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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:	Breeding for improved nitrogen use efficiency (NUE) in South Dakota winter wheat under regenerative agriculture management
Application ID:	3451
Submission Date:	10/14/2024 12:37 PM

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Co-Applicant(s)

Name	Email	Affiliation
No Co-Investigator(s)		

Application Details

Proposal Title

Breeding for improved nitrogen use efficiency (NUE) in South Dakota winter wheat under regenerative agriculture management

Proposal Abstract

Wheat yield improvements result from both variety selection and adoption of improved management practices. However, yield response to improved management practices can be variety-specific. A global analysis estimated low nitrogen use efficiency (NUE) in cereal crops, with only ~40% of applied N being taken up by the crop plants (Omara et al 2019, Raun et al, 1999, 2002). The rest of the applied N is lost to the environment, which increases production costs and is also associated with the degradation of aquatic and terrestrial ecosystems (Nguyen et al., 2019). Because of changing climatic conditions, farming systems should strive to be more sustainable and socially and environmentally responsible while maintaining economic profitability. The SDSU winter wheat breeding program is the only wheat breeding program in the nation that develops new wheat varieties under a 100 % no-till system working closely with producers through thousands of on-farm trials. Winter wheat varieties with increased nitrogen response and NUE could help growers reduce input costs related to nitrogen fertilizers and adverse environmental impacts. Winter wheat growers in the state have shown specific interest (at field days) in winter wheat varieties with improved NUE. However, no information about variety-specific NUE is currently available in South Dakota (SD). Therefore, breeding for winter wheat varieties that efficiently capture and utilize available soil nitrogen into the grain as protein content could be a key step in sustainably fighting the adverse effects of N loss and potentially making wheat more profitable for growers. Genetic dissection of NUE is very challenging because of the complex nature of the genetic factors and their environmental interactions. Previous studies conducted under a range of N conditions in different countries have established that significant genetic variation exists for NUE-related traits in wheat (Brasier et al., 2020). Even though the extent of genetic improvement varied by study, a general agreement among the previous studies was that direct selection under different N rates will accelerate genetic gains in NUE. It is very unlikely that a major gene controls NUE, rather a discovery of small to moderate effect genes or QTLs (Quantitative Trait Loci) will lead researchers closer to the final understanding of the complex nature of NUE (Monostori et al., 2017). Therefore, it is imperative to investigate NUE with diverse genetic materials and various environmental conditions (SD environments) to discover the QTLs responsible for NUE and then deploy these QTLs using modern techniques like genomic selection (GS) in the SDSU wheat breeding program. Keeping these views in mind, we propose to continue our research trials during the 2025 field on the variety-specific nitrogen use efficiency and examine the genetic variation in NUE of winter wheat varieties and advanced breeding lines adapted to South Dakota and the region. Results from the trials will identify lines with better NUE among currently available lines, and new wheat varieties with improved NUE for South Dakota and the region will be released for production. In 2022 and 2023 'SD Pheasant' a new hard red winter wheat variety from SDSU showed good NUE has been released for production.

2025 Total Budget Request

79,977

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.

2025 South Dakota Nutrient Research and Education Council (NREC)

Title: *Breeding for improved nitrogen use efficiency (NUE) in South Dakota winter wheat under regenerative agriculture management* (Locations: Winner, DLRF Pierre, and Brookings) Year 4

PI: Dr. Sunish Sehgal (Associate Professor and Winter Wheat Breeder) Department of Agronomy, Horticulture and Plant Science, SDSU, Brookings 57007, Email: sunish.sehgal@sdstate.edu, Phone: (605) 688-5709

Co-PI(s): Maitiniyazi Maimaitijiang (Assistant Professor, Department of Geography & Geospatial Sciences), SDSU Brookings 57007

A. Summary:

Wheat yield improvements result from both variety selection and adoption of improved management practices. However, yield response to improved management practices can be variety-specific. A global analysis estimated low nitrogen use efficiency (NUE) in cereal crops, with only ~40% of applied N being taken up by the crop plants (Omara et al 2019, Raun et al, 1999, 2002). The rest of the applied N is lost to the environment, which increases production costs and is also associated with the degradation of aquatic and terrestrial ecosystems (Nguyen et al., 2019). Because of changing climatic conditions, farming systems should strive to be more sustainable and socially and environmentally responsible while maintaining economic profitability. The SDSU winter wheat breeding program is the only wheat breeding program in the nation that develops new wheat varieties under a 100 % no-till system working closely with producers through thousands of on-farm trials. Winter wheat varieties with increased nitrogen response and NUE could help growers reduce input costs related to nitrogen fertilizers and adverse environmental impacts. Winter wheat growers in the state have shown specific interest (at field days) in winter wheat varieties with improved NUE. However, no information about variety-specific NUE is currently available in South Dakota (SD). Therefore, breeding for winter wheat varieties that efficiently capture and utilize available soil nitrogen into the grain as protein content could be a key step in sustainably fighting the adverse effects of N loss and potentially making wheat more profitable for growers. Genetic dissection of NUE is very challenging because of the complex nature of the genetic factors and their environmental interactions. Previous studies conducted under a range of N conditions in different countries have established that significant genetic variation exists for NUE-related traits in wheat (Brasier et al., 2020). Even though the extent of genetic improvement varied by study, a general agreement among the previous studies was that direct selection under different N rates will accelerate genetic gains in NUE. It is very unlikely that a major gene controls NUE, rather a discovery of small to moderate effect genes or QTLs (Quantitative Trait Loci) will lead researchers closer to the final understanding of the complex nature of NUE (Monostori et al., 2017). Therefore, it is imperative to investigate NUE with diverse genetic materials and various environmental conditions (SD environments) to discover the QTLs responsible for NUE and then deploy these QTLs using modern techniques like genomic selection (GS) in the SDSU wheat breeding program. *Keeping these views in mind, we propose to continue our research trials during the 2025 field on the variety-specific nitrogen use efficiency and examine the genetic variation in NUE of winter wheat varieties and advanced breeding lines adapted to South Dakota and the region. Results from the trials will identify lines with better NUE among currently available lines, and new wheat varieties with improved NUE for South Dakota and the region will be released for production. In 2022 and 2023 'SD Pheasant' a new hard red winter wheat variety from SDSU showed good NUE has been released for production.*

Goal and Objectives:
The primary goal of this project is to develop winter wheat varieties with improved NUE through the characterization and selection of genetic factors affecting this complex trait under regenerative management practices. The specific objectives of the project are as follows:
Objective 1: To evaluate the effectiveness of different nitrogen application rates on winter wheat genotypes (common varieties and advanced breeding lines) under a no-till system and its effect on grain yield and protein content and identify lines with superior NUE. These trials will be conducted in Winner, Pierre, and Brookings, SD.
Objective 2. Identification of quantitative trait loci (QTLs) and evaluation of genomic selection models for breeding hard winter wheat varieties with improved NUE. This trial is very complex and large therefore it will be conducted at Brookings, SD.

Justification Statement:
Wheat is the third most important crop and the most important food crop of South Dakota, grown on about 1.6 million acres. Winter wheat alone is grown on 860,000 acres in the state and is a major fall-sown crop that provides several advantages to growers including increased yield, fall cover, use of fall moisture, and minimizing soil erosion. Over the last 20 years, we have developed new wheat varieties under a 100% no-till system working closely with producers through on-farm trials, and now South Dakota winter wheat growers are interested in wheat varieties with improved NUE, which can reduce N fertilizer application rates for sustainable and environment-friendly agriculture while maintaining crop yields. The current recommendation for N in SD is 2.5 lbs N/ bushel (Gelderman et al 2012), therefore we need to investigate if current wheat varieties can retain yield and quality at a lower N rate and develop more efficient wheat varieties. The goals of the project directly align with the mission of the NREC which is to increase the efficacy of fertilizers under a no-till system and minimize nutrient loss by developing efficient variety with modern genetic strategies. Most of the previous improvement has come through indirect selection for yield, in environments targeted by breeding programs (Cormier et al 2016), however, the current rate of NUE is far behind the target (Omara et al 2019) and there seems to be consensus on the need to increase NUE. Under this project, winter wheat breeding lines/varieties with better NUE in a no-till system are expected to be identified. QTL(s) with considerable effect on NUE will be identified and bred into the South Dakota wheat germplasm through genome-wide selection. The outcomes of this project include the identification of lines with better NUE, the development, and release of new varieties with higher NUE to benefit winter wheat growers across the state, optimized N fertilizer application rates to minimize the loss of applied fertilizer (e.g. by leaching) by understanding variety x fertilizer rate interaction, and maximized N uptake by increasing grain protein concentration. The outcome of this project would be highly beneficial for the winter wheat growers across the state.

Work Plan:
Objective 1: Evaluate the effectiveness of different nitrogen application rates on winter wheat genotypes (common varieties and advanced breeding lines) under a no-till system and its effect on grain yield and protein content and identify lines with superior NUE. These trials will be conducted in Winner, Pierre, and Brookings, SD.

Year 4: In continuation of trials, replicated field trials will be conducted in the 2024-25 field season to evaluate the variety-specific response of 12 released winter wheat varieties or breeding lines to different levels of nitrogen. The 2025 trials have already been planted (September 2024) at three locations (Winner, Pierre, and Brookings) in SD as suggested by the reviewers. The trials are conducted in 20’

long and 5' wide 7-row plots (7.5-inch row spacing) in three replications using a randomized complete block design. All entries are planted at a seed rate 28 seeds/sq.ft (1.2 million seeds/acre). All lines receive a starter of 10 gallons of 10:34:0 (N:P:K) at the seeding stage (fall). In the spring season, N will be applied as four N treatments (UAN 28%: 0, 50, 100, 150 lbs N) taking into account the pre-plant soil N. A standard base application of S (20 lbs/acre) will be applied to eliminate any effect of sulfur in the trials. The treatment plots will have two buffer plots on either side (left and right) of each N rate treatment. Soil samples will be collected from all the trials in the fall to know the pre-plant soil N quantity and then again in spring (1 month after N application) and after harvest to estimate the amount of N utilized. Multispectral sensors will be used to monitor the growth of wheat. The heading date of lines will be recorded, and the trial plots will be sprayed with 'Prosaro' at flowering to minimize the effect of foliar and head diseases. Plant height and lodging data will be recorded, and the plots will be harvested at maturity to calculate grain yield, grain protein content, grain protein deviation, and test weight. Data for these traits for each line will be compared to estimate the N treatments and genotype effects, and genotypic-specific NUE (yield/N applied) will be determined (Moll et al. 1982). The pre-plant N will be factored in to calculate NUE (Moll et al. 1982). The grain samples will also be subjected to grain quality analysis including milling efficiency, flour protein, ash, wet and dry gluten content, and mixograph analysis. The line(s) demonstrating better NUE will be advanced to the next stages in the breeding program and a new set of advanced breeding lines will be added to the trials in consecutive years.

Objective 2. Identification of quantitative trait loci (QTLs) and evaluation of genomic selection models for breeding hard winter wheat varieties with improved NUE. This trial is very complex and large therefore it will be conducted at Felt farm and Aurora farm near Brookings, SD.

We aim to detect stable and significant marker-trait associations (MTAs) for NUE and N-related traits and implement genome-wide selection (GS) models. A panel of ~260 varieties, advanced breeding lines and germplasm (Training Set) have been planted for the 2025 field season. Each genotype will be planted in small 4-row plots (6'x 5') in two replicates, two N levels (no and high N rate). Data for agronomically important traits like grain yield, grain protein content, grain protein deviation (GPD), test weight, N input-related traits (N-Uptake Efficiency and N-Utilizing Efficiency traits), and spectral reflectance indices (SRI) will be collected at two N input levels (0, 120 lbs. of N/acre). The difference in genotype response to N will be evaluated by ANOVA using mixed linear models in R environment. All the lines will be genotyped using genotyping by sequencing (Poland et al. 2012), and high-density single-nucleotide polymorphism (SNP) marker data will be used to identify potential marker-trait associations by genome-wide association study (GWAS). Further, the training set of advanced breeding lines will be used to evaluate GS models (univariate and multivariate models) and predict the NUE of breeding lines in preliminary yield trials using BGLR package (Pérez and De Los Campos, 2014) and MTM package (de los Campos and Grüneberg, 2016) in R environment. We have previously developed prediction models (Gill et al. 2021) for grain yield, grain protein, and test weight. A set of 5 lines with high NUE and 5 with low NUE selected based on genome-wide prediction will be field validated in year 5.

Outreach: The information generated from the trials will be shared with producers through field days, field inspector schools, professional meetings, extension publications, scientific peer-reviewed journals, etc. Wheat growers across the state will benefit from the outcome of the study. In addition, the outcome

will provide a basis for discussion among researchers, extension educators, product distributors, and others in the farming community.

Potential Outcome and Impacts: Our project outcome will help in identifying varieties or breeding lines that have a better NUE. These varieties will be made available to SD wheat producers along with an optimized nitrogen (N) fertilizer rate. Further, the project will facilitate the development of new improved winter wheat varieties with higher NUE and yield while maintaining the protein content and end-use quality under a no-till management system. It will also facilitate the genetic characterization of NUE traits. Overall, the project will help in enhancing agricultural sustainability by minimizing nutrient loss and enhancing soil health. Later on, similar work could be extended on spring wheat to provide useful information and NUE varieties to the SD producers.

B. Timeline:

Objectives	**2025**	
	1st half	**2nd half**
1. Genotype-specific NUE study	√	√
2. Identify QTL(s) related to NUE and related traits and development of genomic selection models for NUE-related traits	√	√
Publications		√
Project reports		√

C. Project Budget:

Funds of $79,977/year are requested for 2025, for one Ph.D. graduate student salary, research associate salary (.50 FTE), material supplies and travel to trial locations, and grain quality analysis requested for three consecutive years.

D. Short Budget Justification

Graduate Student	26,219	Ph.D. student 49.0% of the time for a year
Research Associate	21,000	0.5 FTE for the RA/ technician for working on the proposal objectives including planting, management, and harvesting of the trials at multiple locations.
Undergraduate Student	4,560	Help with harvesting and processing of grain samples
Fringe Benefits	9,629	15% fringe plus health insurance prorated to percent time for full-time employees and 1% for Graduates and Undergraduates.
Project Travel	5,507	At least 6 trips are taken to the trial locations Winner and Dakota Lakes for planting, fertilizer application, herbicide application, heading notes, disease notes, harvest, etc.
Materials and Supplies	3,000	Field supplies: Fertilizers, stakes, pesticides, fungicides, parts for tractor, planter, combine. Lab supplies including chemicals and materials for grain quality analysis, DNA isolation, genotyping.
Contractual	2,000	Land and greenhouse rent (make crosses with superior lines and generation advancement)
Total direct costs	71915	
Tuition Remission	8,062	Tuition/remission for graduate student
TOTAL	**79,977**	**Grand Total**

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