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Miguel Salceda
University of Missouri

Ranjith P. Udawatta
University of Missouri

Stephen H. Anderson
University of Missouri

Sidath S. Mendis
University of Missouri

Fengjing Liu
Michigan Technological University, fliu7@mtu.edu

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ORIGINAL ARTICLE

Environment

Agroforestry buffers on nitrogen reduction in groundwater on a grazed hillslope

Miguel Salceda[1,2] | **Ranjith P. Udawatta**[1] | **Stephen H. Anderson**[3] | **Sidath S. Mendis**[1] | **Fengjing Liu**[4]

[1]The Center for Agroforestry, School of Natural Resources, University of Missouri-Columbia, Columbia, Missouri, USA

[2]Centro de Investigaciones Hidráulicas e Hidrotécnicas (CIHH), Universidad Tecnológica de Panamá (UTP), Panama City, Panama

[3]School of Natural Resources, University of Missouri-Columbia, Columbia, Missouri, USA

[4]College of Forest Resources and Environmental Science, Michigan Technological University, Houghton, Michigan, USA

Correspondence

Miguel Salceda, The Center for Agroforestry, School of Natural Resources, 302 Anheuser-Busch Natural Resources Building, University of Missouri-Columbia, Columbia, MO, USA.

Email: mskym@umsystem.edu

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Abstract

Agricultural practices often contribute to the transport of solutes into groundwater; thus, low-cost strategies that extract nutrients from groundwater are essential to address water pollution. This study evaluated the effects of agroforestry (tree + grass; AB [cottonwood {*Populus deltoides* Bortr. ex Marsh.}]) and grass buffers (GB; [tall fescue *Schedonorus phoenix* (Scop.) Holub, Red clover {*Trifolium pretense* L.}, and Lespedeza {*Lespedeza* Michx}]) on groundwater nitrogen (N) concentrations. The experiment consisted of two grazing watersheds, one with an AB and another with a GB treatment. Buffers were not grazed since 2001. Three wells representing summit, backslope, and foot-slope positions were installed at each watershed. Water samples were collected biweekly from November 2019 to January 2022 and analyzed for total nitrogen (TN) and dissolved N (DN). Dissolved nitrogen (DN) and TN concentrations after the AB in the foot-slope well were 99% (5.36–0.06 mg L^{-1}) and 85% (9.04–1.37 mg L^{-1}) lower than the mean concentration of the summit and backslope wells. Similarly, DN and TN concentrations after the GB in the foot-slope well were 94% (1.95–0.11 mg L^{-1}) and 62% (2.86–1.07 mg L^{-1}), lower than the mean concentration of the summit and backslope wells. Dissolved N concentrations were lower during warm periods probably due to plant uptake and denitrification in the buffer zone. Results showed that buffers, especially with deep-rooted trees in the proximity of the water table, decreased TN and DN concentrations in groundwater and can be used as a conservation practice to address water pollution.

1 | INTRODUCTION

Agricultural practices can introduce nutrients and other chemicals into groundwater that can be a challenge for the environment and human health. According to DeSimone et al. (2014), 130 million people use groundwater for drinking in

Abbreviations: AB, agroforestry buffer; DN, dissolved nitrogen; GB, grass buffer; OM, organic matter; SOC, soil organic carbon; TN, total nitrogen; USEPA, U.S. Environmental Protection Agency.

the U.S. Often groundwater nitrate concentrations are greater than the maximum nitrate limit (10 mg NO_3^--N L^{-1}) in many regions of the United States (Dubrovsky et al., 2010; Lowrance, 1992; Schoonover et al., 2003). Dubrovsky et al. (2010) reported that 64% of 86 studied shallow aquifers in rural and urban areas exceeded nitrate background levels, and 2388 sampled domestic wells exceeded the nitrate limit for drinking water.

The concentration of nutrients in shallow groundwater is closely related to the agricultural activities of the area (Gurdak et al., 2009). Shallow-unconfined aquifers under agricultural lands are in special risk. For instance, Biddau et al. (2019) found increases in the nitrate concentration for groundwater in 5-m deep wells, during the fertilization period, in an agricultural watershed in Italy. An unconfined permeable aquifer under a raspberry field that was manure treated showed an annual N load increase by 32%, 240%, and 18% after 1, 2, and 3 years, respectively, of the manure application (Loo et al., 2019). Du et al. (2020) found high NH_4^+-N and TN concentrations in areas with higher fertilizer application. The concentration of N in groundwater can increase during the rainy season, suggesting translocation of N compounds from the soils surface to the water table due to leaching (Liu et al., 2017). Another study in the Luobei and Suibin counties in China found that vegetable fields had the highest NO_3^--N concentration in groundwater compared to residential land and other land uses (Du et al., 2020). Jeyaruba and Thushyanthy (2009) reported that the groundwater from areas with intensive agriculture in Sri Lanka was not suitable for drinking purposes because of the elevated nitrate concentration due to excessive use of agricultural inorganic fertilizers. Almasri and Kaluarachchi (2007) compared the effects of reducing inorganic fertilizer and manure on the groundwater nitrate mass in an aquifer. The study found that the reduction of manure had the greatest impact on reduction of nitrate mass.

High levels of nitrate in drinking water (>10 mg NO_3^--N L^{-1}) can be converted into nitrite in the human body, causing methemoglobinemia, which is a disease that affects the oxygen-carrying capacity of blood (New Hampshire Department of Environmental Service, 2006). The report also mentioned that high nitrate levels transformed to nitrite can form nitrosamine, which is a cancerogenic chemical, and can cause reproductive health issues. The excess N in water bodies can cause algae blooms (Kanter & Brownlie, 2019), which reduces the concentration of dissolved oxygen in water, creating zones with low oxygen levels called "Dead zones" (NOAA, 2019).

Agroforestry can reduce nitrogen in groundwater compared to croplands. Among all agroforestry practices, riparian buffers have a greater potential to reduce nitrate than upland forests because of the buffer location within a landscape and favorable environmental conditions (Ullah & Zinati, 2006). The main mechanisms by which agroforestry buffers reduce nitrogen from groundwater are plant uptake, microbial immobilization, and denitrification. Nitrogen plant uptake is the use of N by plants in their biological processes while bacterial denitrification transforms nitrate into dinitrogen gas (Mayer et al., 2005).

Core Ideas

- Shallow groundwater below agricultural practices are especially susceptible to nutrient pollution.
- Tree and grass buffers significantly reduced nutrient concentrations in groundwater.
- Agroforestry (tree + grass) buffers removed more nitrogen than only grass buffers.

Vegetative buffers ranging from 5 to 6-m wide can reduce nitrate concentration in subsurface flow up to 80% (Mayer et al., 2005). Retention time in shallow groundwater is large enough to allow tree roots and bacteria to interact with groundwater and reduce N levels (Hill, 1996; Mayer et al., 2005). Schoonover et al. (2003) found up to 82% reduction of the nitrate load in shallow groundwater by a 10-m wide riparian forest buffer. Dimitriou and Mola-yudego (2017) found that 10-year old poplar plantations had significantly lower NO_3^--N concentrations (five times less) in the groundwater than cereal plantations. According to Mayer et al. (2005), a 30-m wide riparian forest buffer removed 65%–70% of the nitrate in shallow groundwater. Lv and Wu (2021) tested the N removal efficiency of riparian buffer strips (RBS) of 5, 15, 30, and 40-m wide, finding NO_3^--N removal efficiencies of 53.3%, 65.93%, 68.38%, and 69.69%, respectively. Also, Veldidis et al. (2003) found that a forested riparian buffer 38-m wide reduced the nitrate concentration in shallow groundwater up to 78%. Lowrance et al. (1997) reported 85%–90% reductions of nitrate input loads in shallow groundwater in a coastal plain. Schoonover et al. (2003) reported reductions in groundwater nitrate by 90% and 60% by giant cane and a 3.3-m wide forest riparian buffer, respectively. Chandrasoma et al. (2019) estimated that implementation or restoration of 75,520 km of riparian buffers intercepting tile drain water would result in up to 10% reduction of N tile drain in the Midwest. For instance, a 20-m saturated riparian buffer (SRB) in Iowa, showed > 92% nitrate reductions in groundwater. The report concluded that during the study, 228 kg of nitrate was redirected toward the SRB and the buffer zone completely removed groundwater N (Jaynes & Isenhart, 2014). Numerous studies indicate that riparian buffers can remove groundwater nitrate from 10% to 100% and their efficiencies vary with buffer width and characteristics.

Limited studies have determined the impacts of agroforestry buffers on dissolved nitrogen (DN) and total nitrogen

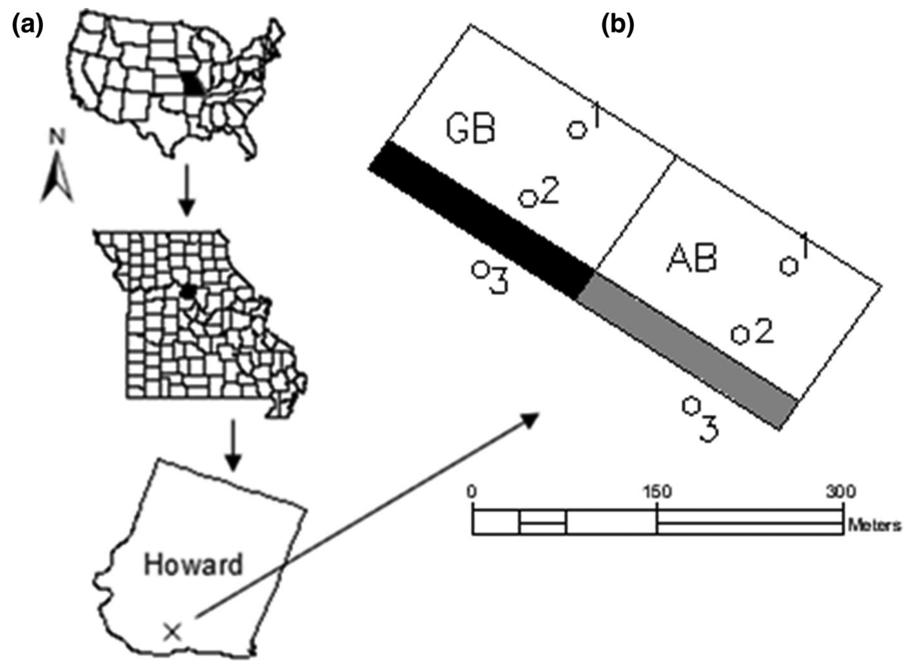

FIGURE 1 The inset map shows the location of the Missouri State, Howard County in Missouri, and the Horticulture and Agroforestry Research Center (HARC) in Howard County (a). Locations of agroforestry (AB) and grass buffer (GB)watersheds. The hollowed circles represent summit (1), backslope (2), and foot-slope (3) well locations at three landscape positions on AB and GB watersheds (b). The black polygon represents the GB, the gray polygon the AB, and white polygons the grazing areas.

(TN) reductions in groundwater on grazed hillslopes. The main objective of this study was to determine the effects of agroforestry and grass buffers on DN and TN concentrations in shallow groundwater on a hillslope under grazing management. The specific objectives were to (i) determine DN and TN concentrations in groundwater from November 2019 to January 2022 and (ii) compare the DN and TN concentrations along streamlines before and after the application of vegetative buffers.

2 | MATERIALS AND METHODS

2.1 | Site description

The study site is located at the Horticulture and Agroforestry Research Center (HARC), New Franklin, Howard County, Missouri, USA (39˚01′05″ N, 92˚45′34″ W) 195 m above sea level (Figure 1a). The study consisted of two watersheds: one with an agroforestry buffer and the other with a grass buffer that were monitored from November 2019 to January 2022. The study watersheds were established in 2000 and were previously managed under tall fescue grass (*Festuca arundinacea* Schreb.). Watersheds were established on a 12% slope landscape by creating a soil berm around a 0.8 ha area and compacting it by using a tractor. The watersheds are 107 m long and 75-m wide (Figure 1b). The total width was divided into a 60-m wide grazing area and a 15-m wide buffer area. The buffer areas are fenced, not grazed, and occupy about 20% of the total area. No fertilizers were added to the watersheds in this study. The N input in the watersheds comes from livestock and natural translocation from the soil surface to the aquifer. A four-wire high tensile electric fence separates cattle from buffer areas. Additional details can be found in Udawatta et al. (2011). The ground cover in the buffer and the grazed area consists of tall fescue [*Schedonorus phoenix* (Scop.) Holub], established in 2000; red clover (*Trifolium pretense* L.), and lespedeza (*Lespedeza* Michx), were incorporated in 2003. In the agroforestry watershed, four rows of cottonwood (*Populus deltoides* Bortr. ex Marsh.) trees were planted into the fescue in 2001 at 3-m spacing between and within rows to create the agroforestry buffers.

The average tree diameter at breast high (1.4 m above ground) and height at the beginning of 2022 was 42 cm and 27 m, respectively. Watersheds were managed with rotational grazing. Grazing areas in each watershed were divided into six equal-sized paddocks for rotational grazing. Cattle grazing was the only mechanism used to remove grass biomass from the grazing areas in the two watersheds. Every year, 450 (992 lbs)–590 kg (1300 lbs) beef cows were placed in the grazing areas and moved to another facility during winter.

Soils in the watersheds are Menfro silt loam (fine-silty, mixed, superactive, and mesic Typic Hapludalfs) with a 12% slope. The pH in the soil ranges from 6 to 7; the organic matter (OM) in the upper horizon is 2.8%. The annual long-term precipitation (1993–2020) for the study area is 1064 mm (https://mrcc.isws.illinois.edu). Approximately 64% of the precipitation falls from April through September. The mean temperature in July is 25.5˚C, and the mean temperature in January is −2.15˚C.

2.2 | Groundwater sampling procedure

Wells 12.2-, 10.7-, and 3.6-m deep at the summit (1), backslope (2), and foot-slope (3) positions (Figure 1b), respectively, were drilled on the agroforestry and grass buffer watersheds. The distance between the soil surface and the water table decreased from the summit positions to the foot-slope positions. Therefore, wells were deeper at the summit positions and shallower at the foot-slope. Submersible Mini Monsoon Pumps (Proactive Environmental Products) were installed in the wells to collect biweekly groundwater samples from November 2019 to January 2022. Wells were emptied 3–4 well volumes before fresh well water samples were collected. Approximately 500 mL of groundwater was collected in polypropylene bottles from each well and transported to the laboratory for analysis. Unprocessed samples were preserved at 4˚C in a refrigerator until analysis.

2.3 | Laboratory analysis

The analysis of the water samples was performed in the laboratory of the Center of Agroforestry and School of Natural Resources of the University of Missouri-Columbia. First, samples were separated into two different containers, unfiltered samples were used for TN and filtered ones for DN analysis. Total N and DN concentrations were determined by following the procedures established by Lachat Quickhem Methods 10-107-04-4- B (Tucker & Jones, 2007) and 10-107-04-1-O (Diamond, 2007), respectively. The TN procedure requires the digestion of samples in an autoclave, adding 5 mL of digestion solution conformed by established proportions of sodium hydroxide and potassium persulfate to a 10-mL sample. The detection limit for the two methods was ≤ 0.002 mg L^{-1}. Filtration was performed by using previously washed, dried, and weighed 934-AH glass microfiber filter paper (Whatman). After filtration, filter papers were placed in an oven at 105˚C for 48 h, and weights of the dry filter papers were recorded.

2.4 | Water table

An Emlid GNSS receiver (Emlid Tech Kft) was used to obtain the well elevations. The Emlid GNSS receiver connects to the geodesic network to provide high vertical and horizontal coordinate accuracy. The water table depth from each well casing (from the top of the casing) was measured biweekly with a 101B water level meter (Solinst Canada Ltd). The difference between the elevation of a well and the water table depth was the water table elevation.

2.5 | Statistical analysis

Groundwater samples were collected biweekly from the six wells on each sampling trip from November 2019 to January 2022. The samples were analyzed for TN and DN concentrations. This study had a longitudinal design where the subjects were each well and repeated measurements were made every other week. Each subject (well) represented a landscape position on its respective watershed. Data for each well were tested for normality using the Shapiro–Wilk and Kolmogorov–Smirnov test at a significance level of $\alpha = 0.05$. The raw data did not follow a normal distribution. Therefore, the natural logarithm of the concentrations was used to achieve normality for DN and TN data. A GEE-type linear model for the log of DN and TN concentrations was run to test the fixed effects and interactions among wells, temperature, and precipitation to account for the repeated effect of the biweekly observations for each well. The fixed effect of the code was tested as a factor and the effects of the temperature and precipitation were assumed to be linear. This study used proc GLIMMIX, SAS 9.4 (SAS Institute), with the residual matrix modeled as AR (1) to account for correlation among subjects. The level of significance for the linear mixed model was selected to be 0.05 and the Tukey post hoc test was used to determine significant differences between factors and their interactions.

3 | RESULTS AND DISCUSSION

3.1 | Precipitation

Monthly precipitations during the 2-year study period deviated from the 1064 mm long-term precipitation (Figure 2). The precipitation during 2019–2020 was similar to the annual long-term mean (102% of the long-term annual precipitation). Seven out of 12 months received below normal long-term mean during 2019–2020. However, monthly precipitation for December 2019, January 2020, March 2020, June 2020, and July 2020 were wet enough to make the overall total surpass the long-term annual precipitation mean. During 2020–2021, the precipitation was 121% of the long-term annual precipitation mean with 5 months below the long-term monthly precipitation. In June 2021, consecutive rain events of 362 mm caused a flooding at the study site. The Fall-Winter period in 2020–2021 was dry, resulting in 63% of the long-term average precipitation.

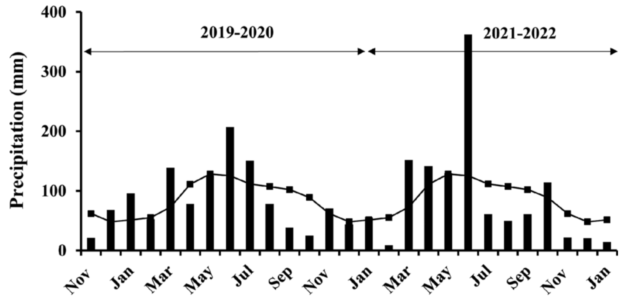

FIGURE 2 Monthly precipitation (bars) and long-term annual precipitation (line) for November-2019–January-2022 at the Horticulture and Agroforestry Research Center (HARC).

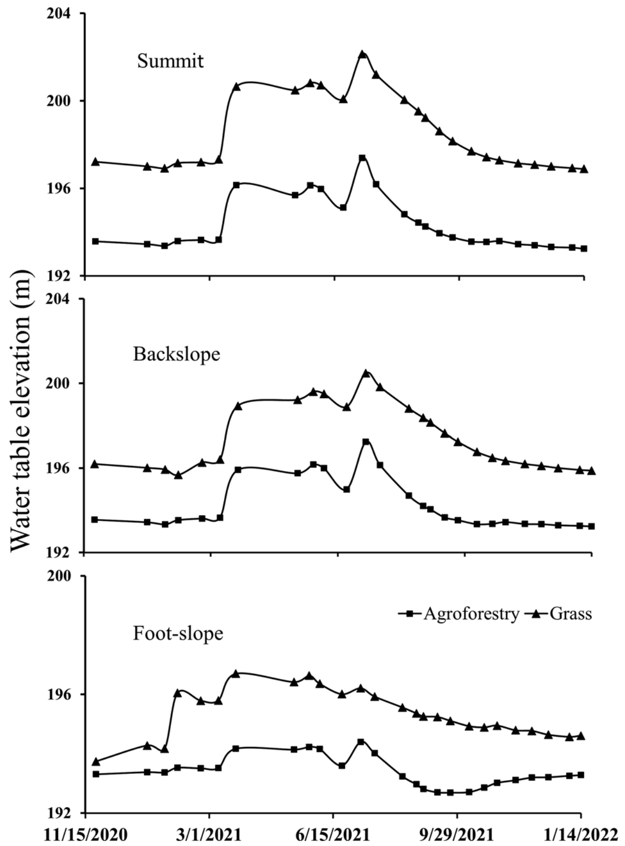

FIGURE 3 Water table elevation at the summit, backslope, and foot-slope position wells in the agroforestry buffer (AB) and grass buffer (GB) watersheds. All the water table elevations are relative to a base point between the two watersheds.

3.2 | Water table

The groundwater level monitoring began in November 2020 at the three landscape positions in the two watersheds. The water table at the summit position in the GB watershed was fairly constant, around 197 m, from November 2020 to March 2021 (Figure 3). Precipitation events from the end of March 2021 to July 2021 gradually raised the water table elevation up to 202 m. The water table began to decline from August 2021 to December 2021 and reached 197 m again. The water table in the summit well of the AB watershed followed the same pattern but retained at 193 m from November 2020 to March 2021. The water table started to increase from the end of March 2021 and reached 197 m by July 2021, then declined back to 193 m by the end of July and remained at 193 m until December 2021. The behavior of the water table in the other wells followed a pattern similar to the summit wells. The smaller rise at the beginning of the rainy season in the water table of the AB can be explained by a greater demand of water for the fast-growing poplar trees and their deeper roots compared with the shallow-rooted grass only treatment of the GB watershed.

The water table behavior followed the premise that the main source of groundwater was precipitation and was consistent over all the wells. A study in the Everglades National Park, FL, found a close relationship between precipitation and water table elevation in a shallow aquifer with porous limestone (Zhang & Migliaccio, 2017). The study tracked the water table elevation after every rain event and found a rising in the water table immediately after rain events. Another study in China found a similar pattern and concluded that the water table raised after rain events and decreased due to evaporation and lack of precipitation (Yan et al., 2017).

Differences in water table elevation between AB and GB indicated the water use by trees and grasses in buffers. In general, respective wells in AB had lower values than GB. Vegetation in the proximity of the water table can influence groundwater recharge, pulling out groundwater when transpiring and reducing soil moisture in the vadose zone (Zhang et al., 2021). As a result, water table fluctuations after precipitation events can be amortized by plants due to decreases in antecedent soil moisture. A study in Fort Worth, TX, found that an area forested with cottonwoods caused a maximum drawdown cone of 29 cm in the water table with an influence radius of 160 m (Braun et al., 2004). Cottonwood trees transpire 6–10 mm of water daily (Nagler et al., 2007) as compared to 5.7–7.1 mm daily by tall fescue (Romero & Dukes, 2016). A meta-analysis showed water table decreases up to 2.5 m due to the tree's influence (Minhas & Dagar, 2016). Variations in soil and geology can also contribute to differences in the piezometric levels of watersheds (Schwartz & Zhang, 2002). Although greater water use by trees lowered the water table elevation in the AB of the current study some minor differences in the water table between the two watersheds can also be attributed to variations in pedology.

3.3 | Total nitrogen at different landscape positions

The mean TN concentration during the study period in the summit, backslope, and foot-slope wells in the AB watershed

TABLE 1 Mean total nitrogen (TN) and dissolved nitrogen (DN) concentrations in summit, backslope and foot-slope wells in the agroforestry buffer (AB) and grass buffer (GB) watersheds during November 2019–January 2022 at the Horticulture and Agroforestry Research Center of the University of Missouri.

Well position	Mean concentration			
	agroforestry buffer		Grass buffer	
	TN	DN	TN	DN
	mg L^{-1}			
Summit	9.75 ± 1.29A	5.69 ± 0.22a	3.10 ± 0.18B	2.22 ± 0.02c
Backslope	8.33 ± 0.98A	5.03 ± 0.10b	2.62 ± 0.16BC	1.68 ± 0.05d
Foot-slope	1.37 ± 0.20C	0.06 ± 0.01e	1.07 ± 0.12D	0.11 ± 0.02f

Note: Mean concentrations with different upper- and lowercase letters for TN and DN, respectively, are significantly different at 95% confidence level. The TN and DN datasets were analyzed separately.

was 9.75, 8.33, and 1.37 mg L^{-1}, respectively, while it was 3.10, 2.62, and 1.07 mg L^{-1} in the GB watershed (Table 1). The combined mean TN concentration of the summit and backslope wells in the AB watershed was 9.04 mg L^{-1}, and it was reduced to 1.37 mg L^{-1} after passing through the AB zone. The mean TN concentration at the foot-slope well was 85% lower than the combined mean concentration of the summit and backslope wells. In the GB watershed, the mean TN concentration of the summit and backslope wells was 2.86 mg L^{-1}, and it was reduced to 1.07 mg L^{-1}. This showed a 62% reduction as compared to the combined TN concentration in the summit and backslope wells.

Differences between the AB and GB watersheds in TN and DN concentrations in the upland wells can be explained by the variability of soil properties and cattle grazing. Preferential paths between the AB and GB watersheds also may have contributed to these differences. Data also showed a slight reduction in TN and DN concentrations from the summit to the backslope wells, not being significant for TN (Table 1). Translocation of fine material from the summit to the backslope positions may have cause the slight N reduction, promoting greater interaction with solutes in infiltrating water. Chen et al. (2002) studied the particle size distribution in a hillslope and found that the coarse soil fraction (>2–0.5 mm) decreased from summit to foot-slope position, while the fine fraction (0.5–0.002 mm) increased. Small differences between the two upland wells within a watershed may have been due to differences in profile material.

The data analysis showed that within each individual watershed the TN concentration in the summit and backslope wells were not significantly different. However, in both watersheds, the TN concentration in the summit and backslope wells were different from the concentrations in their respective foot-slope wells ($p < 0.05$; Table 1). The greater reductions in the AB compared to the GB can be explained by the deeper roots of the trees that can pull nutrients from groundwater, increased retention time, and soil organic carbon (SOC) at deeper horizons compared to the roots in the GB (Figure 4). Gribovszki et al. (2017) studied the groundwater uptake of

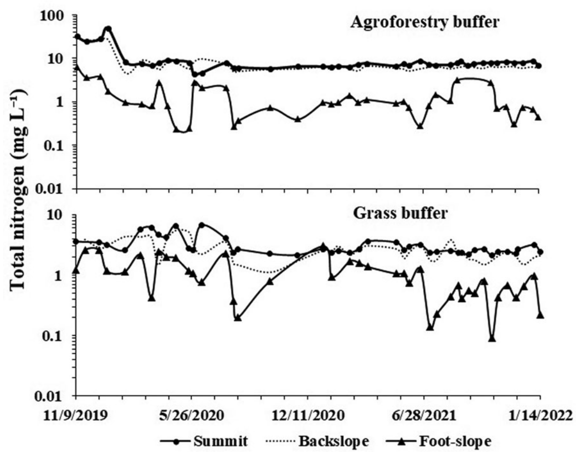

FIGURE 4 Total nitrogen (TN) concentrations in summit, backslope, and foot-slope well positions at the agroforestry and grass buffer watersheds. *Note*: The scale of vertical axis is different.

oaks, poplars, and a managed pasture, indicating that the groundwater use of trees was 1.5–2 times greater than the pasture. Their study also indicated that vegetation with more biomass requires more water to survive and the deep roots help better access to groundwater during dry seasons compared to shallow-rooted vegetation. Another study comparing 15-m wide tree and a fescue buffer found that the tree buffers removed nitrate in groundwater by twofold compared to fescue (King et al., 2016). Deep-rooted trees efficiently capture nutrients from deeper soils than pastures and crops (Udawatta et al., 2011). The Chesapeake Bay Program reported in their Riparian Forest Buffer Fact Sheet that an acre of riparian buffers can remove up to 69% of the non-point source pollution TN from an average agricultural setting (Chesapeak Bay Program, 2011). The fact sheet also indicated TN reductions ranging from 31% to 65% by 10-m wide buffers. A meta-analysis reported that forested riparian zones 1- to 5-m wide can reduce 38% of the TN in groundwater and the efficiency increases up to 75% for 16–77-m wide riparian forest (Lyu et al., 2021). In contrast, lower TN reductions can occur in

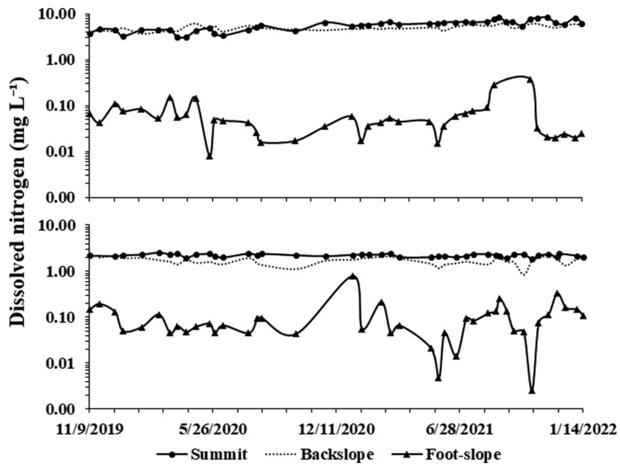

FIGURE 5 Dissolved nitrogen (DN) concentrations in summit, backslope, and foot-slope well positions at the agroforestry and grass buffer watersheds.

well-drained settings that do not permit sufficient retention time for absorption processes (Hoover et al., 2016). Reductions in our study were larger than some studies and smaller than other studies. These differences among studies can be attributed to tree species, age of trees, width of the buffers, soil, and geology.

3.4 | Dissolved nitrogen at different landscape positions

The mean DN concentration in the summit, backslope, and foot-slope wells in the AB watershed was 5.69, 5.03, and 0.06 mg L^{-1}, respectively, and 2.22, 1.68, and 0.11 mg L^{-1} in the GB watershed (Table 1). The DN concentrations of the summit and backslope wells were averaged to compare with the DN concentration of the foot-slope well. The mean DN concentration of the summit and backslope wells in the AB watershed was 5.36 mg L^{-1}, and it was reduced to 0.06 mg L^{-1} at the foot-slope well. After passing through the AB zone, the DN concentration in the foot-slope well was 99% lower than the mean concentration of the summit and backslope wells together. In the GB watershed, the mean DN concentration of the summit and backslope wells was 1.95 mg L^{-1}, and it was reduced to 0.11 mg L^{-1}, showing a reduction of 94% at the foot-slope well. Significant reductions were found when comparing the DN concentration at the foot-slope well with the concentrations at the summit and backslope wells (Figure 5). The mean DN concentration after the AB and GB was reduced by 99% and 94% ($p < 0.05$), respectively, compared to the mean concentration of the summit and backslope wells. Processes such as plant uptake and denitrification may have played an important role in the greater DN reductions compared to TN (Parkyn, 2004).

Several studies found between 55% and 99% nitrate reductions in riparian zones. Schoonover et al. (2003) found that a 10-m wide cane and forest riparian buffer in Illinois reduced nitrate in groundwater by 99% and 61%, respectively. Also, Vellidis et al. (2003) found nitrate reduction of 78% in a three-zone riparian buffer with pines, hardwoods, and grasses, overlaying a shallow restrictive layer in Georgia. Lowrance (1992) reported nitrate reductions of 55% in a 50-m wide riparian forest over poorly drained soils. A study along the lower Calapooia River in Oregon indicated significant differences in denitrification potential between the crop and riparian forest zones. For instance, the study found that the mean denitrification potential rate in the riparian zone was 94% greater than in the cropping zone (Davis et al., 2011). Seitzinger et al. (2006) analyzed denitrification across several environments and indicated that significant denitrification can occur when nitrite or nitrate sources, and electron donors are available and under anoxic conditions. The greater reduction found in the AB compared to the GB can be attributed to carbon supplied by live and dead roots of cottonwoods, associated microbial communities, and anaerobic conditions. Reduction rates observed in the current study agree with findings of other regions. Deep soils at our study site with fast-growing poplar trees and undisturbed buffers may have contributed to larger reductions compared to findings in poorly drained soils and other riparian buffers.

3.5 | Agroforestry buffer versus grass buffer

Even though the final DN and TN concentrations at the AB and GB were similar in magnitude, the reduction in the AB was greater than in the GB because of the greater N content in the summit and backslope wells of the AB watershed. Overall, the DN reduction in the AB was 99% as compared to 94% in the GB. The reduction in TN in the AB was 85% as compared to 62% in the GB. According to the results of this study, there is a positive effect of both AB and GB treatments in N reduction in groundwater.

Grass-only buffers have a denser root system than in the AB. The tree shade on grasses may have reduced the density of grasses in the AB buffer. Thicker root systems and associated microbial communities as found in the GB buffer can reduce C and nutrient leaching compared to deeper rooted trees (Dollinger et al., 2019; Pot et al., 2005). In contrast, dissolved carbon can leach along larger tree roots to deeper soils and supply substrate for microbial communities (Bargués Tobella et al., 2014; Luo et al., 2019). At our study site, increasing precipitation raised DN and TN concentrations in wells of the AB watershed, suggesting the leaching of nutrients with water to deeper soils.

It is important to notice the effectiveness of both systems in N reduction to develop recommendations on environmental settings. In this experiment, both buffers had the same width (15 m) and both showed efficient N reductions (Table 1). Hefting et al. (2006) studied the effectiveness of a forested riparian zone and a grassland riparian zone and found nitrate reductions of 6%–77% and 28%–99% in the forested and grassland riparian zones, respectively. The results of this study are within the same range and small differences can be attributed to differences in climate, soil, geology, and plant species. Aguiar Jr et al. (2015) found similar results to the current study for 60-m wide buffers in Brazil. They reported 99.9% nitrate removal after woody-vegetation buffers and 62% nitrate reduction after grass-only buffers.

Groundwater N pollution is a serious global issue that impacts many regions of the world. Agriculture is often criticized for nutrient and chemical pollution of groundwater. In this current study, agroforestry buffers more efficiently removed DN and TN from groundwater than grass-only buffers. Agroforestry removed 99% of the DN and 85% of the TN before groundwater enters the lake. A 15-m wide buffers at the foot-slope landscape position removed groundwater N within a 60-m distance protecting groundwater and lake water from agricultural N pollution. Findings of the study implies that establishment of agroforestry (tree + grass) buffers along water bodies can help reduce nutrient inputs via groundwater to water bodies and nutrients in the groundwater. Buffer dimensions vary by regions as the removal efficiency differs with soil, climate, management, and buffer characteristics (spp, age, density, etc.).

3.6 | Seasonal effect on N concentrations

The interaction of air temperature and well position was significant ($p < 0.05$) for DN concentrations at the foot-slope wells in the AB and GB watersheds (Figures 6 and 7). Therefore, a Pearson correlation test was conducted for DN concentrations and air temperature at the foot-slope wells in the AB and GB watersheds. The correlation coefficients between temperature and DN concentrations at the foot-slope wells in the AB and GB watersheds were −0.04 and −0.28, respectively (Figure 7). The negative correlation coefficients indicate that the relationship between air temperature and DN concentrations in the foot-slope wells was inversely proportional. As expected, the greater the temperature, the lower the DN concentration in the foot-slope wells; however, the correlation was not strong. No temperature effect was found in TN in this study. Precipitation had no significant effect at the 95% confidence level in DN or TN concentration in this study.

Temperature influences biological processes and plant behavior; therefore, the effects of temperature in the DN concentration were detected only in the foot-slope wells. Air temperature did not have a significant effect on the summit

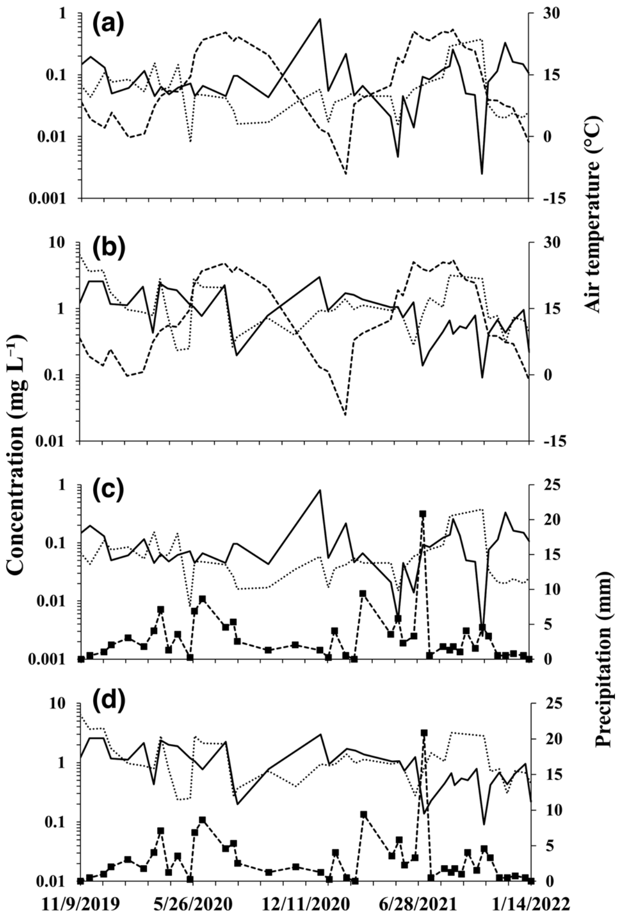

FIGURE 6 Variation of dissolved nitrogen (DN) with temperature in the agroforestry buffer (AB) and grass buffer (GB) watersheds (A). Variation of total nitrogen (TN) with temperature in the AB and GB watersheds (B). Variation of DN concentrations with precipitation in the AB and GB watersheds (C). Variation of TN concentrations with precipitation in the AB and GB watersheds (D). Only the foot-slope wells were presented due to their strategic position to detect the effect of precipitation and air temperature.

and backslope wells because of the greater depth of the water table in those wells and the absence of deep-rooted plants.

Overall, the decreases of DN and TN concentrations with increasing temperature can be associated with an increase in plant N uptake and favorable denitrification conditions. For instance, Boz and Gumiero (2016) found up to 65% lower denitrification rates in soils in Winter 2008 compared to the rates in Spring 2008. Groh et al. (2019) conducted an experiment to analyze the denitrification potential of soils under riparian buffers with a mixture of grasses and woody plants. They found the greatest denitrification potential rates between 18˚C and 23˚C (23˚C was the maximum temperature analyzed). Also, Yao et al. (2020) reported increased N dilution in runoff with increasing runoff volume. Wick et al. (2012) indicated that higher precipitation can enhance N uptake by plants and promote N dilution in groundwater; thereby, decreasing N concentration in groundwater. The results of this study show

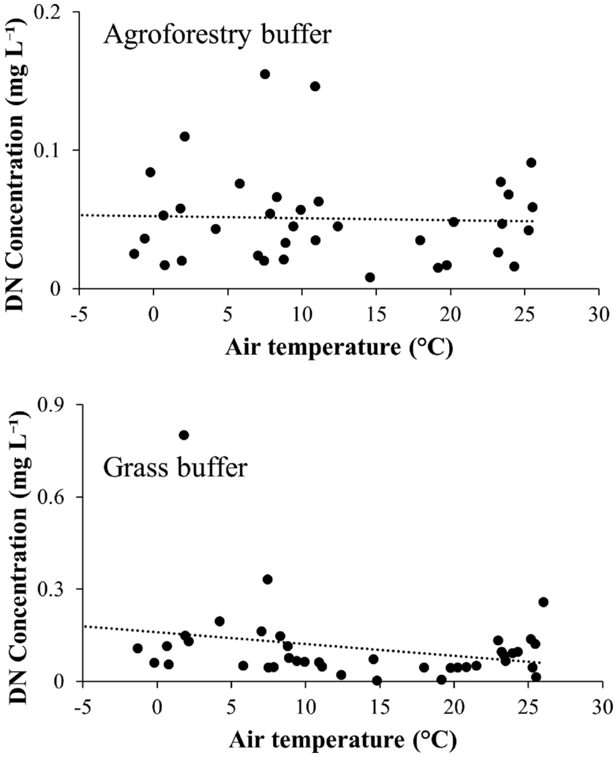

FIGURE 7 Scatter plots of dissolved nitrogen (DN) concentration versus air temperature in the foot-slope wells at the agroforestry and grass buffer watersheds.

that air temperature can indirectly influence the dissolved nitrogen concentration in shallow groundwater. A study found increased nitrate concentrations in groundwater under agricultural fields in Spring, with greater precipitation, compared to Summer concentrations (Lawniczak & Zbierska, 2016). The increased N concentrations in groundwater after precipitation events can be explained by the rapid translocation of N from the soil surface to the water table.

Bosompemaa et al. (2021) studied the effects of switchgrass on soil nitrate during and post-growing seasons. The study indicates that plants incorporate carbon dioxide from the atmosphere and nutrients from the soil to create organic compounds, decreasing nitrate in soils because of active nutrient uptake. The study also compared soil nitrate between plots with and without plants, showing a lower nitrate concentration in soils with plants. The results of the current study align with the findings of Bosompemaa et al. (2021) as the overall N concentration was lower in groundwater during the growing season.

4 | SUMMARY AND CONCLUSIONS

This study evaluated and compared TN and DN removal efficiencies of grass only and tree + grass buffers on grazing watersheds with deep loess soils. Both types of buffers reduced the concentrations of DN and TN in shallow groundwater. The DN concentrations were 94% and 99% lower after water passed the GB and AB, respectively ($p < 0.05$). Similarly, TN concentrations were 62% and 85% lower after the water passed the GB and AB, respectively ($p < 0.05$). The interaction of temperature and well position had a significant effect ($p < 0.05$) on DN concentrations, showing decreasing concentrations with increasing temperature in the foot-slope wells. No significant precipitation effects were found on the concentrations in this study. Precipitation influenced the water table elevation with rising levels in Spring and Summer. Based on the results of this study, 15-m wide tree + grass and grass-only buffers located in areas with shallow groundwater can help reduce the concentrations of DN and TN in groundwater before reaching surface water bodies. Findings of the study suggest that the establishment of sufficiently wide tree + grass buffers between the upland cropping areas and water bodies can help reduce groundwater contamination by nutrients and protect the quality of groundwater.

AUTHOR CONTRIBUTIONS

Miguel Salceda: Conceptualization, data curation, formal analysis, investigation, methodology, project administration, writing – original draft. **Ranjith P. Udawatta**: Conceptualization, funding acquisition, investigation, resources, supervision, validation, visualization, writing – review and editing. **Stephen Anderson** and **Sidath Mendis**: Writing – review and editing. **Fengjing Liu**: Conceptualization, methodology, resources.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ORCID

Miguel Salceda https://orcid.org/0000-0002-3594-5595
Ranjith P. Udawatta https://orcid.org/0000-0002-2097-7922
Stephen H. Anderson https://orcid.org/0000-0002-5664-6121

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