1. Training/Career Development Plan

Personal Statement: My professional goal is to support sustainable human–ecosystem interaction as a leader in agroecological research, a transdisciplinary communicator, and an inclusive educator. In particular, I want to generate and disseminate new knowledge on how land management alters biogeochemistry at the nexus of water, climate, and agriculture.

Sustainable intensification of agriculture represents a so-called *wicked problem*—a challenge that requires collaborative effort from the full spectrum of knowledge, from biophysical to cultural. As such, my approach is to wield both the pipette and pen: as an undergraduate, I dual majored in both Environmental Science and Professional Writing. Now as an Ecology PhD Candidate at Pennsylvania State University (PSU), I sustain this two-pronged interest in producing and sharing agricultural science. This summer I will complement my research as an intern at PSU's Agriculture & Environment Center, where I will engage farmers on practices that balance economic and ecological well-being. These experiences drive me toward my goals in agroecosystem research, communication, and teaching.

Career Goals and Objectives: My career goal is to hold a combined research and teaching position in ecosystem ecology at a university with strong ties to the broader community, such as a land grant. I have 3 major aims as a faculty member: 1) to conduct research that expands the boundaries of scientific knowledge on terrestrial nutrient cycling, 2) to be a leader in ecological communication, and 3) to diversify knowledge by directly engaging stakeholders in a co-production process and by training new researchers in transdisciplinary science.

As a graduate student, I conduct ecosystem research, lead team writing, and link to local riparian buffer networks to strive towards my career goals. Starting my first semester, I explored soil gas emissions using analyses that I will apply to my proposed research (Obj. 1). I am completing a first author manuscript of this work that I will submit to *Ecosystems* by Fall 2021. I am also first author on a team paper that examines how Critical Zone science, an integrative framework for near-surface biogeochemistry, informs forest management. Our manuscript has completed two rounds of internal review, will be submitted to the *Journal of Forestry* by June 2021, and prepares me to craft outputs from this research that resonate with land managers. Further, I connect directly with stakeholders through a National Research Traineeship, where I helped to create communication tools that engage farmers in riparian buffer outreach.

Overall, my graduate record reveals an aptitude for transdisciplinary science which primes me to succeed as a AFRI Fellow. This fellowship provides resources for me to enrich my career development by experimenting at the intersection of food, water, and climate; networking at conferences; conducting agricultural outreach; and developing and teaching my own class.

Training Objectives and Activities: I want to emerge from my doctoral training as a leader in ecological research with a competitive portfolio of communication and teaching experiences. My research objectives are to 1) progress from intermediate to advanced in chamber methods for measuring soil greenhouse gas emissions; and 2) broaden my professional network across and beyond the nation. To reach these goals, I will 1) deploy a Fourier Transform Infrared Analyzer to measure soil greenhouse gas emissions in two laboratory experiments; and 2) present at state (PA DCNR Riparian Forest Buffer Summit), national (North American Agroforestry Conference), and international (2022 European Agroforestry Conference) conferences. Metrics of success include publication of two manuscripts using data from chamber methods and presentations in at least two conferences.

My teaching and communication objectives are to 1) practice engaging directly with agricultural landowners, and 2) translate my communications experience into curricular development. To gain communication experience, I will 1) complete PSU's science outreach course (SC 451, Spring 2022) to hone the skills I need to design and enact impactful agricultural outreach; and 2) demonstrate a riparian buffer to landowners at PSU's Ag Progress Days (Aug. 2022 & 2023), an agricultural exposition that regularly attracts >40,000 attendees of which >60% hold agricultural professions. To gain teaching experience, I will 1) complete the PSU Graduate School Teaching Certificate, and 2) create and teach a technical writing class (ERM 297, Fall 2022) to help Environmental Resource Management undergraduates effectively communicate with agricultural scientists and landowners (see Dr. Robert Shannon's Support Letter). My writing degree and years as a writing tutor uniquely position me to create such a class. Metrics of success include outreach course and teaching certificate completion, and individual impact scores from outreach and teaching surveys (see *Section 4. Evaluation Plan*).

2. Mentoring Plan: A network of mentors will support my doctoral training. Dr. Jason Kaye, Distinguished Professor of Soil Biogeochemistry at PSU, is my primary mentor. Dr. Kaye is a global leader in nutrient cycling, and he spearheads large transdisciplinary projects in agroecosystems. He has successfully supported graduate students on AFRI predoctoral grants. In my project, he will support my experimental design, provide laboratory space and equipment, and host one-on-one weekly meetings to discuss my progress. He has also committed to my professional development by holding semesterly discussions of my Individual Development Plan, a tool to track career goals; by creating a space to gain feedback on my papers, job talks, and presentations in weekly lab meetings; and by facilitating networking from his connections.

Dr. Kaye's former PhD students include Drs. Julie Weitzman (Postdoc, ORISE-US EPA), Alison Grantham (Director of Food Systems Research and Development, Blue Apron), Denise Finney (Assistant Professor, Ursinus College), Charles White (Assistant Professor, PSU), Marshall McDaniel (Assistant Professor, Iowa State Univ.), Michael Castellano (Professor, Iowa State Univ.), and former postdoctoral associates include Drs. Ebony Murrell (Lead Scientist, Crop Protection Ecology, The Land Institute), Arlene Adviento-Borbe (Project Scientist, UC Davis), David Lewis (Associate Professor, Univ. of South Florida), Mac Burgess (Associate Professor, Montana State Univ.), Meagan Schipanski (Associate Professor, Colorado State Univ.), and Elizabeth Hasenmueller (Associate Professor, Saint Louis Univ.).

3. Project Plan: Minimizing nitrogen "pollution swapping"—linking root traits to N_2O emissions in edge-of-field forested riparian buffers

Introduction: Forested riparian buffers are a central strategy for sustainable agricultural intensification, especially in the Chesapeake Bay, the largest estuary in the U.S.[1] Tree roots in agricultural margins intercept leached nutrients, such as nitrogen (N), from entering streams and triggering eutrophication.[2] To reduce N loading to the Chesapeake Bay, Pennsylvania adopted an ambitious goal to plant 95,000 miles of new buffers by 2025.[3] However, planting has fallen short of yearly targets, such that the state requires an extra 40 years to meet its 2025 goal.[4]

One barrier to riparian buffer adoption is the unknown lag time between implementation and provision of ecosystem services. Landowners, including farmers, note that they have little to no certainty of the timeline from first planting trees to having a mature, functioning buffer.[4] Recent critical reviews on best management practices for diffuse nutrient pollution, like agricultural N, echo farmers' concerns with this key knowledge gap.[5] Understanding the rate and time to delivery of ecosystem services will be critical in the next decade of Chesapeake Bay management, because this aligns with targets to meet total maximum day load requirements for N. As such, *the aim of this research is to explore how N ecosystem services change over the life of a forested riparian buffer, and if we can leverage species' traits to impact these services.*

This research emphasizes N ecosystem services, because N "pollution swapping" is a critical challenge for sustainable agriculture. Nitrogen pollution swapping refers to a tradeoff between water quality and climate change goals.[6] When tree roots in edge-of-field buffers intercept leached agricultural nitrate (NO_3^-), roots can directly retain this NO_3^- via sequestration or, more often, indirectly promote NO_3^- removal via microbial uptake, including denitrification.[7] Denitrification is the microbial reduction of NO_3^- into an inert gas, N_2, which comprises most of our air. This process requires oxygen-limited soils, available carbon (C) to donate electrons, available N oxides to accept electrons, and microbes that can perform each step of the reaction. Together these factors, along with abiotic conditions, modify denitrification rates and the product emitted to the atmosphere: either N_2, an ecologically harmless gas, or nitrous oxide (N_2O), a greenhouse gas with ~300x the warming potential of carbon dioxide.[8] As such, the fate of captured NO_3^- in buffers is significant, because we risk counteracting sustainability goals through pollutant swaps: decreasing NO_3^- in streams but increasing N_2O in the atmosphere.

Growing evidence suggests that trees' main role in riparian N removal is to create sites for "complete" denitrification through root activity:[9] decreasing NO_3^- concentrations via root N uptake, altering anaerobic conditions via root respiration (and transpiration), and fueling microbes with root-derived C (Fig. 1). Root physiology varies considerably across root age and tree species;[10] however, researchers often approach buffers with observational studies that compare broad vegetation types (e.g., grass vs. forested buffers) rather than tracking changes across time or species.[11] Instead, a plant trait framework could allow for intentional edge-of-field buffer designs that drive valued N ecosystem services through root activity as buffers age. Overall, the intent of this research is to understand controls on N pollution swapping in edge-of-field forested riparian buffers from adoption to maturation. Specifically, **my objectives are to (1) estimate N pollution swapping from edge-of-field riparian buffers across time; (2) explore how tree root physiology modifies N_2O emissions from buffers; and (3) link species' root physiology to relative N_2O:N_2 emissions in a greenhouse study.**

Rationale and Significance: There is a pressing need to design riparian buffers that capture NO_3^- without emitting greenhouse gases.[12] Globally, riparian areas are a significant source of N_2O,[13] and my work helps to quantify these emissions as buffers age (Obj. 1). With insight into mechanisms that partition denitrification into N_2O and N_2 (Objs. 2 & 3), we can design sustainable buffers that leverage plant traits to drive denitrification in support of the **USDA NIFA Priority 4: "Bioenergy, Natural resources, and Environment."** My objectives also align with USDA Strategic Sub-Goal 5.1 to "Enhance Conservation Planning with Science-Based Tools and Information", for which acreage enrolled in Conservation Reserve Program riparian buffers indicates success.[14] Both increased efficacy of buffers and awareness of time from planting to functioning will erode current farmer-identified barriers to adoption.[4]

My previous experiences prime me to succeed in work that furthers the AFRI Education and Workforce Development goal of advancing science relevant to U.S. agriculture. My proposed activities (e.g., conference networking and an outreach class) prepare me to not only succeed in completing this research, but to disseminate my results within and beyond academia.

Approach: I will conduct 2 field and 1 greenhouse studies to meet my research objectives. Field studies (Objs. 1 & 2) will use a system of 3 replicate buffers in Centre County, PA across 3 age classes: "Newly Established" (<7 yrs), "Transitional" (7–10 yrs), and "Closed Canopy" (15+ yrs). Each buffer has a transect of 2 wells, extending linearly from field edge to stream, with pressure transducers to continuously monitor the water table. This allows us to normalize buffers for comparison by quantity of groundwater flow into each site.[6] Within each buffer are 2 nests of suction lysimeters at 30 and 60 cm depth to capture NO_3^- in transient surface water. This equipment, plus the proximity of all buffers to the PSU campus, make the system ideal for exploring the quantity of and controls on N_2O emissions as buffers age.

Obj. 1 *Estimate N Pollution Swapping:* This study quantifies N_2O emissions and NO_3^- leaching from riparian buffers to estimate N pollution swapping as buffers age. Studies across buffer age gradients are rare and this is the first to measure N_2O emissions across one. I will collect weekly N_2O samples using manual chambers at 5 randomly placed soil collars at each site. My design will follow GRACEnet protocols[15] and balance capturing N_2O variability with feasible processing time. Over 30 minutes, I will collect 4 headspace gas samples to analyze by gas chromatography.[16] I will estimate annual fluxes using linear interpolation between daily fluxes summed for one year.[17] I also will monitor NO_3^- concentrations (via microplate colorimetric assay) from water at and below average root depth. I will calculate annual mass of NO_3^- removal as $[NO_3^-]$ times water volume (as in ref [6]). Overall, these methods allow me to compare the quantity of N losses from buffers to streams and the atmosphere across time. *Expected Outcomes:* Older buffers may emit less N_2O, because older trees have more roots fueling microbes with root-derived C, capturing NO_3^-, and respiring to create anaerobic microsites for complete denitrification. Alternatively, N_2O emissions may remain constant, because young buffers may have lower transpiration rates, which keep soil wetter and anaerobic.

Obj. 2 *Link Tree Physiology to Denitrification:* This study explores hypothesized mechanisms on N_2O emissions (from Obj. 1) by linking tree physiology to denitrification products. At each site, I will install 5 mesh root in-growth cores and 2 PVC cores (controls) filled with a C4 soil/sand mixture (from a long-term corn study site; as in ref. [18]). This method improves root recovery during harvest and detection of root-derived C3 inputs.[18] After one growing season, I will harvest cores to dry and weigh total root biomass; grind and analyze subsamples for total C, N, and $\delta^{13}C$ (via elemental analyzer-isotope ratio mass spectrometer); and analyze soils for bulk density, total C, and $\delta^{13}C$. Also, at the start and harvest of in-growth cores, I will collect collocated soil cores to measure denitrification potential via the acetylene block technique.[19] Briefly, I will collect intact soil cores, inject acetylene into each sealed core's headspace, and measure N_2O for 18 hours via FTIR. Lastly, I will measure leaf area, a proxy for transpiration, using LI-COR Plant Canopy Analyzers. I will monitor soil moisture using collocated Time Domain Refractometry sensors. *Expected Outcomes:* I will regress tree physiology (leaf area, root density, & root-derived C) with direct controls (C and O_2) on denitrification potential across a buffer age gradient to tease apart mechanisms proposed in Obj 1.

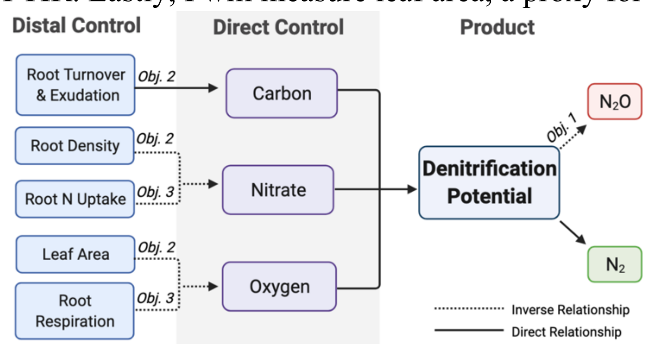

Fig 1. Hypothesized controls of riparian tree physiology on denitrification

Obj 3. *Species-level Controls on Denitrification:* Obj. 2 links root physiology with denitrification potential, but I will not know *which* species' roots are in the cores. Laboratory controls refine mechanisms to the species level, which opens the prospect of intentionally selecting species to promote complete denitrification. I will grow 6 replicates of 2 dominant species from our field sites in 3-gallon pots filled with riparian soils. These species differ in specific root lengths[20] (a proxy for N uptake and correlated with respiration[21]): *Acer rubrum*, *Quercus bicolor,* and bare soil (control). I will saturate pots with N as ^{15}N-labeled NO_3^- tracer at mean field concentrations. This isolates denitrification products from other processes: anaerobic soils assure denitrification dominates N_2O production, while a tracer tracks $^{30}N_2$, which should arise only via denitrification.[22] Under these constraints, I will monitor gaseous products from each pot via (a) hourly samples analyzed for N isotopologues through an isotope ratio mass spectrometer (for 3 replicates) and (b) continuous samples via automatic chambers coupled to a FTIR. I also will monitor direct controls ($[NO_3^-]$ as in Obj. 1 and soil pO_2 via gas samplers) and distal controls (respiration via gas-exchange cuvettes and N uptake via root ^{15}N) on denitrification. Overall, this study will reveal how some species might create better conditions for complete denitrification. *Expected Outcomes:* As roots consume O_2 and NO_3^-, soils should become O_2-limited while soil dissolved organic C:NO_3^- ratios increase—conditions that favor complete denitrification.[23] Thus, species with higher root respiration and N uptake will correlate with lower N_2O:N_2 emissions.

Analysis & Use of Results: Along with analyses described within objectives, I will use repeated measures ANOVA to find significant differences between response variables. Buffer age, along with physiology and soil conditions (Objs 2 & 3), will be used as variables in multiple regression analysis and Random Forest models[24] (which I have used successfully) to target properties that predict N_2O emissions. I will perform all statistical analyses in R software.

Pitfalls, Limitations, & Hazards: The acetylene block technique (Obj. 1) can underestimate denitrification;[25] however, this problem is less notable in systems with high NO_3^- concentrations, such as agricultural margins, and can be corrected.[26] The pot study (Obj. 3) is an imperfect analogue for field conditions, but I cannot separate roots by species in the field. As such, Obj. 3 is a first step: If some species show promise at promoting complete denitrification, then I will seek field contrasts in future work. I will minimize hazards for all objectives through yearly PSU Worker Protection Standard and Environmental Health & Safety Training.

Documenting Progress & Networking: I will update my *LinkedIn* and ResearchGate profiles with research outputs. I will also document progress through PSU's Annual Graduate Student Activity Report and my Individual Development Plan, a tool for tracking career goals.

Project Timeline	**2021–22**				**2022–23**				**2023–24**			
Fiscal Quarter	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Research: Conduct Experiment 1			X	X	X							
Conduct Experiment 2			X	X	X							
Conduct Experiment 3							X	X	X			
Teach: Complete Certificate			X	X	X	X						
Develop & Teach Class (ERM 297)								X	X	X	X	
Communicate: Outreach Course			X									
Demonstrate at Ag Progress Days				X				X				
Disseminate: Submit Manuscripts										X	X	X
Present at Conferences								X	X	X		
Evaluate: Mentor Meetings	X	X	X	X	X	X	X	X	X	X	X	X

4. Evaluation Plan

Milestones & Indicators of Success: Dr. Kaye will evaluate my progress and outputs in weekly meetings. My timeline and metrics of success from my *Training/Career Development Plan* will be indicators of achieved milestones, e.g., students will evaluate my teaching efficacy in ERM 297 via end-of-semester evaluations. Also, I will evaluate my teaching and outreach success using individual impact scores, a strategy I learned from a Professional Development in Environmental Outreach Workshop.[27] I will end class and outreach activities with a brief survey that scores individual impact (average change in awareness, knowledge, and attitude) minus intention to adopt behavior (for farmers to adopt buffers or for students to apply skills from my class in the future). Through this method, I can evaluate both my short- and long-term impact.

Disseminating Results: Each objective will culminate in an academic article targeted at international (*Agroforestry Systems*) or high-impact journals (*Global Change Biology*). I plan to produce oral and poster presentations at state, national, and international conferences. Also, root traits from riparian species are sparse in the literature. As such, I will make a lasting contribution to global research by submitting data from Objs. 2 & 3 to the Global Root Trait Database.[28]