# Maximizing Canopy Conductance to Enhance Spring Wheat Yield Potential in the Upper Midwest

M Walid Sadok, Dept. of Agronomy & Plant Genetics, U of M

## Research Questions

**Background.** Increasing wheat canopy conductance has potential to enhance productivity of wheat cropping systems. This is because canopy conductance controls the plant's ability to trading water to fix atmospheric $CO_2$, which is necessary to fill the grain with carbohydrates and protein. In wheat, we have shown in two different production environments (Australia and Minnesota) that increases in canopy conductance are associated with historic yield increases from 1890-2008 and 1992-2016 respectively. More recently, research carried out under this project showed that MN breeders were indirectly selecting against a decrease in canopy conductance, indicating the importance of this trait to increase yield potential (Tamang et al. 2019, In revision). The long-term objective of this research is to identify major genetic loci associated with this complex trait and pyramid them in the pipeline of the University of Minnesota wheat breeding program to deliver to producers varieties with higher yield potential. This will be achieved using a precision-phenotyping (the Gravimetric Phenotyping or GraPh) platform to enable 'high-fidelity' screening of whole-plant canopy conductance within large populations, developed by the Sadok lab. In the first year of this research, we: 1) screened -using the GraPh platform- the parents of the Minnesota Nested Association Mapping Population (MNAMP), a highly diverse group of wheat lines consisting of RB07 and 25 other exotic lines (developed through funding from the MWR&PC to Brian Steffenson), 2) phenotyped three families descending from parents with contrasted conductance totaling 150 lines and 3) identified -for the first time- quantitative trait loci (QTL) associated with enhanced conductance. **Goals.** This phase of research had the following goals: 1) continue phenotyping the families from the MNAMP population to enable the capture all of the large-effect QTL available in that population, 2) run a QTL analysis to identify markers associated with enhanced canopy conductance, and 3) phenotype an independent breeding population to enable confirmation of these QTL in different background.

## Results

**Goal 1).** We continued phenotyping families from the MNAMP population. This year, we successfully phenotyped de novo 3 families (totaling 150 lines, >450 plants) from the MNAMP population. **Goal 2)** Using the phenotypic data assembled so far, we undertook a multi-population QTL analysis of canopy conductance. The QTL analysis revealed several genetic markers associated with enhanced canopy conductance in this population. More importantly, among the QTL detected, we identified a potentially major locus on Chr1B, single-handedly explaining approx. 20% of the phenotypic variance, indicating that is potentially a major QTL. In this loci, the presence of the allele from RB07 is conferring the increase in canopy conductance, consistently with our previous findings. If confirmed (see recommended future research), the marker associated with this QTL is likely to be a prime candidate to be added to the pipeline of the U of M wheat breeding program to design wheat cultivars with enhanced canopy conductance. **Goal 3).** In addition to the above, we have successfully phenotyped an independent mapping population consisting of 145 recombinant inbred lines (RIL) replicated 3 times (> 435 plants), descending from a cross between MN-adapted parental lines MN99394-1-2 and MN99550-5-2. This population was developed by U of MN wheat breeder Jim Anderson and data from this population will be used to confirm the QTLs previously detected in this different genetic background.

## Application/Use

Increasing canopy conductance can lead to numerous yield-related benefits for Minnesota wheat. Higher canopy conductance is associated with increased ability of the plant for water and nitrogen uptake from the soil. This in turn may decrease risks of nitrogen leaching and waterlogging. In addition, higher canopy conductance is associated with increased fixation of $CO_2$ and other mobile nutrients needed for filling the grain and with protecting the canopy from heat stress during the summer, via evaporative cooling. The proposed research aims at maximizing all of these benefits by identifying genetic markers associated with increased canopy conductance. Those genes will be integrated into the University of Minnesota wheat breeding program to deliver new cultivars with maximized canopy conductance and increased yield potential.

## Materials and Methods

For this research, the plants were grown under naturally fluctuating conditions in a well-maintained greenhouse at the University of Minnesota. Plants were grown in a setting that mimic field conditions (large pots, fertilized top soil, high density) in where where key environmental conditions were carefully monitored (light, temperature, relative humidity, watering regime). After 4-5 weeks, plants were transferred inside the GraPh precision-phenotyping platform. This platform tracks canopy conductance as a function of whole-plant transpiration response - measured gravimetrically - to increasing atmospheric vapor pressure deficit. This allows for a very precise estimation of whole-plant canopy conductance which is very difficult to accurately measure in the field because of the confounding influence of uncontrollable variations in light, temperature and wind speed.

## Economic Benefit to a Typical 500 Acre Wheat Enterprise

In temperate production environments such as Minnesota, increasing canopy conductance would lead to enhanced yields as suggested by our work showing correlation between increases in canopy conductance and yield increases in historic Minnesota wheat lines. In this regard, data from the second year showed great promise. The detection of a potentially major QTL (Figure 1) conferring increased canopy conductance makes it possible to design cultivars with more aggressive gas exchange to increase yield potential under most growing conditions of Minnesota. We can reasonably assume that yield increases resulting from enhanced canopy conductance could be achieved over a period significantly shorter than 15 years, which is the duration over which we were able to positively correlate yield increases and canopy conductance in historic wheat lines. However, although much shorter, it is important to note that this pre-breeding project requires a time horizon of 4 to 6 years to integrate beneficial canopy conductance genes into advanced breeding lines.

## Related Research

Matching canopy conductance to the resources offered by the production environment is now a major goal for wheat breeding programs across the globe. In well-watered environments such as Minnesota, increasing canopy conductance provides an opportunity for enhancing yield potential, by increasing water, nutrient and $CO_2$ uptake. Indeed, over a given day, desired genotypes for Minnesota would be those that maintain a maximal conductance during most of the day. However, in water-limited environments such as the western part of the U.S. spring wheat region, our research showed that genotypes that decrease their canopy conductance at midday would increase yields through a water-saving strategy. Since our screening method allows us to identify favorable canopy responses under well-watered (i.e., high conductance) and water-limited (i.e., low conductance) environments, the research conducted in this project will be valuable not only for Minnesota but also to wheat breeding programs of more drought-prone neighboring states such as the North Dakota and South Dakota HRSW breeding programs. This research is also relevant to address future water-deficit events that are predicted to occur in certain regions in Minnesota. As a result of these benefits, Dr. Sadok's research program in this area has expanded to include collaborations with colleagues in Tunisia, Morocco, Jordan and Australia with the goal of helping breeders develop cultivars with canopy conductance that maximize yield potential in various production environments.

## Recommended Future Research

In this second year, we continued progress towards identifying QTL controlling canopy conductance in wheat. We continued phenotyping the MNAMP population developed by Brian Steffenson, identified new QTL controlling canopy conductance in this population, and we successfully phenoptyped an independent breeding population developed by wheat breeder Jim Anderson. Also, we are currently undertaking QTL analysis of canopy conductance data from this breeding population. Furthermore, our research has generated data to be published in a scientific international journal and presentations at three major international conferences, where the support of the MWR&PC has been acknowledged. Moving forward, our major goals for next year are to 1) ensure the proper replication of the phenotyping of the 6 MNAMP families to capture of major QTL in this population and 2) confirm those QTL in an independent genetic background represented by the breeding population developed by Jim Anderson.

For this to be achieved, we have set the following timetable:
- End of 2018/early 2019: analyze data, identify canopy conductance QTL in the new breeding population.
- 2019: replicate phenotyping of MNAMP families, analyze data, perform final joint QTL analyses to identify major genes, write-up manuscripts, release genetic markers to wheat breeders.

## Publications

**8.1. Peer-reviewed publication in international scientific journal:**
[Support of MWR&PC acknowledged in the paper]

Tamang, B.G, Schoppach, R., Monnens, D., Steffenson, B.J., Anderson, J.A. & Sadok, W. 2019. Variability in temperature-independent transpiration responses to evaporative demand correlate with nighttime water use and its circadian control across diverse wheat populations. Planta (In revision).

**8.2. Peer-reviewed abstract & oral presentation in international conferences:**
[Support of MWR&PC acknowledged in the presentations]

Tamang, B.G, Schoppach, R., Steffenson, B.J., Anderson, J.A. & Sadok, W. 2018. Unconscious selection and plant hydraulics: Did breeders select against water-saving traits in well- watered Minnesota and for them in drought-prone Australia? Contributed talk at the American Society of Agronomy and Crop Science Society of America annual meeting, Baltimore, MD, USA, November 4-7, 2018. »

» Sadok W. 2018. Vascular traits and water use in crops: a promising potential for drought tolerance in a changing climate. Invited talk at the Gordon Research Conference: Multiscale Plant Vascular Biology, West Dover, VT, USA, June 17-22, 2018.

Sadok W. 2018. Gravimetric phenotyping of canopy conductance in wheat and maize reveals novel mechanisms, traits and genetic loci involved in drought tolerance in the field. Contributed talk at Phenome 2018, Tucson, AZ, USA, February 14-17, 2018.

## Appendix

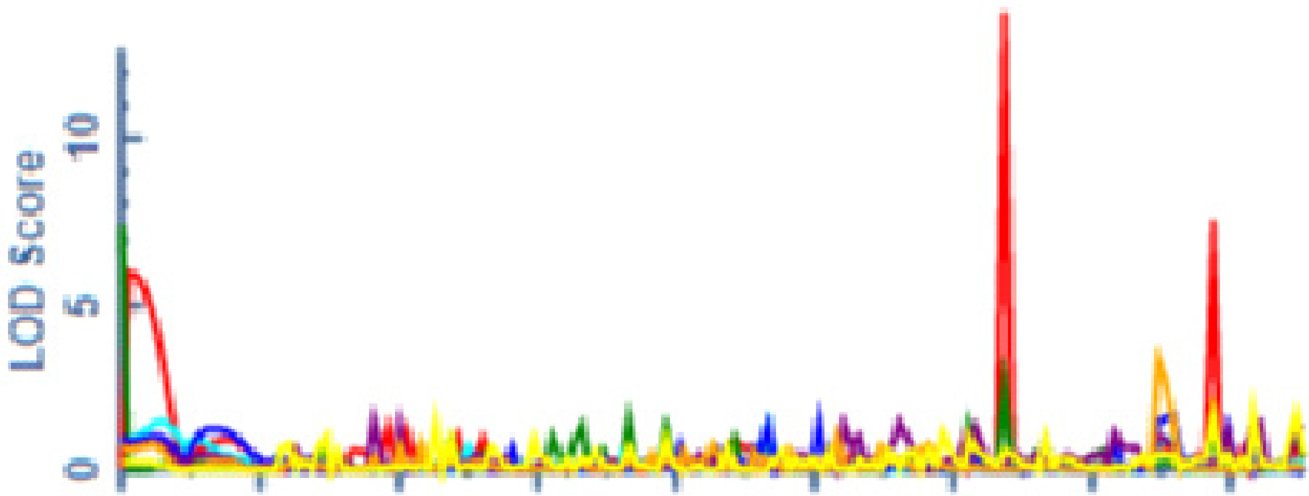


**Figure 1.** Likelihood of odds ratios of QTL controlling canopy conductance detected on Chr#1B. The highest peak represents the potentially major QTL detected.