Differences in atmospheric phosphorus deposition amongst rural and urban land use locations in Missouri

Crystal Rein[a], Sarahi Viscarra Arellano[b], Karl Friesen-Hughes[d], Ashley King[d], Alexia Marten[d], Corey Sanderson[d], Jason J Venkiteswaran[c], Helen Baulch[b], Nora Jessie Casson[d], Colin J Whitfield [b], Rebecca North [a]

a University of Missouri; b University of Saskatchewan; c Wilfrid Laurier University; d University of Winnipeg

Abstract

Atmospheric phosphorus (AP) produced by both anthropogenic and natural processes influences phytoplankton productivity and alters carbon processing in water bodies, resulting in potential impairment and toxic phytoplankton blooms. The production of AP, which is oftentimes transported vast distances by wind dispersal in the form of enriched mineral dust, can be re-deposited by wet (precipitation based) or dry (continual) deposition. Both rural and urban locations in Missouri experience varying anthropogenic activities; therefore, distinguishing between varying land use locations at these sites provides insight as to why AP may differ. The objective of this study is to determine if AP deposition differs among rural and urban land use locations in Missouri. When soil has been recently agitated and readily exposed, we hypothesize this additional P in the atmosphere will result in higher bulk deposition flux totals (BD) in rural locations. AP was collected from three rural locations and three urban locations, using a standard sized utility bucket, altered to reduce debris. After each two-week sampling period, a total sample water volume for each site is collected, total P is analyzed (TP), which determines the BD flux of each site by factoring the time it took to collect each sample (4 samples over approximately 70 days). Rural locations had the highest BD. Rural locations were not significantly different than urban locations ($F_{5,18} = 1.667$, $p = 0.194$). Further analysis of AP and the implication on water bodies is needed, as AP analysis is exceedingly rare. A multitude of differing land use practices results in variables that contribute significantly to the production of AP.

Introduction

Phosphorus (P) is considered one of the six macronutrients essential for life due to its function in DNA and RNA replication (Scheerer et al., 2019) making it a vital macronutrient for all biota, as it limits plant productivity (Mallin & Cahoon, 2020). As a key component of life, P is essential to aquatic ecosystems. Soils represent the largest stock of P in terrestrial ecosystems; therefore, determining the amount of P within an aquatic system is a critical first step in identifying if P availability is potentially limiting functionality (He et al., 2021). P is found in either organic form (manure, biosolids, decomposed matter) or inorganic form (chemical fertilizers and animal waste) and is chemically unique because it does not take a gaseous form, resulting in a physical cycling process of weathering, adsorption, and desorption in the substrate.

Throughout the substrate and surrounding watershed soils, P is lost in particulate and dissolved forms, and the primary source of P loading into streams (Eimers et al., 2018). Ecosystems are greatly impacted when an excess of sediment-bound P is absorbed to soil particles, especially when those soils are eroded (Bennett et al., 2001). Despite the foundational role of P, a decline in global water quality has been linked to the excessive loading of P by both anthropogenic and natural processes, as excessive P can be considered a pollutant (Yuan et al., 2007).

In the United States, since the preindustrial era, the rise of P loading within watersheds, via attachment to sediments, has increased the likelihood of P runoff into waterways (Bennett et al., 2001). Excessive P loading is largely due to rainfall-driven runoff, with approximately 75 – 90% of P entering the stream via erosion in the form of unused commercial fertilizers, manure from livestock production, and untreated or incompletely treated human sewage (Mallin & Cahoon, 2020). During erosion events, various watershed land use practices introduce excessive nutrients into sediments, negatively impacting tributaries via over enrichment (Bennett et al., 2001). For environments with geologically low-P values in surrounding watershed soils, atmospheric deposition can be an important source of P (Eimers et al., 2018). The physical displacement of P, transported by wind dispersal in the form of enriched mineral dust is re-deposited by either wet (precipitation based) or dry (continual) deposition (Du et al., 2019), known as atmospheric phosphorus deposition (AP).

The corresponding total AP for a specific location provides insight as to which land use practices (rural or urban) contribute to a higher P deposition (Hill et al., 2011). By comparing the distinct land use practices of rural and urban sites in Missouri against varying North American AP totals, it is possible to draw conclusions about which land use practices result in higher P concentrations. Additionally, once a distinction is made between which land use practices result in higher AP, an analysis can be conducted as to which watersheds and aquatic ecosystems are in jeopardy (Chen et al., 2021).

Point sources of P are distinguishable, but non-point sources (NPS) require further study to conceptualize the origin and physicochemical forms of P (Huisman & Karthikeyan, 2012). The widespread dispersal of AP results in a NPS of P, which contributes to pollution in water bodies. In urban settings, like Lake Simcoe, ON, Canada, it is estimated that AP contributes an additional 25 – 50% of total P loading to the lake (Brown et al., 2011). In the state of Missouri, this unaccounted source of P has yet to be considered for rural and urban locations. Efforts have been made by the National Atmospheric Deposition Program (NTN) to monitor precipitation chemistry in Missouri (Ashland and Butler sites) using an automated collector during precipitation events (wet-based); however, total P is not yet monitored by this program. Anthropogenic activities contribute significantly to the production of AP through largescale agriculture, soil erosion, forest fires, stubble burning, gravel road debris, coal-burning, industrial emissions, vehicle exhaust, construction, use of fertilizers, and burning of fossil fuels (Pan et al., 2021).

In fact, Pan et al., (2021) collected AP data from 396 sites between 1954 – 2021 and found a significant increase in AP between 2001 and 2021, especially in Europe and Asia. The study reported an increase of AP of 4.4 Tg yr^{-1}, higher than the earlier estimate of 3.5 Tg yr^{-1} and estimated that mineral dust and combustion-related emissions were responsible for ~27% and more than 50% of anthropogenic AP sources, respectively (Pan et al., 2021). Within the last two decades, the increase of AP in Europe has been linked to agricultural activity, while Asia has experienced an increase in AP due to the burning of fossil fuels and coal (Pan et al., 2021).

Both rural and urban locations in Missouri experience varying anthropogenic activities. Distinguishing the land use practices at these sites provides insight as to why AP may differ between land use locations. Oftentimes, rural land use practices such as largescale agriculture, soil erosion, forest fires, stubble burning, and gravel road debris contributes to AP production, whereas AP dispersal in urban locations is attributed to coal-burning, industrial emissions, vehicle exhaust, construction, use of lawn fertilizers and burning of fossil fuels (Pan et al., 2021). By comparing the distinct land use practices of rural and urban sites against AP, it is possible to draw conclusions about which land use practices result in higher AP. By measuring AP approximately every two weeks from six different locations, three of which are urban locations and three being rural, the objective is to compare bulk deposition flux (BD) in rural and urban settings and determine which land use practices contribute to a higher total BD. It is the goal of this research to determine if AP deposition differs among rural and urban land use locations in Missouri. The hypothesis is BD at urban and rural locations will differ due to land use practices;

however, recently agitated soil and readily exposed P will result in higher BD totals in rural locations.

Methods

BD was collected at each land use location (Tables 1 & 2) using a standard sized utility bucket, which was altered to reduce debris by attaching a mesh screen to the opening (20 squares within a 2.54 cm^2). BD was collected from six different locations, three of which being rural locations in Cooper County and Moniteau County, Missouri (Table 1) and three urban locations in St. Louis, Missouri (Table 2). Collection dates for urban and rural locations were approximately every two weeks beginning on October 9th, 2021. Each site was sampled four times, ending on December 20th, 2021 (Table 3). During each sample period, each sample was photographed to analyze the total amount of organic matter filtered through the screen. Organic debris was qualitatively ranked from zero (no organic material) to ten (highest amount observed) (Table 4). Due to the distance between urban and rural sites, climate variables such as wind direction, wind speed and precipitation were gathered using the NOAA Weather Prediction Center via the Surface Analysis Archive (NOAA, 2021).

Field Deployment

AP deposition collectors were placed in an open area free of overhead vegetation. Screened buckets were positioned parallel to the ground and were attached to rebar posts to raise the deposition collectors 1.5 meters above the ground to avoid P contamination from underlying brush and soil. The screens were tightly fashioned to the opening of the buckets, which resulted in a slight depression in the middle of each bucket. Consequently, wet (precipitation based) and dry (continual) deposition were collected in the bucket. Each P collector is adorned with bird scare tape to repel birds and animals. A second bulk deposition bucket was deployed at each location and covered with a lid to represent a field blank.

Experimental Approach

Total P analysis was conducted using an ascorbic acid method following persulfate digestion via spectrophotometer (Baird, et. al., 2017). Analysis conducted at each land use site converted AP to reflect a geometric mean bulk phosphorus (P) deposition for both urban and rural land use locations, measured in and indicated as bulk deposition flux (BD flux). After calculating the diameter of a standard utility bucket, (29.8 cm), and utilizing the below listed conversation equation, AP concentrations were converted into total atmospheric P deposition flux (kg $ha^{-1}yr^{-1}$) to compare against North American BD Flux measurements (Figure 1 and Table 3).

$$\frac{\text{micrograms}}{\text{cm}^2} * \frac{(1\ \text{kilogram})}{(10^9\ \text{micrograms})} * \frac{10^8\ \text{cm}^2}{1\ \text{hectare}}$$

$$= \frac{\text{micrograms}}{\text{cm}} * \frac{(10^8\ \text{cm}^2)}{(10^9\ \text{hectare})}$$

$$\frac{\text{kg}}{\text{hectre}} * \frac{(1)}{(70\ \text{days})} * \frac{365\ \text{days}}{1\ \text{year}}$$

A Shapiro-Wilk normality test was performed on natural log transformed data ($p = 0.059$), resulting in a continuous variable, which was followed by a one-way ANOVA.

Table 1. Urban Location Characteristics, Land Use Practices, and Possible Nearby Atmospheric Phosphorus Sources (AP).

Location ID & Characteristics	Coordinates	Surrounding Vegetation / Topography	AP Wind-Blocks	Land Use Practices
C1 – Maplewood • Urban – Residence • Backyard • Fertilized lawn	38.61432386, -90.32073036	Little to no leaf litter on ground. Lawn bordered by decorative grasses. Classic suburban lawn. Surrounded by old growth trees. Fewest number of trees surrounding location. Flat topography.	Wooden 7-foot privacy fence located less than one meter from AP collector. Dense residential confinement surrounding the location.	Highly fertilized lawn – regular application High concentration of fertilizers used on lawn and surrounding suburban lawns Heavy traffic (100 m) Recent construction – nearby soil is recently agitated & exposed (100 m)
C2 – Glendale • Urban – Residence • Backyard • Small family garden	38.58636978, -90.38016856	Understory primarily dense with vegetation and leaf litter. Current squash/pumpkin production. Significant number of nearby old growth trees surrounding AP collector. Highest number of trees surrounding AP collector. Flat topography.	Wooden 7-foot privacy fence located less than one meter from AP collector. Dense residential confinement surrounding the location.	High concentrations of fertilizers used on surrounding suburban lawns Heavy traffic (100 m) Nearby golf course Soil is recently agitated, tilled & exposed (0 m) Butternut squash harvest underneath and surrounding AP collector during sample period.
C3 – Dogtown • Urban – Residence • Backyard • Small family garden	38.62210724, -90.31018482	Significant leaf litter on ground. Lawn bordered by decorative grasses. Classic suburban lawn. Surrounded by old growth trees. Flat topography.	Metal 4-foot chain link fence located less than one meter from AP collector. Medium residential confinement surrounding the location.	High concentrations of fertilizers used on surrounding suburban lawns Heavy traffic (<100 m) Nearby soil is recently agitated, tilled & exposed Recent soil agitation from gathering and digging of herbs and vegetables in the garden.

Table 2. Rural Location Characteristics, Land Use Practices, and Possible Nearby Atmospheric Total Phosphorus Sources (AP).

Location ID & Characteristics	Coordinates	Surrounding Vegetation / Topography	AP Wind-Blocks	Land Use Practices
C4 – Happy Hollow • Rural – Residence • USDA Certified Organic Farm • Large scale production of produce	38.81964234, -92.4756042	Cover cropping techniques, crop rotations, compost applications, hay mulch, and added minerals and nutrients to soil. Standard orchard setting. Trees evenly distributed throughout field.	Dense old growth forested area to the west of the AP collector. Site is positioned in valley. Protected from wind.	Nearby soil is recently agitated, tilled & exposed Livestock adjacent to property Located on low traffic gravel road Largescale combine harvesters used in surrounding farms
C5 – Prairie Home • Rural – Residence • Small scale family farm	38.83860768, -92.54309623	Recent earth work adjacent to AP collector. Large amounts of exposed soil. Moderate amount of old growth trees nearby.	No natural topography to protect site from wind. Spacious setting.	Nearby soil is recently agitated, tilled & exposed (3 meters away) Livestock adjacent to property Located on high traffic gravel road Largescale combine harvesters used in surrounding farms
C6 – Veggie Patch • Rural – Residence • Large scale traditional farm	38.92209724, -92.60228961	Residential yard fertilized regularly. Rolling hills to the east and the south protect from wind	Dense old growth forested area located to the north, east and west of the AP collector. Trees furthest from the collector.	Recently harvested and tilled corn field (<1 m) Located on low traffic gravel road Located closest to interstate highway.

Results

During the sampling period (Table 2), rural locations experienced an average increase of 0.05 kg $ha^{-1}yr^{-1}$ BD flux amongst C4 and C5 sites (Figure 1 & Table 3), relative to urban sites C1, C2 and C3. It is difficult to determine if rural anthropogenic factors result in higher P than urban factors, as the average of one urban location (C1) was 0.16 kg $ha^{-1}yr^{-1}$ BD flux, while the average of two rural locations (C4 & C5) were 0.19 kg $ha^{-1}yr^{-1}$ BD flux and 21 kg $ha^{-1}yr^{-1}$ BD flux, respectfully (Table 3). Consequently, urban and rural sites were not significantly different, as the one-way ANOVA revealed there was not a statistically significant difference in BD between locations C1-C6 ($F_{5,18} = 1.667$, $p = 0.194$).

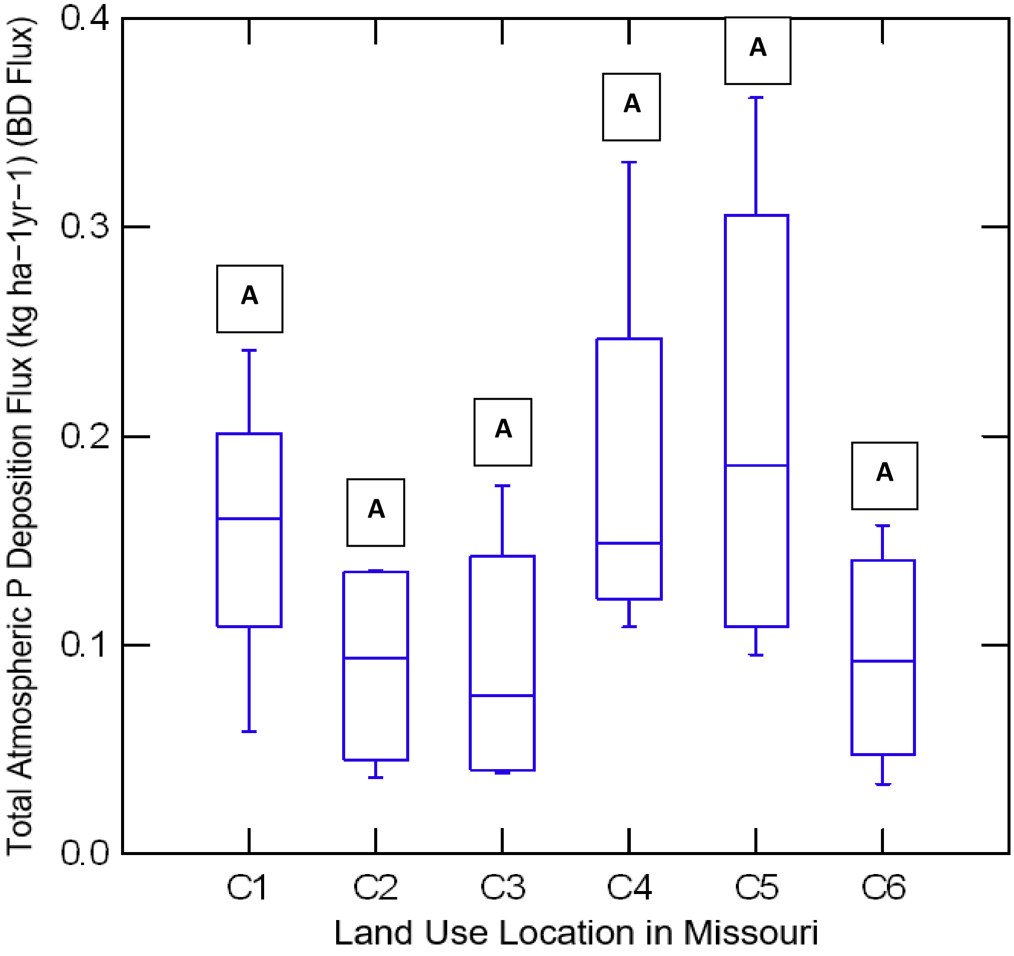

Figure 1. Comparing atmospheric phosphorus deposition (AP) totals amongst urban (C1, C2, C3) and rural (C4, C5, C6) land use locations in the state of Missouri. The annual North American BD flux is 0.41 (kg $ha^{-1}yr^{-1}$), whereas the global BD flux value is 0.32 (kg $ha^{-1}yr^{-1}$), showing a spatial difference in the amount of AP transported (Pan et al., 2021). Over the span of seventy-days, BD flux averages for urban land use locations averaged 0.11 (kg $ha^{-1}yr^{-1}$) and 0.16 (kg $ha^{-1}yr^{-1}$) for rural location, respectfully.

Table 3 – Urban and Rural Total Atmospheric P Deposition Flux (kg ha^{-1}yr^{-1}; BD Flux)

Sampling Periods (Approximately 14 days)	**Land Use**	**Total Atmospheric P Deposition Flux (kg ha^{-1}yr^{-1}; BD Flux)**
	Urban	
October 9th – October 23rd	C1	0.06
October 9th – October 24th	C2	0.05
October 10th – October 24th	C3	0.04
October 23rd – November 6th	C1	0.24
October 24th – November 6th	C2	0.04
October 24th – November 6th	C3	0.04
November 6th – November 26th	C1	0.16
November 6th – November 26th	C2	0.13
November 6th – November 26th	C3	0.18
November 26th – December 18th	C1	0.16
November 26th – December 19th	C2	0.14
November 26th – December 19th	C3	0.11
Total		**1.35**
Urban Average		**0.11**

Sampling Periods (Approximately 14 days)	**Land Use**	**Total Atmospheric P Deposition Flux ($\text{kg ha}^{-1}\text{yr}^{-1}$) (BD Flux)**
	Rural	
October 11th – October 24th	C4	0.33
October 11th – October 25th	C5	0.25
October 12th – October 26th	C6	0.06
October 24th – November 6th	C4	0.16
October 25th – November 12th	C5	0.36
October 26th – November 12th	C6	0.03
November 6th – November 26th	C4	0.14
November 12th – November 28th	C5	0.10
November 12th – November 28th	C6	0.16
November 26th – December 19th	C4	0.11
November 28th – December 20th	C5	0.12
November 28th – December 20th	C6	0.12
Total		**1.94**
Rural BD Flux Average		**0.16**

Table 4 – Urban and Rural Organic Debris Collected in Sample Bucket

Location	Sample Period #1	Sample Period #2	Sample Period #3	Sample Period #4	Debris Average (1-10 Rating)
C1 – Maplewood	9	10	2	2	6
C2 – Glendale	8	5	4	1	5
C3 – Dogtown	8	3	4	7	6
C4 – Happy Hollow	8	3	2	6	5
C5 – Prairie Home	6	10	1	6	6
C6 – Veggie Patch	4	2	.5	3	2

Table 5 – Urban and Rural Climate Variables *(Dates omitted when conditions were identical)*

Date (Noon)	Urban Wind Direction	Urban Wind Speed (kph)	Rural Wind Direction	Rural Wind Speed (kph)	Urban Precipitation (mL)	Rural Precipitation (mL)
10/24/2021	NW	16	SW	8	0	2.8
10/25/2021	E	32	SE	16	0	0
10/26/2021	SW	8	NW	8	0	0
10/27/2021	NW	16	NW	16	0	10.2
10/28/2021	W	16	SW	16	15	20.6
10/30/2021	SE	16	CALM	0	0	0
10/31/2021	E	8	SE	16	0	0
11/01/2021	CALM	0	CALM	0	2.5	1
11/05/2021	W	8	NW	8	0	0
11/11/2021	NE	16	NE	16	1.8	7.4
11/14/2021	NE	32	SE	24	2.3	2.8
11/17/2021	NW	32	NE	32	0	0
11/18/2021	E	16	SE	8	0	0
11/20/2021	NW	16	CALM	0	0	0
11/21/2021	NW	8	CALM	0	0	0
11/22/2021	SE	8	CALM	0	0	0
11/23/2021	NW	8	CALM	0	0	0
11/24/2021	NW	8	NW	8	0.3	16
11/25/2021	NW	8	NW	8	4.3	2.5
11/29/2021	NW	8	NE	8	0	0
12/01/2021	NW	16	NW	16	0.3	0.5
12/07/2021	SW	8	NW	8	0	0
12/08/2021	NE	16	CALM	0	0	0
12/10/2021	NW	8	W	16	23.4	8.6
12/11/2021	W	32	SE	16	0	0
12/14/2021	NW	8	NW	8	1.3	0
12/15/2021	NW	24	NE	24	0	0
12/16/2021	NE	8	SE	8	7.9	0
12/17/2021	CALM	0	CALM	0	5.3	3.6
12/18/2021	SE	16	SE	16	22.9	0
SUM					87.3 ml	76 ml

Discussion

During the seventy-day sampling period, Missouri BD averages were 0.11 (kg $ha^{-1}yr^{-1}$) for urban locations and 0.16 (kg $ha^{-1}yr^{-1}$) for rural locations. Consequently, it is difficult to determine if rural anthropogenic factors result in higher P than urban factors, as the average of one urban location is relatively close to the average of the highest rural location and a one-way ANOVA test revealed there was not a statistically significant difference in BD between locations C1-C6. A lack of significant difference between AP collected at urban and rural locations is due to several variables, such as the difference in organic debris collected at the end of each two-week sampling period (Table 4) and thirty days of inconsistent climate conditions between urban and rural sites out of a seventy-day sampling period (Table 5).

Impacts of Rural Land Use Practices on AP Totals:

To minimize the production of rural AP, multiple agriculturally based conservation efforts can be implemented. Oftentimes, rural land use practices such as largescale agriculture, deforestation, and construction of ditches and tile-drain systems, will increase particulate P in rural areas via runoff and erosion, which migrate into catchment zones (Poff et al., 1997). Combine harvester, tillage, and stubble burning also impact soil erosion, which disrupts P particles and results in airborne AP (Renwick et al., 2018). Additionally, CAFOs (confined animal factory operations) contribute a foreign source of P that leads to an increase in BD flux (Glibert, 2020). When these anthropogenic land use practices are coupled with the increase of natural P from eolian processes, it is likely BD flux totals when compared to urban sites will be higher (Figure 1).

Impacts of Urban Land Use Practices on AP:

As a result of unique land use practices such as nearby construction and regular fertilizer application, the Maplewood location (C1) had the highest BD flux total amongst the urban locations (Table 3). Because this location experienced multiple anthropogenic factors such as application of high concentrations of chemical fertilizers underneath the collector, presence of heavy traffic (approximately 100 meters from the collection site), high debris from surrounding vegetation, and continual construction along the high traffic thoroughfare, the average BD Flux collected at C1 was equivalent to AP measured at rural locations (C4 & C5). The prevailing wind necessary to transport P particles from the construction site to the collection location would require a western or southwesterly wind. At the Maplewood location, the occurrence of the wind blowing from the construction site was seven of the seventy days sampled, as the prevailing wind was mainly from the northwest, which is common for this region (NOAA, 2021). If the wind direction would have placed the Maplewood collector more frequently in the direction of the recently agitated and exposed soil from the construction site, the likelihood of the BD flux total being higher at the Maplewood location is possible.

Impacts of Wind Direction, Wind Speed and Precipitation on AP Totals:

Wind direction, wind speed and precipitation totals have a large impact on the transport of AP. Based on a study conducted at Lake Simcoe, Ontario, from 1995 – 2007, on average 35% of AP occurs during the spring, 45% during the summer months, 13% during autumn and just 7% of AP during the winter months, with summer totals having the potential to greatly fluctuate (Brown et al., 2011). Therefore, in hopes of obtaining a more significant snapshot of the impact AP plays in rural and urban areas, a longer period of time should be implemented to properly compare seasonality affects in Missouri. Additional seasonality changes to AP rates are important to consider in rural locations, as agricultural practices will increase AP totals, especially when considering seasonal variation in evapotranspiration, fertilizer application, and an increase uptake in P from leaf fall during the autumn months (Minervini, 2009).

Impacts of Eolian Processes on AP Totals:

The loss of P induced by wind erosion causes lasting land degradation (Du et al., 2019). Based on the proximity of the rural locations to the Missouri River, 2.3 – 5.7 miles, when wind blocking is not available, the eolian processes which significantly modify dunes and gravel bars along the river, could provide a significant source of AP at two of the rural locations – Happy Hollow (C4) and Prairie Home (C5; Sweeney et al., 2019). During the collection dates (Table 5), the prevailing wind direction for twelve of the 70 days at the rural locations was from the Southeast (NOAA, 2021), which would transport a readily available source of P directly to the specified rural locations. Therefore, the coordinates of the rural locations (Table 2), coupled with the eolian processes from the Missouri River, results in a natural source of P loading that does not exist for the urban locations.

When compared to Happy Hollow (C4) and Prairie Home (C5), the only sample location situated within valleys and protected by ridgelines was Veggie Patch (C6), which demonstrated a lower amount of AP measured over time, despite numerous nearby anthropogenic factors. Topographical wind barriers (Table 2) play a key role in P transport, as readily available AP during harvest time has difficulty being transported past wind barriers such as dense old growth forests, ridgelines, and peaks along the landscape. Despite being less than one meter away from the plowing of a cornfield and the usage of chemical fertilizers, during the sampling period, recent soil agitation did not illicit a rise in BD flux at the Veggie Patch location (C6).

Impacts of Organic Debris on AP Totals:

Changes in AP have important ecological implications, especially when attached to organic matter via leaf litter or pollen (Brahney et al., 2013). When the overall character of dissolved organic matter changes in an ecosystem, the ecological integrity also changes, as the metabolism, food webs, and biochemical processes are consequently altered (Rodríguez-Cardona et al., 2022). In a study conducted in the Black Forest in Germany, and consisting of two neighboring watersheds, BD fluxes at all sites were 1/3 less than surface P inputs from litterfall and pollen (Sohrt et al., 2019). Missouri data also mimics this trend, as AP collectors with the highest amount of debris (Table 5) experienced the highest totals of BD Flux. Additionally, the AP collector at the Veggie Patch location was placed furthest from nearby trees, resulting in the smallest amount of organic deposition collected at any of the sites sample locations and the lowest total of BD flux. Debris in the collection devices consisted of seed litter, grass clippings, leaf litter, pollen, and small insects.

Management Strategies to Reduce AP:

Management strategies that reduce point sources of P lead to improvements in water quality (Ator et al., 2020). In a study conducted in the Chesapeake Bay watershed, it was determined that an increase in sediment loading via construction infill contributed to an increase in P flux to the bay from its largest tributary (Ator et al., 2020). Their overall findings were that conservation efforts to reduce inputs via infill and construction projects substantially decreased the pool from which P can be transported (Ator et al., 2020). This additional pool of P which is then transported via wind and precipitation deposition should be considered when construction projects along aquatic waterways are proposed. When taking into account these additional inputs of P, planning and zoning commissions must limit proposed P inputs in the form of construction near impaired waterways. It is the responsibility of local and state officials to enforce zoning laws that protect delicate watersheds from additional P loading, as AP is a NPS that is rarely considered when awarding permits along waterways.

NPS is difficult to measure and regulate, because it originates from dispersed sources and varies widely with environmental conditions such as climate, seasonality, regionality, climate change, and land use practices. In the past, management practices are solely focused on waterways that are currently impaired, rather than identifying and remedying land use practices which influence the increase of P runoff (Bennett et al., 2001). Based on a global analysis of P and the human impacts that lead to eutrophication in waterways, reducing P inputs by minimizing land use practices that contribute to P will slow the transport of AP. At the same time, it will be important to reduce P concentrations in soils already over enriched with P because of past budget imbalances (Bennett et al., 2001).

Conclusions

A multitude of natural and anthropogenic factors affect the BD flux concentrations at urban and rural land use locations. Therefore, conservation efforts to decrease the known anthropogenic factors that cause high pools of AP should be monitored on public lands, as well as private residences. The annual North American BD flux average is 0.41 (kg $ha^{-1}yr^{-1}$; Pan et al., 2021). During the seventy-day sampling period, Missouri BD flux averages totaled 0.11 (kg $ha^{-1}yr^{-1}$) for urban locations and 0.16 (kg ha−1yr−1) for rural locations. Currently, the amount of AP in the state of Missouri is significantly less than the North American average, yet efforts can still be made to minimize AP. Simple actions such as decreasing the application of chemical fertilizers, limiting construction permits along fragile aquatic ecosystems, controlling runoff and erosion, limiting impervious surfaces near fragile catchment areas, and proper management of human and livestock sewage are essential to the quality of watersheds, lakes, and streams. Efforts should be made to analyze AP annually, as it presents a clear addition to the amount of P available for transport. Public outreach and education of the implications of using chemical fertilizers should be shared with citizens in both urban and rural locations. Additionally, rural locations which are prone to soil erosion via eolian processes should be educated on the benefits of establishing old growth forests to protect against the spread of P into potentially impaired waterways. AP analysis is exceedingly rare. A better understanding of the implications of nutrient loading in the form of AP is needed to protect potentially impaired waterways. This research has shown that a multitude of differing land use practices and natural processes results in numerous producers of AP. The measurement of AP can be utilized to better understand future nutrient loading budgets, which will help to identify the origin and physicochemical forms of P in waterways. This rarely gathered AP data may provide researchers with the missing puzzle piece to turn AP from an unknown non-point source into a well-known source of nutrient loading.

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