Wheat SOW for National Predictive Modeling Tool Initiative (NPMTI)

Establishing the infrastructure to develop predictive tools for wheat diseases and support grower management decisions

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Background. Wheat in the United States is affected by many types of foliar diseases. These foliar diseases limit the productivity and quality of the wheat crop in the United States every year, with total losses exceeding $200 million in lost revenue for key wheat producing regions (6,7). The magnitude of the disease-related losses within a state or wheat producing region vary annually and are strongly influenced by environmental conditions (weather and cropping system factors such as tillage and crop rotation) that favor the survival, reproduction, and movement of pathogens within and across fields or regions. Yield losses are further influenced by the genetic susceptibility of wheat varieties grown regionally, the timing of disease onset relative to crop growth, and on whether pesticides are applied and applied correctly. *Identifying risk factors related to the presence and abundance of inoculum, host susceptibility, favorable weather conditions, and quantifying their relationship of these factors with disease development will help farmers better manage disease, avoid unnecessary pesticide applications and avoid yield losses.*

Rust diseases of wheat are among the most widespread and damaging diseases in North America (1,4). Although, these rust fungi do not survive in crop residues, they readily persist as mycelia in winter wheat seedings during the adverse temperature extremes of the winter and under snow cover. In spring, the rust become established in wheat fields near these overwintering sites and is dispersed throughout a wheat producing region. The timing of inoculum movement influences the risk of severe disease, with the highest risk of epidemics correlated with dispersal events that occur between jointing and flowering stages of wheat growth (2,3). Once established within a region, temperature, moisture, and resistance gene profiles in the landscape generally govern local disease development. Each rust disease has a unique temperature range that favors its development. For example, stripe rust is favored by temperatures between 7–12 C and extended periods of high relative humidity (>6 h) (5). These periods of high relative humidity are highly correlated with both dew and frequent rainfall events that favor infection and pathogen reproduction. Similar processes influence the development of leaf rust and stem rust.

Preliminary analyses indicate that predictive models of rust diseases are most robust when they account for potential overwintering of rust, disease development in source regions, and subsequent development throughout a wheat producing region (5,7). Interestingly, these initial models did not directly account for inoculum movement. Incorporating this information to predictive models could greatly enhance model accuracy.

Of course, these rust diseases are not the only threat to wheat production. Parastagonospora leaf blotch (*Parastagonospora nodorum*) also effects wheat in many parts of the country. This residue-borne fungus is dispersed via rain-splashed pycnidospores or wind-blown ascospores. The disease becomes established on

seedling plants in the fall or early spring and is spread within crop canopy. The leaf blotch causes significant yield losses (> 40%) when the disease becomes established on the upper leaves of wheat prior to flowering and during the early stages of grain development.

Epidemics of Parastagonospora leaf blotch are often associated with frequent rainfall events that favor pathogen dispersal and stimulate the moisture events that favor infection processes (3). Much like the rust diseases, previous efforts to predict leaf blotch focus on infection events and assume the pathogen is already present. These assumptions often lead to overestimates of disease risk and a better understanding of factors influencing pathogen survival and inoculum movement could improve predictions of disease.

Objectives. Additional information about the role of environment in pathogen survival, movement of inoculum, and disease develop is essential to the development of robust predictive models of rust diseases and Parastagonospora leaf blotch. Therefore, the first year of the wheat Predictive Model Tool Initiative will focus on the following objectives: *1) Develop a database of historical disease epidemics in the U.S that will serve as a foundation for the modeling effort; 2) Quantify the relationships among pathogen inoculum density, disease development, and weather in small plot trials; and 3) Quantify the relationships among pathogen inoculum, disease development, and weather in commercial fields.*

Rationale. The proposed research will lead to the development of predictive models and tools that will help wheat growers evaluate the risk of disease. As growers learn to use these tools, they will maximize the efficacy of management decisions, reduce disease-related yield losses, and help ensure that U.S. wheat production remains a viable economic crop in the U.S. Experience with forecasting other diseases of wheat indicates that growers quickly learn to use information provided to decide if and when fungicide applications are needed to suppress disease development. These fungicide decision support tools will help inform fungicide applications to suppress disease-related yield loss when the risk of disease is high, but also help growers avoid unnecessary fungicide applications when risk of disease is low. The judicial use of fungicides reduces input costs for wheat farmers, delays the development of fungicide resistance, and lowers potentially negative impacts of pesticides on our natural resources.

Objective 1. *Develop a database of historical disease epidemics in the U.S that will serve as a foundation for the modeling effort*. The cooperators in the wheat NPMTI will identify and compile best-available historical records of cereal rust and leaf blotch epidemics at the state and regional levels. This effort includes interviews with wheat disease experts in each state to gather eyewitness accounts of epidemics in addition to gathering records of site-specific observations from replicated wheat variety evaluations, and fungicide efficacy experiments that could also provide valuable information.

The disease observations will be coupled with weather and cropping system data. Weather information will include ground-based weather stations maintained by NOAA and universities as well as georeferenced weather products that adjust for elevation, terrain, and vegetation cover (ex. PRISM, Oregon State University). This combination of weather observations provides both the site-specific weather needed for model development and the spatially gridded weather products that facilitate model testing and application. All weather observations will undergo a rigorous quality assessment/evaluation process.

Project cooperators will use the resulting database to establish hypotheses about the biological processes driving disease epidemics based on research literature and the experience of regional wheat disease experts. We will also develop preliminary models of disease risk based on historical observations of epidemics. The

process of model development will include variable selection facilitated by correlation analysis, boosted classification regression trees, random forests, and principal component analysis. The most useful variables will be used to develop preliminary models using linear regression, logistic regression, and machine learning analytical approaches. These models will become the foundation of the wheat predictive effort. The observations collected in replicated research plots and commercial fields will be used to evaluate model performance before public deployment (see objectives 2 and 3 below).

The wheat NPMTI team will also work with the project cooperators at the Los Alamos National Labs to develop web-based tools supporting the application and delivery of the preliminary predictive disease models. These collaborations will help move the NPMTI toward tangible products for wheat producers and establish important impact for the initiative.

Objective 2a. Quantify associations among pathogen inoculum density, disease development, and weather variables in small plot trials.

Residue-borne diseases: The objective of this study is to quantify associations among crop residue cover, airborne inoculum density, weather, and the onset and intensity of wheat diseases caused by residue-borne pathogens. **The first years of the project will focus on *Parastagonospora nodorum.*** In the future, the NPMTI wheat team will expand its focus to consider *Zymoseptoria tritici*, *Pyrenophora tritici-repentis*, and *Blumeria graminis* f. sp. *tritici.*

Residue treatments: The experiment will be established on a research farm identified by the Principal Investigator (PI), either in a **no-tilled wheat field (field-type 1) or in a field previously planted to a non-host crop (field-type 2).** In the selected field, **a minimum of two and a maximum of four residue blocks will be established, with estimated wheat surface residue cover of <20 and > 80% (if two levels); <20, 50-60, and >80% (if three levels); or <20, 40, 60, and >80% (if four levels)**. In the no-tilled fields, residue blocks will be established by employing different types or levels of tillage and crop rotation, whereas for trials being established in a field following a non-host crop, residue treatment will be established by spreading different amounts of previously baled wheat straw from fields with disease incidence in the previous season, to accomplish the desired levels of surface cover. To minimize interplot interference, each residue block will be planted in a separate field on the same farm or in separate sections of the same field (see **Fig. 1** for example plot and block dimensions and possible layouts).

Small plots within residue blocks: In each residue block, 2 to 4 plots will be planted, depending on the number and combination of diseases being investigated (**Table 1**). For instance, for **option 1** (with a single disease), 2 plots of the same susceptible cultivar will be planted on separate dates (early and late), or 2 different, but "equally" susceptible cultivars of different maturities (early- and late-maturing), will be planted on the same date. Variations are expected among the locations based on space and equipment availability. As the number of diseases expand in the future, it will be important to include additional varieties. For example, in **option 2,** it may be possible to use a single cultivar that is susceptible to both diseases planted on 2 separate dates (early and late) or 2 cultivars that are susceptible to both diseases but of different maturities (early- and late-maturing) planted on the same date. The other 4 options (**3**–**6**) are for working with 2 or 3 diseases, taking into consideration the challenge of telling the leaf spotting diseases apart and the difficulty of finding a cultivar that is susceptible/resistant to 3 or more of the 4 diseases. **In this first year, the focus is on Parastagonospora leaf**

blotch, efforts should be made to select a cultivar or cultivars that is/are resistant to the other leaf spotters, particularly in regions where multiple leaf spotting diseases are common. Plots will not be treated with a foliar fungicide.

Sampling and data collection

Surface residue cover. Prior to planting in the fall and/or prior to jointing in the spring, the amount of wheat residue on the soil surface will be estimated in each residue block using a line transect method. When the residue blocks are established using baled straw as described above, the level of residue cover will be estimated after the residue is spread within the plots. Four line transects along a 25- or 50-ft-long tape (depending on the size of the residue block) will be extended along a "W"-shaped path and the presence/absence of wheat residue will be recorded at consecutive points (at 1-ft intervals) along the tape. The total number of points with residue, divided by the total number of points along the "W" will be estimated as a measure of the proportion of surface residue cover.

Residue sampling. Wheat stubble, consisting of 5–10 pieces of wheat stems, will be collected at 20 equally spaced (roughly) points along the "W" path described above (5 samples per transect) and bulked into a single composite sample per residue block. Samples will be air-dried as needed, weighed, paper-bagged, labeled, and shipped, along with a sample submission form to **National Agricultural Genotyping Center (NAGC), 1616 Albrecht Blvd N, Fargo, ND 58102**, for DNA extraction and qPCR analysis.

Airborne spore sampling. Solar-powered Burkard High-volume Multi-Vial Cyclone Samplers (**Fig. 2**) will be deployed in the center of each residue block (labeled **B** in **Fig. 1**). Each unit will be mounted on a tripod, with the air intake approximately 1 m above the ground. Air will be sampled at a rate of approximately 16.5 liters/min, with particles collected during every 24-h period transferred to a separate 1.5-ml vial (if the carousel is programmed to rotate for daily sampling) or in the same vial (carousel maintained fixed for weekly sampling). Sample vials will be collected/replaced at weekly intervals, stored at -20^{o}C, and subsequently sent to the NAGC laboratory for DNA extraction and qPCR analysis.

DNA extraction and qPCR analysis. The NAGC Lab will develop standardized protocols to quantify pg DNA of each pathogen in each spore sample. Standard curves will be used to relate pg DNA to actual spore concentration.

Disease assessment. The intensity of Parastagonospora leaf blotch, and rust (LR, SR, and StR) will be rated in a cluster of 5 tillers at 20 arbitrarily selected locations in each plot. In each cluster, the flag leaf (F), and the first (F-1), second (F-2), and third (F-3) leaves below the flag leaf will be visually inspected at weekly intervals from Feekes 9 to 11.2 and disease severity (percentage of the leaf area covered with lesions or pustules of the disease in question) will be estimated with the aid of standard area diagrams. Disease incidence (as a proportion) at each growth stage and leaf position will then be calculated from severity as the number of symptomatic leaves (separate for each disease) divided by the total number of leaves rated at the specific leaf position.

Weather monitoring: Air temperature, relative humidity, rainfall, solar radiation, and surface wetness (where available) data will be collected using an available on-site weather station (**preferred**) or a station located within

a few miles of the trial location. Where possible, loggers will be programmed to collect data at 30-min intervals between planting and harvest. Weather data could also be obtained from other sources and processed as described under **Obj. 1**.

Objective 2b. Quantify associations among airborne inoculum concentration on onset, development, and spread of leaf, stripe, and stem rust in small plot trials.

Rust diseases: The objective of this study is to quantify associations between airborne inoculum density and the onset and intensity of leaf, stripe and stem rusts of wheat as influenced by weather variables.

Small plot establishment: PIs will monitor the onset and spread of rust diseases in non-fungicide-treated plots of known rust-susceptible cultivars at their respective research farms. **The preferred approach would be to plant replicate plots of cultivars that are susceptible to 1 or most of the 3 rust diseases in or close to the plots in Obj. 2a** (see Fig. 2). However, PIs also have the option of **a)** planting an independent set of plots of rust-susceptible cultivars, **b)** using untreated check plots of known susceptible cultivars in a trial already established on their research farm, or **c)** monitoring rusts in non-inoculated disease screening nurseries.

Sampling and data collection

Airborne spore sampling. The sampling protocol will be similar to that described above under **Obj. 2a** using the same set of spore samplers or a separate sampler if rust will be monitored in an independent set of plots or in a disease screening nursery that is far from the plots in Obj. 2a.

DNA extraction and qPCR analysis. See Obj. **2a**

Disease assessment. Leaf, stripe, and stem rusts will be rated in a cluster of 5 tillers at 20 arbitrarily selected locations in each plot. In each cluster, the flag leaf (F) and the first (F-1) below the flag leaf, and the stem, in the case of stem rust, will be visually inspected at weekly intervals from Feekes 9 to 11.2, and disease severity (percentage of the leaf/stem area covered with pustules of the disease in question) will be estimated with the aid of standard area diagrams. Disease incidence (as a proportion) at each growth stage and leaf position will then be calculated from severity as the number of symptomatic leaves/stems (separate for each disease) divided by the total number of leaves/stems rated at the specific leaf position. Disease spread from identified foci will also be quantified by estimating severity and incidence at regular distances in ordinal directions from each focus with accommodations made for spatial orientation in the research field.

Weather monitoring: See **Obj. 2a**.

Objective 3. Quantify associations among pathogen inoculum, disease development, and weather variables in commercial fields.

PIs will select a total of 20 production wheat fields, consisting of any 1 of more of the following **1)** fields planted to wheat the previous season, **2)** fields planted to wheat two seasons prior, **3)** fields adjacent to a field that was planted to wheat the previous season, and **4)** fields in which state variety performance trials are established.

For instance, the fields selected in fall 2020, should have been planted to wheat in the fall of 2019 (and harvested in the spring of 2020) or 2018 (and harvested in the spring of 2019) or be adjacent to a field that was planted to wheat in the fall of 2020. PIs in states that produce both winter and spring wheat will have the option of planting winter wheat into or adjacent to a field previously planted to spring wheat.

Sampling and data collection

Surface residue cover. Prior to planting in the fall and prior to jointing in the spring, the amount of wheat residue on the soil surface will be estimated in each field (or in the adjacent field that was planted to wheat the previous season) using a line transect method. Four transects along a 100-ft-long tape will be extended across the field along a "W"-shape path and the presence/absence of wheat stubble will be recorded at consecutive points (at 4-ft intervals) along the tape. The number of points with residue, divided by the total number of points along the "W" will be estimated as a measure of the proportion of surface residue cover.

Residue sampling. Wheat stubble, consisting of 10–15 pieces of wheat stems, will be collected at 20 equally spaced (roughly) points along the "W" path described (5 samples per transect) and bulked into a single composite sample per field. Samples will be air-dried as needed, weighed, paper-bagged, labeled, and shipped, along with a sample submission form to **National Agricultural Genotyping Center (NAGC), 1616 Albrecht Blvd N, Fargo, ND 58102**, for DNA extraction and qPCR analysis (see "Residue Sampling" under objective 2 for details).

Airborne spore sampling. Solar (battery)-powered Burkard High-volume Multi-Vial Cyclone Samplers will be deployed in at least 5 of the 20 fields, preferentially, selected from those in which state variety performance trials are established. Each unit will be mounted on a tripod, with the air intake approximately 1 m above the ground. Air will be sampled at a rate of approximately 16.5 liters/min, with particles collected over a 7-day period in the same vial (carousel maintained fixed for weekly sampling). Sample vials will be collected/replaced at weekly intervals, stored at -20C, and subsequently sent to the NAGC laboratory for DNA extraction and qPCR analysis.

DNA extraction and qPCR analysis. See Obj. 2a

Disease assessment. SLB, PM, TS, SLS, Parastagonospora glume blotch, and rust (LR, SR, and StR) intensity will be rated in a cluster of 10 tillers at 40 arbitrarily selected locations in each field. In each cluster, the flag leaf or stem (in the case of stem rust) will be visually inspected between Feekes 9 and 10 and again between Feekes 10.5.1 and 11.2, and disease severity (percentage of the leaf/stem area covered with lesions or pustules of the disease in question) will be estimated with the aid of standard disease diagrams.

Weather monitoring: Air temperature, relative humidity, rainfall, and surface wetness (where available) data will be collected using an available on-site weather station or a station located within a few miles of the trial location. Weather data could also be obtained from other sources and processed as described under Obj. 1.

References

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Table 1. Options for establishing plots in residue blocks (Obj. 2) to monitor one or more residue-borne diseases[a]

Opt	Disease(s)			PLOT			
				1	2	3	4
1	*LS or PM*			Susceptible - early-planted **or** early-maturing	Susceptible - late-planted **or** late-maturing	…	…
2	*LS*	*PM*	…	Susceptible to both - early-planted **or** early-maturing	Susceptible to both - late-planted **or** late-maturing	…	…
3	*LS*	*PM*	…	Susceptible to LS - Resistant to PM - Planted early	Susceptible to LS - Resistant to PM - Planted late	Susceptible to PM - Resistant to LS - Planted early	Susceptible to PM - Resistant to LS - Planted late
4	*LS1*	*LS2*		Susceptible to LS1 - Resistant to LS2 - Planted early	Susceptible to LS1 - Resistant to LS2 - Planted late	Susceptible to LS2 - Resistant to LS1 - Planted early	Susceptible to LS2 - Resistant to LS 1- Planted late
5	*LS1*	*LS2*	*PM*	Susceptible to LS1 n PM - Resistant to LS2 - Planted early	Susceptible to LS1 n PM - Resistant to LS2 - Planted late	Susceptible to LS2 - Resistant to LS1 - Planted early	Susceptible to LS2 - Resistant to LS1 - Planted late
6	*LS1*	*LS2*	*LS3*	Susceptible to LS1 - Resistant to LS2 n LS3	Susceptible to LS2 - Resistant to LS1 and LS3	Susceptible to LS3 - Resistant to LS1 and LS2	…

[a]LS = leaf spotter or leaf spotting diseases that include Parastagonospora leaf blotch, Septoria tritici leaf spot and, and tan spot, PM = powdery mildew

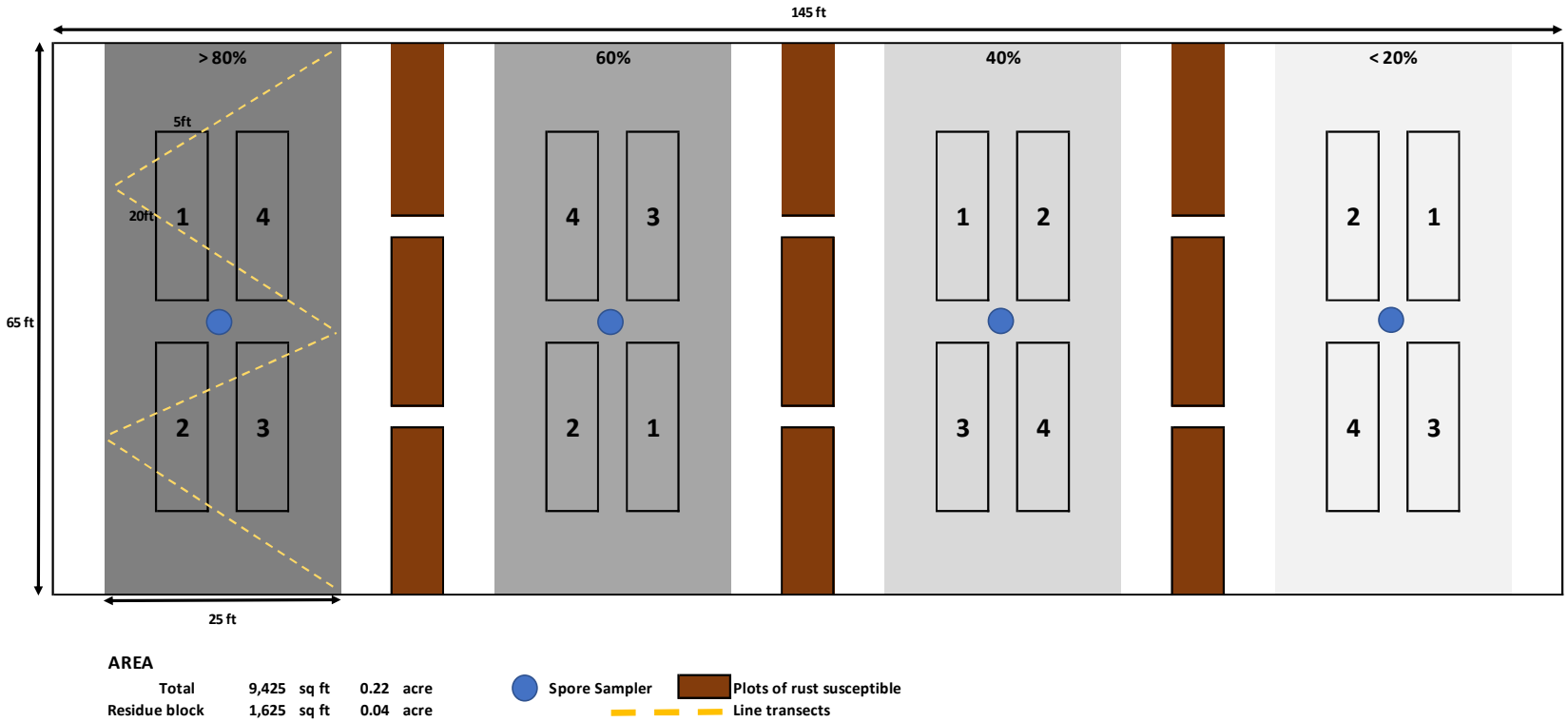

Fig. 1. An example plot plan

Burkhard spore sampler

HOBO weather stations from ONSET