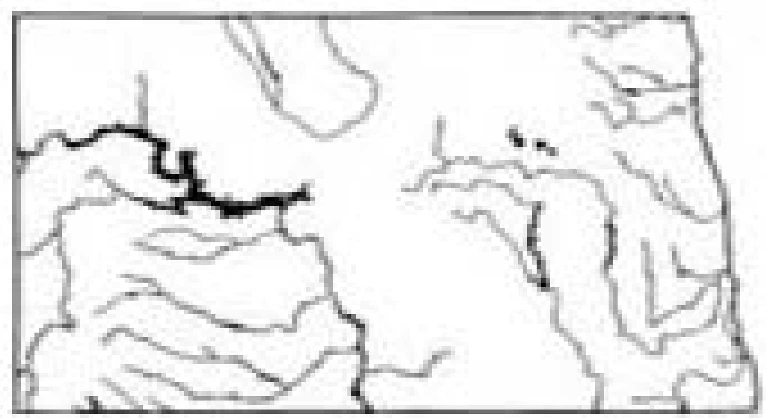

Technical Report No: ND16-01

THE CYCLING AND FATE OF PHOSPHORUS AT AN ABANDONED FEEDLOT

by

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North Dakota Water Resources Research Institute
North Dakota State University, Fargo, North Dakota
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TABLE OF CONTENTS

Contents Page

LIST OF FIGURES

Figure Page

LIST OF TABLES

Table | Page

ABSTRACT

Nutrients, including nitrogen and phosphorus are important in various ecosystems, but when mismanaged can cause adverse health and ecological problems. It is hypothesized that nitrogen can cause a short-term contamination of soils and groundwater beneath feedlots, but phosphorus can cause both short- and long-term contamination in well-drained iron and calcium rich soils. To test this hypothesis, a feedlot abandoned more than a decade ago was used as a model for this research because of the existence of different soil types, apparent variable plant vigor, and the hydrological conditions prevailing. This research aims at determining the sources and sinks of nutrients, characterizing nutrients distribution, and quantifying phosphorus budget.

Soil, groundwater, surface water, and plant tissue samples were collected and analyzed for nutrients. It was observed that nitrogen concentration was less at the source (feedlot pens) due to processes including denitrification, volatilization, leaching, and transportation in the wetlands characterized by high plant vigor. In contrast, phosphorus was sequestered in soils at the source area that had high organic matter, iron, and calcium content, making it unavailable for plant consumption.

This research provides insight into the viability of feedlots abandoned more than a decade as a source of phosphorus to supplement the primary sources of phosphorus used in fertilizer. Phosphorus concentrations in some areas exceed 50 mg kg^{-1}, which implies no soil phosphorus fertilization is required for plant growth. Agronomists and stakeholders in agriculture and food security should take a holistic approach and conduct feasibility studies on using sequestered phosphorus in abandoned feedlot soils as alternative source of phosphorus fertilizer.

ACKNOWLEDGMENTS

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This report is based on a dissertation submitted to the Graduate School of the University of North Dakota in Grand Forks, North Dakota.

INTRODUCTION

Human activities, including cattle feedlot operations and agriculture, have resulted in elevated nutrients (nitrogen and phosphorus) concentrations in wetlands and other parts of the ecosystem (Ancell et al., 1997). Most of the excessive nutrients in soil and water near feedlots are from agricultural activities (Mielke and Ellis, 1976; Olson et al., 2005) including manure mismanagement, resulting in large concentrations of odorous gases, including hydrogen sulfide and ammonia. Excessive phosphorus and nitrate in surface and groundwater have been a major concern for the world (Tappin, 2002).

During stormwater runoff events when feedlots are operational or abandoned, natural processes such as weathering and erosion can result in elevated concentration of nutrients in soils (Dauden and Quilez, 2004), surface water (Knight et al., 2000; Thorne et al., 2007), and groundwater (Mielke and Ellis, 1976). The nutrients are either transported by wind as particles (Harper et al., 2010; Sankey et. al, 2012) or by storm events through preferential pathways (Sharpley et al., 2003) and can accumulate in nearby wetlands (Hopkinson, 1992), be sequestered in soils (Craft, 2007), adsorbed on biomass (Stewart et al., 1990; Ciria et al., 2005), or transported in streams. This has created environments favorable for eutrophication or hypertrophic conditions. Eutrophication promotes algae growth and bacteria contamination (Smith and Schindler, 2009), resulting in reduced dissolved oxygen concentration in surface water (Wyngaard et al., 2011). This can affect water quality and also cause death of aquatic and riparian species (Carpenter et al., 1998). This has led to the enactment of the Harmful Algal Bloom and Hypoxia Research and Control Amendments Act (Public Law 113-124) by the United States Senate on February 26, 2014. This law aims at promoting the development of new technologies for predicting, monitoring, and mitigating harmful algal bloom and hypoxia conditions.

Nutrients, including nitrogen and phosphorus undergo different biogeochemical processes involving soil, water, microbes, and vegetation. Nitrogen, through the aid of bacteria (nitrifying, denitrifying, and nitrogen fixing) and soil conditions (including presence of nitrogen, organic matter, pH, temperature, and the amount of moisture and oxygen present) (Jones and Jacobsen, 2001), is converted to other forms through processes including volatilization, denitrification, and/or dissimilatory reduction (Van Oostrom and Russell, 1994; Vymazal, 2007). In contrast, phosphorus accumulates in soils (Walbridge and Struthers, 1993) through immobilization, sorption and precipitation, and/or incorporation in plants (Clarkson, 1966) and micro- and macro-organisms (Mitsch and Gosselink, 1993; Wang et al., 2012). It is hypothesized that nitrogen can cause a short-term contamination of soils and groundwater in areas saturated with nutrients while phosphorus can cause both short- and long-term contamination, especially in well-drained carbonate and iron-rich soils.

In view of this, an abandoned feedlot in the Glacial Ridge National Wildlife Refuge was used as a model in characterizing the behavior of phosphorus and nitrogen. This site was selected for this research because of the existence of soils with a range of textures and hydrological condition, and the apparent variable plant vigor. Secondly, the feedlot is underlain by till at shallow depth and largely bounded by wetlands, thus constituting a comparatively simple hydrogeological system. Finally, the former pens within the feedlot are underlain by sandy soil that provides good drainage. The main objectives of this study is to: 1) determine the sources and sinks of nutrients in the area, 2) quantify and characterize nutrient distribution in surface water, groundwater, plant tissue, and soils, and 3) determine the budget of phosphorus and its relationship to nitrogen within the former feedlot and adjacent wetlands.

MATERIAL AND METHODS

Site Description

The former Crookston Cattle Company feedlot (47^{o} 43.6’ N; 96^{o}19.2’ W) and the Crookston Prairie Unit of Pembina Trail Scientific and Natural Area (47^{o} 42.0’ N; 96^{o}20.7’ W) comprise the study area. These areas are located in the Glacial Ridge National Wildlife Refuge near Crookston and Mentor, Minnesota (Fig. 1). The two sites are within the Red River watershed and they lie along prominent sandy beach ridges developed approximately 12,000 years ago, on the eastern margin of former glacial Lake Agassiz (Wright, 1972).

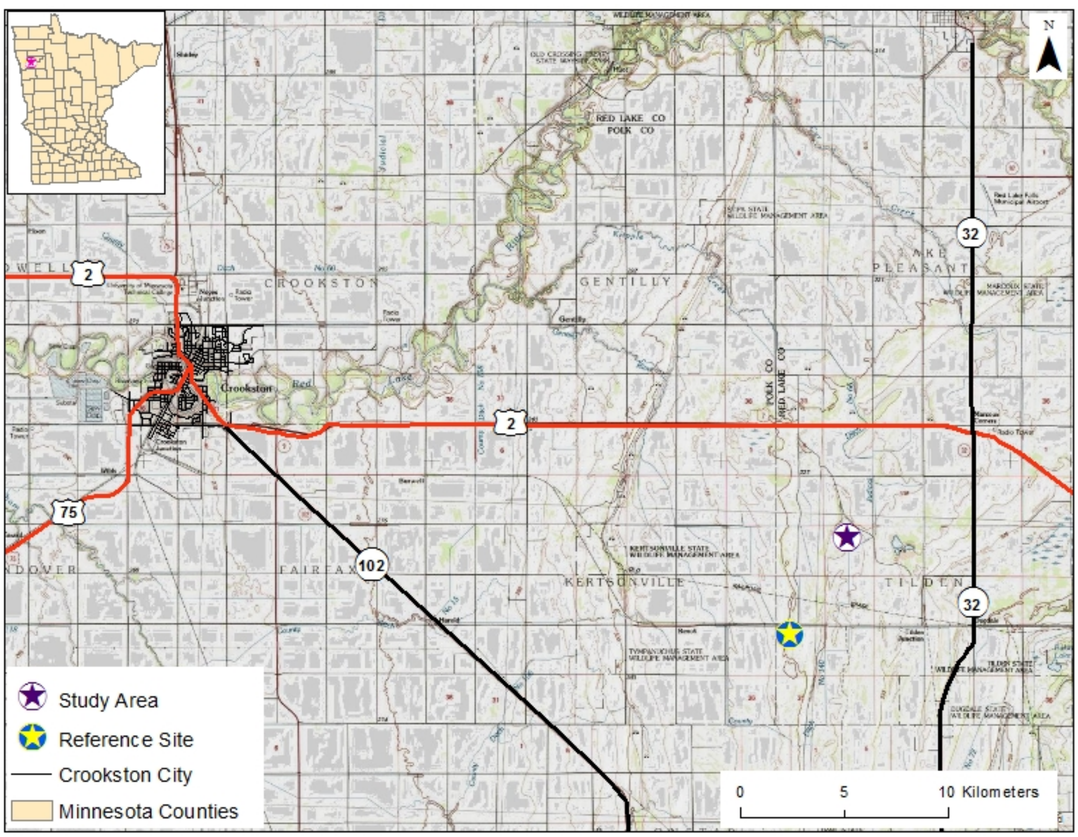

Fig. 1: Study area showing the major roads and the city of Crookston, Minnesota (After Google image, 2014).

The feedlot, which operated from 1970 to 2000, contained as many as 2,500 cattle at one time. It is surrounded on the north and south by wetlands characterized by grassland vegetation dominated by largely non-native bluegrass (Poa sp.), quackgrass (Elymus repens), and smooth brome (Bromus inermis) on the beach ridge, and reed canary grass (Phalaris arundinacea) and hybrid cattail (Typha sp.) in the wetlands. The Pembina Trail Preserve SNA was used as a reference site for this study since it has no record of anthropogenic disturbance. Most of the study was conducted within the abandoned feedlot.

Climate in the area is classified as mid-latitude continental, with hot summers and long cold winters. The average annual precipitation measured from 1981 to 2010 amounts to 690 mm (MCWG, 2014), with June being the wettest month.

The study area has a low-relief topography, with approximately 3 m of relief and lies at an elevation of 333.7 m above mean sea level (AMSL) on the beach ridge and 330.3 m AMSL in the wetlands. Most of the surface and landforms in the area were produced by glaciation during the Late Quaternary Period. During the Pleistocene Epoch, the advancement of the Laurentide Ice Sheet as lobes likely caused the deposition of surficial geologic materials. Some of the lobes retreated, resulting in the formation of the glacial Lake Agassiz and the sandy beach ridges along the eastern margin of glacial Lake Agassiz (Wright, 1972), which forms part of the study area. The Quaternary Red Lake Falls Formation immediately underlies the beach ridges in the vicinity of the feedlot. This formation is carbonate-rich and overlain by light gray to yellow brown silty, sandy pebbly-loam, deposited as a result of southward glacial flow (Harris et al., 1974).

According to the U.S. Department of Agriculture (USDA, 2012), the area is characterized by five major soil series ranging from well-drained to poorly drained soils. These include

Sandberg loamy sand, Syrene sandy loam, Strathcona fine sandy loam, Hedman loam, and Radium loamy sand.

Site Characterization

The area was characterized by using fourteen shallow monitoring wells (BRW, BTB, DVPT, FLE, FLW, MW1 (U), NWW, PGB, PGN, POND, SGS, SPN, SWW, and WDP), five deep monitoring wells (MW1L, MW2, MW3, MW4, and MW5), and dugouts or uncased pits (OP1, OP2, OP3, OP4, and OP5), along with data from the U.S. Geological Survey Well G8 (*USGS 474346096185501*) installed for monitoring water quality (Fig. 2). The shallow wells were used to determine the groundwater flow direction, while the deep monitoring wells were used to determine the connectivity of the geologic materials, and also determine the vertical flow of groundwater in the study area. Groundwater data obtained from the U.S. Geological Survey

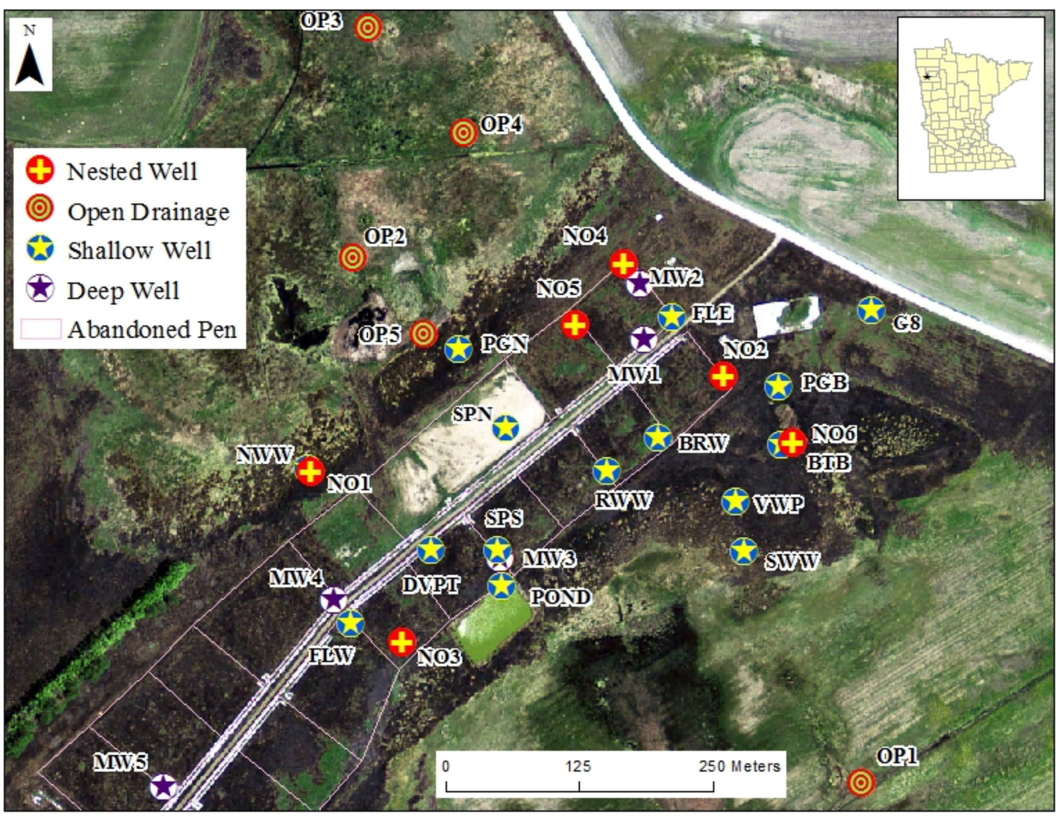

Fig. 2: Location of the monitoring wells and the uncased pits.

National Water Information System (NWIS; http://waterdata.usgs.gov/nwis) were used to tabulate the concentration of groundwater nutrients in Well G8 since the feedlot was abandoned.

Groundwater elevation was determined using a water level meter after the monitoring wells have been surveyed using an EAGL Electronic Laser Level (model 1000) and their locations taken with an Etrex Vista Hcx Garmin Global Positioning System.

Groundwater Sample Collection and Analyses

Both filtered and unfiltered groundwater samples were collected from both shallow and deep monitoring wells using a decontaminated polyethylene bailer after the wells were thoroughly purged and allowed to recover. Thorough purging was done by removing a minimum of three well-bore volumes of water from the wells before groundwater samples were collected. The unfiltered samples were immediately analyzed for pH, electrical conductivity, and temperature using a calibrated waterproof ExStik® II pH/Conductivity/TDS meter in the field. A second sample was filtered through a disposable 0.45μm filter membrane using a peristaltic pump and placed in sterilized one liter (L) and two 250 mL high-density polypropylene bottles. One of the filtered samples in the 250 mL polypropylene bottles was preserved with concentrated hydrochloric acid to maintain a pH of less than 2. This prevented the precipitation or formation of metal complexes, which may influence analytical results. Another unfiltered sample was placed into a 120 milliliter (mL) round amber glass sample bottles, with no headspace. This portion of the sample was used for carbon analysis and bottled this way to minimize the exchange of carbon dioxide with the headspace atmosphere or minimize the bacterial decomposition of analytes. Finally, a 250 mL unfiltered sample was stored for analysis of total phosphorus.

The filtered and unfiltered samples were placed in an ice-filled chest immediately after bottling. The samples were transported from the field within a few hours and refrigerated in the laboratory. Chemical analyses were carried out prior to the recommended maximum storage duration information provided by University of North Dakota's Environmental Analytical Research Laboratory (EARL) according to APHA et al. (1998).

Chemical analyses of the water samples were performed at EARL. A Shimadzu TOC analyzer (Model Vcs_N) was used to analyze for total carbon, inorganic carbon, and total organic carbon. The filtered unpreserved samples were used for nitrate-nitrogen, nitrite-nitrogen, and soluble or dissolved reactive phosphorus analyses. Nitrate-nitrogen and nitrite-nitrogen were measured using ion chromatography (Dionex DX-120, USA.). The filtered preserved samples were used for ammonium-nitrogen analysis. Soluble reactive phosphorus, total phosphorus, and ammonium-nitrogen were measured using a HACH DR/2010 spectrophotometer. Soluble reactive phosphorus, total phosphorus, and ammonium-nitrogen analyses used ammonia nesslerization, ascorbic acid, and acid-hydolyzable digestion methods, respectively.

Laboratory quality assurance and quality control were done to ensue acceptable analytical accuracy and precision. These included using duplicate samples and reagent blanks in the analysis, and matrix spike analysis. The overall analytical recovery was between 80-120% for all of the elements analyzed.

Soil Sample Collection and Analyses

Sixty-three O- and A-horizon and sixty-one B-horizon composite samples were collected across the beach ridge at various depths perpendicular to the trend of the beach ridge and the feedlot (Table 1; Fig. 3). The samples were collected from late June to July 2013 using an auger and a hand scoop after the top layer of desiccated and partially decayed organic materials was removed. To obtain a homogeneous sample representative of the entire sampling interval, each sample was disaggregated and thoroughly mixed. The composite soil samples were transported on ice and kept frozen until analysis.

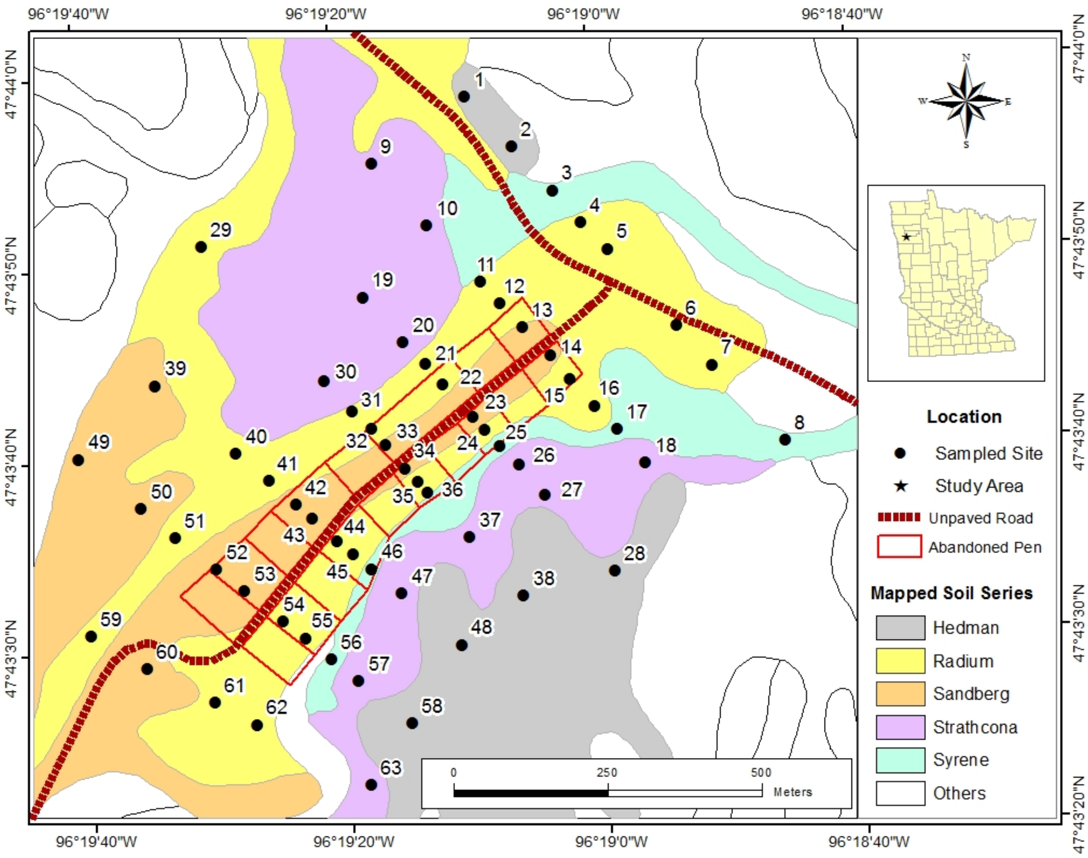

Fig. 3: Study area showing the soil series, sampled sites, and the location of the former pen areas.

Prior to chemical analysis, the samples were split into two portions. One part was immediately used for pH and electrical conductivity analysis, while the other part was air-dried at room temperature for organic matter, nitrate-nitrogen, total nitrogen, ammonium-nitrogen, total phosphorus, total carbon, total organic carbon, calcium, and iron. Samples for chemical analyses were pulverized, mixed, and sieved through a number 10 sieve (2 mm wire mesh) prior to analysis at the Soil and Plant Testing Laboratory of the North Dakota State University (NDSU).

Table 1: Soil series (USDA, 2012) and depths sampled

Site	Easting (UTM)	Northing (UTM)	Soil Series	O- & A-Horizons Interval	B-Horizon Interval
1	700984	5290096	Hedman	28	23
2	701060	5290016	Hedman	28	23
3	701126	5289945	Syrene	28	18
4	701172	5289894	Radium	36	45
5	701215	5289851	Radium	36	45
6	701327	5289728	Radium	36	45
7	701385	5289665	Radium	36	45
8	701503	5289543	Syrene	28	18
9	700833	5289987	Strathcona	25	18
10	700923	5289889	Strathcona	25	18
11	701010	5289798	Radium	36	45
12	701041	5289763	Radium	36	45
13	701078	5289724	Sandberg	48	48
14	701123	5289680	Sandberg	48	48
15	701155	5289641	Radium	36	45
16	701195	5289598	Radium	36	45
17	701231	5289561	Syrene	28	18
18	701277	5289507	Strathcona	25	18
19	700819	5289772	Strathcona	25	18
20	700885	5289700	Strathcona	25	18
21	700921	5289665	Radium	36	45
22	700949	5289632	Radium	36	45
23	700997	5289580	Sandberg	48	16
24	701016	5289558	Radium	36	45
25	701041	5289532	Syrene	28	18
26	701072	5289503	Strathcona	25	18
27	701114	5289454	Strathcona	25	18
28	701227	5289332	Hedman	28	23
29	700557	5289854	Radium	36	45
30	700756	5289637	Strathcona	25	18
31	700803	5289589	Radium	36	45
32	700834	5289560	Radium	36	45

The coordinates are in meters. Datum: NAD 1983 and zone 14. The intervals for both O- and A- and B-horizon samples are in cm.

Table 1 (*Continued*)

Site	Easting (UTM)	Northing (UTM)	Soil Series	O- & A-Horizons Interval	B-Horizon Interval
33	700855	5289535	Sandberg	48	16
34	700887	5289497	Sandberg	48	16
35	700908	5289475	Radium	36	45
36	700925	5289458	Radium	36	45
37	700992	5289386	Strathcona	25	18
38	701079	5289292	Hedman	28	23
39	700483	5289629	Sandberg	48	16
40	700614	5289521	Radium	36	45
41	700668	5289477	Radium	36	45
42	700711	5289438	Sandberg	48	16
43	700737	5289415	Sandberg	48	16
44	700778	5289380	Radium	36	45
45	700804	5289359	Radium	36	45
46	700833	5289335	Syrene	28	18
47	700882	5289295	Strathcona	25	18
48	700979	5289212	Hedman	23	23
49	700359	5289511	Sandberg	48	16
50	700460	5289431	Sandberg	48	16
51	700516	5289384	Radium	36	45
52	700582	5289334	Sandberg	48	16
53	700628	5289299	Sandberg	48	16
54	700690	5289250	Radium	36	45
55	700728	5289223	Radium	36	45
56	700768	5289189	Syrene	28	18
57	700813	5289154	Strathcona	25	18
58	700899	5289086	Hedman	28	23
59	700380	5289225	Radium	36	45
60	700470	5289173	Sandberg	48	16
61	700580	5289119	Radium	36	45
62	700648	5289084	Radium	36	45
63	700833	5288987	Strathcona	25	18

The coordinates are in meters. Datum: NAD 1983 and zone 14. The intervals for both O- and A- and B-horizon samples are in cm.

Soil pH and electrical conductivity analyses were done using the U.S. EPA SW846 or 9054D method according to U.S. EPA (2004), while organic matter analysis was done using the loss on ignition method according to ASTM (2000) procedure.

Plant Tissue Sample Collection and Analyses

Plant tissue samples were collected during four consecutive days in mid July 2013, two days after soil sampling. Graminoids (grass or grass-like monocotyledonous and herbaceous plant species) were sampled at the same locations the soils were collected. The graminoids sampled included reed canary grass (*Phalaris arundinacea*), smooth brome (*Bromus inermis*), Kentucky bluegrass (*Poa pratensis*), hybrid cattail (*Typha* sp.), sedges (*Carex* sp.), redtop (*Agrostis gigantea*), and quack grass (*Elymus repens*).

To minimize bias and ensure good representation of nutrient distribution, healthy and seedless graminoids were sampled. Forty to fifty dominant plants were sampled within a 1.5 m radius around the soil sampled points. The plants were clipped at 6 to 8 cm from ground level. The sampled plant tissues were kept in an open paper box to enable proper air circulation and prevent sample decomposition or formation of molds, which can affect analytic results.

The plant shoots (stems and leaves) were cleaned, air-dried at room temperature, blended, passed through a # 30 sieve (0.60 mm wire mesh), and transported to the Soils Testing Laboratory of the University of Wisconsin-Madison for total phosphorus, total nitrogen, total carbon, zinc, copper, iron, and manganese analyses.

Statistics and Spatial Distribution Analysis

Systat 12 statistical software (Systat Software, Inc. Chicago, IL, USA) was used to perform analysis of variance (ANOVA) on the data obtained. This was used in assessing the significance of relationships in the nutrients distribution.

Spatiotemporal distribution of the soil nutrients was done using Golden Software Surfer 10 software by applying the radial basis function algorithm with an anisotropy ratio of 0.5 at a 315^{o} azimuth. This ratio and azimuth provided the best fit for the soil pattern along the southwest-northeast-trending beach ridge. Testing of the spatiotemporal nutrient distribution and spatial autocorrelation analysis were done using Global and Local Moran's Index (I) in ArcGIS 10.1 software (Environmental Systems Research Institute, Inc. Redlands, CA, USA). The Moran's *I*, which is a cross-product of the deviation from the mean, is based on Equation 1 (Moran 1950):

$$I = \frac{N \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}(x_i - \overline{x})(x_j - \overline{x})}{\left(\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}\right) \sum_{i=1}^{n} (x_i - \overline{x})^2} \qquad \text{Equation (1)}$$

Nutrient Budget

The nutrient budget at the feedlot was based on a mass balance approach involving the mass of phosphorus in the soils, plant tissues, and groundwater sampled within the confined animal holding area of the feedlot. Since most of the phosphorus in the soil was sequestered on the beach ridge with minimal movement into the wetlands, the animal holding area (nutrient hotspots) was considered as an area of interest for the budget.

This budget was based on the assumption that assimilated soil nutrient is part of the plant tissue nutrient and the decomposed and decaying senesced plant tissues concentrations were part of the soil. The area has a flat topography; hence, surface runoff and erosion were neglected. It was assumed that the amount of phosphorus assimilated by soil microbes was insignificant and the amount of phosphorus deposited from the atmosphere was equal to the amount of phosphorus released into the atmosphere as dust, although both are likely insignificant to the budget.

The area of interest (former pen) covers approximately 130,000 m^2 and it is situated on the Radium and Sandberg soils. These soils have estimated bulk densities of 1.25 and 1.36 g cm^{-3}, respectively. The depths of the A- and B-horizons for the Radium soil are 36 and 84 cm and that of the Sandberg soil are 48 and 64 cm, respectively from the land surface. The average concentration of phosphorus within the Radium and Sandberg soils beneath the pen was used to estimate the mass of phosphorus. This is based on equation (2):

$$\text{Mass (kg)} = \text{Mass Concentration (mg kg}^{-1}) * \text{Bulk Density (kg m}^{-3}) * \text{Area (m}^{2}) * \text{Thickness (m)} * 1\ \text{(kg)}/1{,}000{,}000\ \text{(mg)} \qquad \text{Equation (2)}$$

where mass concentration is the concentration of phosphorus in the Radium or Sandberg soils over an area of 130,000 m^2 (pen area), thickness is the depth of the Radium and Sandberg soils, and bulk density is their individual bulk densities. The standard deviation of the mass concentration is used to estimate the uncertainties associated with the estimated mass based on equation (2). This equation was also used to estimate the mass of phosphorus in manure deposited within the pen location using an estimated bulk density of manure.

The mass of phosphorus in the groundwater underneath the area of pen was estimated considering the average concentration of phosphorus in the groundwater within a geologic material with a porosity of 0.15, which is typical of coarse-grained sediments with fines (Fetter, 2001). The average saturated thickness within the sand overlying till at site was obtained from the well logs of the deep monitoring wells MW1 to MW5. The estimated average saturated thickness of the groundwater system was 2.80 m. The mass of phosphorus in the groundwater is estimated using Equation (3):

$$\text{Mass (kg)} = \text{Mass Concentration (mg L}^{-1}) * 1000\ \text{(L m}^{-3}) * \text{Area (m}^{2}) * \text{Saturated Thickness (m)} * 1\ \text{(kg)}/1{,}000{,}000\ \text{(mg)} * \text{porosity (\%)} \qquad \text{Equation (3)}$$

where mass concentration is the average concentration of phosphorus in the groundwater; the standard deviation of the groundwater phosphorus concentrations was used to estimate the uncertainties associated with the mass of groundwater phosphorus.

The estimated mass of phosphorus within the plant tissue was based on the average concentration of the phosphorus in the dry plant tissue per unit sample area, which was applied to the area of interest. The plant tissue samples were dried and weighed to obtain the dry mass per unit sampled area. The estimated mass of plant tissue phosphorus is based on Equation (4):

$$\mathrm{Mass_{phosphorus}} = \mathrm{Av}\left(\frac{\mathrm{Mass_{sample}}}{\mathrm{Area\ Sampled}}\right)\frac{(\mathrm{kg})}{(\mathrm{m^2})} * \mathrm{Area}\ (\mathrm{m^2})\ * \frac{\mathrm{P_{Conc}}(\%)}{100\ (\%)} \qquad \text{Equation (4)}$$

where $\mathrm{Mass_{phosphorus}}$ is the estimated mass of phosphorus in the plant tissue, Av ($\mathrm{Mass_{sample}}$/Area Sampled) is the average of the total mass of the dried plant tissue sampled per unit area sampled (0.40 kg m^{-2}), and P_{conc} is the concentration of phosphorus in the plant tissues.

The mass of phosphorus lost from the time the feedlot was abandoned till now was based on conservation of mass equation:

$$\Delta\mathrm{Storage_{phosphorus}} = \mathrm{Mass_{input}} - \mathrm{Mass_{output}} \qquad \text{Equation (5)}$$

where $\mathrm{Mass_{input}}$ is the mass of phosphorus from the manure and $\mathrm{Mass_{output}}$ is the sum of the mass of phosphorus in the soils, plant tissues, and groundwater. The mass of phosphorus in the various media (soil, groundwater, or plant tissue) with respect to what is obtained at the reference site is based on the formula:

$$\mathrm{Mass_{Actual}} = \mathrm{Mass^{i}_{(Feedlot)}} - \mathrm{Mass^{i}_{(Reference)}} \qquad \text{Equation (6)}$$

where i is the medium of interest (soil, groundwater, or plant tissue), $\mathrm{Mass_{(Feedlot)}}$ is the mass of phosphorus in the medium of interest obtained from the feedlot, $\mathrm{Mass_{(Reference)}}$ is the mass of phosphorus in the medium obtained from the reference site, and $\mathrm{Mass_{(Actual)}}$ is the actual mass of the phosphorus in the medium.

RESULTS AND DISCUSSION

Hydrogeology and Hydrogeochemistry

Groundwater movement is important to redox conditions, nutrient availability, and biogeochemical processes. Groundwater undergoes various chemical reactions as it flows through the sandy beach ridge into the wetlands, thereby affecting water quality in the groundwater system at the feedlot.

The highest groundwater elevations were measured from the beach ridge wells and the lowest elevations obtained from the ditches in the wetlands. A gentle groundwater mound occurs on the beach ridge, where it appears to be preferentially recharged and flows a few tens or hundreds of meters through the coarsest and thickest sediments before being discharged into the nearby wetlands (Fig. 4). A clayey till underlies the site, forming an impervious lower boundary at a depth ranging from approximately 0.3 cm in the wetlands to approximately 8.0 m on the beach ridge.

The water table roughly parallels the orientation of the beach ridge, with flow perpendicular to the beach ridge. The water table at the area is shallower in the wetlands with most of the ditches filled during the wet seasons, but on the beach ridge a maximum range of 0.46 to 0.91 m depth was measured.

Groundwater recharge and discharge cause fluctuation in the water level, which can influence groundwater geochemistry. The rise and fall in the water table creates oxidation-reduction conditions, which influences the release of adsorbed phosphorus from aluminum, iron, and calcium oxides/hydroxides, and also affects the leaching of nitrogen compounds or ions from the O- and A-horizons. These released nutrients move vertically or laterally through into various receptors (ponds and wetlands), where they are there available for plants and microorganisms.

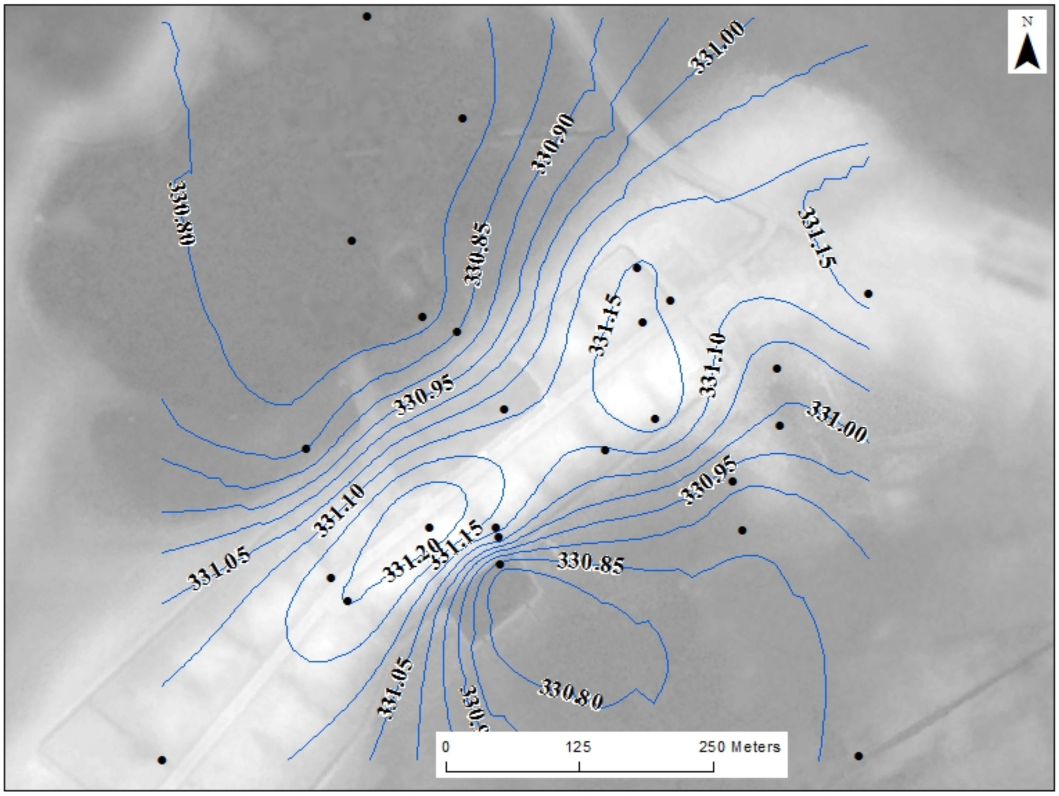

Fig. 4: Water table contours in the vicinity of the feedlot (May 24, 2013). The equipotential lines were obtained from the interpolation of data from Table 2.

pH affects the solubility of minerals, with lower pH accelerating the release of cations from minerals. The measured pH ranged from 7.18 in the deep well of nested well NO6 to 10.64 in the POND (Table 3), which is an indication of dissolution and buffering effect of the carbonates in the soils. Dissolution caused the speciation of ion, which influenced the measured electrical conductivity of the surface water and groundwater. Measured electrical conductivity ranged from 312 $\mu S\ cm^{-1}$ in well SPN to 3250 $\mu S\ cm^{-1}$ in uncased pit (OP4).

Table 2: Water level measured in 2013 at the feedlot

Well	May 24	May 31	June 21	Jul 25	Oct 16	Oct 23	Nov 30
BRW	9.75	9.40	-	9.77	-	-	10.32
BTB	4.66	-	-	-	-	-	-
DVPT	9.18	8.87		9.12	9.85	9.80	9.74
FLE	7.31	6.95	6.78	7.26	8.19	8.12	7.88
FLW	9.33	8.95	8.59	8.99	9.76	9.74	-
USGS G8	-	-	7.69	-	8.99	-	-
MW1(L)	18.58	20.84	8.51	17.88	20.30	20.08	16.95
MW1(U)	7.87	7.45	7.22	7.71	8.65	8.60	8.36
MW2	7.18	7.06	7.16	7.76	8.53	8.46	8.24
MW3	6.8	6.38	6.22	6.82	7.51	7.40	7.33
MW4	10.97	11.65	9.53	9.76	11.13	11.09	-
MW5	9.84	9.42	8.93	9.32	10.02	10.03	-
NWW	4.40	3.87	4.7	3.85	4.83	4.88	-
PGB	5.73	6.00	8.84	5.73	-	6.16	6.16
PGN	4.54	3.73	3.57	5.48	-	5.10	5.16
POND	3.61	3.77	-	4.14	4.49	4.50	4.61
SGN	2.54	-	-	-	-	-	-
SPN	8.54	7.99	8.04	8.60	9.20	9.22	9.18
SPS	9.42	9.02	8.78	-	-	-	9.89
SWW	3.46	3.30	-	3.28	-	-	4.87
VWP	4.84	4.71	-	4.71	-	-	-

The water level (depth to water) measurements are in feet.

Groundwater nitrogen, which normally occurs as nitrate, nitrite, and ammonium, are very mobile and move through preferential subsurface pathways into the wetlands where they undergo biogeochemical changes for plants and microbes assimilation. Groundwater nitrate concentration at the feedlot was variable with high concentrations at the beach ridge compared to the wetlands. Nitrate-nitrogen concentrations range from 0.1 to 14.4 mg L^{-1}, with some wells having concentrations below the detection limit (0.1 mg L^{-1}) (Table 3).

Table 3: Hydrogeochemical data (7/25/2013)

Well	Easting	Northing	Temp	pH	EC	TC	IC	TOC	NO_2-N	NO_3-N	NH_4-N	SRP	TP
BRW	701104	5289603	18.9	7.58	872	111	95	16	0.2	14.4	0.06	0.09	0.47
DUG*	700819	5289772	19.5	8.00	969	144	89	55	<0.1	<0.1	0.07	0.02	0.49
DVPT	700892	5289498	18.9	7.65	720	48	43	5	0.1	5.2	0.01	0.02	0.05
FLE	701118	5289716	18.5	7.50	386	55	44	10	0.6	12.6	0.26	0.03	0.4
FLW	700816	5289429	18.4	7.48	448	61	51	10	1.2	11.6	0.08	0.04	0.52
G8	701304	5289722	18.4	7.20	832	90	56	34	<0.1	1.9	0.03	0.01	0.15
MW2	701087	5289747	12.2	7.61	534	75	64	12	0.01	<0.1	1.36	<0.01	0.05
MW3	700941	5289471	15.4	7.40	920	112	91	21	1.4	3.6	0.25	0.03	0.06
MW4	700800	5289451	17.8	7.50	460	48	46	2	<0.1	<0.1	0.11	<0.01	<0.01
NWW	700776	5289574	18.3	7.60	1554	219	178	40	<0.1	<0.1	<0.01	0.01	0.16
PGB	701218	5289651	18.4	7.36	640	102	86	15	0.1	3.1	0.56	0.04	0.18
PGN	700918	5289686	18.7	7.38	413	86	76	10	0.1	7.9	0.05	0.05	0.06
POND	700958	5289464	19.9	7.18	1328	151	109	42	0.1	0.1	0.84	0.02	0.06
SPN	700962	5289612	19.2	7.88	312	45	36	9	0.1	2.3	0.10	<0.01	0.01
SWW	701185	5289496	18.3	7.88	854	198	187	11	<0.1	<0.1	0.60	0.26	0.40
VWP	701156	5289561	18.9	7.43	984	95	88	7	0.1	2.2	<0.01	0.02	0.04

The chemical species which include TC (total carbon), IC (inorganic carbon), TOC (total organic carbon), NO_2-N (nitrite-nitrogen), NO_3-N (nitrate-nitrogen), NH_4-N (ammonium-nitrogen), SRP (soluble reactive phosphorus), and TP (total phosphorus) are in mg/L, while field parameters including EC (electrical conductivity), T (temperature) and pH are in units of µS cm^{-1}, ^{o}C, and standard units, respectively. Easting and Northing are in meters. Datum: NAD 1983 and zone 14. < indicate below detection limit. TC, IC, and TOC have a detection limit of 1 mg L^{-1}; NO_2-N and NO_3-N have a detection limit of 0.1 mg L^{-1}; and NH_4-N, DRP, and TP have a detection limit of 0.01 mg L^{-1}. *DUG is the same as OP2.

Table 4: Groundwater chemistry of nested well (NO3) samples collected on 7/25/2013

Well Type	EC	Temp.	pH	Salinity	TDS	TC	IC	TOC	SRP	TP	NO_2-N	NO_3-N	NH_4-N
S	888	18.0	8.04	0.5	524	133	102	31	0.02	0.05	0.30	10.2	<0.01
S*	892	18.0	8.04	0.5	530	125	109	17	0.02	0.04	0.42	10.5	<0.01
I	1472	17.8	8.08	1.0	1023	117	98	19	0.01	0.02	0.49	1.5	0.24
D	1150	17.6	8.64	0.8	798	98.45	78	21	0.01	0.01	0.53	0.1	0.42

Table 5: Groundwater chemistry of nested well (NO6) samples collected on 7/25/2013

Well Type	EC	Temp.	pH	Salinity	TDS	TC	IC	TOC	SRP	TP	NO_2-N	NO_3-N	NH_4-N
S	587	18.0	7.64	0.3	346	94	78	16	0.24	0.48	<0.1	<0.1	0.30
S*	592	18.2	7.33	0.3	350	92	73	19	0.19	0.54	<0.1	<0.1	0.38
I	1108	17.2	8.30	0.6	654	86	70	16	0.12	0.14	<0.1	<0.1	2.30
D	926	16.9	10.63	0.5	544	83	71	12	0.01	0.09	<0.1	<0.1	8.48

Field parameters electrical conductivity (EC), Temperature (Temp), total dissolved solids (TDS), and salinity are in the units of µS cm^{-1}, ^{o}C, standard unit, mg L^{-1}, and percent, respectively while chemical species total carbon (TC), inorganic carbon (IC), organic carbon (OC), soluble reactive phosphorus (SRP), total phosphorus (TP), nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), and ammonium (NH_4^+) are in mg L^{-1} with TP and SRP measured as phosphorus. S, I, and D represent shallow, intermediate, and deep nested well with asterisks represent duplicated sample. < represent sample with concentrations below detection limit. TC, IC, and OC have a detection limit of 1 mg L^{-1}; NO_2-N and NO_3-N have a detection limit of 0.1 mg L^{-1}; SRP, TP and NH_4^+ have a detection limit of 0.01 mg L^{-1}.

Groundwater movement seems to influence nitrate concentrations at the site, with the wetlands having lower concentrations compared to the beach ridge. The low concentration of nitrate in the wetlands is associated areas characterized by dense community of graminoids during the time of sample collection. These plants absorb nitrate from water for luxuriant growth (Sharrow and Wright, 1977).

Groundwater nitrogen data from Well G8 indicated a steady decline in combined nitrate and nitrate concentration until 2008 when the concentration fell below 2.5 mg L^{-1} (as nitrogen) and leveled off at less than 2 mg L^{-1} (as nitrogen) (Fig. 5). The nitrate reduction in the well G8 and the wetlands could be due to the formation of different nitrogen compounds or ions through various biogeochemical processes, including denitrification, ammonification, and dissimilatory nitrate reduction to ammonia.

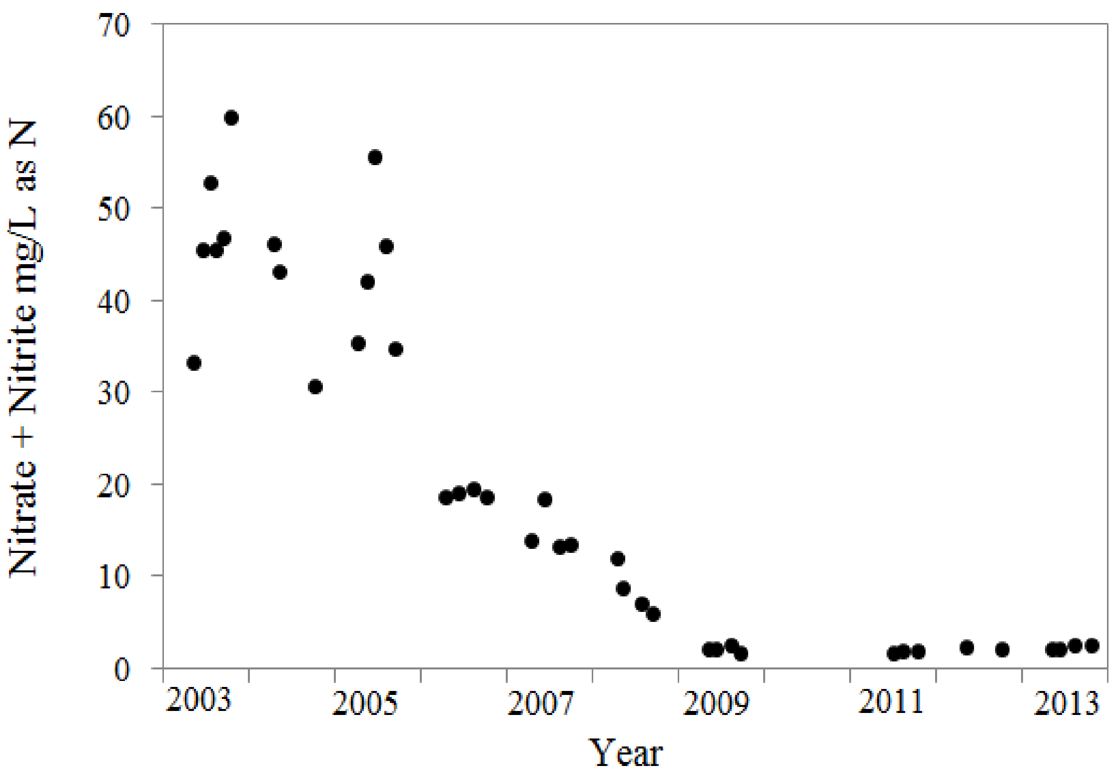

Fig. 5: Decrease in nitrate and nitrite concentrations in the USGS Well G8 from 2003 to 2013. Data were from the National Water Information System Website.

Nitrite, which is obtained when nitrate is reduced, had concentrations less than 1 mg L^{-1} as nitrogen in most of the wells, except in wells FLW and MW3. Wells G8, MW4, NWW, SWW, NO6, and the uncased pits had concentrations below the detection limit. Ammonium-nitrogen concentrations ranged from 0.01 mg L^{-1} in wells DVPT and VWP to 8.48 mg L^{-1} in deep well of the nested well NO6; all of the wells had concentrations less than 1 mg L^{-1}, except well MW2 and intermediate and deep NO6 (Table 5).

In contrast, the concentration of phosphorus did not show any distinct distribution pattern with respect to the beach ridge and the wetlands. Groundwater phosphorus concentration greater than 0.04 mg L^{-1} was measured in samples obtained in most parts of the wetland and the beach ridge, apart from wells MW4, DVPT, SPN, and uncased pit (OP2 or DUG). This is attributed to the release and subsequent dissolution of some of the adsorbed phosphorus, which moves into the wetlands. This may account for the elevated concentration of phosphorus in the groundwater at the study area. Apart from the release of adsorbed phosphorus, elevated concentrations of phosphorus in the wetlands could be attributed to the contribution of organic phosphorus from decomposed organic materials (e.g. Craft and Richardson, 1993; Pant and Reddy, 2001).

Soil Chemistry

Nitrate-nitrogen concentration in the O- and A-horizon composite samples ranged from 0.5 to 26.5 mg kg^{-1} (Table 6; Fig. 6), while the B-horizon had concentrations ranging from 0.5 to 20.0 mg kg^{-1} (Table 7). Soil nitrate concentration showed high values from the margins of the wetland into the wetland, with low concentration on the beach ridge where the animal confinement area is. Farther into the wetlands, nitrate concentrations were low compared to the margins.

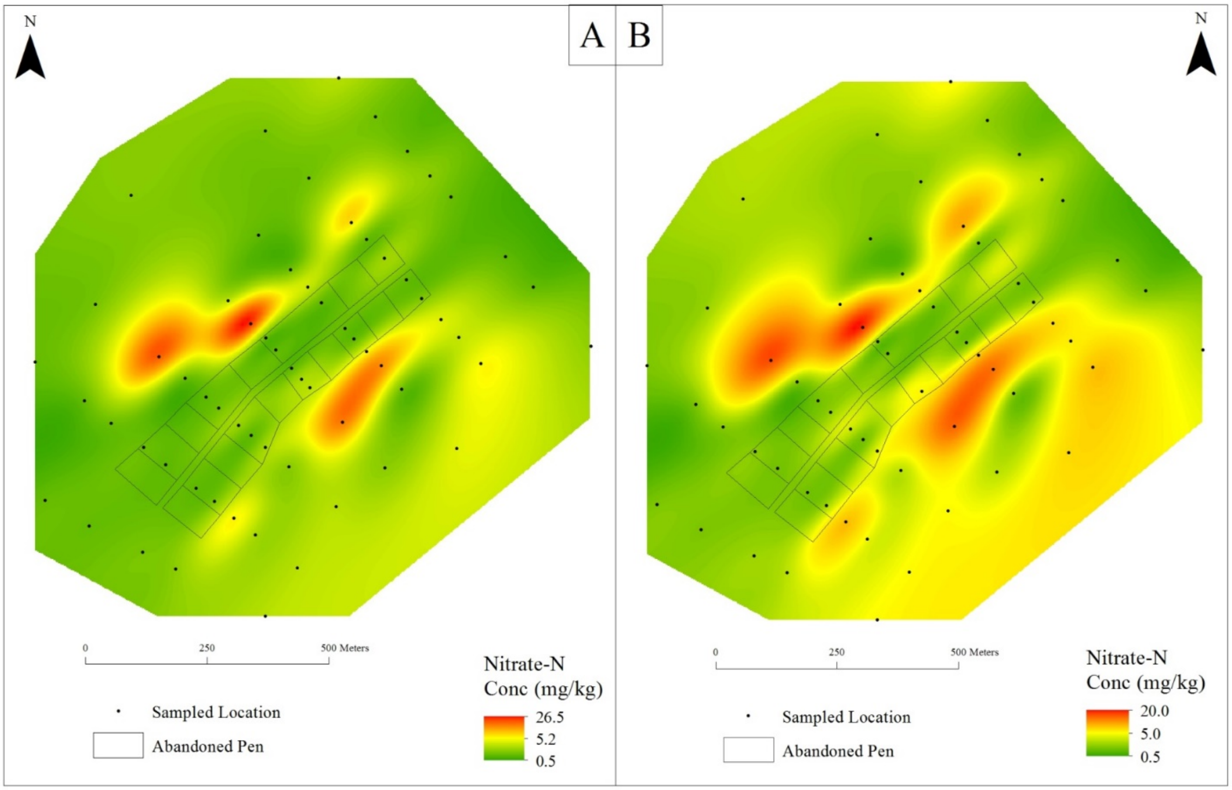

Fig. 6: Distribution of soil nitrate-N in O- and A-horizon (A) and B-horizon composite (B) samples (values are in mg kg^{-1} with red and green representing high and low concentrations, respectively). The soil nitrate data were interpolated using radial basis function.

Although the same pattern was observed in the B-horizon samples, but with wider spatial distribution, their nitrate concentrations were higher than that of the O- and A-horizon composite samples. The spatial distribution of soil nitrate was analyzed using global Moran's I, which indicated Z-score between -1.65 and +1.65. This suggests that the mapped pattern displayed in Fig. 6 was not significant, but a result of random distribution. When the feedlot was operational, there were no regulations requiring the use of liners. Cattle compaction of the manure-covered soil effectively decreases infiltration and greatly reduces the seepage of leachates (e.g., Kurz et al., 2006). When the feedlot was abandoned, the manure seals decomposed, which resulted in the transport of manure constituents from the beach ridge into the wetlands. The mapped pattern displayed in Fig. 6 could be used a tracer for the preference surface and shallow subsurface pathways of nitrate from the former pen location into the wetlands.

Soil nitrate in the B-horizon was higher than that of the O- and A-horizon. The ratio of nitrate concentration in the B-horizon to that of the A-horizon (nitrate enrichment factor) had values ranging from 0.0 to 40. Values ranging from 0.0 to 0.5 and 0.5 to 1.0 indicate minimal and intermediate leaching, while values greater than 1.0 indicate intense leaching (Fig. 7.).

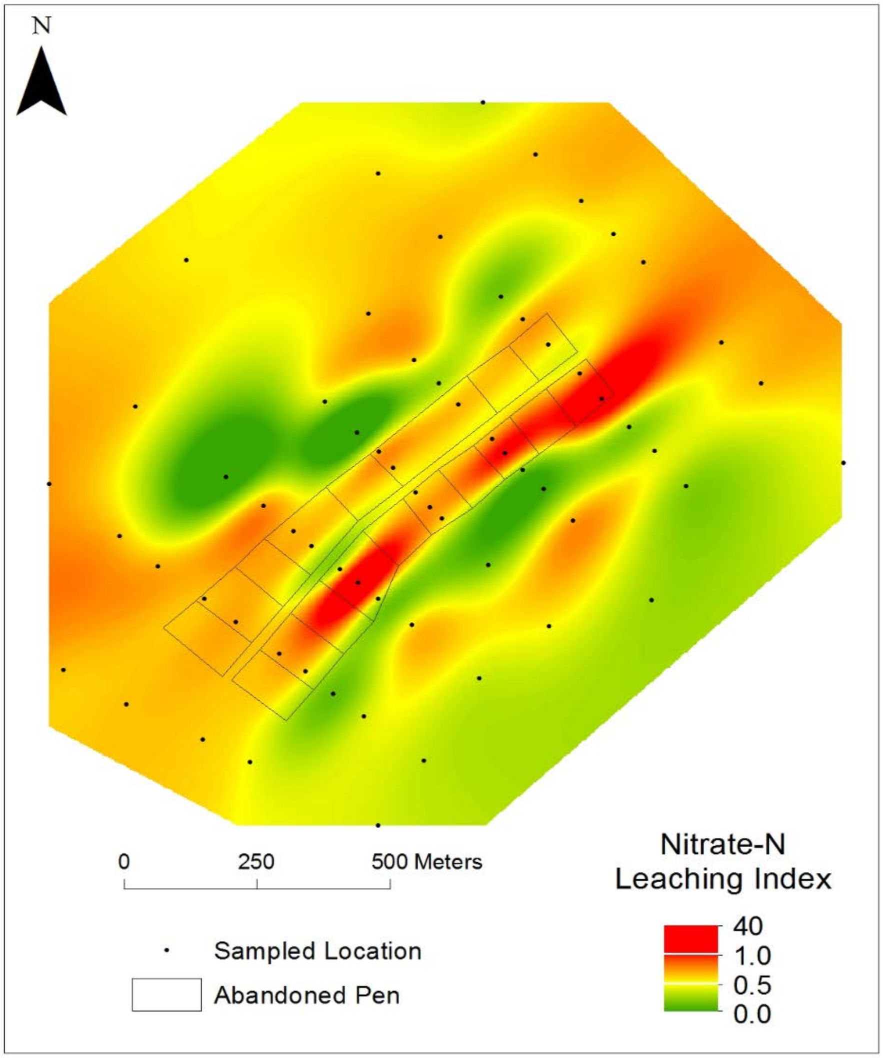

Fig. 7: Spatial distribution map showing areas with leached soil nitrate-N (red and green represent areas with high and low degree of leaching, respectively). The differences between the nitrate concentrations in the A- and B-horizon samples data were interpolated using radial basis function

Table 6: Soil chemical species analyzed from the O- and A-horizon composite samples

Site	NO_3-N	TN	P	Fe	Ca	TC	OC	IC
1	7.5	0.63	8	68.5	11240	7.36	5.72	1.63
2	2.0	0.93	4	7.6	14900	12.71	8.16	4.56
3	2.0	0.70	3	19.7	12160	10.99	5.87	5.11
4	4.0	0.41	40	30.0	7260	4.42	4.21	0.21
5	1.5	0.42	104	96.0	6340	4.42	4.42	0.00
6	0.5	0.11	17	20.7	4660	1.42	1.15	0.28
7	1.0	0.27	73	110.0	6460	2.95	2.43	0.52
8	4.5	0.71	4	11.6	10740	9.92	6.53	3.39
9	2.5	1.11	7	68.5	6000	15.89	9.88	6.01
10	2.0	0.59	6	59.0	6480	6.38	6.38	0.00
11	14.5	1.19	7	60.5	60.5	12.42	12.36	0.06
12	1.0	0.31	7	10.6	6220	3.05	3.05	0.00
13	5.5	0.27	71	90.5	7500	3.49	2.41	1.08
14	1.0	0.29	98	53.5	6760	3.10	2.80	0.30
15	3.0	0.36	112	46.0	6180	4.22	4.13	0.09
16	10.5	0.30	16	78.0	5680	3.36	2.97	0.39
17	8.5	0.64	4	16.8	5220	7.68	6.20	1.48
18	12.5	1.62	5	21.6	10400	18.73	14.66	4.07
19	0.5	0.215	2	27.5	10060	5.62	1.77	3.85
20	2.0	0.76	3	61.5	10640	14.06	6.96	7.10
21	9.0	0.30	73	18.9	8900	3.46	3.04	0.42
22	0.5	0.02	3	4.5	3700	1.16	0.11	1.05

NO_3-N, TN, P, Fe, and Ca represent nitrate-nitrogen, total nitrogen, phosphorus, iron, and calcium are in mg Kg^{-1} while TC, OC, and IC represent total carbon, organic carbon, and inorganic carbon are in percent (%).

Table 6 (*Continued*)

Site	NO_3-N	TN	P	Fe	Ca	TC	OC	IC
23	1.0	0.36	104	63.5	9800	5.12	3.66	1.46
24	0.5	0.11	76	43.0	8120	3.42	1.24	2.18
25	12.0	1.66	110	72.5	8300	17.15	17.10	0.05
26	21.0	1.36	8	74.0	11220	13.97	12.26	1.71
27	2.0	0.14	2	16.6	9800	5.51	0.94	4.57
28	10.5	0.83	4	17.1	12280	10.95	7.21	3.74
29	3.5	0.58	12	72.0	7700	6.05	6.05	0.00
30	8.0	2.05	7	113.5	10820	24.82	18.88	5.94
31	26.5	1.08	54	103.5	11060	12.51	10.80	1.71
32	1.0	0.11	83	55.0	4760	1.30	1.06	0.24
33	0.5	0.03	9	17.9	2940	0.28	0.23	0.05
34	0.5	0.31	113	53.0	9760	5.72	3.37	2.35
35	6.5	0.39	112	49.5	8080	5.78	3.47	2.32
36	7.5	0.62	104	45.0	3700	5.33	5.28	0.06
37	22.0	0.58	15	21.4	10680	8.10	5.17	2.93
38	4.0	0.32	3	19.0	9220	4.24	2.51	1.74
39	2.5	0.25	10	38.5	6140	2.67	2.67	0.00
40	24.0	1.56	8	98.5	11860	18.65	14.65	4.00
41	1.5	0.30	5	13.9	6260	3.15	3.15	0.00
42	0.5	0.21	93	26.5	6920	2.75	2.54	0.21
43	2.0	0.26	89	70.0	8640	4.79	2.11	2.68
44	5.0	0.19	37	20.1	10440	4.01	1.55	2.46

NO_3-N, TN, P, Fe, and Ca represent nitrate-nitrogen, total nitrogen, phosphorus, iron, and calcium are in mg Kg^{-1} while TC, OC, and IC represent total carbon, organic carbon, and inorganic carbon are in percent (%).

Table 6 (*Continued*)

Site	NO_3-N	TN	P	Fe	Ca	TC	OC	IC
45	0.5	0.16	56	32.5	10440	2.61	1.10	1.51
46	6.0	0.43	111	77.0	6580	4.56	4.49	0.07
47	4.0	0.65	5	9.8	11640	9.89	7.06	2.82
48	7.5	0.40	3	18.4	6880	4.64	3.26	1.38
49	1.0	0.26	4	22.1	5560	2.67	2.67	0.00
50	1.0	0.16	8	17.9	4620	1.68	1.68	0.00
51	1.5	0.235	4	48.0	4820	2.39	2.39	0.00
52	1.5	0.37	112	47.0	5520	3.65	3.44	0.21
53	0.5	0.15	98	86.0	4280	1.51	1.36	0.15
54	0.5	0.43	121	60.0	6440	4.87	3.97	0.89
55	2.5	0.29	105	72.0	5380	2.91	2.75	0.17
56	13.0	0.71	7	41.5	10600	9.72	6.89	2.83
57	6.5	0.89	5	14.3	11680	10.64	7.90	2.74
58	7.5	0.48	8	39.5	9300	5.02	4.39	0.63
59	1.0	0.24	8	53.5	4940	2.49	2.49	0.00
60	1.0	0.28	12	38.5	5280	2.86	2.86	0.00
61	2.5	0.08	5	8.0	5200	1.36	0.77	0.59
62	4.0	0.21	66	49.5	6120	2.01	2.01	0.00
63	7.5	0.74	4	42.5	11060	10.21	6.83	3.38

NO_3-N, TN, P, Fe, and Ca represent nitrate-nitrogen, total nitrogen, phosphorus, iron, and calcium are in mg Kg^{-1} while TC, OC, and IC represent total carbon, organic carbon, and inorganic carbon are in percent (%).

Table 7: Chemical species concentration and soil properties of the B- horizon samples

Site	NO_3-N	TN	P	Fe	Ca	TC	OC	IC	SOM	pH	EC
1	1.5	0.25	2	16.4	10840	6.28	1.94	4.33	2.9	8.33	114.9
2	1.5	0.10	2	4.2	10940	5.20	0.83	4.37	2.3	8.30	664.0
3	1.0	0.07	29	7.0	9280	2.36	0.51	1.85	1.5	8.48	110.0
4	1.5	0.10	7	6.0	5860	1.35	0.91	0.45	1.0	8.30	89.2
5	1.0	0.10	83	25.5	4200	1.41	0.91	0.51	10.2	8.00	130.0
6	0.5	0.05	6	6.0	3560	0.47	0.47	0.00	1.8	8.33	38.6
7	0.5	0.06	10	10.5	7020	1.51	0.50	1.01	4.0	8.51	51.8
8	0.5	0.10	2	5.2	11040	3.37	0.89	2.48	1.9	8.33	284.0
9	0.5	0.19	3	19.6	8340	6.51	1.72	4.78	3.1	8.95	278.0
10	2.0	0.10	3	16.2	10720	3.74	0.67	3.07	0.2	9.07	103.2
11	3.5	0.32	4	51.0	4320	3.73	3.26	0.46	3.2	8.72	277.0
12	1.0	0.07	6	6.8	5460	1.58	0.72	0.86	3.9	9.62	45.0
14	1.5	0.21	93	42.5	6860	3.98	2.14	1.84	10.0	8.43	87.9
15	20.0	0.14	112	53.5	6480	1.55	1.35	0.20	0.8	8.63	381.0
16	1.5	0.16	7	49.0	4160	1.26	0.91	0.35	8.9	9.25	573.0
17	3.5	0.20	1	10.4	7020	4.66	1.73	2.93	3.6	8.42	125.2
18	3.0	0.18	1	11.6	9100	4.80	1.61	3.20	4.4	8.61	208.0
19	0.5	0.16	2	11.0	7460	3.90	1.39	2.51	4.4	8.83	302.0
20	0.5	0.08	2	19.0	9900	3.73	0.73	3.00	6.6	9.39	109.7
21	1.0	0.10	22	12.1	9480	2.75	1.02	1.72	2.7	9.15	474.0
22	0.5	0.02	2	5.4	3020	1.06	0.08	0.98	3.9	8.74	404.0

NO_3-N, TN, P, Fe, and Ca represent nitrate-nitrogen, total nitrogen, phosphorus, iron, and calcium are in mg Kg^{-1} while TC, OC, IC, and SOM represent total carbon, organic carbon, inorganic carbon, and soil organic matter are in percent (%). pH is in standard unit and electrical conductivity (EC) is in µS cm^{-1}.

Table 7 (*Continued*)

Site	NO_3-N	TN	P	Fe	Ca	TC	OC	IC	SOM	pH	EC
23	2.5	0.03	15	10.3	3460	0.93	0.23	0.70	3.9	8.86	106.8
24	10.5	0.16	93	45.5	8580	3.83	1.65	2.18	0.8	8.27	406.0
25	2.0	0.04	63	30.0	4480	0.51	0.38	0.13	3.4	8.77	551.0
26	4.5	1.35	12	97.5	8820	13.97	12.70	1.27	1.8	8.35	567.0
27	3.0	0.82	4	61.5	8860	10.78	7.04	3.74	2.6	8.50	584.0
28	2.0	0.19	1	8.6	7080	5.66	1.43	4.23	1.9	8.12	1284.0
29	1.0	0.08	2	33.5	4380	0.92	0.83	0.09	1.8	7.82	162.0
30	2.0	0.10	3	13.7	10140	5.51	0.85	4.66	5.3	8.74	297.0
31	3.0	0.19	8	19.1	10860	4.27	1.79	2.48	2.4	8.73	432.0
32	1.5	0.03	4	9.5	4480	0.84	0.17	0.67	2.4	9.07	432.0
33	0.5	0.04	25	17.5	2720	0.58	0.31	0.27	2.3	9.08	336.0
36	7.5	0.23	105	93.0	5000	2.48	2.15	0.33	1.3	8.31	617.0
37	11.0	0.16	3	8.6	9380	6.17	1.19	4.98	2.3	9.24	533.0
38	1.0	0.08	1	9.1	6060	4.10	0.53	3.57	4.0	8.15	1308.0
39	1.5	0.17	5	19.6	4900	1.91	1.71	0.21	1.3	8.48	156.1
40	1.5	0.19	5	16.9	11120	4.99	2.03	2.96	2.7	7.80	34.4
41	3.0	0.27	6	12.8	6440	3.27	2.62	0.65	2.6	9.04	446.0
42	0.5	0.09	48	12.3	4180	1.32	0.82	0.51	2.9	8.85	393.0
43	1.0	0.20	57	67.5	3820	2.57	2.08	0.49	1.6	9.05	336.0
44	0.5	0.13	11	70.5	5920	1.59	1.48	0.11	5.7	9.36	60.5

NO_3-N, TN, P, Fe, and Ca represent nitrate-nitrogen, total nitrogen, phosphorus, iron, and calcium are in mg Kg^{-1} while TC, OC, IC, and SOM represent total carbon, organic carbon, inorganic carbon, and soil organic matter are in percent (%). pH is in standard unit and electrical conductivity (EC) is in μS cm^{-1}.

Table 7 (Continued)

Site	NO_3-N	TN	P	Fe	Ca	TC	OC	IC	SOM	pH	EC
45	20.0	0.14	47	74.0	4120	1.52	1.44	0.08	0.3	8.76	490.0
46	2.0	0.10	61	15.8	8080	1.17	0.79	0.38	5.2	8.69	581.0
47	1.5	0.08	5	5.5	10580	2.91	0.70	2.21	2.3	8.85	748.0
48	1.5	0.15	1	7.6	8840	4.62	0.98	3.64	3.6	8.18	535.0
49	2.5	0.16	5	15.7	6600	2.32	1.40	0.92	3.1	8.27	80.1
50	0.5	0.06	6	7.5	3640	0.73	0.73	0.00	1.6	8.00	59.4
51	2.0	0.14	3	15.3	3900	1.71	1.63	0.09	3.1	7.72	70.2
52	1.0	0.09	98	17.0	3820	1.07	0.99	0.08	4.2	7.86	342.0
53	1.5	0.45	112	65.0	6800	5.58	4.17	1.41	1.3	7.73	147.8
54	1.5	0.14	98	56.5	4380	1.48	1.34	0.15	9.7	7.65	79.2
55	1.0	0.18	104	69.0	4840	1.78	1.66	0.13	9.0	7.83	90.3
56	0.5	0.07	3	10.3	9120	1.09	0.68	0.42	5.8	8.40	125.5
57	1.0	0.11	3	7.8	11540	4.18	0.84	3.34	3.6	7.86	1241.0
58	1	0.08	2	6.9	9740	3.08	0.54	2.54	5.7	8.38	177.5
59	0.5	0.06	9	13.5	3980	0.69	0.69	0.00	2.6	9.05	236.0
60	0.5	0.86	2	5.0	3300	0.45	0.32	0.14	5.3	9.58	30.4
61	1.5	0.09	6	46.5	5360	1.51	1.02	0.49	5.5	9.44	91.5
62	0.5	0.24	30	92.5	7860	2.66	2.40	0.25	8.9	8.82	424.0
63	2.0	0.06	1	5.9	8320	1.64	0.51	1.12	5.7	8.38	146.0

NO_3-N, TN, P, Fe, and Ca represent nitrate-nitrogen, total nitrogen, phosphorus, iron, and calcium are in mg Kg^{-1} while TC, OC, IC, and SOM represent total carbon, organic carbon, inorganic carbon, and soil organic matter are in percent (%). pH is in standard unit and electrical conductivity (EC) is in µS cm^{-1}.

Apart from anthropogenic input (manure), decomposition of organic matter is one of the processes involved in increasing soil nitrate in the wetlands, depending on microbial activities and substrate (Fenchel and Jorgenson, 1977; McLatchey and Reddy, 1998). Wetland areas with high nitrate concentrations were characterized by monotypic and dense communities of *Typha* sp. and *Phalaris arundinacea*. Apart from leaching, the high soil nitrate could be attributed to assimilation and nitrogen fixation by wetland plants (e.g. Zhu and Sikora, 1995). Graminoid including *Typha* sp. have bacteria associated with their roots (Bristow, 1973; Biesboer, 1984) that can fix nitrogen at a higher rate (Eckardt and Biesboer, 1988). These plant species transport oxygen into the rhizosphere, creating an oxidized zone (Cronk and Fennessy, 2001) for nitrification to occur (Schimel et al., 1989), thereby increasing the soil nitrate concentration.

Soil phosphorus in the O- and A-horizon composite samples had concentrations ranging from 2.0 to 121.0 mg kg^{-1} (Table 6, Fig. 8), while the B-horizon had concentrations ranging from 1.0 to 112.0 mg kg^{-1} (Table 7). Phosphorus concentrations in the O- and A-horizon composite samples had higher concentrations compared to that of the B-horizon samples, apart from site 24 that showed otherwise. Soil phosphorus concentrations are high only within the feedlot pens along the beach ridge and paths that served to drain liquid waste. These areas were associated with management practices including manure handling, piling, and storage. The spatial distribution of phosphorus concentration was consistent with the alignment of the pens on the beach ridge.

Statistical analysis of the soil phosphorus distribution in Fig. 8 using global Moran's I indicated Z-score beyond +2.58 standard deviations and p-values less than 0.01 for both O- and A-horizon and B-horizon composite samples. This indicates that the spatial distribution pattern of phosphorus, especially on the beach ridge in the vicinity of the former pen location, is a result of a significant autocorrelation. Local Moran's I analysis indicated that the beach ridge is the local hotspots of phosphorus at the site.

Soil phosphorus from the beach ridge had concentrations greater than 16 mg kg^{-1}, indicating an excessive amount of phosphorus (Marx et al., 1999; Franzen, 2010) as compared to that of the wetlands. Most of the excess soils phosphorus is associated with the Radium and Sandberg soils, which are well-drained and have high sorption capacities. The elevated phosphorus in the beach ridge soils and low phosphorus in the wetlands indicates that phosphorus was immobilized in the Radium and Sandberg soils on the beach ridge, during and after the feedlot operation was abandoned, with minimal movement into the wetlands.

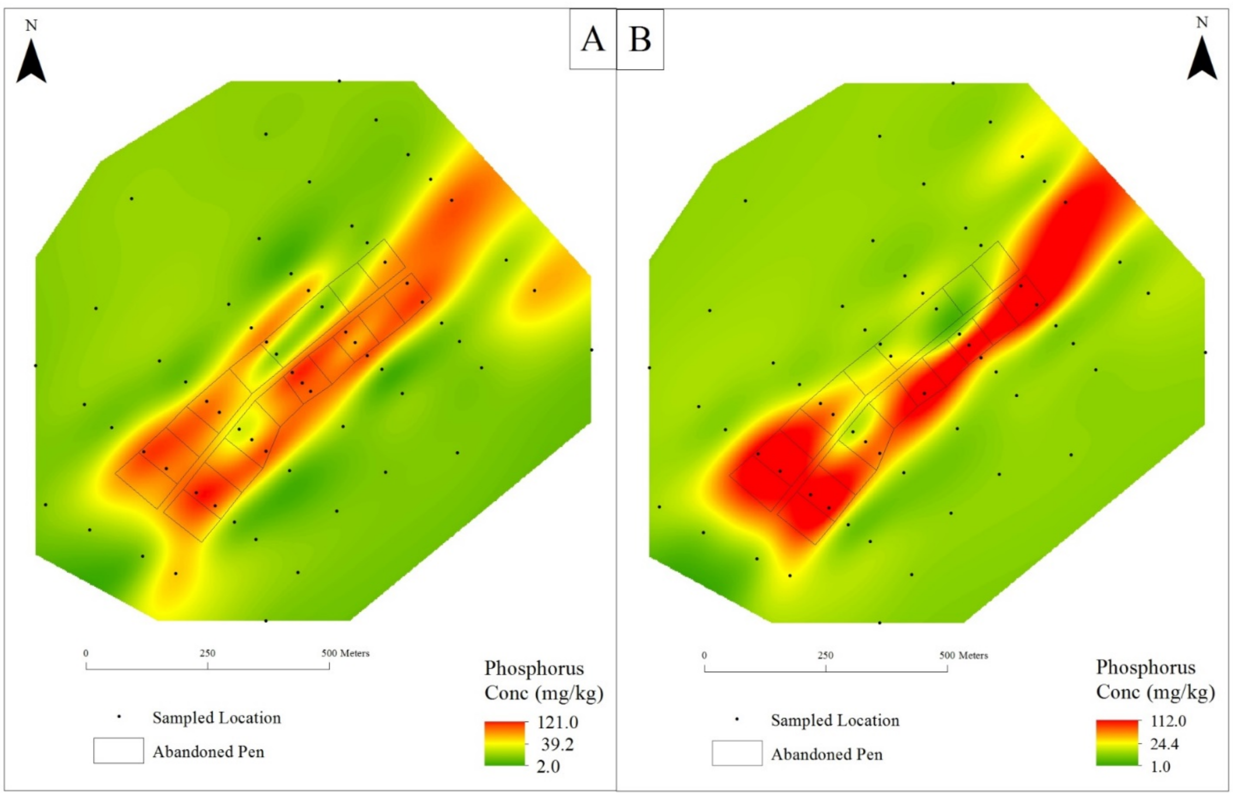

Fig. 8: Distribution of soil phosphorus in the O- and A-horizon (A) and B-horizon composite (B) samples (values are in mg kg^{-1} with red and green representing high and low concentrations, respectively). The soil nitrate data were interpolated using radial basis function.

Soil iron concentration in the O- and A-horizon composite samples ranged from 4.5 to 113.5 mg kg^{-1} and that of the B-horizon samples ranged from 4.2 to 97.5 mg kg^{-1}. Iron concentrations in soil O- and A- horizons of the north wetland and beach ridge were greater than that of the southern wetland soils (Fig. 9). Soil iron may be associated with fluctuation in groundwater levels and the oxidation-reduction conditions involved in the precipitation of iron at the soil-water interface near the water table. The wetland in the north has a large connected open ditch compared to the south, with water table at the surface. Oxidation of ferrous iron results in the precipitation of ferric hydroxides, which accumulates as reddish-brown stains on soils. This oxidation-reduction process may have decreased the concentrations of iron in soils associated with parts of the wetland. Certain graminoids (including *Typha* sp.) help in the mobilization of ferric iron in the rhizosphere (Ghaly et al., 2008), which is absorbed by the roots into the cells

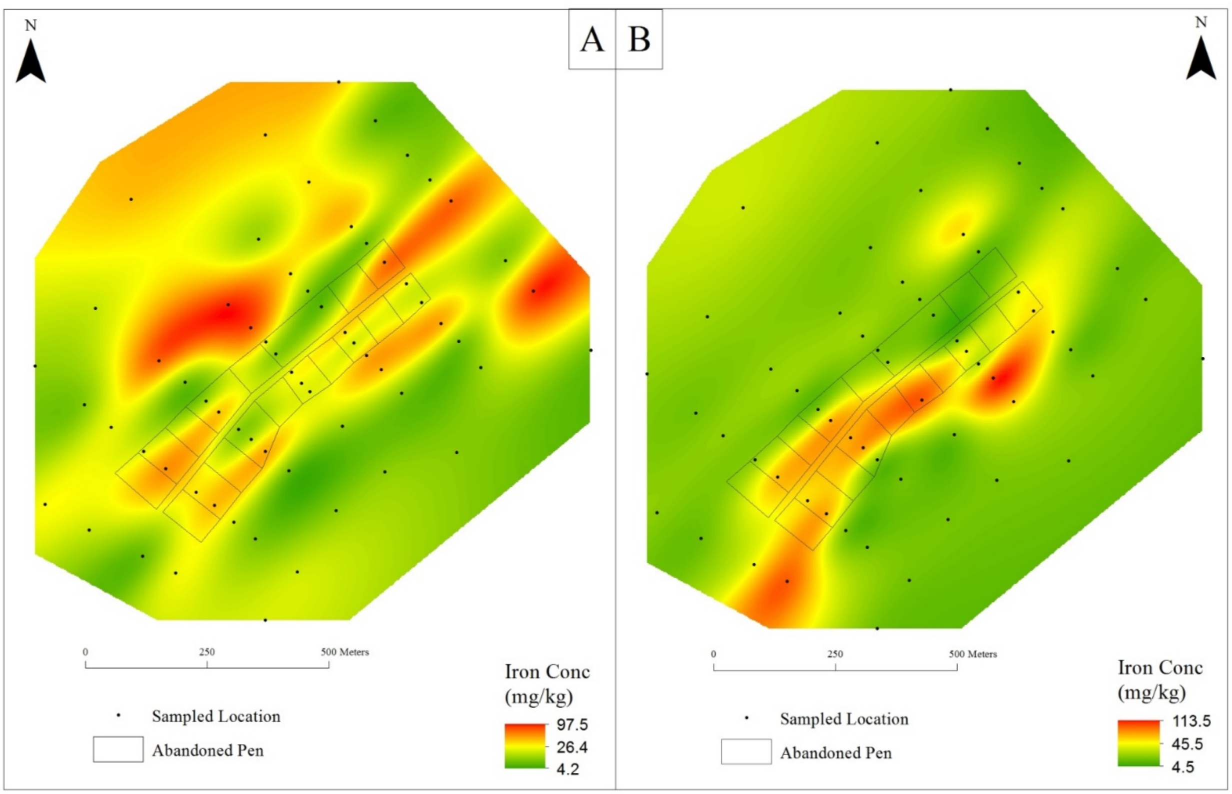

Fig. 9: Distribution of soil iron in the O- and A-horizon (A) and B-horizon composite (B) samples (values are in mg kg^{-1} with red and green representing high and low concentrations, respectively). The soil nitrate data were interpolated using radial basis function.

creating an iron-depleted rhizosphere.

Soil calcium concentration in the O- and A-horizon composite samples ranged from 60.5 to 14,900.0 mg kg^{-1}, while the B-horizon samples had concentrations ranging from 2720.0 to 11,540.0 mg kg^{-1}. Calcium, similar to iron, did not show any regular pattern within the O- and A-horizon samples but showed a regular distribution pattern away from the beach ridge samples in the B-horizon (Fig. 10). When compared to the wetlands, most of the beach ridge samples had low concentrations of calcium. High concentration of calcium within the wetlands could be a possible indication of groundwater discharge zones. The wetlands are dominated by Strathcona, Hedman, and Syrene soils, which are characterized by high carbonate content (USDA, 2012).

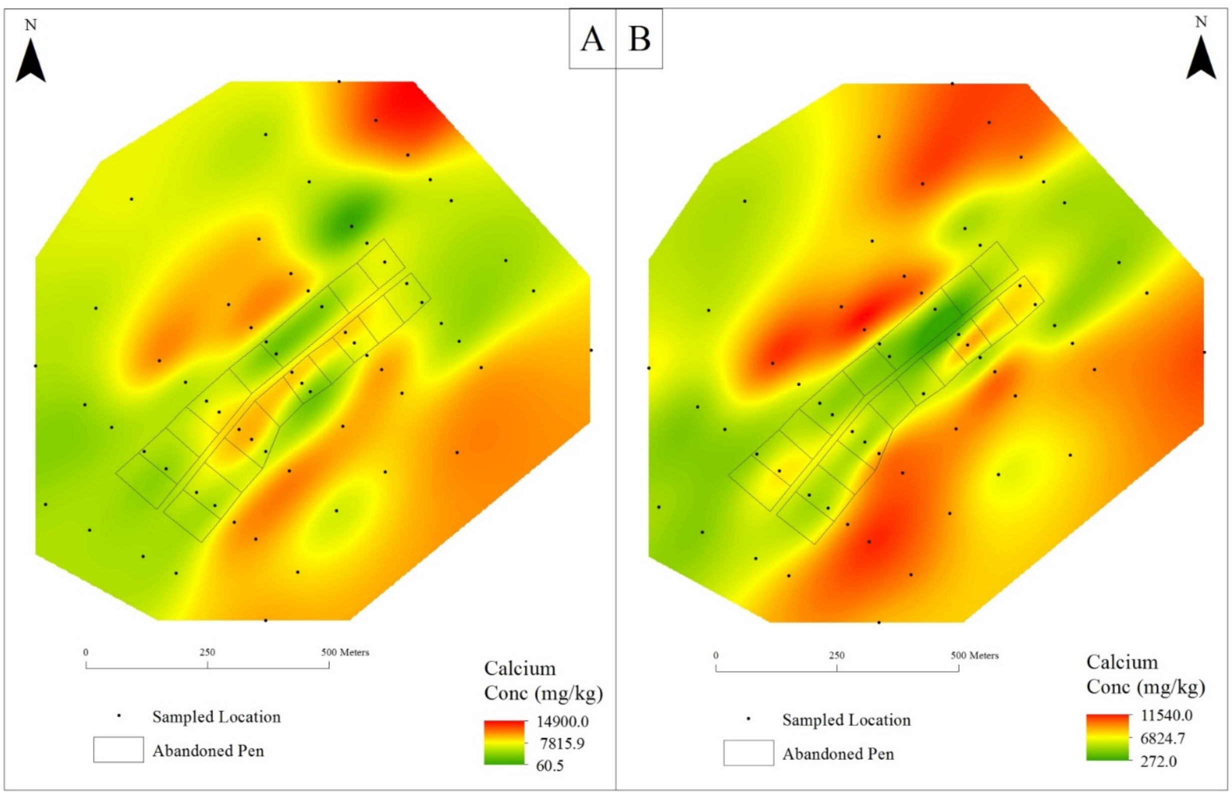

Fig. 10: Distribution of soil calcium in the O- and A-horizon (A) and B-horizon composite (B) samples (values are in mg kg^{-1} with red and green representing high and low concentrations, respectively). The soil nitrate data were interpolated using radial basis function.

There is an upward movement of groundwater solute through advection in the wetlands (e.g. Siegel, 1989) and evaporation results in the deposition of high concentration of soil calcium.

Although the spatial distribution of iron and calcium in the O- and A-horizon soils showed random distributions, analysis of the pattern displayed by the B-horizon samples indicated Z-scores of 3.06 and 2.32 for iron and calcium, respectively. Iron displayed high concentrations in the southern pen. Calcium in the B-horizon displayed clustered pattern of elevated concentrations in both northern and southern parts of the study area.

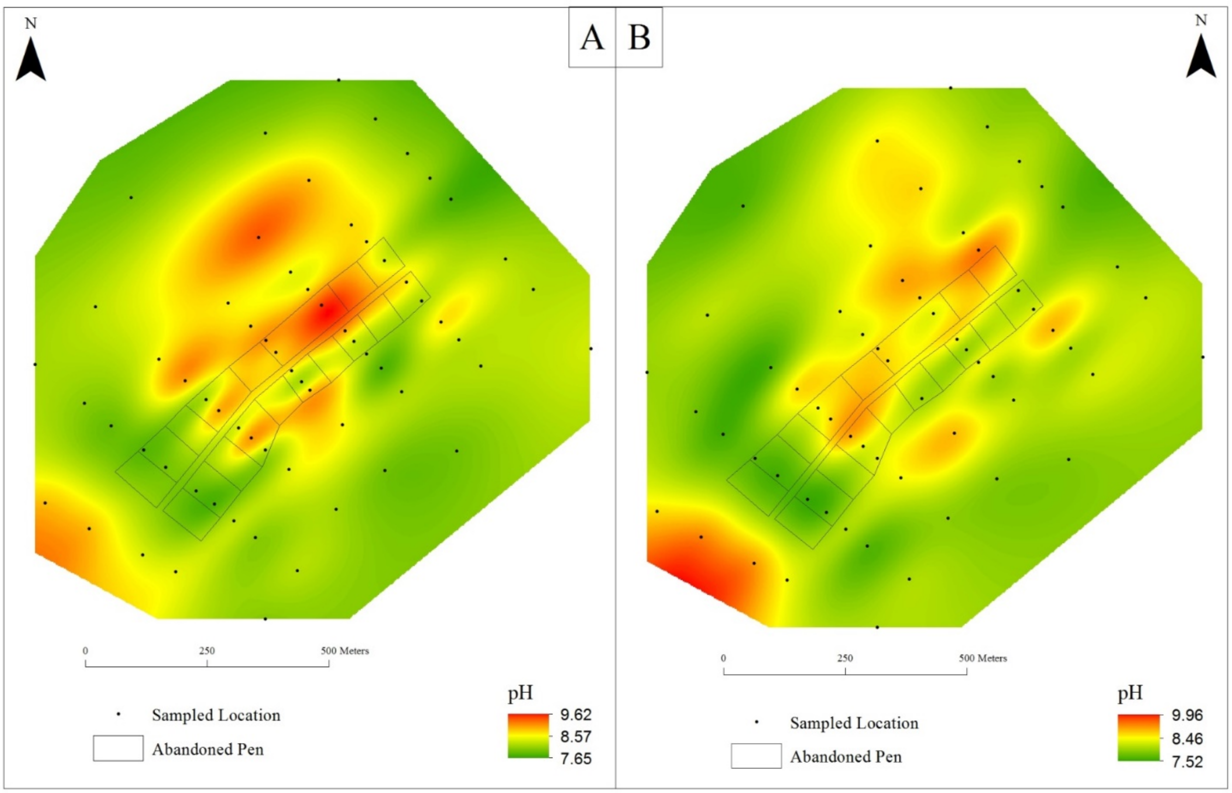

Fig. 11: Distribution of soil pH in O- and A-horizon composite (A) and B-horizon composite (B) samples (values are in standard units with red and green representing high and low values, respectively). Data interpolation was done using radial basis function.

Soil physiochemical properties had variation in their distributions. Soil pH ranged from 7.52 to 9.96 in the O- and A-horizon composite samples and .65 to 9.62 in the B-horizon composite samples. Soil pH showed the same pattern in both horizons, with the B-horizon samples having high pH values compared to that of the O- and A-horizon composite samples in most of the areas (Fig. 11).

Measured electrical conductivity within the O- and A-horizon composite samples ranged from 22 to 2260 µS cm-1 and 30 µS cm-1 to 1308 µS cm-1 in the B-horizon composite samples. Soil electrical conductivity showed variability with areas associated with groundwater discharge and high calcium concentrations having high values. Within the B-horizon, the pattern of electrical conductivity might be attributed to subsurface movement of dissolved chemical species from the excavated lagoon into southern wetland (Fig. 12). The high electrical conductivity measured in the B-horizon is associated with the Hedman and Strathcona soils in the southern wetland. The elevated electrical conductivity from the wetland areas indicates greater concentrations of soluble minerals in the soils.

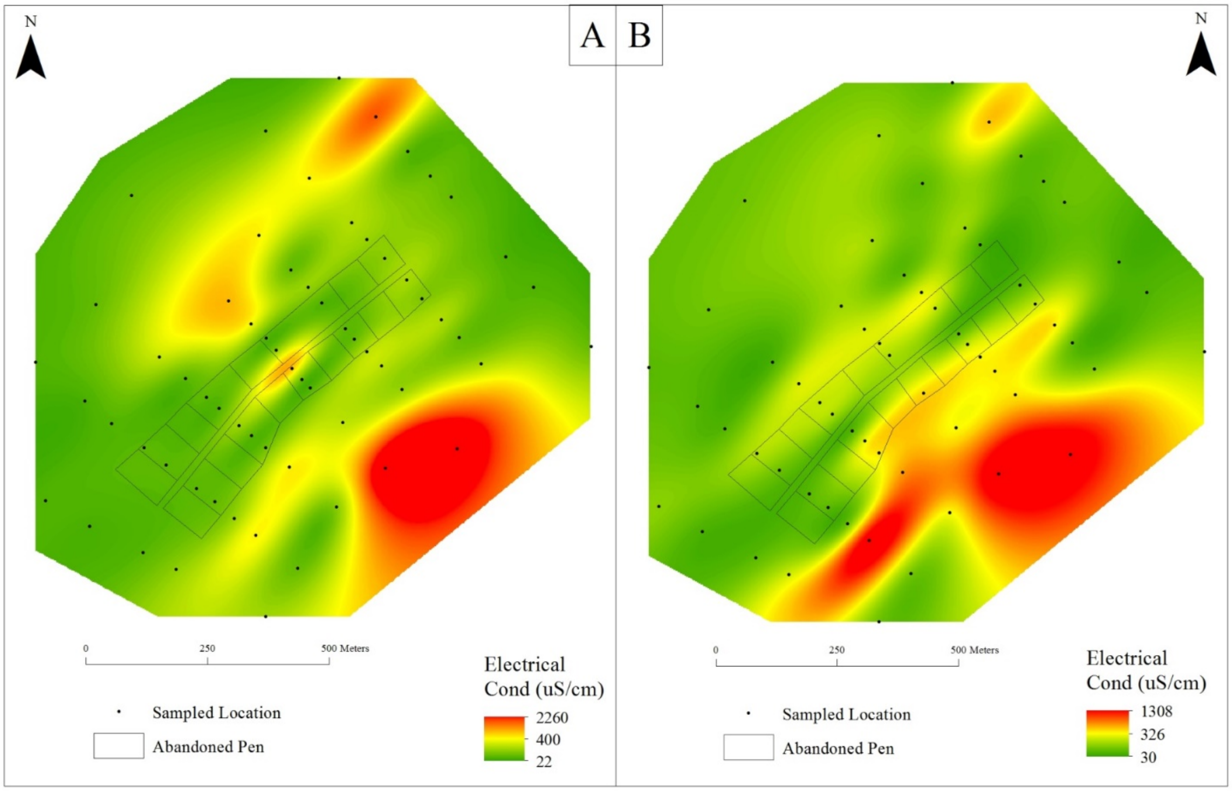

Fig. 12: Distribution of soil electrical conductivity in O- and A-horizon composite (A) and B-horizon composite (B) samples (values are in standard units with red and green representing high and low values, respectively). Data interpolation was done using radial basis function.

Soil organic matter, formed from the decomposition of organic materials, varied within the study area. The O- and A-horizon composite samples had content ranging from 0.1 to 44.8 %, while the B-horizon samples had organic matter content ranging from 0.2 to 10.2 %. Elevated electrical conductivity and greater organic matter content were associated with wetland soils. The increase in wetland organic matter content undoubtedly relates to a greater abundance of plants and organic material decomposition.

Spatial statistical analysis of the physiochemical properties indicated random distribution for the organic matter content in both O- and A-horizon composite samples and B-horizon samples, but clustered pattern for pH and electrical conductivity in both horizons.

Plant Tissue Chemistry

The primary macronutrient composition in the plant tissue varied in the order: potassium > total nitrogen > total phosphorus. The concentration of potassium varied from 1.02 to 3.41 %. Total nitrogen concentrations ranged from 0.7% to 2.2% (Table 8; Fig. 13) and that of total phosphorus ranged varied from 0.1 to 0.4% (Fig. 14).

The secondary macronutrient composition in the plant tissues varied in the order: calcium > magnesium > sulfur. Calcium, magnesium, and sulfur had concentrations ranging 0.2 to 2.1%, 0.1 to 0.4%, and 0.1 to 0.4 ppm, respectively. The micronutrients in the plant tissues had decreasing concentrations in the order: iron > zinc > copper. Iron, zinc, and copper had concentrations ranging from 45.9 to 796.6 ppm, 8.8 to 33.4 ppm, and 0.5 to 7.5 ppm, respectively.

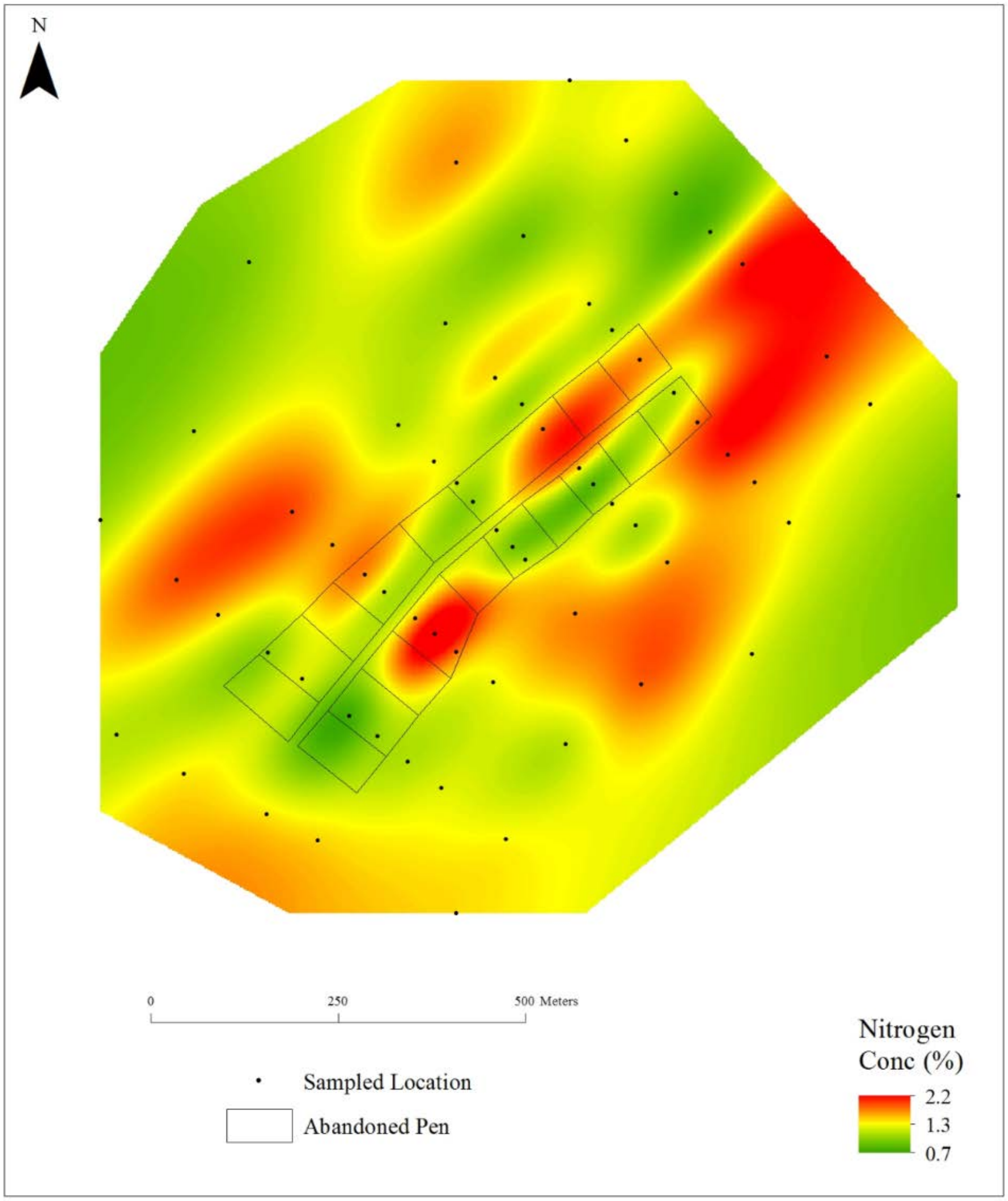

Fig. 13: Spatial distribution of total nitrogen in the plant tissues (dry weight). Concentration is in percentage with red and green representing high and low percentages, respectively). Data interpolation was done using radial function basis.

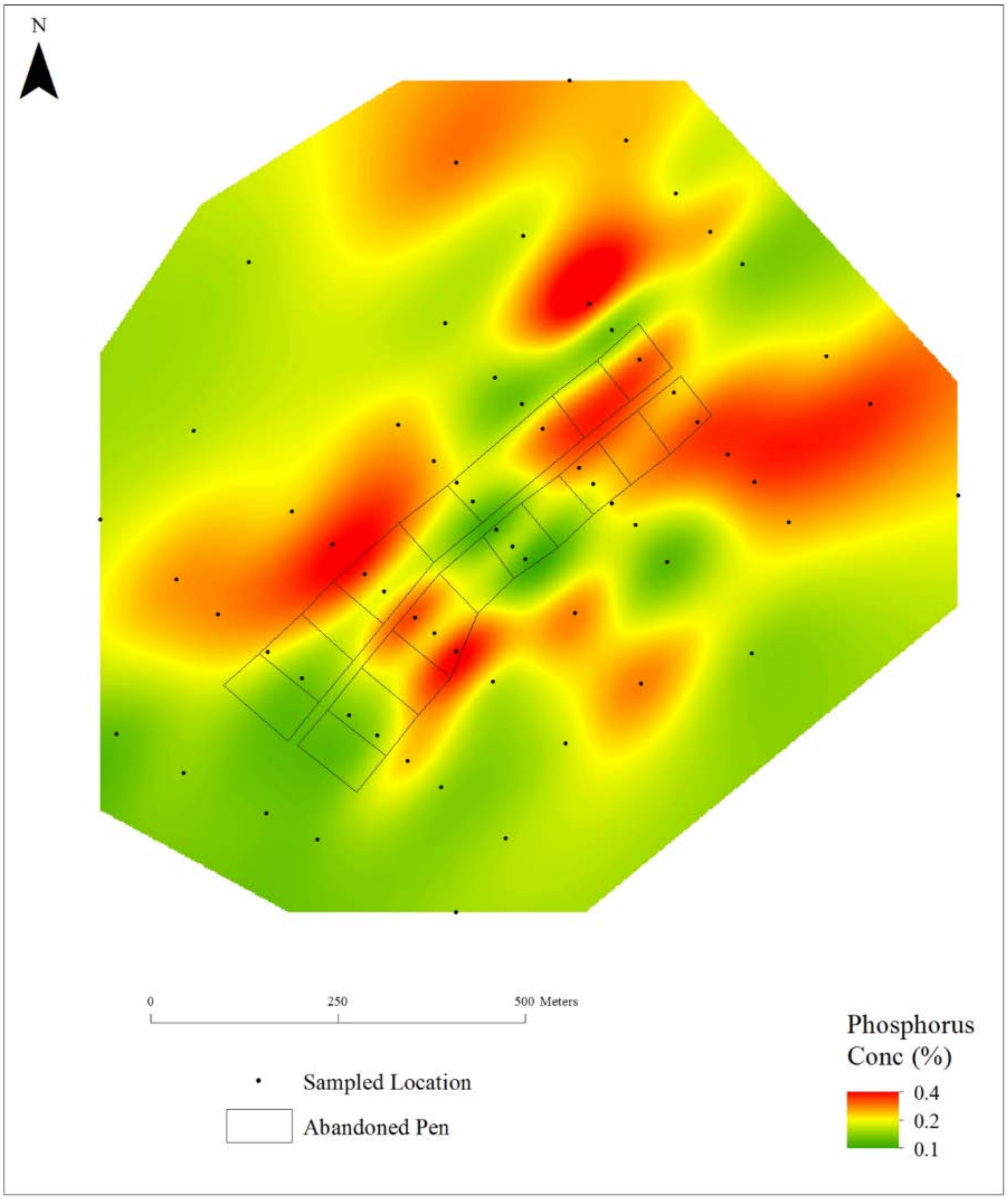

Fig. 14: Spatial distribution of total phosphorus in the plant tissues (dry weight). Concentration is in percentage with red and green representing high and low percentages, respectively). Data interpolation was done using radial function basis.

Table 8: Chemical species analyzed from the plant tissues (dry weight)

Site	TN	TP	K	Ca	Mg	S	Zn	Fe	Cu
1	1.3	0.3	1.8	0.5	0.2	0.2	20.0	227.4	2.8
2	1.3	0.3	1.5	0.3	0.1	0.2	23.4	116.0	3.6
3	0.9	0.2	1.5	0.5	0.2	0.1	13.0	266.3	3.0
4	0.9	0.3	1.1	0.4	0.1	0.1	17.0	278.6	1.6
5	1.9	0.1	2.7	0.6	0.3	0.4	32.3	148.3	4.9
6	1.9	0.2	2.3	0.5	0.2	0.2	24.8	78.2	2.7
7	1.4	0.3	2.1	0.4	0.2	0.2	19.1	69.8	1.9
8	1.0	0.2	1.8	0.3	0.1	0.1	14.1	71.3	2.7
9	1.6	0.3	2.0	0.4	0.1	0.2	18.9	74.8	2.8
10	0.9	0.2	1.2	2.1	0.2	0.1	16.4	796.6	4.1
11	1.3	0.4	2.4	0.4	0.3	0.2	26.9	138.9	3.1
12	1.1	0.1	2.0	0.4	0.2	0.1	20.7	50.2	4.4
13	1.6	0.3	2.8	0.4	0.2	0.3	33.4	152.6	3.5
14	1.1	0.2	1.8	0.5	0.2	0.1	17.3	78.5	3.6
15	1.7	0.3	2.2	0.5	0.2	0.2	17.4	120.9	4.2
16	1.9	0.3	2.2	0.6	0.2	0.2	19.7	88.7	4.3
17	1.6	0.3	2.2	0.5	0.2	0.2	21.4	76.1	4.4
18	1.4	0.3	1.9	0.4	0.2	0.1	20.1	67.2	2.2
18*	1.2	0.3	1.9	0.3	0.1	0.1	19.6	67.0	4.5
19	1.1	0.2	1.9	0.5	0.2	0.1	17.1	80.4	3.9
20	1.4	0.2	2.3	0.4	0.2	0.3	28.7	129.6	4.1
21	1.1	0.1	1.5	0.5	0.2	0.1	15.0	286.8	1.9
22	1.7	0.3	2.1	0.4	0.2	0.2	21.1	66.6	3.4
23	1.4	0.3	1.7	0.5	0.2	0.2	20.5	98.6	2.3
24	0.8	0.2	1.3	0.3	0.1	0.1	16.1	79.8	2.0
25	1.3	0.2	2.0	0.5	0.2	0.2	17.6	318.6	3.6
26	1.1	0.2	1.8	0.4	0.1	0.1	13.1	82.4	2.4
27	1.5	0.1	1.7	0.3	0.2	0.3	20.0	92.9	3.9
28	1.3	0.1	2.1	1.0	0.3	0.2	16.4	121.5	4.5
29	1.0	0.2	1.6	0.6	0.3	0.2	18.4	213.8	6.3
30	1.2	0.3	3.4	0.9	0.4	0.2	16.0	191.3	7.5
31	1.3	0.3	2.8	0.3	0.3	0.3	33.1	125.9	3.0
32	1.2	0.2	1.8	0.8	0.3	0.2	20.9	207.1	4.0

TN, TP, K, Ca, and Mg are in percent (%) while S, Zn, Fe, and Cu are in ppm. * represents duplicated samples and < indicates below detection limit.

Table 8 (Continued)

Site	TN	TP	K	Ca	Mg	S	Zn	Fe	Cu
33	1.0	0.2	1.0	0.7	0.3	0.4	19.1	190.8	2.5
34	1.2	0.1	1.4	0.7	0.2	0.2	23.7	244.6	5.1
35	0.9	0.2	1.2	0.4	0.2	0.1	10.9	82.3	1.6
36	1.1	0.1	1.2	0.5	0.2	0.1	18.5	127.8	1.9
37	1.6	0.3	2.3	0.3	0.1	0.2	18.1	54.3	0.6
38	1.7	0.3	2.4	0.3	0.2	0.2	20.3	55.3	3.1
39	1.1	0.2	1.6	0.4	0.2	0.2	17.6	219.7	1.3
40	1.8	0.2	2.5	0.4	0.2	0.2	16.9	101.0	1.4
41	1.6	0.4	1.7	0.5	0.2	0.2	18.8	79.8	1.5
42	1.6	0.3	2.3	0.4	0.1	0.2	18.7	67.8	2.3
43	1.2	0.2	1.0	0.4	0.1	0.1	15.3	184.3	<0.5
44	1.5	0.3	2.0	0.5	0.1	0.2	16.8	64.4	1.4
45	2.2	0.2	2.7	0.6	0.1	0.3	24.0	59.3	2.1
46	1.7	0.4	2.5	0.5	0.2	0.2	26.9	62.7	3.9
47	1.3	0.2	1.9	0.5	0.2	0.1	14.4	60.6	<0.5
48	1.2	0.2	1.6	0.4	0.1	0.1	15.7	209.9	<0.5
49	1.1	0.2	1.5	0.4	0.2	0.1	13.4	121.3	<0.5
50	1.8	0.3	2.4	0.5	0.2	0.2	20.4	91.0	1.7
51	1.4	0.3	2.4	0.4	0.2	0.2	18.1	69.6	1.1
51*	1.4	0.3	2.4	0.4	0.2	0.2	18.5	64.9	3.4
52	1.0	0.2	1.8	0.4	0.1	0.1	14.9	52.2	0.9
53	1.2	0.1	1.3	0.3	0.2	0.2	14.8	76.8	2.3
54	0.7	0.1	1.4	0.3	0.2	0.2	17.1	102.1	<0.5
55	1.0	0.2	1.5	0.2	0.2	0.2	8.8	123.8	<0.5
56	1.1	0.2	2.0	0.5	0.3	0.2	19.1	68.3	1.8
57	1.3	0.2	1.5	0.4	0.3	0.2	21.8	86.9	0.7
58	1.4	0.2	2.1	0.6	0.2	0.2	26.4	114.8	3.6
59	1.1	0.1	1.2	0.4	0.2	0.2	16.2	61.3	<0.5
60	1.4	0.1	1.1	0.4	0.2	0.2	13.7	53.8	<0.5
61	1.4	0.1	1.5	1.0	0.3	0.2	12.5	555.3	2.3
62	1.4	0.1	1.6	0.7	0.2	0.2	12.2	45.9	2.4
63	1.4	0.2	1.5	0.3	0.1	0.2	13.7	45.9	<0.5

TN, TP, K, Ca, and Mg are in percent (%) while S, Zn, Fe, and Cu are in ppm. * represents duplicated samples and < indicates below detection limit.

The plant tissue nutrients analyzed did not show any distinct pattern relative to the wetland or beach ridge. This could be attributed to the time the sample was collected, prevailing climatic conditions, soil type, soil nutrient availability, or human disturbance of the soil. Excavated locations (sites 22, 31, and 32) were characterized by sparse vegetation. Areas, which formerly were used as drainage for animal liquid waste have sparse vegetation due to the effect of erosion.

The beach ridge, which is underlain by Sandberg and Radium soils, had high concentration of iron and phosphorus. Although the area had elevated concentration of soil phosphorus, it was characterized by senesced plants, sparse vegetation, and non-vegetation. The soil phosphorus may have been sequestered by iron and calcium, making it unavailable for plant uptake. This may have resulted in plant stress due to interference in the uptake of essential micronutrients, especially zinc, iron, and copper (McCauley et al., 2009) located on the beach ridge. The stunted growth observed in some area could be attributed to soil nitrate concentration limiting the intensity and robustness of vegetation in the beach ridge soils. Within the wetlands, some of the graminoids had low tissue nutrient content. Apart from variations in soil nutrients content, plant development and elongation may have also contribution to decline in plant tissue nutrient (Hopkinson and Schubauer, 1984), since most of the assimilated nutrients by graminoids and other plant species are invested in the development of new leaf materials (Chapin and Slack, 1979) and shoots, hence low tissue nutrient content.

Groundwater Effect on Soils and Plant Tissue

Fluctuations in the water table elevation regulate biogeochemical processes and it also influences the nature of wetland soils (McNamara et al., 1992; Boomer and Bedford, 2008). Within wetlands, the water table is near the ground surface. Fluctuation in the water elevation causes chemical reactions and changes in redox conditions, which can result in the release or sorption of soil nutrients. Soil nutrients behave differently with nitrate being very mobile, while phosphorus is less mobile or immobile depending on the soil pH, redox condition, presence of organic material, and moisture content.

Elevated soil phosphorus occurs along the beach ridge, where it is immobile or has minimal movement. Groundwater total phosphorus concentration in the beach ridge is also high, with lower concentrations at the margins of the wetlands. Groundwater concentration increases from the margins of the wetlands with elevated concentrations in the wetlands. This is an indication that groundwater phosphorus has two sources: immobile soil phosphorus and phosphorus from organic matter. During precipitation, snowmelt, flooding, or increase in soil moisture, the sequestered phosphorus in the beach ridge soil is slowly released in solution, which probably moves in the direction of the groundwater. The release of adsorbed phosphorus normally occurs under anaerobic condition at the water-soil interface where there is fluctuation in the elevation of the water table. This results in the flushing of adsorbed phosphorus (e.g. Devito et al., 2000) from the soil to release adsorbed phosphorus into solution. The release of phosphorus results in spikes of elevated concentrations in groundwater and surface water.

Although the wetland soils have low concentrations of phosphorus, the surface and groundwater samples collected from some of the wetland wells had elevated concentrations. Compared to the beach ridge soils, wetlands have larger amounts of organic matter that plays a role in nutrient sequestration. The water level in wetlands fluctuates thereby causing a rapid flushing of adsorbed phosphorus from the water-soil interface or release of phosphorus from wetland soils and organic matters. When the wetlands are saturated or flooded, decomposition of organic matter is slow. Biological and physicochemical reactions are involved in the dissolution of nutrients from organic matter and accumulation of dissolved organic compounds, which can be incorporated into the groundwater and surface water. Also, drying and rewetting of soil can deplete soil phosphorus but also result in phosphorus pollution of surface and groundwater (e.g. Turner and Haygarth, 2001).

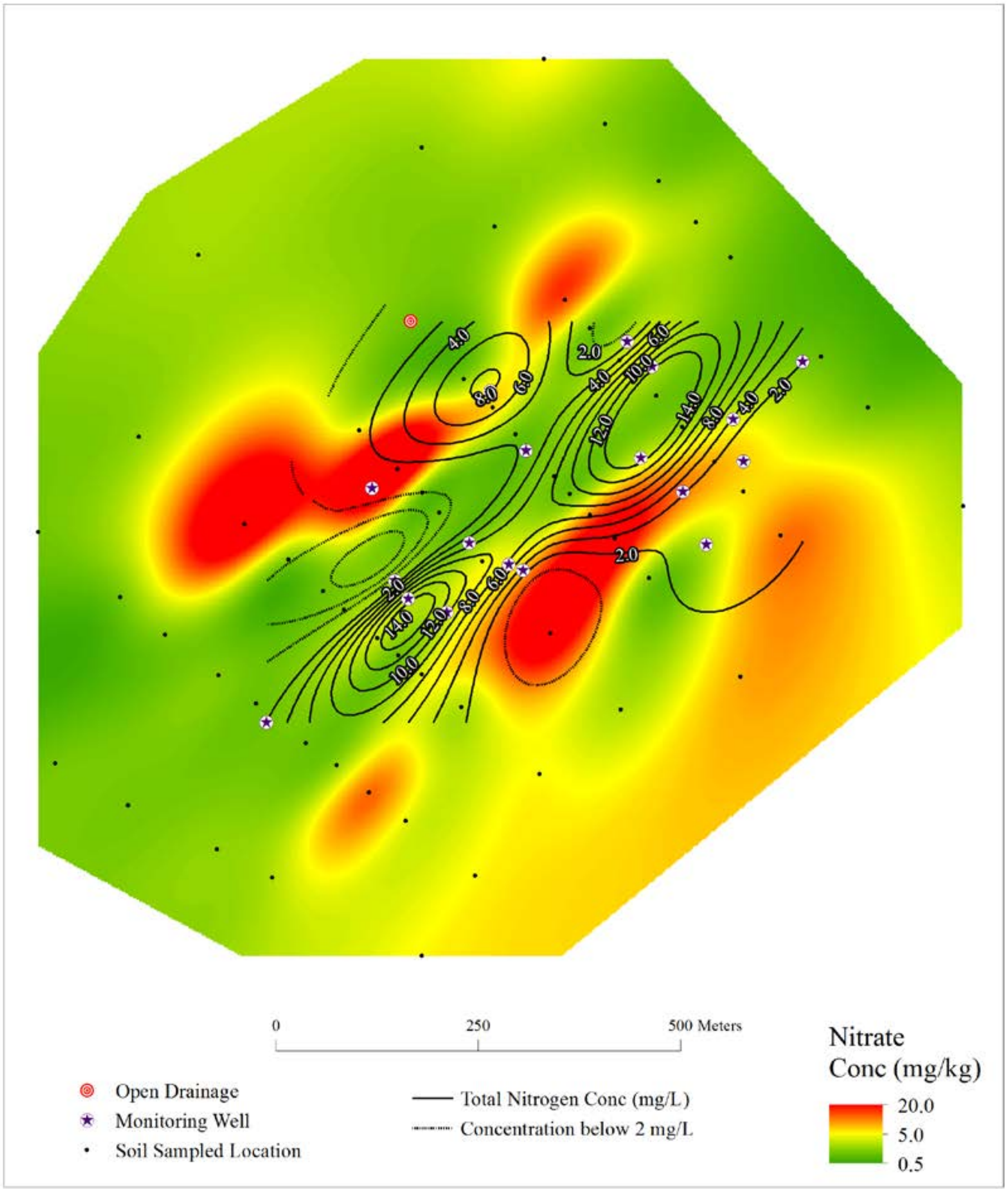

Fig. 15: Relationship of total nitrogen in groundwater to soil nitrate. Soil data were interpolated using radial basis function while groundwater data were interpolated using in kriging interpolation method.

Nitrogen had variable concentrations in both soil and water, with most wetland areas having low to non-detected concentrations in surface and groundwater (Fig. 15). The concentrations within the wetlands were due to activities of microbes and plants through processes including denitrification, volatilization, plant uptake, and microbial assimilation, which may have caused variable nitrogen concentrations. The beach ridge has low soil nitrate but high nitrate concentration in groundwater. This was caused by accumulation of leached soil nitrate into the groundwater system. Groundwater enriched with nitrate moves through pathways into receptors (wetlands). As the groundwater moves from the beach ridge into the wetlands, microbes play important roles in the oxidation-reduction condition (e.g. DeSimone, 1998), which result in reducing the concentration of nitrate in the groundwater. The reduction process occurs during the decomposition of organic material, where the nitrate is used as a terminal electron acceptor in the process of denitrification. Denitrification is the one of the processes that removes nitrate from wetland water (Hill, 1996). The process is influenced by microbes, hydrology, soil processes, and vegetation type (Hanson et al., 1994).

Plant uptake and microbial assimilation are also important processes involved in the reduction of nitrate from groundwater in wetlands (e.g. Lowrance et al., 1984; Findlay et al., 2003). The wetlands have large communities of graminoids with *Typha* sp., *Carex* sp., *Phalaris arundinacea*, and *Bromus inermis*. Although surface water and groundwater are a contributory factor in plant species diversity (Stromberg et al., 2007; Mata-González et al., 2012), plant species richness declines as soil nutrient availability increases (Bedford et al., 1999). The wetlands are dominated by *Bromus inermis*, *Typha* sp., and *Phalaris arundinacea*, which are aggressive in the assimilation of nutrients and have elevated concentrations of nitrogen and phosphorus in their tissues due to luxury uptake. The dominance of *Typha* sp. in the inner wetland is due to the increased water depths and the extended hydroperiods; this may have affected species diversity and enhance cattail growth (e.g. Mata-González et al., 2012).

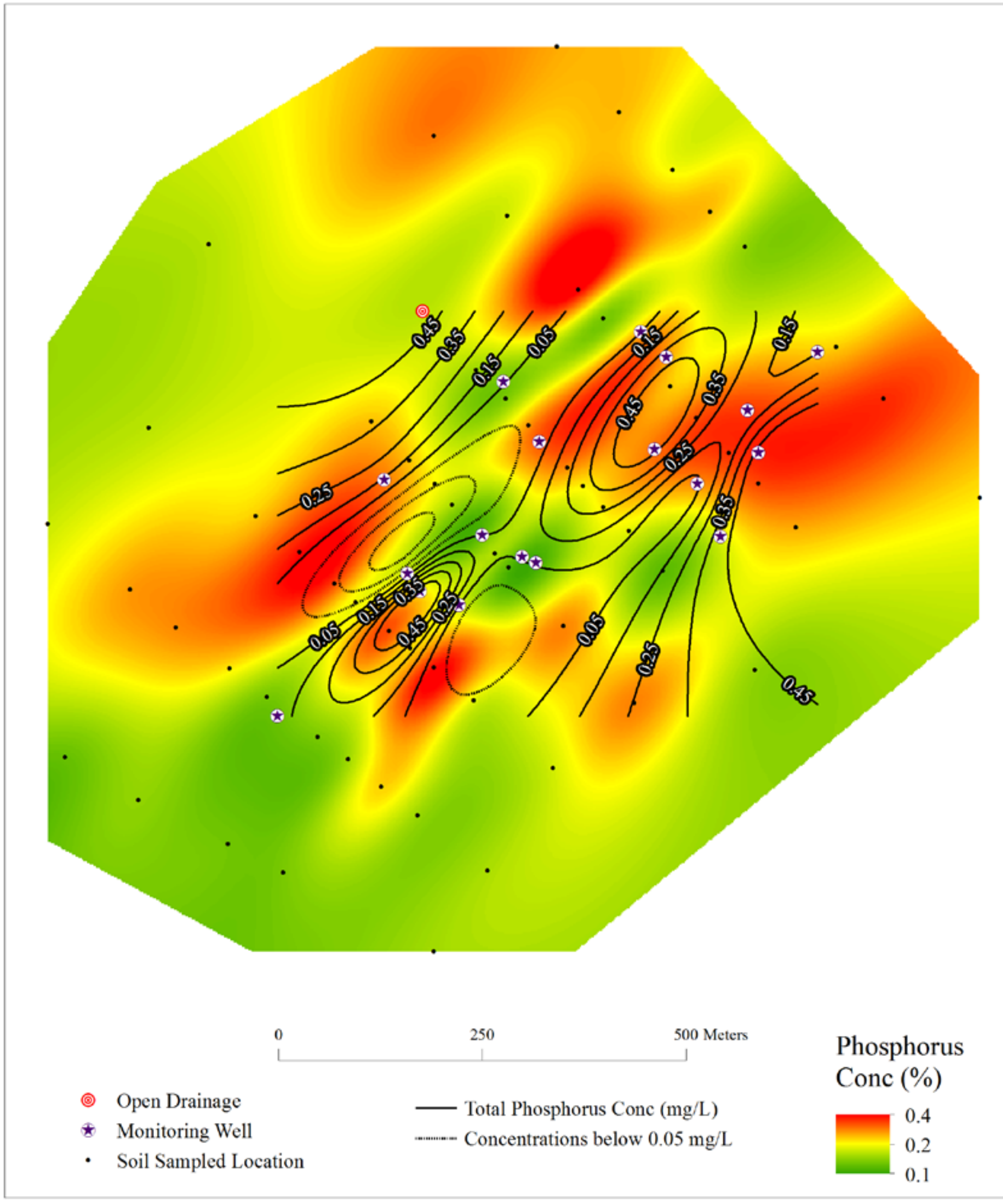

Fig. 16: Relationship of total phosphorus in groundwater to plant tissue total phosphorus. Plant tissue data were interpolated using radial basis function while groundwater data were interpolated using in kriging interpolation method.

Most of the plants with elevated phosphorus concentrations in their tissues are located within areas characterized by elevated concentrations of groundwater phosphorus (Fig. 16).

However, plant tissue nitrogen varied with groundwater nitrate concentration (Fig. 17), and this can be attributed to species diversity and biogeochemical processes on the beach ridge and within the wetlands.

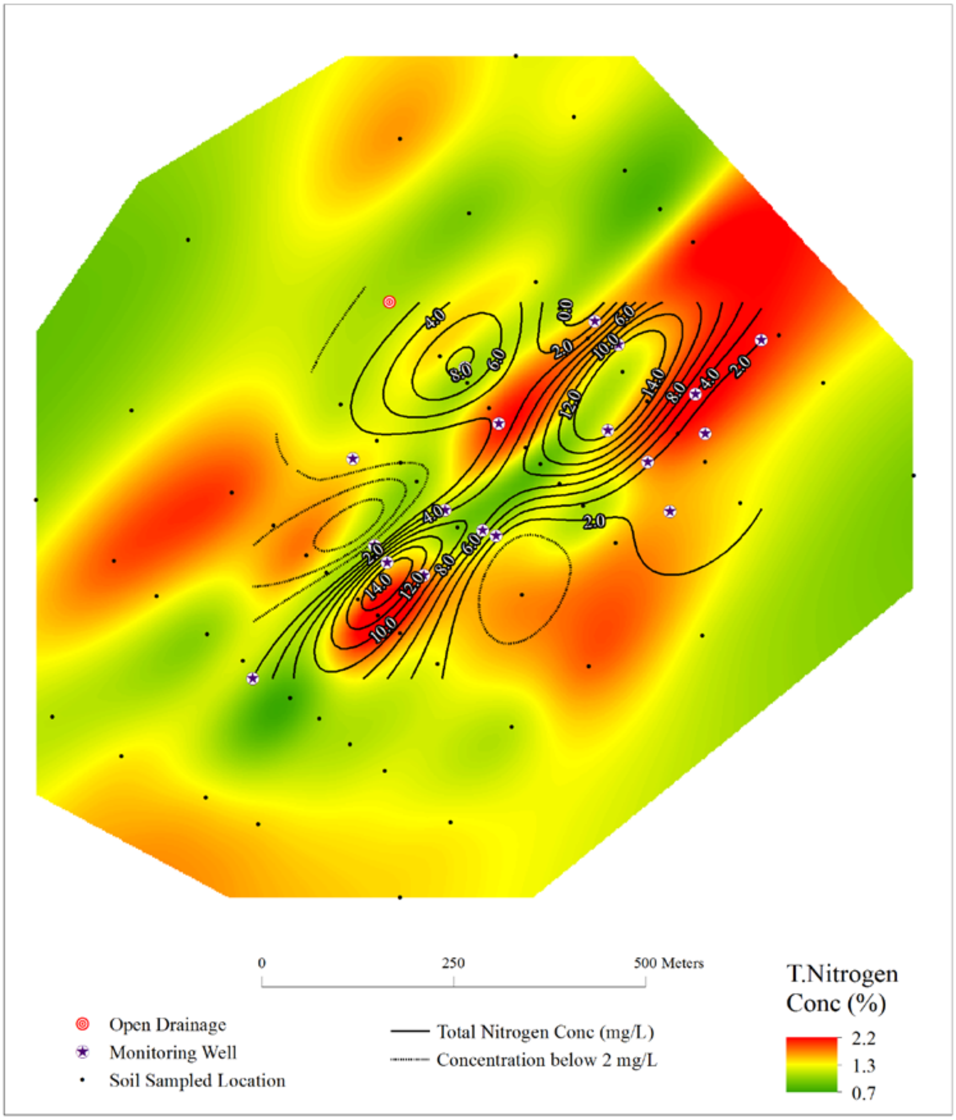

Fig. 17: Relationship of total nitrogen in groundwater to plant tissue total nitrogen. Plant tissue data were interpolated using radial basis function while groundwater data were interpolated using in kriging interpolation method.

Phosphorus Budget

The mass of phosphorus in the Sandberg and the Radium soils ranged from 18,600 to 23,400 kg, with a mean and standard deviation of 21,000 and 2,400 kg, respectively (Table 9).

Table 9: Total phosphorus stored in soil, plant tissue, and groundwater at the feedlot

Medium	Max (mg kg^{-1})	Min (mg kg^{-1})	Average (mg kg^{-1})	St. Dev (mg kg^{-1})	Thickness (m)	Bulk Density (mg kg^{-1})	Mass (kg)	Uncertainty (kg)
A-Horizon (Sandberg)	113	71	97.3	13.6	0.48	1360	8,300	1,200
B-Horizon (Sandberg)	121	56	96.1	22.2	0.16	1360	2,700	630
A-Horizon (Radium)	112	15	70.5	36.8	0.36	1250	4,100	2,200
B-Horizon (Radium)	112	4	80.4	40.0	0.45	1250	5,900	2,900
Total							**21,000**	**2,400***

Medium	Max (%)	Min (%)	Average (%)	St. Dev. (%)	X (kg m^{-2})		Mass (kg)	Uncertainty (kg)
Plant Tissue	0.32	0.09	0.20	0.10	0.41		110	43
Total							**110**	**43**

Medium	Max (mg kg^{-1})	Min (mg kg^{-1})	Average (mg kg^{-1})	St. Dev. (mg kg^{-1})	Saturated Thickness (m)	Porosity	Mass (kg)	Uncertainty (kg)
Groundwater	0.52	0.05	0.25	0.21	2.8	0.15	14	11
Total							**14**	**11**

The calculated mass is based on the average of the phosphorus concentrations in the various medium and the uncertainty is also based on the standard deviation of the concentrations. X is the ratio of the mass of the graminoid per unit square meter. * is obtained from the standard deviation of the mass of phosphorus within the soils. The calculated area for the confinement area (pen) is 130,000 m^2.

Table 10: Total phosphorus stored in soil, plant tissue, and groundwater at the reference site

Medium	Average (mg kg^{-1})	Thickness (m)	Bulk Density (mg kg^{-1})	Mass (kg)	Uncertainty (kg)
A-Horizon (Sandberg)	8.0	0.48	1,360	680	
B-Horizon (Sandberg)	27.0	0.16	1,360	760	
A-Horizon (Radium)	43.0	0.36	1,250	2,500	
B-Horizon (Radium)	36.0	0.45	1,250	2,600	
		Total		**6,600**	**1,100***

Medium	Average (%)	St. Dev. (%)	X (kg m^{-2})	Mass (kg)	Uncertainty (kg)
Plant Tissue	0.10	0.02	0.41	53	11
		Total		**53**	**11**

The calculated mass is based on the average of the phosphorus concentrations in the various medium and the uncertainty is also based on the standard deviation (St. Dev.) of the concentrations. X is the ratio of the mass of the graminoid per unit square meter. * is obtained from the standard deviation of the mass of phosphorus within the soils. The estimated mass is based on the area of the pen at the feedlot (130,000 m^2). The phosphorus concentration within the groundwater was below detection level.

Phosphorus within plant tissues ranged from 67 to 153 kg, with a mean and standard deviation of 110 and 43 kg, respectively. The estimated phosphorus within the groundwater samples ranged from 3 to 25 kg with a mean and standard deviation of 14 and 11 kg, respectively.

At the reference site, the mass of phosphorus was estimated based on the area of the pen location at the feedlot. The estimated mass of phosphorus within the soils was 6,600 $\pm$ 1,100 kg and that within the plant tissues was 53 $\pm$ 11 kg (Table 10). With the groundwater samples, phosphorus concentration was neglected because of the non-detected concentration in the wells at the reference site.

The difference in the mass of phosphorus within the feedlot soils and that of the reference site was approximately 15,000 kg and that of the plant tissues was approximately 57 kg.

Table 11: Phosphorus budget

Medium	Mass (Feedlot) (kg)	Mass (Ref. Site) (kg)	Difference (kg)
A-Horizon (Sandberg)	8,300	680	7,600
B-Horizon (Sandberg)	2,700	760	1,900
A-Horizon (Radium)	4,100	2,500	1,600
B-Horizon (Radium)	5,900	2,600	3,320
	Total		**14,000**
Plant tissue	110	53	57
	Total		**57**
Groundwater	14	-	14
	Total		**14**

The concentration of phosphorus in livestock manure is variable due to differences in the feed, antibiotics, and supplements. According to Sharpley (1996), the average concentration of phosphorus in manure from a beef feedlot is 4,000 mg kg^{-1}. The average depth of a cattlecompacted layer of soil and manure in a pen is approximately 76 mm (Sweeten et al., 1985) and the estimated bulk density of manure is 1.0 g cm^{-3} (ASAE, 2003). Assuming the pen area has a uniformly distributed concentration of 4000 mg kg^{-1} of phosphorus in the 76 mm of cattle compact layer of soil and manure, the estimated mass of phosphorus within the animal holding area was 40,000 kg based on Equation (2). An average cow excretes 10 kg of phosphorus in manure annually (Sweeten, 1979) and assuming 90 percent of the manure is scraped from the soil in the pen. This implies about a kilogram of the phosphorus is left in the soil. Therefore, the amount of phosphorus deposited in the soil after 20 years of operation for 2,000 to 2,500 cattle is the product of the amount of phosphorus left for twenty years and total number of cattle. The value obtained for the amount of phosphorus initially deposited in the soil ranges from 40,000 to 45,000 kg, which is similar to the value obtained using Equation (2). The estimated amount of phosphorus in the soil was 21,000 kg (Table 9). Therefore approximately 19,000 kg (48 percent) of the originally deposited phosphorus from the manure has been lost after 20 to 25 years when the feedlot was abandoned.

CONCLUSIONS

Feedlot operations generate large amounts of manure that contain nutrients, antibiotics, supplements, and other constituents, which when improperly managed can have potential deleterious effects on the environment. Nitrogen in wet manure can cause short-term contamination of soils and groundwater beneath active feedlots due to the effect of denitrification, volatilization, and leaching. This processes results in the formation of other forms of nitrogen compounds with low concentrations that are non-toxic to the environment.

Contrarily, most of the phosphorus in the wet manure is sequestered in soils with high organic matter, iron, calcium, and carbonates, making it unavailable for plant assimilation.

Sequestration normally takes place at the source of the contamination, where there is less mobility of phosphorus. Anaerobic conditions that may have developed during floods, precipitation, or snow melt may cause the release of sequestered phosphorus into soluble forms that are either assimilated by plants or transported through preferential pathways into the surrounding receptors. This can boost plant vigor and growth of algae, which can result in eutrophication in the receptor.

The quantified mass of excess phosphorus in the soils, groundwater, and plant tissue from the feedlot pen area with respect to values obtained from the undisturbed site was approximately 14,000 kg (Table 11). The amount of phosphorus in the soils was far greater than plant tissues and groundwater combined. Comparing the amount of phosphorus originally deposited from manure (40,000 kg) to that of the soils and plant tissues (21,000 kg), approximately 48 percent of the originally deposited phosphorus has been lost to the various receptors at the feedlot since it was abandoned 20 to 25 years ago.

RECOMMENDATIONS

One important observation made based on the data obtained in this research is recovering soil phosphorus for use as fertilizer from abandoned feedlots. . Feedlot operations generate large amounts of phosphorus that is immobilized within soils at confined animal holding areas. Studies of soils from feedlots revealed elevated concentrations of phosphorus greater than 1000 mg kg^{-1} (Cole and Todd, 2003; Gilley et al., 2008; Vaillant et al., 2009). According to Horneck et al. (2011), no fertilizers should be added to the soil with phosphorus content exceeding 50 mg kg^{-1}; high concentration of phosphorus in the soil does not increase plant yield, but rather encourages luxurious absorption of nutrients by plant roots.

Soil phosphorus from feedlots with concentrations greater than 50 mg kg^{-1} can be harnessed as fertilizer for farming, especially in phosphorus sequestered soils. Soils from newly abandoned feedlots have high salt content compared to the older abandoned feedlots (Eghball and Power, 1994). Most feedlots are simply abandoned: erosion occurs and invasive native and exotic plants often germinate and thrive, especially during the wet seasons. Agronomists, soil scientists, hydrologists, other scientists, and major stakeholders in agriculture and food security should take a holistic approach in assessing the viability of abandoned feedlots as a source of phosphorus. The use of abandoned feedlots to supplement the primary sources of phosphorus used in fertilizer can delay the depletion of these critical reserves.

The phosphorus budget at the site described in this report indicated that most of the phosphorus released from the manure into the soil was absorbed and assimilated by plants, which suggests the use of graminoids for phytoremediation. Graminoids situated near feedlots are enriched with nutrients, which can be made available for livestock consumption in the form of forage. Phytoremediation of phosphorus using graminoids may be effective in mitigating elevated soil concentrations. Other practices such as prescribed burning, ploughing, and irrigation should also be encouraged to help release and recycle immobilized phosphorus.

Some of the areas on the beach ridge were dominated by invasive species including thistle. These areas were characterized by high soil phosphorus and low nitrate concentration. It would be interesting to investigate the relationship between soil conditions and the presence of some of these species. It is believed the invasive species are very competitive and dominate areas characterized by good soil conditions and plant available soil nutrients. This study would be helpful for farmers, agronomists, scientists, and major stakeholders in agriculture in ways to control the growth of invasive species and making nutrient available for plants.

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