hydrology

MDPI

Article

Characterization of Nutrient and Metal Leaching in Roadside Ditches Maintained with Cool and Warm Season Grasses

Alex Boger [1] and Laurent Ahiablame [2,*]

[1] Department of Agricultural and Biosystems Engineering, South Dakota State University, 1400 North Campus Drive, Brookings, SD 57006, USA; Alex.Boger@jacks.sdstate.edu

[2] University of California Division of Agriculture and Natural Resources, 9335 Hazard Way, Suite 201, San Diego, CA 92123, USA

* Correspondence: lmahiablame@ucanr.edu; Tel.: +1-858-822-7673

Received: 29 April 2019; Accepted: 5 June 2019; Published: 7 June 2019

Abstract: Roadside ditches play an important role in the quantity and quality of receiving waters. Very little, however, is known about the fate and transport of nutrients and trace metals in roadside ditches, especially their leaching to shallow groundwater. This study sought to document selected water quality constituent levels in infiltrated water (i.e., leachate) in roadside ditches maintained with permanent vegetation. Leachate sampling wells were installed in four roadside ditches, and water samples were collected from the wells following major rainfall events during the years 2016 and 2017. The samples were analyzed for nutrient and metal concentrations. Results indicated that nutrient concentrations in the water samples range from 0.00600 to 0.0107 mg/L for orthophosphate (PO_4–P), 0.00500 to 6.80 mg/L for nitrate (NO_3–N), 0 to 0.007 mg/L for nitrite (NO_2–N), and 0.0100 to 314 mg/L for chloride (Cl^-). Concentrations of the metals examined varied between 0.0100 and 104 mg/L in water samples. While there was no specific pattern in both nutrient and metal concentrations when roadside ditches maintained with cool season grass were compared to those of warm season grass ditches, results suggest that grass types will likely affect differently uptake of nutrients and metals in the ditches.

Keywords: pollutant leaching; monitoring well; road pavement; nonpoint source pollution; South Dakota

1. Introduction

Roadside ditches are important features of the drainage network in the United States. They are mostly designed to rapidly convey storm runoff downstream, reducing the risk of potential road closure as a result of flooding and water logging [1–3]. On average, about 20% of storm runoff is captured by roadside ditches in a watershed [4]. As such, roadside ditches can be considered best management practices for flood reduction [1,3,4].

While roadside ditches intercept and efficiently drain runoff from adjacent roads, fields, and parking lots [5,6], they are also conduits of road salts, fertilizers, pathogens, and various contaminants in runoff to streams and rivers, leading to deterioration of downstream water quality [1,2,7]. Unmanaged ditches can contribute considerable amounts of suspended sediment and other pollutants to receiving waters, modify natural downstream streamflow, cause erosion along stream banks, and contribute to groundwater quality impairment [2,3,5]. By quickly discharging runoff and related pollutants to receiving waters, roadside ditches are comparable, by analogy, to high-velocity faucets [4,8,9].

To help to mitigate contaminant transport in roadside ditches, they are often designed and maintained with permanent vegetation either within or along the ditch in the form of swales and filter strips [10,11]. Roadside swales are large, shallow, and grassy channels contiguous to roadways, designed to slow storm runoff, promote infiltration, and filter out contaminants while conveying the stormwater [6,10,11]. Roadside filter strips are usually small strips of land in permanent vegetation implemented on the side of the road to perform similar functions as filter strips [12].

Research showed varying results related to the effectiveness of roadside swales and filter strips at removing nonpoint source (NPS) pollutants in runoff (e.g., [9,11,13,14]). For example, monitoring of two swales on a major four lane state route in Maryland, United States, showed variable removal of total Kjeldahl nitrogen (TKN), ranging from −106% to 77.4% [15]. The variability was apparent mainly during summer months when high levels of extraneous organic matter such as grass clippings and fallen leaves were present in the swales [15]. The study reported that the swales examined were effective in treating most rainfall events, except extreme rainfall events that led to reduction in swale performance [15]. Li et al. [13] also found −12% to 56% removal of dissolved phosphorous (DP) from monitoring of six grassed swales in Texas (three in College Station and three in Austin, Texas, United States). Using artificial runoff on a 65 m long and 4 m wide swale with a 1.6% longitudinal slope, Deletic et al. [16] reported an average total nitrogen (TN) and total phosphorous (TP) removal of 46% and 56%, respectively. The researchers explained that flow rate added high variability to the performance of the swales but found that nutrient removal generally appeared to decrease along the length of the swale. An evaluation of roadside filter strips in North Carolina also revealed considerable reductions in NO_3–N, NO_2–N, metal, and total suspended solids (TSS) concentrations [17,18].

Water quality implications of roadside ditches is not a new topic; however, research and design efforts mainly focus on factors including vegetation cover and density, longitudinal slope, and soil type that influence the performance of roadside swales and filter strips (e.g., [10,13,17]). The influence of roadside ditches on downstream water quality and biogeochemical functions has not been extensively considered in their design [1,5], pointing to the need to evaluate the watershed-scale implications of these systems. The impacts of roadside ditches as affected by cool and warm season grasses on groundwater quality is also not well documented. This study sought to report leaching of water quality constituent levels in roadside ditches maintained with permanent vegetation, adding data to the information system on the fate and transport of NPS pollutants in roadside ditches. The specific objectives of this study were to (1) determine the concentration of selected nutrient and metal constituents in infiltrated water in roadside ditches; and (2) explore if native and non-native grasses (i.e., cool and warm season) affect water quality constituent leaching in roadside ditches. Throughout this report, the term leachate refers to infiltrated water in the unsaturated ditch soil.

2. Materials and Methods

2.1. Study Sites

Two study sites were prepared in South Dakota (SD), United States, for the study (Figure 1). Each study site consisted of two experimental set ups, one on each side of the road. One roadside set-up is maintained in cool season grass while the other is planted with warm season grass. The first study site was prepared on 16 June 2016 on Interstate Highway I-29, about 2 km south of Trent, SD exit (43.97424° N, 96.75806° W). The site is located in Moody County, SD, which averages about 660 mm per year on Egan–Wentworth complex silty clay loam (2 to 6% slope), with an average daily temperature range of −16 to 26 °C. The second site, located in Hughes County SD, was prepared on 18 May 2016 on SD State Road 34, approximately 24 km west of Pierre, state capital of SD (44.2928° N, 100.0067° W). This site receives approximately 500 mm of rainfall per year, with −14 to 30 °C daily temperature. Dominant soil at the study site is Ree loam, 0 to 2% slope. I-29 and Highway 34 are 23 and 10 m wide, respectively. The experimental sites were respectively referred to as Trent and Pierre sites throughout the paper. Land use at the sites is prime farmland, planted predominantly in corn and soybeans.

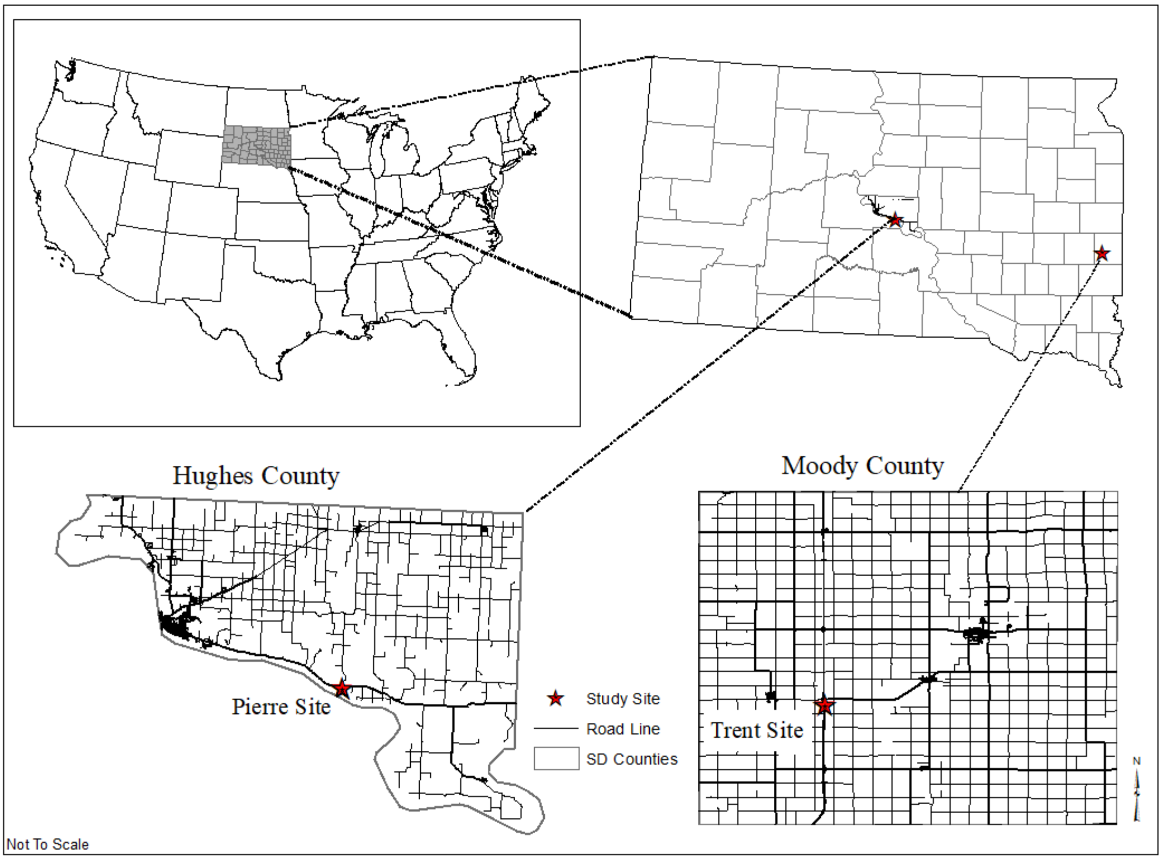

Figure 1. Sites for nutrient and metal leaching study in roadside ditches in South Dakota.

These sites were outfitted with twenty (20) 3.8 cm diameter, 1.5 m long polyvinyl chloride (PVC) pipes for leachate sampling wells (Figure 2). The wells were installed 15 m apart in two rows of five on each side of the road (Figure 3). The total length of each row was 75 m, and the two rows were 6.5 m apart. One row of the wells was installed on the slope half way between the top (i.e., edge of the road pavement) and the bottom of the ditch (i.e., deepest point of the ditch) on both sides of the road. The other row was installed on the slope half way between the ditch bottom and edge of right-of-way on the land side of the ditch. It should be noted that the ditches were very shallow, so installing the wells on both sides allows having more representative samples. As mentioned earlier, leachate in this study describes the infiltrated and percolated water in the unsaturated ditch soil, captured in the monitoring wells.

Figure 2. Leachate sampling well in roadside ditches (**a**) during installation and (**b**) after installation.

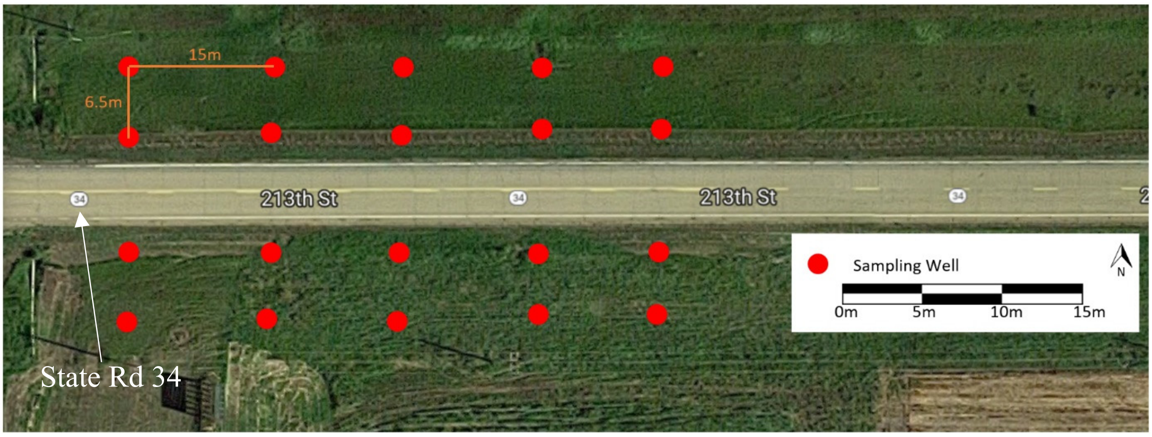

Figure 3. Schematic diagram of leachate sampling locations in roadside ditches during this study in South Dakota.

2.2. Field Data Collection

Leachate samples were collected within 36 h following major rainfall events using a syringe and a 1.8 m, 6.3 mm inside diameter of a transparent polyvinyl chloride (PVC) tube. Both the syringe and tube were cleaned using field equipment cleaning standard procedures for water sampling and analysis of inorganic constituents [19]. During sampling, the tube was connected to the syringe and lowered carefully into the well. The syringe was then used to pull water into the tube, then deposited into a cleaned 120 mL high-density polyethylene (HDPE) Nalgene bottle. The collected water sample was kept on ice in the dark in a plastic cooler until it was transported to the laboratory for analysis. Once in the laboratory, a set of the samples was filtered using 30 mL HDPE syringes and 0.45 µm nylon syringe filters into clean 120 mL Nalgene bottles. The filtered samples were then frozen until being analyzed for nutrients. Before analysis, the samples were completely thawed while kept in the dark at 4 °C until being analyzed within 48 h. It should be noted that the samples were held in freezer storage for varying lengths of time, from five to 20 days prior to analysis. The remaining unfiltered samples were delivered, within 24 h of sampling events, to an analytical laboratory (Ward Laboratories Inc., Kearney, Nebraska, United States: https://www.wardlab.com/), where they were subsequently analyzed for metals. A total of 96 leachate samples were collected during five sampling surveys from the Pierre site, and 219 samples during 11 surveys from the Trent site over the study period, which was between May 2016 and October 2017.

2.3. Data Analysis

The water samples were analyzed for NO_3–N, NO_2–N, PO_4–P, and Cl^- using automated colorimetry methods (USEPA 353.1, 353.2, 365.1, and 325.2, respectively) [20–23] with Seal AQ2 Discrete Analyzer (Seal Analytical, Mequon, Wisconsin). Axially viewed inductively coupled plasma–atomic emission spectrometry (USEPA 200.5; Rev. 4.2; [20]) was used for determination of aluminum (Al), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) concentrations in the water samples [24,25].

A two-sample t-test was used to determine differences in means of concentrations of nutrients and metals leached between cool and warm season grasses at a significance level of 0.10. Prior to the analyses, the datasets were log-transformed in this study, as the original data were not normally distributed.

3. Results and Discussion

3.1. Nutrients and Metals Leached in Roadside Ditches

Concentrations of nutrients and metals in infiltrated water in the studied roadside ditches, regardless of cool and warm season grasses, varied from 0.00500 to 314 mg/L for nutrients and from 0.0100 to 104 mg/L for metals (Tables 1 and 2). The data for all nutrient and metal concentrations showed high variability, ranging from 90% variation for NO_3–N at the Trent site to 400% for Al at the Pierre site (Tables 1 and 2). With similar mean rainfall amounts during the study period, the average nutrient concentrations at the Trent site generally appears to be lower than nutrient concentrations at the Pierre site, except for Cl^- concentrations. While the intent of the study was not to compare the two sites, it is worth noting that the Trent site is an interstate highway which receives frequent deicing salt during winter due to higher traffic volume compared to the Pierre site, a state road, with less deicing maintenance and less traffic. Heavy metals detected in the ditch water at both sites may come from vehicles—for example, through the wear and abrasion of tires and brake linings. Based on the closest leachate sampling well data to the two sites (http://apps.sd.gov/nr69obswell/default.aspx, South Dakota Department of Environment and Natural Resources), groundwater level at the two sites is relatively the same (~4 m). However, the top soil (3 m) at the Trent site is sandy, while the Pierre site has a very clayey top soil. Nutrient and metal constituents in the ditch water may be susceptible to leaching more quickly in the sandy soil with diluted concentrations passing the monitoring wells than in the Pierre clayey soil with reduced infiltration but more concentrated leaching. The large surface area of the clay soil particles is likely to retain and release more nutrient and metal constituents to runoff than water quality constituents in sandy soil. In addition, clay particles are easily compacted when wet and would likely limit infiltration and increase runoff with dissolved nutrient and metal constituents.

Even though water quality constituent levels in the samples collected in this study revealed some potential for downstream water pollution with respect to the national drinking water quality standards, only a few of the water quality constituents examined exceeded these standards (Tables 1 and 2). Nutrient concentrations examined in this study are comparable to results published by other researchers (Tables 1 and 2; e.g., [14,26]). For example, Yousef et al. [14] found a mean PO_4–P concentration of 0.495 mg/L in runoff for a field evaluation of two grassed swales in central Florida. Stagge et al. [15] reported means of 1.25 and 0.94 mg/L for NO_3–N and NO_2–N concentrations, respectively, in runoff from a swale in Maryland, United States. With less than 1 mg/L in samples collected from groundwater monitoring wells at six study sites in Iowa, roadside ditches were shown to have typical reduced NO_3–N concentrations in groundwater for watershed-scale treatment of NPS pollution [26]. Metal concentrations in the present study were generally higher than those found in other studies (Tables 1 and 2; e.g., [11,18]). While Al and Mn concentrations have not been extensively examined with regard to roadside ditch water quality, Cu, Fe, and Zn have often been studied in surface runoff from roadside ditches in many studies (e.g., [13,17,27–29]. This can be explained by the fact that Al and Mn concentrations generally occur with relatively low concentrations in runoff, as found in the present study (Tables 1 and 2). Concentrations of metals reported for surface runoff in the literature are comparable to the concentrations examined in this study [28,30,31].

Differences in water quality constituent levels between studies (i.e., between the present study and the literature) could be due to differences in site characteristics, including climate, best management practice (BMP) design and construction, upland usage at the study sites, and most importantly, the medium of interest. This study focused on shallow groundwater, while the literature has largely focused on runoff in the ditches. Clearly, the data suggest that roadside ditches have the potential to contribute to groundwater and downstream water pollution, especially with metal concentration levels. Pollution would depend on rainfall intensity and the condition of the sites as well as ditch and BMP design and maintenance. To increase protection of water quality in the receiving waters from roadside ditches, factors that influence the performance of vegetated BMPs in roadway settings could be improved (see [11,32,33]). In fact, roadside ditches can serve as linear wetlands for groundwater NPS pollution treatment when managed well [26,33]. Studies showed that dense vegetation, increasing BMP width, and treatment length, as well as a slope less than 10%, can enhance water quality in roadside vegetated BMP [11]. Infiltration of contaminated water in roadside ditches may poses high risk for shallow groundwater contamination [2]. As roadside ditches receive input from a wide variety of stormwater-contributing areas, identification of contaminant sources could aid in ditch design improvement for effective management of groundwater resources. In this context, Alberti et al. [34] developed a methodology to identify source areas having high potential to contribute NPS pollutants.

3.2. Impacts of Cool and Warm Season Grasses on Nutrients and Metals Leached in Roadside Ditches

When mean nutrient concentrations were compared between roadside ditches maintained with warm and cool season grasses at the two study sites, there was no specific pattern to derive a clear conclusion, except for Cl^- concentrations, which were significantly higher in warm season grass than cool season grass at the two sites ($p = 0.013$; Figures 4 and 5). This could be attributed to the fact that cool season grass is likely more tolerant to a salt environment from deicing salts and grows more in these areas, creating more leaf litter on the ditch floor that may filter out salt residues, leading to lower concentrations of Cl^- in leachate compared to the warm season grass. For most heavy metal contaminants, warm grass seems to influence their cycling, as depicted by concentrations of Cu, Mn, and Zn compared to Fe concentrations. Since most of the sampling events took place during spring and summer, coinciding with warmer temperatures, and considering that warm season grasses, which thrive better during the warm season, likely uptake more metals [35] compared to cool season grasses, there are no statistically significant differences in mean concentrations between warm and cool season grasses for many of the contaminants.

Comparison between warm and cool season grasses at the individual study sites shows varying results with increased and decreased nutrient concentrations (Figures 4 and 5). Research suggests that plants in warmer environments tend to accumulate more nutrients than those growing in cold environments [36]. This was explained by the fact that warmer temperatures in cold ecosystems may result in increased microbial activity, decomposition and mineralization rates, and soil N and P availability, leading to increased plant uptake of N and P [36]. Results from the present study seem to be consistent with that pattern for NO_3–N and PO_4–P at the Pierre site. Measurements of metal concentrations at the individual sites also reveal varying results, although the data suggest more metal uptake by warm season grasses than cool season grasses (Figures 4 and 5). In addition, green-up and evapotranspiration, which may impact when and how much water percolates through the root zone, were not explicitly examined in this study. The study of these processes in a ditch environment could be useful in understanding the influence of grass type on pollutant cycling.

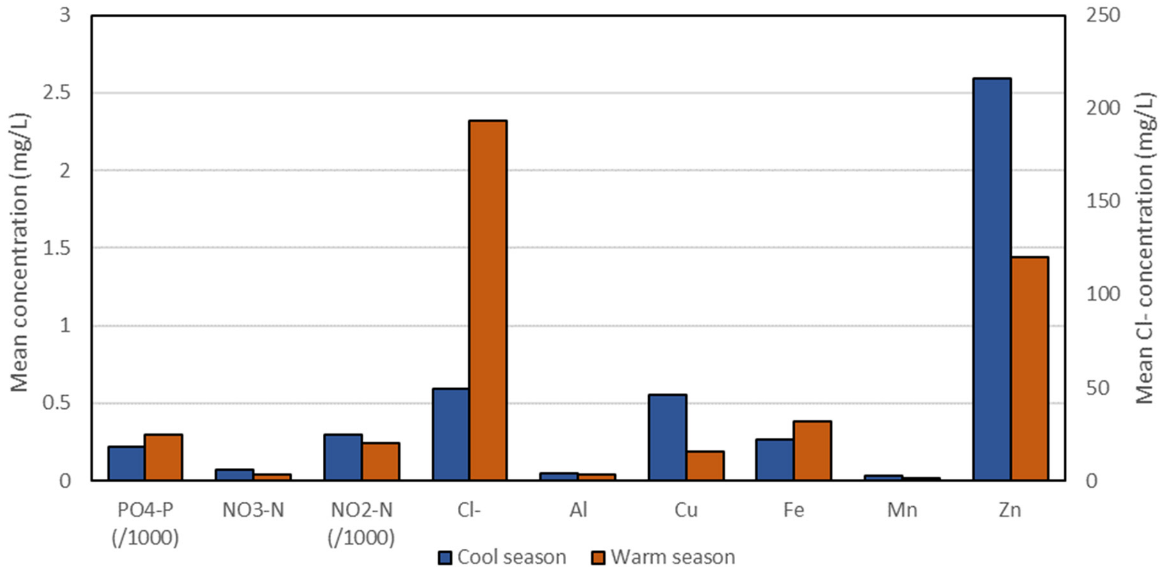

Figure 4. Comparison of dissolved nutrient and metal concentrations in infiltrated water in roadside ditches maintained with warm and cool season grasses on I-29 near Trent, South Dakota, United States.

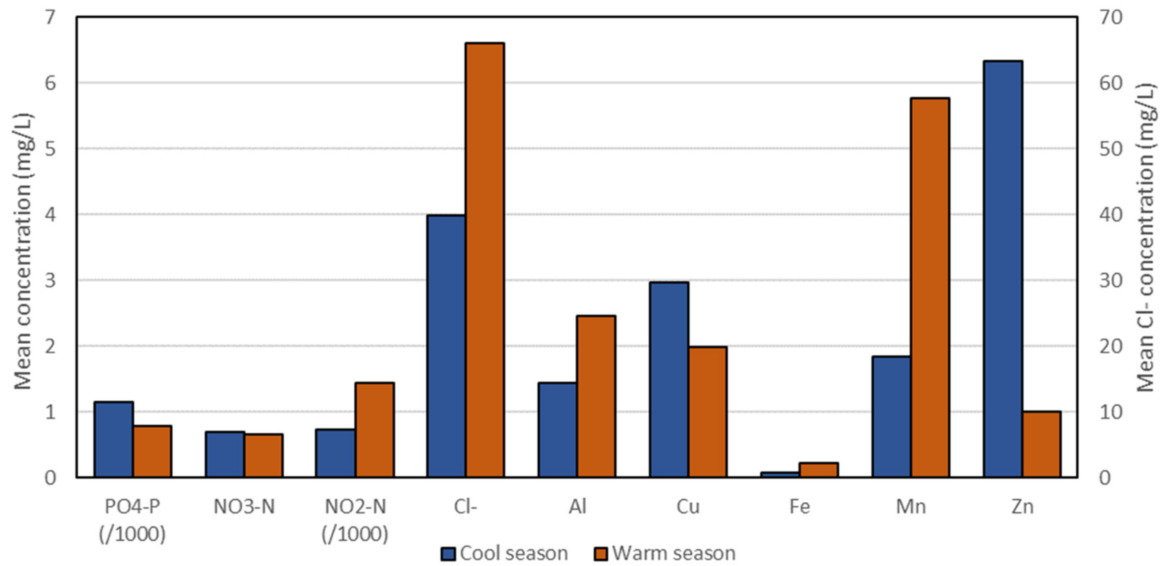

Figure 5. Comparison of dissolved nutrient and metal concentrations in infiltrated water in roadside ditches maintained with warm and cool season grasses on highway 34 near Pierre, South Dakota, United States.

Table 1. Summary for dissolved nutrient and metal concentrations measured in infiltrated water in roadside ditches on I-29 near Trent, South Dakota, United States. Numbers in parentheses represent the total samples collected. Water samples were collected for major rainfall events between May 2016 and October 2017.

	Rainfall	**PO_4–P**	**NO_3–N**	**NO_2–N**	**Cl^-**	**Al**	**Cu**	**Fe**	**Mn**	**Zn**
	mm	**µg/L**	**mg/L**	**µg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
Samples below limit of detection	-	6 (219)	54 (219)	8 (219)	84 (219)	84 (219)	84 (219)	48 (219)	90 (219)	78 (219)
Minimum	4.00	0.0140	0.00500	0.00500	0.00900	0.0100	0.0100	0.0100	0.0100	0.100
Maximum	33.0	10.7	0.200	2.18	314.2	0.220	3.65	0.830	0.130	11.1
Median	216	0.345	0.0480	0.253	88.0	0.0550	0.307	0.124	0.0310	1.53
Mean	19.0	0.100	0.0320	0.156	42.8	0.0350	0.100	0.0200	0.0200	0.300
Coefficient of variation	42%	376%	93%	139%	115%	105%	206%	173%	94%	194%

Table 2. Summary for dissolved nutrient and metal concentrations measured in infiltrated water in roadside ditches on State Route 34 in Pierre, South Dakota, United States. Numbers in parentheses represent the total samples collected. Water samples were collected for major rainfall events between May 2016 and October 2017.

	Rainfall	**PO_4–P**	**NO_3–N**	**NO_2–N**	**Cl^-**	**Al**	**Cu**	**Fe**	**Mn**	**Zn**
	mm	**µg/L**	**mg/L**	**µg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
Samples below limit of detection	-	3 (96)	27 (96)	4 (96)	42 (96)	42 (96)	24 (96)	45 (96)	44 (96)	44 (96)
Minimum	14.0	0.00600	0.0130	0.0400	0.0130	0.100	0.0100	0.0100	0.0100	0.0100
Maximum	37.0	6.90	6.80	7.17	289.7	103.6	65.9	35.0	1.84	23.1
Median	22.0	0.947	0.669	1.10	55.4	4.06	3.81	2.450	0.165	1.94
Mean	20.0	0.700	0.400	0.745	22.2	0.500	1.03	0.205	0.0400	0.540
Coefficient of variation	31%	110%	148%	119%	124%	393%	273%	236%	215%	222%

4. Conclusions and Recommendations

This study characterized pollutant content in infiltrated water in four roadside ditches in South Dakota. The study also evaluated the effects of warm and cool season grasses on pollutant leaching at each of the study sites. The findings, based on the samples collected between 2016 and 2017 from the four roadside ditches, are as follows:

- Dissolved nutrient and metal concentrations examined in infiltrated water samples were generally low, with a range of 0.005 to 7 mg/L for PO_4–P and NO_3–N. High Cl^- concentrations were frequently examined in the samples analyzed. This is likely due to application of deicing salts on the road for maintenance for snow accumulation. Concentrations of metal pollutants in the infiltrated water samples collected show a range of 0.010 to 103.600 mg/L. The data for all nutrient and metal concentrations show high variability, ranging from 90% to 400% coefficient of variation.
- Comparison of nutrient and metal concentrations between warm and cool season grassed ditches led to varying results. While there were no specific patterns in both nutrient and metal concentrations in cool and warm season grassed ditches, there was a clear indication that warm and cool season grasses will likely influence nutrient and metal uptake and release differently.

While these results provide insight into nutrients and metals leaching to shallow groundwater in roadside ditches maintained with cool and warm season grasses, the study is very preliminary, and findings from this study are mostly negative, especially with respect to the grass types. The main reason behind this study is to introduce the subject with the hope that the study will generate some additional ideas for more research in this direction for understanding groundwater quality implications of roadside ditch systems.

Multiple future research opportunities have come to light during the course of this study. A few ideas are listed hereafter. A replication of this study would benefit from documentation of runoff baseline data for soil nutrient and metal composition from the roads and adjacent areas (e.g., fertilizer application rates and crop types adjacent to field sites) during rainfall–runoff events. Collecting background samples from the ditches and areas not influenced by the ditches would be an excellent addition to evaluate water quality impacts of the ditches. Consideration should be given to evaluation of the effects of specific grass types beyond the broad grouping of warm and cool season grasses such as smooth brome (*Bromus inermis*) and switchgrass (*Panicum virgatum*) on shallow groundwater quality. Exploring the relationship between rainfall intensity and water purification functions of vegetated BMPs and examining the fate and transport of bacteria (e.g., fecal coliforms) in roadside ditches are also interesting ideas for extending this study. Future research efforts should consider exploring the aforementioned ideas with natural rainfall or using rainfall simulations where the amount, intensity, and frequency of rainfall can be controlled.

Author Contributions: A.B. designed and performed the experiments as part of his MS thesis; he gathered and analyzed the data. L.A. conceived the experiments; he reviewed the experimental design and data results; L.A. contributed materials and analysis tools. A.B. wrote the first draft of the paper; L.A. reviewed and edited the paper.

Funding: This project was funded by H.G. Buffet Foundation and Dakota Lakes Research Farm. In-kind support was provided by the Department of Agricultural and Biosystems Engineering at South Dakota State University and University of California Agriculture and Natural Resources.

Acknowledgments: The authors are grateful to Dwayne Beck for his constructive comments throughout this study. Thanks also to Scott Cortus for his tremendous assistance during experimental site installation. Many thanks to Esther Mosase for assistance with Figure 1 presented in this study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Falbo, K.; Schneider, R.L.; Buckley, D.H.; Walter, M.T.; Bergholz, P.W.; Buchanan, B.P. Roadside ditches as conduits of fecal indicator organisms and sediment: Implications for water quality management. *J. Environ. Manag.* **2013**, *128*, 1050–1059. [CrossRef] [PubMed]
2. Buchanan, B.; Easton, Z.M.; Schneider, R.L.; Walter, M.T. Modeling the hydrologic effects of roadside ditch networks on receiving waters. *J. Hydrol.* **2013**, *486*, 293–305. [CrossRef]
3. Forman, R.T.; Sperling, D.; Bissonette, J.A.; Clevenger, A.P.; Cutshall, C.D.; Dale, V.H.; Fahrig, L.; France, R.L.; Heanue, K.; Goldman, C.R.; et al. *Road Ecology: Science and Solutions*; Island Press: Washington, DC, USA, 2003.
4. Schneider, R. Roadside Ditches. Factsheet. Available online: https://cpb-us-e1.wpmucdn.com/blogs.cornell.edu/dist/0/5949/files/2016/08/RoadsideDitches-fact-sheet-pdf-2j1nacx.pdf,2016 (accessed on 20 October 2018).
5. McPhillips, L.E.; Groffman, P.M.; Schneider, R.L.; Walter, M.T. Nutrient cycling in grassed roadside ditches and lawns in a suburban watershed. *J. Environ. Qual.* **2016**, *45*, 1901–1909. [CrossRef] [PubMed]
6. Ahmed, F.; Gulliver, J.S.; Nieber, J.L. Field infiltration measurements in grassed roadside drainage ditches: Spatial and temporal variability. *J. Hydrol.* **2015**, *530*, 604–611. [CrossRef]
7. USEPA (United States Environmental Protection Agency). *National Water Quality Inventory: Report to Congress*; 2004 Reporting Cycle, EPA-841-R-08-00; Washington, DC, USA, 2009. Available online: https://www.epa.gov/sites/production/files/2017-12/documents/305brtc_finalowow_08302017.pdf (accessed on 10 April 2017).
8. Buchanan, B.P.; Falbo, K.; Schneider, R.L.; Easton, Z.M.; Walter, M.T. Hydrological impact of roadside ditches in an agricultural watershed in Central New York: Implications for non-point source pollutant transport. *Hydrol. Process.* **2013**, *27*, 2422–2437. [CrossRef]
9. Smith, M.C. Metal Migration through Roadside Ditch Systems. Master's Thesis, State University of New York at Binghamton, New York, NY, USA, 2015.
10. Yu, S.L.; Kuo, J.-T.; Fassman, E.A.; Pan, H. Field test of grassed-swale performance in removing runoff pollution. *J. Water Resourc. Plan. Manag.* **2001**, *127*, 168–171. [CrossRef]
11. Boger, A.R.; Ahiablame, L.; Mosase, E.; Beck, D. Effectiveness of roadside vegetated filter strips and swales at treating roadway runoff: A tutorial review. *Environ. Sci. Water Res. Technol.* **2018**, *4*, 478–486. [CrossRef]
12. Barling, R.D.; Moore, I.D. Role of buffer strips in management of waterway pollution: A review. *Environ. Manag.* **1994**, *18*, 543–558. [CrossRef]
13. Li, M.-H.; Barrett, M.E.; Rammohan, P.; Olivera, F.; Landphair, H.C. Documenting stormwater quality on Texas highways and adjacent vegetated roadsides. *J. Environ. Eng.* **2008**, *134*, 48–59. [CrossRef]
14. Yousef, Y.; Hvitved-Jacobsen, T.; Wanielista, M.; Harper, H. Removal of contaminants in highway runoff flowing through swales. *Sci. Total Environ.* **1987**, *59*, 391–399. [CrossRef]
15. Stagge, J.H.; Davis, A.P.; Jamil, E.; Kim, H. Performance of grass swales for improving water quality from highway runoff. *Water Res.* **2012**, *46*, 6731–6742. [CrossRef] [PubMed]
16. Deletic, A.; Fletcher, T.D. Performance of grass filters used for stormwater treatment—a field and modelling study. *J. Hydrol.* **2006**, *317*, 261–275. [CrossRef]
17. Barrett, M.; Lantin, A.; Austrheim-Smith, S. Storm water pollutant removal in roadside vegetated buffer strips. *Transp. Res. Rec.* **2004**, *1890*, 129–140. [CrossRef]
18. Winston, R.J.; Lauffer, M.S.; Narayanaswamy, K.; McDaniel, A.H.; Lipscomb, B.S.; Nice, A.J.; Hunt, W.F. Comparing bridge deck runoff and stormwater control measure quality in North Carolina. *J. Environ. Eng.* **2014**, *141*, 04014045. [CrossRef]
19. USGS (United States Geological Survey). *National Field Manual for the Collection of Water-Quality Data*; US Geological Survey, Techniques of Water Resources Investigations: Reston, VA, USA, 2004.
20. O'Dell, J. *Determination of Phosphorus by Semi-Automated Colorimetry. Method 365.1*; Environmental Monitoring Systems Laboratory, Office of Research and Development, US Environmental Protection Agency: Cincinnati, OH, USA, 1993.
21. O'Dell, J.W. *Determination of Nitrate-Nitrite Nitrogen by Automated Colorimetry, Method 353.2*; Environmental Monitoring Systems Laboratory, Office of Research and Development, US Environmental Protection Agency: Washington, DC, USA, 1993.
22. Chinchilla, C.R. Automated colorimetric method for nitrate analysis. *Technol. Oper.* **2008**, *13*, 1–4.

23. Nelson, P. *Index to EPA Test Methods*; United States Environmental Protection Agency: Region I, Boston, MA, USA, 2003.
24. Hou, X.; Jones, B.T. Inductively coupled plasma/optical emission spectrometry. *Ency. Anal. Chem.* **2000**, *11*, 9468–9485.
25. Martin, T.D. *Method 200.5 Determination of Trace Elements in Drinking Water by Axially Viewed Inductively Coupled Plasma-Atomic Emission Spectrometry*; US Enviromental Protection Agency: Cincinnati, OH, USA, 2003; p. 45268.
26. Schilling, K.E.; Streeter, M.T.; Clair, M.S.; Meissen, J. Subsurface nutrient processing capacity in agricultural roadside ditches. *Sci. Total Environ.* **2018**, *637*, 470–479. [CrossRef] [PubMed]
27. Barrett, M.E.; Irish, L.B., Jr.; Malina, J.F., Jr.; Charbeneau, R.J. Characterization of highway runoff in Austin, Texas, area. *J. Environ. Eng.* **1998**, *124*, 131–137. [CrossRef]
28. Barrett, M.E.; Walsh, P.M.; Malina, J.F., Jr.; Charbeneau, R.J. Performance of vegetative controls for treating highway runoff. *J. Environ. Eng.* **1998**, *124*, 1121–1128. [CrossRef]
29. Bäckström, M.; Viklander, M.; Malmqvist, P.-A. Transport of stormwater pollutants through a roadside grassed swale. *Urban Water J.* **2006**, *3*, 55–67. [CrossRef]
30. Jankaitė, A.; Baltrėnas, P.; Kazlauskienė, A. Heavy metal concentrations in roadside soils of Lithuania's highways. *Geol.* **2008**, *64*, 237–245. [CrossRef]
31. Akbar, K.F.; Hale, W.H.; Headley, A.D.; Athar, M. Heavy metal contamination of roadside soils of Northern England. *Soil Water Res.* **2006**, *1*, 158–163.
32. Lucke, T.; Mohamed, M.A.K.; Tindale, N. Pollutant removal and hydraulic reduction performance of field grassed swales during runoff simulation experiments. *Water* **2014**, *6*, 1887–1904. [CrossRef]
33. Trenouth, W.R.; Gharabaghi, B.; Farghaly, H. Enhanced roadside drainage system for environmentally sensitive areas. *Sci. Total Environ.* **2018**, *610*, 613–622. [CrossRef] [PubMed]
34. Alberti, L.; Colombo, L.; Formentin, G. Null-space Monte Carlo particle tracking to assess groundwater PCE (Tetrachloroethene) diffuse pollution in north-eastern Milan functional urban area. *Sci. Total Environ.* **2018**, *621*, 326–339. [CrossRef] [PubMed]
35. Fritioff, Å.; Kautsky, L.; Greger, M. Influence of temperature and salinity on heavy metal uptake by submersed plants. *Environ. Pollut.* **2005**, *133*, 265–274. [CrossRef] [PubMed]
36. Luo, W.; Elser, J.J.; Lü, X.T.; Wang, Z.; Bai, E.; Yan, C.; Wang, C.; Li, M.H.; Zimmermann, N.E.; Han, X.; et al. Plant nutrients do not covary with soil nutrients under changing climatic conditions. *Glob. Biogeochem. Cycles* **2015**, *29*, 1298–1308. [CrossRef]