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Application Summary

Competition Details

Competition Title:	2025 South Dakota Nutrient Research and Education Council Invited Proposals
Category:	SDAES
Cycle:	2025
Submission Deadline:	10/15/2024 5:00 PM

Application Information

Application Title:	Precise Management of Phosphorus in South Dakota Agricultural Soils
Application ID:	3446
Submission Date:	10/15/2024 10:36 AM

Personal Details

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Co-Applicant(s)

Name	Email	Affiliation
No Co-Investigator(s)		

Application Details

Proposal Title

Precise Management of Phosphorus in South Dakota Agricultural Soils

Proposal Abstract

Phosphorus (P) is crucial for crop growth, but managing it effectively in agricultural soils, especially with extreme pH levels, remains a challenge. Traditional soil testing methods often fail to accurately predict P availability, leading to under- or over-application of fertilizers, which can harm both yields and the environment. This research aims to enhance phosphorus management for South Dakota farmers by developing new strategies for predicting P absorption and desorption rates and improving fertilizer recommendations. The project will create Quantity-Intensity (Q-I) curves for 15 soil types in Eastern SD, classify soils based on buffering capacity, and establish plot-scale studies to predict corn yield responses to phosphorus fertilization. Deliverables include data on P Buffering Capacity, practical guidelines for farmers, and extensive knowledge sharing through workshops, publications, and field days. The three-year project requests $277,776 to support a PhD student, research assistants, necessary materials, and logistics.

2025 Total Budget Request

92,130

Acknowledgment

Acknowledgement of Terms and Conditions

[Acknowledged] I have read and agree to abide by the South Dakota Nutrient Research and Education Council Terms and Conditions attached to this RFP.

Title: Precise Management of Phosphorus in South Dakota Agricultural Soils

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Summary: Phosphorus (P) is a vital nutrient for crops, essential for healthy growth and high yields. However, managing P effectively in agricultural soils is challenging. Traditional soil testing methods often don't accurately predict how much P is truly available for plants, especially in conditions when soil pH is either very high (>7.8) or very low (<5.0). Not fully understanding these soil pH impacts could lead to either under-application or over-application of fertilizers that may negatively impact grain yield. Over-application is economically non-viable and harms the environment, contributing to water pollution. This research aims to address these issues by precisely measuring and predicting P absorption and desorption rates for various soil types, its response to corn yields, and improving fertilizer recommendations for South Dakota farmers. <u>The main goal of this research is to improve how phosphorus is managed in agricultural soils in South Dakota above and beyond current P management</u>. To achieve this, the project has three key objectives: (a) We will develop Quantity-Intensity (Q-I) curves for various soil types to understand the dynamics of phosphorus availability in 15 different soil types in Eastern SD from 3 different Major Land Resource Areas (MLRAs) regions (Ref to Figure 1 in Appendix A) defined by USDA NRCS. This will be done in Year 1. (b) We will classify soils based on buffering capacity (in Year 1 of the project) to establish a plot scale study in Years 2 and 3 in predicting corn yield responses to phosphorus fertilization and different management (broadcast vs. banded in a no-till system). (c) Based on our findings, we will develop a database with guidelines for farmers to help them apply phosphorus more efficiently while maximizing profit and minimizing environmental impacts. This project will produce several important deliverables: (a) We will generate detailed data on Phosphorus Buffering Capacity for different soils in Eastern SD. (b) We will create practical guidelines for farmers on optimizing phosphorus use based on soil type, conditions, and economics. (c) We will share our findings through workshops, field days, peer-reviewed publications, and extension articles to ensure farmers, agronomists, and other stakeholders can apply the new knowledge effectively. The research is expected to benefit farmers and the environment significantly. We request $277,776 for a three-year project, with $92,130 for Year 1, $91,965 for Year 2, and $93,681 for Year 3. This funding will support a PhD student and two hourly research assistants, purchase necessary materials (like the Diffused Gradient Thin (DGT) films), cover travel expenses for sample collection and maintain plots and related logistics at the experimental station, and outsource a few lab analyses.

Goals and Objectives: The primary goal of this project is to enhance phosphorus (P) management in South Dakota's agricultural soils by developing a more accurate and effective database on P absorption and desorption rates through Precision Ag techniques that can guide optimal P fertilization practices, thereby improving crop yields, reducing environmental impact, and promoting sustainable farming. It will be a multi-year project, and the specific Objectives are:

a. Quantify Soil Buffering Capacity [Year 1 and 2]: Measure phosphorus available in distinct soil types using multiple soil P extraction methods (Olsen P, Bray P, Mehlich-3 P, DGT). Develop quantity-intensity curves for each soil group.
b. Classify Soils Based on Buffering Capacity [Year 1, 2, 3]: Group soils into categories based on P fixation potential, soil test phosphorus, and other parameters such as pH, organic matter, salts, texture, and soil health properties.
c. Evaluate Phosphorus Response in Soils [Year 2, 3]: Conduct phosphorus rate studies using broadcast and banded applications to determine response curves for crop yield. Identify relationships between phosphorus buffering indices (PBI) and yield responses within plots.
d. Develop a Phosphorus Buffering Index (PBI) [Year 1,2,3]: Develop a quantitative index to assess the soil's capacity to buffer added phosphorus, enabling precise P recommendations for producers.
e. Outreach and Education [Year 1, 2, and 3]: Develop and disseminate practical phosphorus management guidelines for South Dakota farmers based on the most effective soil testing methods identified in the study to optimize phosphorus use, increase farm profitability, and minimize environmental risks.

Justification Statement: The project stems from the limited information on phosphorus (P) absorption and desorption rates and its interactions with changes in pH and organic matter in South Dakota soils, which is essential for developing sustainable soil management practices, optimizing nutrient availability for plant growth, and supporting ecosystem restoration. The rate of phosphorus desorption in soils can significantly affect its availability to plants, especially when soil P levels are low. Understanding the kinetics of P desorption is crucial for evaluating soil health and nutrient dynamics. The Diffusive Gradients Thin Films (DGT) technique offers a more precise and dynamic method for assessing phosphorus availability compared to traditional soil testing methods like Mehlich 3-P, Olsen P, and Bray P. DGT provides high-resolution data on P profiles in soil porewaters, mimics the way plant roots absorb phosphorus, and can be used directly in the field to study P mobility over time. The new advances and information expected from this project include: (a) The project will generate data for the P buffering capacity of different soils in Eastern SD. In years two and three, the responses to crop yield will be reported to provide a better understanding of phosphorus dynamics in South Dakota soils. (b) Based on the findings, the project will develop guidelines for farmers that optimize phosphorus application rates according to soil type and associated conditions (soil pH and organic matter content). The anticipated economic and environmental benefits of this research are significant: (a) By understanding the effect of soil properties (pH and OM) on the soil's ability to supply phosphorus, farmers will be able to apply phosphorus more precisely, leading to improved crop yields and reduced input costs. This will enhance farm profitability and promote more efficient fertilizer use. (b) Accurate phosphorus management will reduce the risk of over-application and subsequent phosphorus runoff into water bodies, thereby helping to protect water quality and prevent environmental degradation. This aligns with broader goals of promoting sustainable agricultural practices and preserving natural resources.

Work Plan for Year 1

Research Objective: The primary objective of this research is to construct phosphorus Quantity-Intensity (Q-I) curves for various soil types to understand the dynamics of phosphorus availability and its environmental implications. The Q-I curves will help evaluate phosphorus buffering capacity, predict potential phosphorus loss, and inform site-specific fertilizer management strategies.

Experimental Design and Setup

Soil Sample Collection: Fifteen representative soils from three Major Land Resource Areas (MLRAs)—59, 63, and 143—covering approximately 600,000 hectares in Eastern South Dakota have been selected for the study. The soils and their specific characteristics are summarized in Table 1 (Appendix A). Soil samples will be collected from multiple depths (0-3, 3-6, and 6-9 inches) to capture vertical variation in phosphorus distribution and assess changes in availability along the soil profile. At least three replicate samples will be collected per site and depth to ensure spatial variability is adequately captured.

Initial Soil Characterization: Each soil sample will undergo a comprehensive baseline analysis to quantify the following parameters: (a) Soil pH: Critical for understanding phosphorus solubility and availability. (b) Organic Matter Content (OM): A soil health indicator influencing phosphorus retention capacity and release. (c) Soil Texture: Determined as the percentage of clay, silt, and sand influencing phosphorus retention and leaching. (d) Cation Exchange Capacity (CEC) and Anion Exchange Capacity (AEC): Reflect the soil's capacity to hold positively and negatively charged nutrients, including phosphorus. (e) Baseline Phosphorus Levels: These are measured using established extraction techniques such as Olsen-P, Bray P, Mehlich-3 P, and DGT to benchmark initial phosphorus availability. (f) Soil Health Properties and other salts

Phosphorus Quantity-Intensity (Q-I) Curve Construction: Calculating phosphorus quantity-intensity (Q-I) curves is a systematic process that involves measuring and analyzing the relationship between the quantity of phosphorus in the soil and its intensity or availability in the soil solution. This relationship is crucial for understanding soil phosphorus dynamics and optimizing fertilizer management practices. The following outlines the steps typically involved in calculating Q-I curves: The first step involves collecting soil samples from the area of interest. These samples should represent the variability of the soil types present. The samples are then air-dried and sieved to remove larger particles, ensuring uniformity for subsequent analyses (Lambano et al., 2022). A series of phosphorus solutions with varying concentrations are prepared. These solutions are applied to the soil samples in controlled laboratory conditions. The concentrations typically range from low to high levels to cover the potential phosphorus availability in the soil (Nawara et al., 2017). After applying the phosphorus solutions, the soil samples are allowed to equilibrate for a specified period. This allows the phosphorus to interact with the soil matrix, leading to adsorption and desorption processes that reflect the soil's capacity to retain phosphorus (Ehlert et al., 2003). Following the equilibration period, the concentration of phosphorus in the soil solution is measured. This can be done using various extraction methods (Olsen-P, Bray P, Mehlich-3 P, and DGT), such as water extraction or using a dilute calcium chloride solution (Ehlert et al., 2003). The concentration of phosphorus in the solution represents the intensity (I) factor in the Q-I relationship. The amount of phosphorus retained by the soil is determined by subtracting the concentration of phosphorus in the soil solution from the initial concentration applied. This value represents the quantity (Q) of phosphorus that the soil can hold (Lin, 2011). The data collected from the measurements are then plotted on a graph, with the quantity of phosphorus (Q) on the x-axis and the intensity of phosphorus (I) on the y-axis. The resulting curve typically exhibits a characteristic shape that indicates the soil's phosphorus buffering capacity (Bangroo et al., 2020). The slope of the Q-I curve provides insights into the soil's phosphorus buffering capacity. A steeper slope indicates a higher buffering capacity, meaning the soil can retain phosphorus effectively, while a flatter slope suggests a lower buffering capacity (Lalitha & Dhakshinamoorthy, 2015). The maximum phosphorus buffer capacity (MPBC) can also be calculated from the curve, which is essential for assessing the soil's ability to supply phosphorus to plants over time (Lambano et al., 2022). Advanced statistical models may be applied to the Q-I data to derive predictive equations that can be used for fertilizer recommendations and assess the risk of environmental phosphorus loss (Nawara et al., 2017).

Phosphorus Buffering Index (PBI) Calculation: The Phosphorus Buffering Index (PBI) will be derived for each soil type using the formula:

$$PBI = \frac{\Delta Q}{\Delta I}$$

where: ΔQ = Change in phosphorus quantity (mg P/kg of soil) and ΔI = Change in phosphorus intensity (mg P/L of soil solution). A high PBI value indicates a strong capacity to buffer added phosphorus, resulting in a lower risk of phosphorus loss, whereas a low PBI suggests a higher likelihood of phosphorus mobility and environmental impact.

Interpretation and Modeling: The correlation and regression techniques will be employed to explore the relationship between phosphorus buffering capacity and key soil properties (pH, OM, texture, CEC, and other soil properties). Significant soil attributes that influence phosphorus availability will be identified. Multivariate approaches will be used to classify soils based on phosphorus dynamics, allowing for a more nuanced understanding of phosphorus retention mechanisms.

Outputs and Next Steps: (a) Use the Q-I curves and PBI values to tailor phosphorus fertilizer recommendations for different soil types and establish the field trial for years 2 and 3. (b) Identify soils with low buffering capacities prone to phosphorus loss that could contribute to water quality issues such as eutrophication. (c) Develop site-specific P management plans to optimize crop phosphorus uptake while minimizing environmental losses. (d) Mitigation strategies for high-risk soils, such as implementing buffer strips or controlled drainage systems, are recommended. Year 2 and 3 Plot-Scale Study on Phosphorus Buffering Capacity and Corn Yield Response (Please refer to Appendix B)

Potential Impacts for Activities in Year 1

Calculating phosphorus quantity-intensity (Q-I) curves and phosphorus buffering indices (PBI) for different soils has significant implications for agronomic practices and environmental management. These calculations provide insights into how soils interact with phosphorus, crucial for optimizing fertilizer use and mitigating the risks of phosphorus runoff into water bodies. One of the primary impacts of calculating Q-I curves is the ability to assess the phosphorus sorption characteristics of various soils. Lambano et al. (2022) noted that soils' maximum phosphorus buffer capacity (MPBC) is a critical factor influencing agricultural productivity and environmental sustainability. By determining the MPBC, it is convenient to identify soils capable of retaining phosphorus effectively, which is essential for ensuring that crops, such as corn, have adequate access to this nutrient throughout their growth cycles. This understanding can lead to more precise fertilizer application strategies, thereby enhancing crop yields while minimizing excess phosphorus application that could lead to environmental degradation. Furthermore, the PBI derived from Q-I curves helps evaluate the risk of soil phosphorus loss. Ayenew et al. (2018) emphasize that phosphorus availability is governed by the concentration of phosphorus in the soil solution, the amount of phosphorus in the solid phase, and the soil's capacity to maintain adequate phosphorus levels. By quantifying these factors, land managers can make informed decisions about phosphorus management practices that reduce the likelihood of nutrient runoff, which significantly contributes to water quality issues such as eutrophication. In addition to environmental benefits, understanding the phosphorus dynamics through Q-I curves can directly influence agricultural productivity. For instance, studies have shown that higher phosphorus availability correlates with improved corn yields, as indicated by favorable Q-I relationships (Pereira et al., 2020). This relationship emphasizes the importance of tailoring phosphorus applications based on soil-specific characteristics, leading to increased fertilizer use efficiency and enhanced crop performance. Moreover, the long-term implications of phosphorus management practices can be evaluated through Q-I curves. Research by Zhang et al. (2011) highlights how continuous fertilization impacts the Q-I relationships in soils, which can inform future management practices and help develop sustainable agricultural systems. Farmers can adapt their practices to maintain soil health and productivity by understanding how different soils respond to phosphorus over time. Lastly, integrating Q-I curves into broader agricultural and environmental management frameworks can facilitate the development of best management practices (BMPs) tailored to specific soil types. This approach can help optimize phosphorus use efficiency, enhance crop yields, and protect water quality, thereby addressing both agricultural productivity and environmental sustainability goals (Udawatta et al., 2011; Nelson et al., 2022).

TIMELINE

Year	Task	Description	Key Performance Indicators (KPIs)	Deliverables
Year 1	**Task 1: Initial Soil Sample Collection & Characterization**	Collect soil samples from 15 representative sites across MLRAs (59, 63, and 143) at two depths (0-3 inches, 3-6 inches). Analyze baseline properties such as soil pH, OM, texture, CEC, and baseline phosphorus levels using Olsen-P, Bray P, Mehlich-3 P, and DGT methods.	- Successful collection of 15 representative soil samples from each MLRA region.	- Comprehensive baseline soil property report.
			- Completion of baseline characterization for each soil property.	- Dataset on phosphorus levels for each depth and site.
			- Comprehensive database with initial phosphorus levels and soil health indicators.	- Soil health indicator report for targeted MLRAs.

	Task 2: Phosphorus Q-I Curve Construction	Measure phosphorus quantity (Q) using standard extraction techniques (Olsen-P, Bray P, Mehlich-3 P). Determine phosphorus intensity (I) using soil solution extraction and ICP spectrometry. Plot Q-I curves for each soil type and develop a mathematical model.	- Complete Q and I measurements for all collected samples.	- Q-I curve plots for each soil type.
			- Generate Q-I curves for each soil type and depth.	- Preliminary report on phosphorus buffering capacities.
			- Initial model for predicting phosphorus availability.	- Initial model of phosphorus availability.
	Task 3: Phosphorus Buffering Capacity Assessment	Calculate the Phosphorus Buffering Index (PBI) for each soil type based on Q-I curves. Identify the saturation point for each soil.	- Accurate calculation of PBI values for 15 soil types.	- Phosphorus Buffering Index (PBI) table.

			- Identification of critical phosphorus saturation points for each soil type.	- Report on soil-specific phosphorus saturation points.
Year 2	**Task 4: Plot Trials and Phosphorus Application Experiments**	Establish plot-scale studies at research farms with varying soil phosphorus buffering capacities. Apply varying phosphorus fertilization rates (0, 50, 100, 150, 200 kg P/ha) using both broadcast and banded application methods.	- Successful establishment of experimental plots.	- Detailed plot setup and treatment plan.
			- Phosphorus treatments applied across multiple replicates.	- Report on initial crop response to phosphorus treatments.
			- Baseline soil and crop growth data collected.	
	Task 5: Corn Yield Response Analysis	Monitor and record corn growth parameters (biomass, plant height). Collect yield data and assess crop response to varying P rates.	- Data collected on corn growth stages and yield components.	- Year 2 yield-response data report.
			- Initial analysis of yield response under different P rates and application methods.	- Growth parameter dataset for corn.

				- Yield comparison summary for different P treatments.
	Task 6: Soil Phosphorus Dynamics Analysis	Collect post-treatment soil samples and repeat Q-I curve construction to assess changes in phosphorus dynamics. Analyze the impact of phosphorus rates on soil health indicators.	- Completion of post-treatment soil sampling and analysis.	- Year 2 soil phosphorus and health impact report.
			- Development of Q-I curves for post-treatment soils.	- Updated Q-I curves post-phosphorus treatment.
			- Analysis of soil health changes due to P treatments.	- Comprehensive soil health assessment.
Year 3	**Task 7: Yield-Response Modeling and Statistical Analysis**	Develop yield-response models for each soil type using regression analysis. Perform ANOVA to evaluate treatment	- Regression models developed for yield response.	- Yield-response models and equations.
			- Significant treatment effects identified through ANOVA.	- Statistical report on treatment effects.

		effects on soil P availability, crop yield, and soil health.	- Completion of comprehensive statistical analysis.	- Final summary of phosphorus impact on yield and soil health.
	Task 8: Predictive Modeling and Risk Assessment	Utilize Q-I curves and PBI values to develop predictive models for phosphorus loss potential. Conduct multivariate analysis to explore interactions between soil properties, P rates, and phosphorus loss.	- Development of predictive models for P loss.	- Predictive models for phosphorus loss.
			- Identification of high-risk soils prone to phosphorus runoff.	- Risk assessment report identifying high-risk soils.
			- Risk assessment models validated.	
	Task 9: Development of Site-Specific Management Strategies	Use findings from Q-I curves and PBI values to refine site-specific phosphorus management recommendations. Develop guidelines for tailored phosphorus application strategies to minimize environmental impact.	- Customized phosphorus management strategies developed for each soil type.	- Final phosphorus management strategy guidelines.
			- Recommendations validated through stakeholder feedback.	
			- Comprehensive phosphorus management plan for site-specific soils.	- Extension materials and stakeholder outreach report.

BUDGET

A. Salaries and Wages					
Sushant	Mehan	0	0	0	0
Vander Luis	Nunes	0	0	0	0
Hans	Klopp	0	0	0	0
Anthony	Bly	0	0	0	0
Sarah	Sellars	0	0	0	0
Other Personnel		35,074	36,127	37,213	108,414
Total Salaries		**35,074**	**36,127**	**37,213**	108,414
B. Fringe Benefits		351	361	372	1,084
E. Project Travel		12,000	12,000	10,000	34,000
F. Materials and Supplies		10,000	10,000	10,000	30,000
G. Publication Costs		500	500	2,800	3,800
H. Contractual		25,000	25,000	25,000	75,000
Total direct costs		82,925	83,988	85,385	252,298
I. Tuition Remission		9,205	7,977	8,296	25,478
Indirect		0	0	0	0
TOTAL		**92,130**	**91,965**	**93,681**	**277,776**

Budget Justification

Principal Investigator: Sushant Mehan
Project Title: Precise Management of Phosphorus in South Dakota Agricultural Soils
Date: 10/07/2024

Other Personnel Costs – Total Cost $35,074

No salary and benefits are requested for any senior personnel associated with this project.

$24,574 is requested to support one graduate student(s) participating in this project. They will: be assisting in collection of soil samples from designated sites across different Major Land Resource Areas (MLRAs), organizing and managing soil and experiment data, performing statistical analyses.
$10,500 is requested to support two undergraduate student(s) participating in this project. The students will: assist in collection of soil samples ensuring proper sampling protocols from multiple depths 0-3 and 3-6 inches.

Fringe Benefits Costs – Total Cost $351

One percent fringe is calculated for graduate and undergraduate personnel for a total of $351.

Travel Costs – Total Cost $12,000

Domestic Travel:

Name:	PI, Graduate Student, and Undergraduate Student					
Meeting/Purpose	Soil Sample Collection					
Year(s):	1	# Trips:	10	# Days:	10	Totals
Mileage:	5000					
Per Diem:	1200					
Lodging:	4125					
Airfare:	1500	Registration:		1500		
				Total for Meeting:		11,525

Miscellaneous = $475

Other Direct Costs – Total Cost $44,705

- **Materials and Supplies:** $10,000 is requested for the following supplies. Chemical reagents, lab instruments, and cuvettes.

- **Publication/Documentation/Dissemination:** $500 is requested for the publication costs.

- **Contractual/Consultant:** $25,000 is requested for outsourcing some soil sample analysis from Ward Lab in NE, who will assist the PI and Co-PI with the following activities: Soil Health Analysis and other soil tests. There are estimated to be around 100 samples from 15 different sites, and the cost per sample will be $250.

- **Tuition Remission**: $9,205 is requested for one student. Tuition Remission is based on a base tuition rate of $3694 in Year 1, increasing by $200 each year after that, plus a program fee rate set by the South Dakota Board of Regents based on the graduate student's specific program's need.

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APPENDIX A

Table 1. Summary Table of Soil Properties and Phosphorus Buffering Capacity Across Major Land Resource Areas (MLRAs) in South Dakota. The table shows the ranges for soil attributes, including Organic Matter, Carbon Content, Cation Exchange Capacity (CEC), pH, Available Water Capacity, and Drainage Class, categorized by Soil Mapping Units (MUKEY). This classification highlights the variability in soil properties and phosphorus dynamics within each soil type, providing insights for tailored nutrient management strategies.

MUKEY	Area (ac.)	Soil Name	Organic Matter (%)	carbon	Cation Exchange Capacity (CEC)	pH	Available Water Capacity	Drainage Class
353058	90453.7	Agar silt loam, 0 to 2 percent slopes	0.25 - 6.0	0.0 - 10.0	16.2 - 30.0	6.4 - 8.2	0.13 - 0.21	Moderately well drained – Well drained
353083	76506.7	Highmore silt loam, 0 to 2 percent slopes	0.25 - 6.0	0.0 - 14.0	16.2 - 30.0	6.4 - 8.2	0.13 - 0.21	Well drained – Moderately well drained
353105	78395.2	Mobridge silt loam, 0 to 2 percent slopes	0.25 - 6.0	0.0 - 15.0	16.2 - 35.7	6.3 - 8.4	0.13 - 0.23	Moderately well drained – Poorly drained
353287	75455.5	Highmore silt loam, 0 to 2 percent slopes	0.25 - 6.0	0.0 - 14.0	16.2 - 30.0	6.4 - 8.2	0.13 - 0.21	Well drained – Moderately well drained
353797	73253.7	Glenham-Java-Prosper loams, 1 to 6 percent slopes	0.25 - 5.0	0.0 - 20.0	15.0 - 35.7	6.5 - 8.1	0.13 - 0.22	Well drained – Poorly drained
354587	147461	Houdek-Prosper loams, 1 to 6 percent slopes	0.25 - 6.0	0.0 - 25.0	12.5 - 28.0	6.5 - 8.2	0.14 - 0.21	Well drained – Poorly drained
354851	103308	Houdek-Dudley complex, 0 to 2 percent slopes	0.25 - 5.0	0.0 - 20.0	17.1 - 35.7	6.5 - 8.2	0.13 - 0.23	Well drained – Moderately well drained
355020	95073.6	Eakin-Ethan complex, 2 to 6 percent slopes	0.25 - 5.0	0.0 - 20.0	17.1 - 35.7	6.4 - 8.1	0.13 - 0.23	Poorly drained – Moderately well drained
417076	104533	Forman-Buse-Aastad loams, 1 to 6 percent slopes	0.25 - 5.0	0.0 - 25.0	17.1 - 31.8	6.5 - 8.2	0.12 - 0.22	Poorly drained – Moderately well drained
417077	100034	Forman-Buse-Aastad loams, 2 to 9 percent slopes	0.25 - 5.0	0.0 - 25.0	17.1 - 31.8	6.5 - 8.2	0.12 - 0.22	Poorly drained – Very poorly drained
417302	62092.8	Poinsett-Buse-Waubay complex,	0.25 - 6.0	0.0 - 25.0	13.0 - 27.0	6.4 - 8.2	0.12 - 0.22	Well drained –

		1 to 6 percent slopes						Very poorly drained
417503	74449.2	Poinsett-Buse-Waubay complex, 1 to 6 percent slopes	0.25 - 6.0	0.0 - 25.0	13.0 - 27.0	6.4 - 8.2	0.12 - 0.22	Well drained – Very poorly drained
417685	65410.6	Barnes-Buse-Svea loams, 1 to 6 percent slopes	0.25 - 5.0	0.0 - 25.0	17.1 - 31.8	6.5 - 8.2	0.12 - 0.22	Somewhat poorly drained – Moderately well drained
417943	239907	Clarno-Bonilla loams, 0 to 2 percent slopes	0.25 - 5.0	0.0 - 23.0	11.5 - 31.8	6.5 - 8.2	0.13 - 0.23	Well drained – Somewhat poorly drained
2862749	95409.6	Houdek-Prosper loams, 0 to 2 percent slopes	0.25 - 6.0	0.0 - 20.0	17.1 - 28.0	6.5 - 8.2	0.14 - 0.21	Well drained – Poorly drained

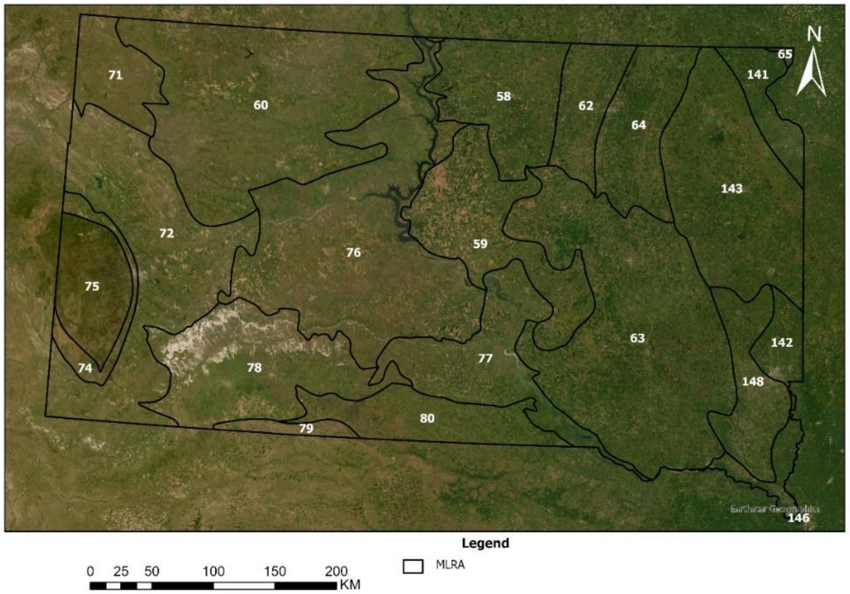

Figure 1: Map of Major Land Resource Areas (MLRAs) in South Dakota showing distinct regions classified by their geographical and soil characteristics. Each numbered MLRA boundary delineates unique land resource units used for land-use planning, agricultural management, and environmental assessment. The map provides a spatial overview of different soil types and resource management units critical for soil nutrient management and sustainable agricultural practices.

APPENDIX B

Research Objective: The primary objective of this plot-scale study is to evaluate the influence of phosphorus (P) buffering capacity on corn yield response under varying phosphorus fertilization rates. By understanding how soils with different buffering capacities respond to phosphorus additions, we aim to optimize fertilizer application strategies for sustainable crop production and mitigate potential environmental impacts.

Experimental Design

Study Site Selection

(a) Location: Representative agricultural plots will be identified at northeastern and southeast research farms with varying phosphorus buffering capacities.
(b) We will characterize each plot's soil properties, including:
  a. Soil texture (sand, silt, and clay composition)
  b. Organic matter (OM) content
  c. Soil pH and cation & anion exchange capacity (CEC & AEC)
  d. Baseline soil phosphorus levels using standard soil tests (e.g., Olsen-P, Bray P, Mehlich-3 P)
(c) Plot Design: Each study site will be divided into multiple plots (replications) with randomized complete block design (RCBD) to minimize spatial variability.

Phosphorus Treatment Application

Phosphorus Fertilization Rates: Apply varying phosphorus (P) fertilization rates (40, 80, 120, 140, and 160 kg P/ha) across the plots using broadcast and banded application methods. Rates will be determined based on soil test recommendations and adjusted to test P saturation limits for each soil type.

Application Timing: Phosphorus applications will be timed according to corn growth stages (e.g., at planting, V4, and V6 stages) to evaluate the effect of application timing on P availability and corn growth. During the experiments, nitrogen, potassium, and micronutrients will be ensured that they are not limited.

Data Collection and Analysis

(a) Collect soil samples at multiple depths (e.g., 0-3, 3-6, and 6-9 inches) before and after phosphorus applications to track changes in soil P content. Measure phosphorus in soil using multiple extraction methods: Olsen-P, Bray P, and Mehlich-3 P.
(b) Record corn growth parameters at key developmental stages (e.g., root length, plant height, biomass accumulation). Assess corn yield at harvest.
(c) Use standard soil tests (Olsen-P, Bray P, Mehlich-3 P, DGT) to determine phosphorus quantity (Q) in the soil. Measure phosphorus concentration in the soil solution to represent phosphorus intensity (I). Plot phosphorus quantity (mg P/kg soil) against intensity (mg P/L soil solution) for each soil type and treatment. Use the Q-I curve to

identify the phosphorus buffering capacity and calculate each soil's phosphorus buffering index (PBI).

(d) Evaluate the corn yield response to phosphorus applications across different plots. Regression analysis will be used to determine relationships between phosphorus buffering capacity (from Q-I curves), applied phosphorus rate, and yield response.
(e) Develop yield-response models for each soil type to establish optimal phosphorus application rates for maximizing corn yield. Compare response models between plots with different soil buffering capacities.

Statistical Analysis:

(a) Perform Analysis of Variance (ANOVA) to evaluate treatment effects (P rate, application method, timing) on soil phosphorus availability, corn growth parameters, and yield.
(b) Regression models will be used to correlate phosphorus buffering capacity with corn yield response.
(c) Develop predictive models to estimate phosphorus availability based on soil P levels and buffering capacity.
(d) Conduct multivariate analysis to explore the interaction of soil properties (e.g., pH, OM, texture) and phosphorus dynamics.
(e) Quantify the impact of different phosphorus rates on soil health indicators (e.g., microbial biomass, water-extractable phosphorus).
(f) Use Q-I curves and soil phosphorus saturation points to develop models predicting phosphorus loss potential under different management scenarios (broadcast vs. banded in a no-till system).