertilizer applied to newly converted corn will increase nitrogen export (Raymond et al., 2012) and make nutrient reductions more difficult to achieve (INRS, 2013).

Studies have shown that converting perennial vegetation to row crops leads to water quality deterioration, particularly with respect to nitrate. While many studies have used modeling to quantify the effects (e.g., Johnes, 1996; Donner et al., 2004; Schilling et al., 2008; Costello et al., 2009), fewer field monitoring studies have been conducted to directly measure this change. Huggins et al. (2001) found that residual soil nitrate increased 125% the first year following conversion of brome grass to corn. Schilling and Spooner (2006) reported nitrate concentrations in surface water increasing by more than 10 mg/l over a 4 year period in a small Iowa watershed following conversion of Conservation Reserve Program (CRP) grassland to row crop. Likewise, Zhou et al. (2010) observed that nitrate levels in the vadose zone and groundwater significantly increased following grassland to cropland conversion in their study of perennial filter strips. Nitrate concentrations increased from <2 mg/l to more than 11 mg/l at a toeslope landscape position following land use change to row crops (Zhou et al., 2010). During a riparian zone restoration, Schilling and Jacobson (2008) observed nitrate concentrations increasing from <1 to 40 mg/l when the overlying grass cover was removed.

With current trends of converting grasslands to row crop agriculture, there is a critical need to evaluate the effects of land use change on groundwater quality in a large river floodplain system. Our field study focused on comparing groundwater hydrology and nutrient dynamics associated with three land cover types (grassland, floodplain forest and cropland) commonly found on floodplains. Since the cropland site consisted of newly converted grassland, we were also able to document effects of land use conversion on groundwater quality. The specific objectives of our study were to: 1) evaluate spatial and temporal variations in groundwater hydrology and quality patterns associated with three floodplain land cover types; and 2) quantify changes in groundwater quality following land conversion from grassland to row crop in a floodplain. Study results provide much-needed information on the effects of different land covers on floodplain groundwater and point to challenges ahead for meeting nutrient reduction goals if row crop land use continues to expand into floodplains.

2. Materials and methods

2.1. Study area

The study was conducted at The Nature Conservancy (TNC) property located on the floodplain of the Cedar River in Muscatine County, Iowa (lat 41°23′21″, long 91°19′09″) (Fig. 1). The climate of the region is humid, continental with average annual precipitation of about 864 mm. The average summer temperature is 25 °C whereas the winter temperatures can reach −26 °C. The average growing season is about 170 days in a typical year. A U.S. Geological Survey (USGS) stream gage is located on the Cedar River approximately 1 km north of the site (Cedar River near Conesville, station number 05465000) (Fig. 1). The Cedar River watershed draining to the Conesville gage encompasses 20,163 km^2 (7785 mi^2), an area that includes much of eastern Iowa that is dominated by agricultural land use. The long-term mean discharge in the river is approximately 5200 cfs.

Three land covers representative of common floodplain uses were evaluated in this study (Fig. 1). The grass site consists of a monotypic stand of *Phalaris arundinacea* (reed canary grass), a common perennial grass found throughout humid areas of northern United States and Canada (Galatowitsch et al., 1999) that is considered among the most invasive species found in wetlands and other lowland areas (Zedler and Kercher, 2004). The woods site was dominated by typical floodplain species, including Swamp white oak (*Quercus bicolor*), swamp hickory (*Carya cordiformis*), American elm (*Ulmus Americana*), hawthorns (*Crataegus* sp.) and scattered occurences of Osage orange (*Maclura pomifera*) and Honey locust (*Gleditsia triacanthos*), with a weedy understory including abundant nettles (*Urticacaeae*) and scattered sedges (*Cyperacaea*).

Unlike the existing grass and woods sites, the cropped site was carved out of the grass area especially for this study. Prior to land cover conversion, the cropped area was in reed canary grass although historical photographs of the area indicate that the land was cropped in the past as recently as the early 2000's. In 2011, a local farmer was retained by TNC to cultivate the floodplain. In April 2011, the grass was burned and the field was planted in soybeans. In June 2011, field applications included phosphorus in the form of monoammonium phosphate $(NH_4)H_2PO_4$ (40 lbs/ac) and potassium from potash (~95% KCl) at a rate of 70 lbs/ac. Glyphosate was applied for weed suppression at this time. In March 2012, granular application of 11-52-60 NPK (lbs/ac) was applied to the cropped field in preparation for corn planting. In June 2012, the corn was side-dressed with 32% liquid N (urea ammonium nitrate solution) at a rate of 220 lbs/ac (70.4 lbs/ac as N). In 2013, the field was not planted in crops due to wet conditions and flooding of local access roads. Instead, in August 2013, the field was planted with rye and radishes as a preventative cover crop.

2.2. Methods

Monitoring wells were located in a crossing pattern at each of the three land covers targeted for investigation (Fig. 1). Nested shallow and deep wells were installed in the center of the grid. All shallow wells were installed using a truck-mounted Geoprobe™ hydraulic percussion system to a depth of 2.4 m below ground surface with the well screen placed at a depth of 0.9–2.4 m. A 1.5 m riser attached to the screen extended the well above the land surface. At the deep well in the middle of each land cover plot, the well was installed to a depth of 5.2 m below ground surface.

A borehole geophysical log of ground conductivity was collected during well installation using the Geoprobe™ at the center of each plot (location of center well). In March 2011, a surface geophysical survey of the monitoring well area was conducted using a Geonics EM-31 unit. The EM-31 maps changes in ground conductivity (inverse of resistivity) using an electromagnetic induction technique with an effective depth of penetration of approximately 6 m (www.geonics.com). The EM-31 survey consisted of walking survey lines oriented east–west across the area. Values were recorded with coordinate locations in a continuous manner and appended and recording values in a continuous mode that were stamped with the coordinate locations using a high-precision GPS. The survey points were contoured with the kriging routine in ArcGIS.

Following well installation, the wells were located with GPS and the top of the casings were surveyed to a site-established benchmark. The wells were developed by surging and overpumping using a Waterra sampling system. The 18 monitoring wells were sampled on 12 occasions during the 2011 to 2013 study period. Water levels in wells were measured to the nearest millimeter at the time of sampling. 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 oxidation–reduction potential (ORP) using a YSI Model 556 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 for DO and ±20 mv for