FOR ADMINISTRATIVE USE
Program Area Code   Proposal Code

Minnesota Wheat Research and Promotion Council

RESEARCH PROPOSAL GRANT APPLICATION

1. NAME AND ADDRESS OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE

Name: Regents of the University of Minnesota
Address: Sponsored Projects Administration
450 McNamara Alumni Center, 200 Oak Street SE, Minneapolis, MN 55455-2070

2. TITLE OF PROPOSAL
A Novel High-Throughput Phenotyping Pipeline to Deliver More Productive and Stress Resilient Minnesota Wheat Varieties

3. PRINCIPAL INVESTIGATOR(S)	**4. PI #1 BUSINESS ADDRESS**
PI# 1 Name: Walid Sadok	Department of Agronomy and Plant Genetics 411 Borlaug Hall 1991 Upper Buford Circle St. Paul, MN 55108
PI# 2 Name: Daniel M. Monnens	
PI# 3 Name: James A. Anderson	

5. PROPOSED PROJECT DATES	**6. TOTAL PROJECT COST**	**7. PI #1 PHONE NO.**
January 1, 2022 – December 31, 2022 Note: Research Reports are Due November 15th of Each Year	$48,185	612-625-8291

8. RESEARCH OBJECTIVES: (List objectives to be accomplished by research grant)

Our main goal is to develop a new remote-sensing technology to help wheat breeders rapidly and cheaply identify superior breeding lines that are equipped with high-performing, high-yielding canopies. This technology aims at saving time and resources by rapidly capturing canopy thermal signatures, using unmanned aerial vehicles (UAVs) equipped with infrared (thermal) and RGB cameras, ground-truthing sensors, sophisticated algorithms and high-performance computer processing. We have successfully deployed this technology during the first year on a preliminary yield trial consisting of over 500 breeding lines and were able -using this technology- to identify superior breeding lines that exhibited better yields under the droughty conditions of last summer.

Our specific goals for this year are to i) finalize our image processing pipeline and ii) replicate the field-based experiment in a second year. We expect this new development to lead to suite of fully validated protocol and algorithms along with the identification of superior breeding germplasm to support the U of M wheat breeding program.

Signature Of Principal Investigator	**Date**	**Phone Number**
	1/8/2022	612-625-8291
Signature Of Authorized Representative	**Title**	**Date**
	Associate Director	1/11/22

Address Of Authorized Representative	**Phone Number**
Amy Rollinger, Office of Sponsored Projects Administration 450 McNamara Alumni Center, 200 Oak Street SE, Minneapolis, MN 55455-2070	612-624-2038

Minnesota Wheat Research and Promotion Council
RESEARCH PROJECT PROPOSAL
(2-pages maximum)

Abstract

We are developing a new technology, based on remote-sensing of canopy thermal signatures, that could make it possible for wheat breeders to rapidly and cheaply identify superior breeding lines that are equipped with high-performing, high-yielding canopies. This novel pipeline relies on unmanned aerial vehicles (UAVs) equipped with thermal and RGB cameras, ground-truthing sensors, sophisticated algorithms and high-performance computer processing. In our first year, we deployed this technology on a preliminary yield trial comprising over 500 breeding lines. While data analysis is still ongoing, our preliminary results point to a promising potential of this technology, by enabling us to identify superior lines that ended up exhibiting better yields under the droughty conditions of last summer. Our goal for this proposal is to confirm these findings in a second year and finalize the pipeline. The development of this new technology will directly support the U of M wheat breeding program and, as a result, help farmers benefit from more productive and stress-resilient Minnesota-adapted wheat.

Describe the background for your proposed project and the importance of this project to the profitability of wheat production in MN

Maintaining wheat canopy health under variable field conditions is critical to stabilizing or improving wheat yields. This is because by capturing light, nitrogen and other nutrient resources from the roots, wheat canopies are the engine that fuels reproductive growth and therefore grain yields. While a highly productive and healthy canopy is a very desirable trait for a breeder, such canopies are nearly impossible to detect with the naked eye, which is not equipped to detect certain wavelengths that varieties emit when they are under-performing or stressed. For a breeding program, this challenge has to be addressed to enable rapid screening of hundreds if not thousands of breeding lines. To tackle this problem, in the first year, we started developing a drone-based remote-sensing technology that is based on thermal imaging which is being tested to support the U of M wheat breeding program. This method differentiates between productive and underperforming canopies based on their thermal 'signatures'.

While there are existing drone-based approaches to monitor crops, our method is unique as it relies on advanced thermal imaging technology coupled with energy balance modeling, and is informed by physiology-based ground truthing techniques. This combination ensures that differences in thermal images among genotypes actually captures differences in cultivar physiology rather than differences due to weather changes. This distinction is critical because traits that are 'masked' by the environment have low heritability and are more difficult to genetically improve.

In the first year, we tested and deployed our technology on a population of 508 breeding lines that are part of the U of M wheat Preliminary Yield Trials (PYT), an experiment that is 40% larger than the initially planned trial (360 lines). This experiment enabled us to identify a group of 80 promising breeding lines that out-yielded the best performing check by up to 16 bu/a. Furthermore, our preliminary findings indicate that our thermal sensing technology was able to capture differences in canopy temperature under the hot/dry St Paul summer season of 2021, suggesting that our technique could help breeders explain genetic differences and help choose lines for advancement and use as parents in new crosses. For instance, we identified potentially superior genotypes that were able to cool their canopies under high temperature stress, by maintaining water loss by transpiration, while other lines did not express this trait and ended up exposing their canopies to heat stress. One of the best performances in this preliminary trial was exhibited by MN-Washburn, which canopy was up to 9°F cooler than MN-Torgy, and which outyielded MN-Torgy by about 6 bu/A, (a 11-12% increase). This does not mean that MN-Torgy is a substandard variety, but rather, that under these specific droughty conditions in St Paul, MN-Washburn performed better last year--and that more replication is needed.

A challenge, however, was that our expert in thermal imaging leading the project was offered a position to join a company and left the project in the early phases of the trial, which considerably slowed down the data analytics pipeline. We were lucky to find a replacement in Daniel Monnens (co-PI), who was able to conduct flights in a timely manner, and who is currently analyzing a substantive amount of data using high-performance computing and sophisticated algorithms. Building on such promising findings, our goal for the incoming year is to i) finalize the automated extraction of thermal images and their correction using environmental and physiological data, ii) improve the overall protocol, and iii) identify promising genotypes based on a replication of the trial this second year.

Research methods

Field experiment: The experimental design will be an augmented incomplete block design with 4 checks in each block (14 blocks). A total of 512 genotypes including 4 checks will be planted in (4.5 ft x 8 ft) yield plots at the U of M St Paul campus. After planting, aerial thermal images will be collected weekly with a thermal camera (Vue Pro R 640) mounted on an unmanned aerial system (UAS; Inspire 2, DJI) using a specialized gimbal. Flights will always take place on sunny days around solar noon, i.e., between 13:00 and 13:30 hours. Along with the thermal images, RGB (Red-Green-Blue) images will be collected using the drone RGB camera and gimbal (Zenmuse X5S, DJI). These RGB images are needed to align with the thermal images to differentiate soil from crop temperature and estimate the change in canopy cover over time, and to obtain an estimation of plant height. To ensure that the remote-sensing approach effectively captures canopy temperature, we will also deploy ground-truthing temperature sensors (thermocouples) to be installed physically on plants during flag leaf appearance so that we have an estimate of temperature as experienced by the plants.

Image & data analysis: will be performed to extract reliable temperature signatures from images after correction based on flight conditions and canopy growth dynamics and these will be studied in relation to the plant's genetic make-up, physiological status and yield performance. It will be based on a two-step approach, with the first one consisting in finalizing the analytics pipeline of the first year (Jan-Feb 2022) and the second one based on both years, which will end on December 2022. At the end of this campaign, our expectation is that the data analysis pipeline will be completed and much faster moving forward, as all the algorithms & protocol will be validated.

Timeline for completion

January-February 2022: Finalizing the first draft of the data analytics pipeline. March-April 2022: Equipment testing and calibration, planting. May-August 2022: Drone flying, data acquisition, harvest. September-December 2022: Final data analysis and reporting.

Outreach plan

We hope to disseminate our findings to growers at the winter Prairie Grains Conference in 2022. We will also communicate updates on our research online on the U of M extension portal and also through ad hoc meetings and field days to growers and other agriculture professionals. Our results will be disseminated more broadly to the scientific community through presentations in major conferences such as the Crop Science Society of America meetings. We expect this research will generate publishable results targeting scientific journals with a large and diverse readership such as Crop Science.

List other current or pending funding sources for this project:

Justification: Salary (75% Researcher) $37,440 and fringe benefits (28.7%) $10,745 totaling $48,185 for researcher to assist carrying out scope of work for project.

Anderson and Sadok have received funding for a graduate student from USDA-NIFA. This funding will support a graduate student who will start in the fall of 2022 or spring of 2023. The student is expected to participate and further support this UAV-based remote-sensing, which should enable us to deploy our technology on a larger number of trials.

Research group (other collaborators not listed as PIs):

The research group consists of co-PIs whose name is already listed.

Relationship to past projects and research conducted by you or others in the region:

This research builds directly on a successful project previously funded by the MWR&PC. The goal of that project was to identify the genetic basis of canopy conductance on wheat, an important trait that directly drives yield performance, but which can only be reliably measured under controlled environment conditions. We successfully identified the genetic basis of canopy conductance and we used genotypes having 'lazy' and 'hardworking' versions of canopy conductance genes to develop the current, field-based remote-sensing method. We were able to find that genotypes with high conductance (having the 'hardworking' version of the conductance genes) actually have cooler canopies in the field, consistent with the biophysics of canopy transpiration. Thus, we were able to extend our ability to identify superior canopies without the need of relying on controlled environment research, which will make our method more readily useable in wheat breeders' fields across the region and beyond.

Minnesota Wheat Research and Promotion Council

RESEARCH PROJECT PROPOSAL BUDGET

Project Title: A Novel High-Throughput Phenotyping Pipeline to Deliver More Productive and Stress Resilient Minnesota Wheat Varieties

Principal Investigator(s) / Project Director(s) Walid Sadok, Daniel M Monnens, James A Anderson	Funds Requested For Year 1 (2022)	 Year 2 (2023)	 Year 3 (2024)
A. Salaries and Wages	$	$	$
1. Co-principal Investigator(s)			
2. Senior Associates			
3. Research Associates – Post Doctorate			
4. Other Professionals	37,440		
5. Graduate Students			
6. Prebaccalaureate Students			
7. Secretarial - Clerical			
8. Technical, Shop and Other			
B. Fringe Benefits	10,745		
C. Consulting and Professional Services			
D. Supplies and Services			
E. Travel			
F. Sub-Contracts			
G. Repairs & Maintenance			
H. Rentals & Lease			
I. Other Expenses			
TOTAL AMOUNT OF THIS REQUEST (per year)	**$48,185**	**$**	**$**