Using phenotyping tools to maximise whole canopy photosynthesis in wheat

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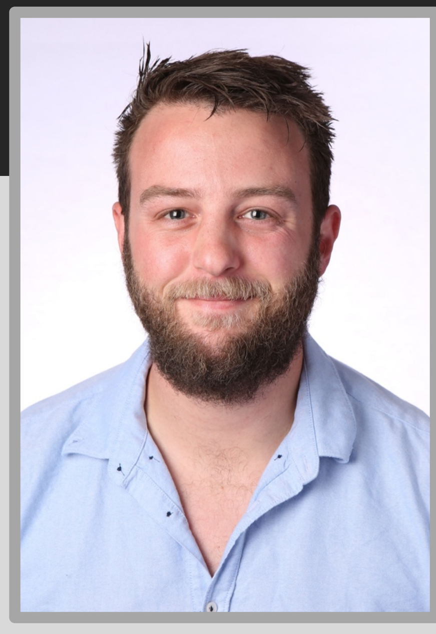


Background

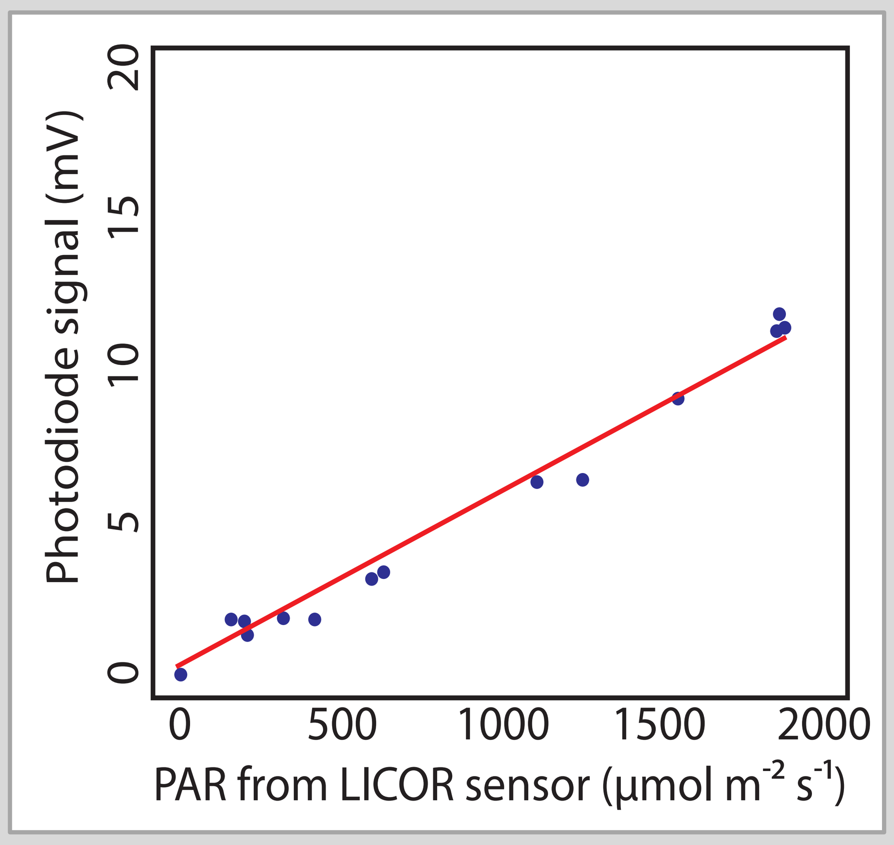
Whole canopy photosynthesis is substantially reduced by inefficient vertical distribution of photosynthetic capacity relative to irradiance; specifically, sun-exposed upper leaves have too little photosynthetic nitrogen and shaded lower leaves have too much. Redistribution of this nitrogen could increase canopy carbon capture and nitrogen use efficiency by up to 20% (Buckley *et al.*, 2013), and has the potential to increase grain yield. We have developed novel plant phenotyping tools to identify variation in the distribution of photosynthetic capacity distribution relative to light availability in wheat canopies. Contrary to a growing trend, these phenotyping tools are not based on remote sensing but are rather conventional phenotyping tools that we have designed specifically for high throughput measurements. We have tried to keep the cost of these phenotyping tools to a minimum by keeping the designs relatively simple and using "off the shelf" components.

PARbars

Low cost ceptometers

We have developed low cost ceptometers for the measurement of integrated photosynthetically active radiation (PAR) across a 1 m length. Each PARbar consists of 50 photodiodes and a 3 kΩ shunt resistor connected in parallel providing a single differential voltage signal. PARbars use narrow band photodiodes only sensitive to the photosynthetically active spectrum, avoiding any need for costly filters. The materials for each PARbar cost roughly USD $75, considerably less than existing alternatives, and take about one hour to assemble. This has allowed us to build 80 PARbars for use in the field this year. Completely weatherproof, we will be able to continuously measure light distribution over time in wheat canopies.

Photodiodes are superglued to an acrylic diffuser bar, soldered to copper wire and sealed in waterproof epoxy.



Signal output from PARbar photodiode vs the PAR output of a LICOR quantum sensor.

A fully assembled PARbar ceptometer. The acrylic diffuser and photodiodes are mounted on an aluminium channel for rigidity. A waterproof connector is used to connect to the datalogger.

PARdots

Low cost quantum sensors

We used the same photodiodes found in our PARbars to build individual weatherproof quantum sensors, called PARdots. These consist of a single photodiode mounted onto an acrylic diffuser disc and sealed in epoxy. Each sensor gives a differential voltage output amplified using a shunt resistor at the datalogger. This simple design has allowed us to keep the cost of each PARdot to roughly USD $2.

PARdot quantum sensor.

OCTOflux

High throughput gas exchange

We have designed and built a new field-portable gas exchange system that can measure photosynthetic capacity (A_{max}) at a lower cost and with far greater throughput than existing systems. OCTOflux operates on a fairly simple design, using a solenoid switching manifold to direct reference air or sample air from one of eight custom built leaf chambers through a single channel infrared gas analyser. The whole system is controlled and data collected using an Excel VBA program. With OCTOflux a set of eight A_{max} measurements can be recorded in as little as 15 minutes, a vast improvement over conventional gas exchange systems.

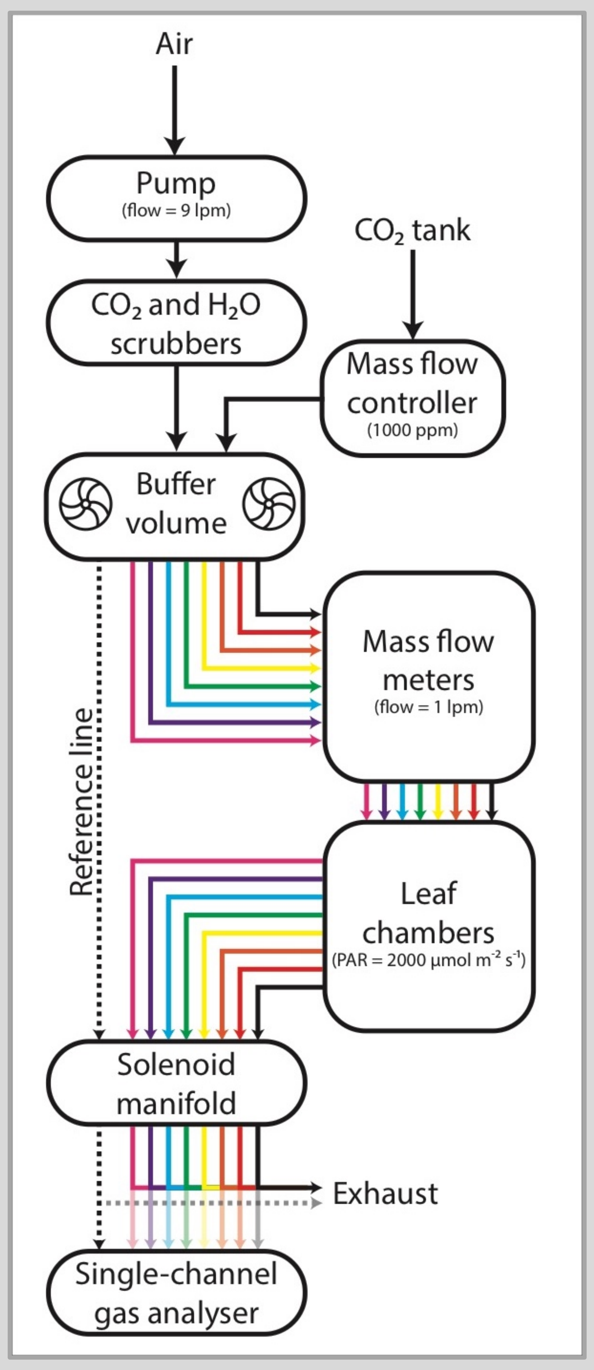
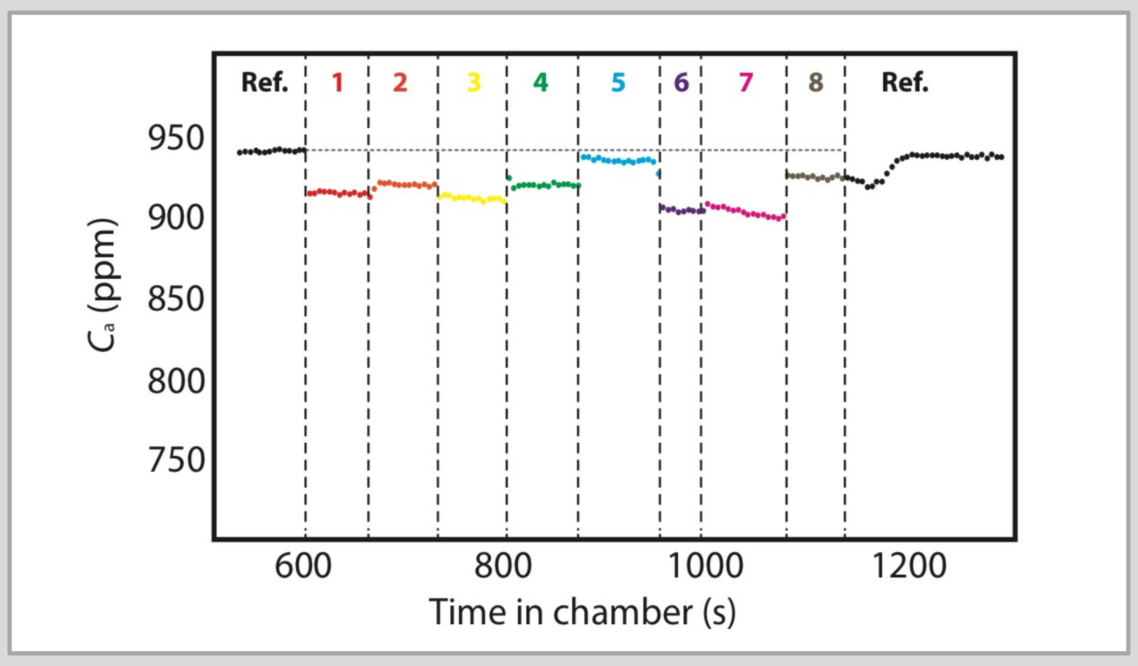


Diagram of OCTOflux. Air is scrubbed of water and CO_2, then CO_2 is reinjected at 1000 ppm. The gas flow is split into nine gas lines: one reference (dotted) and eight sample (coloured) lines. As leaves equilibrate to saturating CO_2 and light, solenoid valves direct reference gas through the IRGA. During measurement, the valves direct air from each sample chamber through the IRGA sequentially.

Top right – a wheat leaf in a custom-built OCTOflux leaf chamber with LED light source. Top left – Control centre of OCTOflux with leaf chambers docked for transport. Bottom left – OCTOflux prototype testing in the field in Narrabri, NSW. Bottom right – OCTOflux set up with each leaf chamber on a tripod.



Preliminary data showing the stability of the system. Each dashed vertical line represents a switch from one gas line to another using the solenoid switching manifold. Each leaf takes approximately 5 min to equilibrate to chamber conditions.

Future steps

We intend to fully validate our phenotyping instruments in the field, against calibrated infra-red gas analysers and quantum sensors. This year we will phenotype a diverse set of 250 wheat lines using OCTOflux and PARbars. This will allow us to identify key traits and genetic markers associated with efficient redistribution of foliar nitrogen. We will share our findings with partners in the breeding industry, CIMMYT and the International Wheat Yield Partnership to develop higher-yielding varieties for the future. We aim to publish these results in peer-reviewed literature and will openly provide detailed instructions of how we built these phenotyping tools online.

Acknowledgements

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References

Buckley, T. N., Cescatti, A. & Farquhar, G. D. 2013. What does optimization theory actually predict about crown profiles of photosynthetic capacity when models incorporate greater realism? *Plant Cell and Environment,* 36, 1547-1563.

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IWYP International Wheat Yield Partnership
Research to Deliver Wheat for the Future