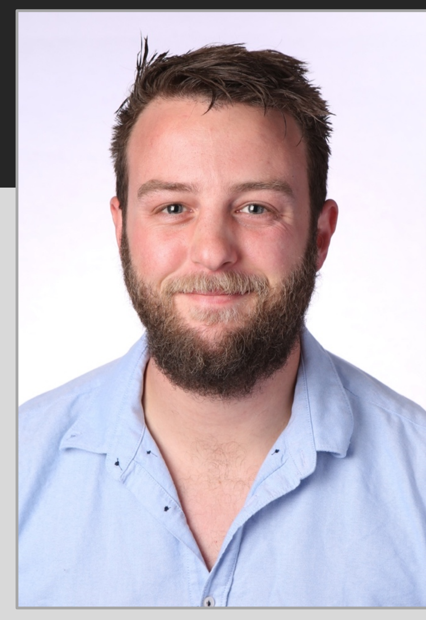
Tackling the physiological phenotyping bottleneck with low-cost, enhanced throughput gas exchange and ceptometry



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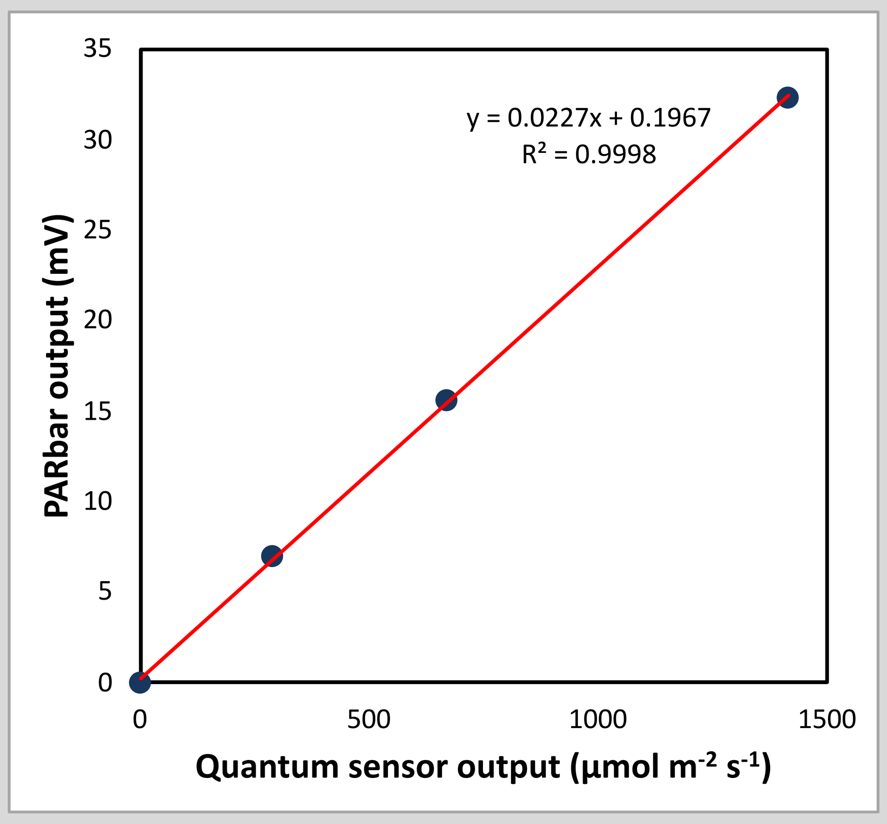
The physiological phenotyping bottleneck

Plant breeders have long been interested in improving physiological traits of crop species in their breeding programs, however have been limited by slow and expensive physiological phenotyping equipment. As a result, previous efforts to phenotype these properties in the field have had very low throughput or were only able to provide a snapshot of the conditions a plant experiences. We have developed novel plant phenotyping tools for the high throughput measurement of leaf gas exchange and diurnal canopy light environment to overcome this phenotyping bottleneck. Contrary to a growing trend, our phenotyping tools are not based on remote sensing but are rather conventional phenotyping tools that we have designed specifically for high throughput measurements. To make these tools accessible to the widest possible range of potential users in the research and education community, we have tried to keep the cost of these tools to a minimum by keeping designs relatively simple and using "off the shelf" components.

PARbar
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 connected in parallel providing a single differential voltage signal. PARbars use narrow band photodiodes sensitive only 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. Completely weatherproof, we are able to continuously measure light distribution over time in wheat canopies. Due to their low cost we were able to build 80 ceptometers for use in the field this year.

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.

OCTOflux
High throughput gas exchange

We have designed and built a new field-deployable gas exchange system that can measure CO_2-saturated net photosynthetic rate (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 and sample air from one of eight custom built leaf chambers through a differential infrared gas analyser. The entire 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 20 minutes, a vast improvement over conventional gas exchange systems. With OCTOflux we are able to measure A_{max} of over 100 leaves per day.

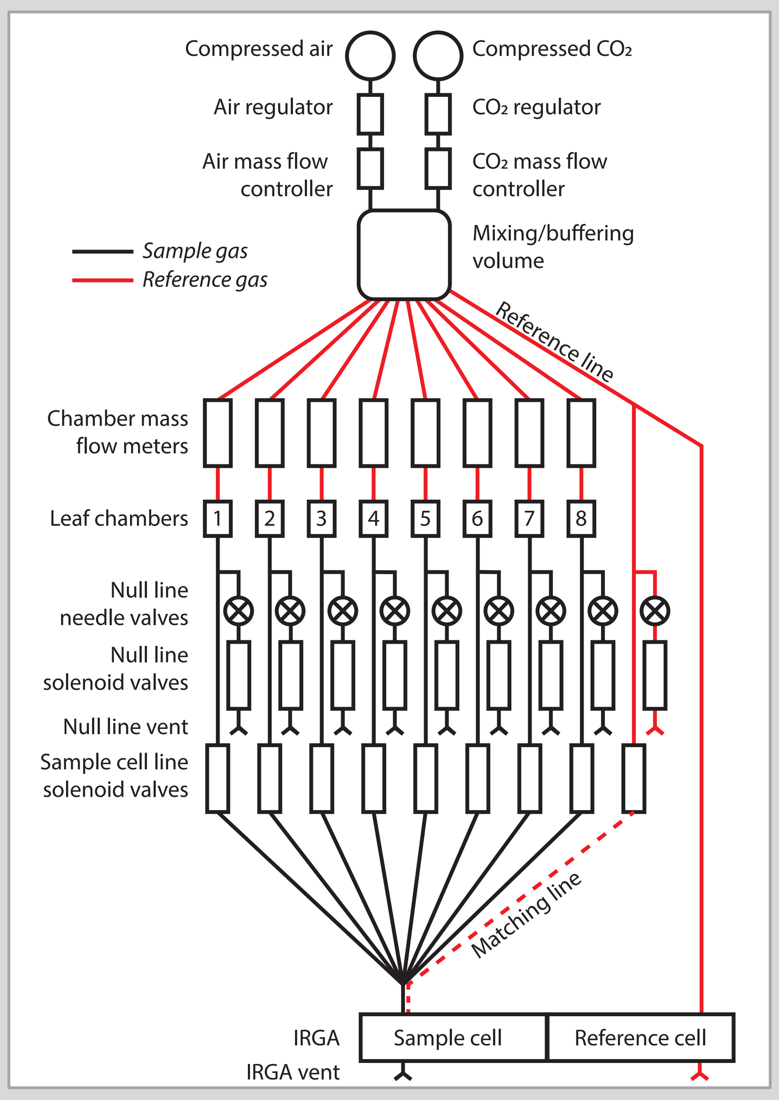
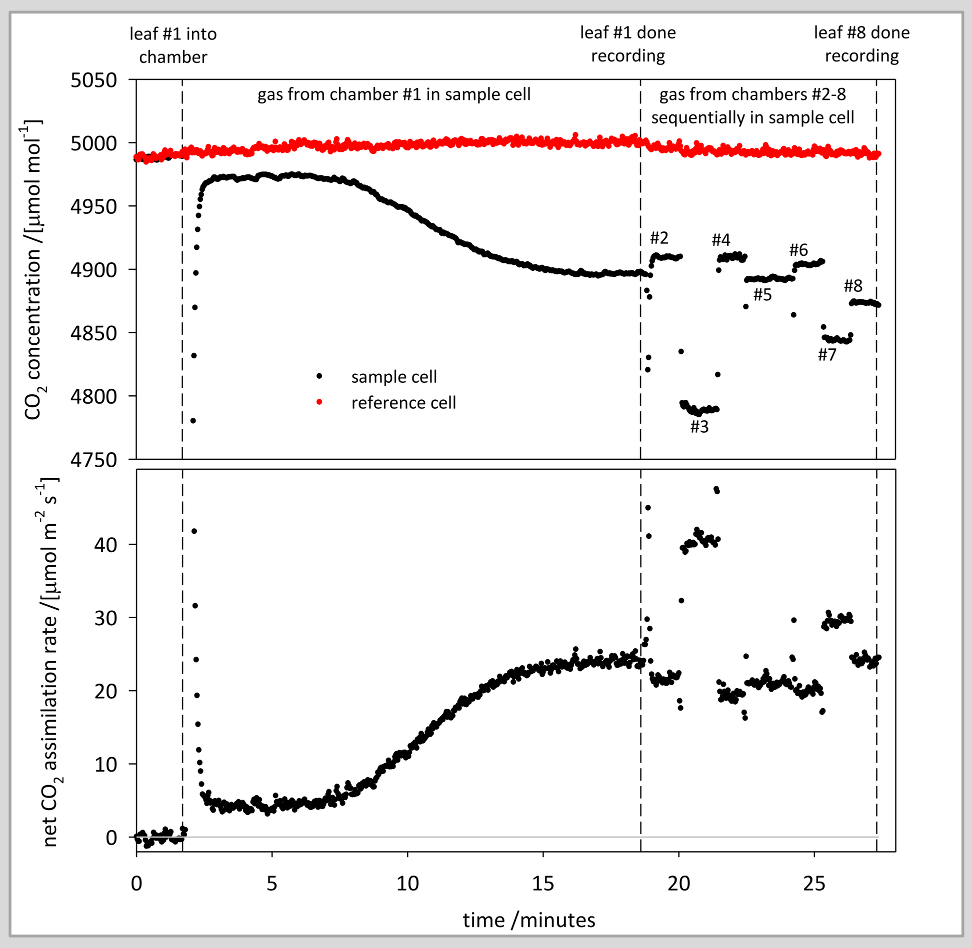


Diagram of OCTOflux. Compressed air and CO_2 from cylinders are mixed to provide an air mixture with a CO_2 concentration of 5000 ppm. The gas flow is split into nine gas lines: one reference and eight sample lines. A solenoid switching manifold is used to selectively direct air from a sample chamber through the sample cell of the IRGA, or to match the analysers using reference gas.

Right – Four of eight custom designed OCTOflux leaf chambers. Left – Control centre of OCTOflux with leaf chambers docked for transport.



A typical OCTOflux measurement cycle showing the CO_2 concentration at the top and A_{max} at the bottom.

PARdot
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 USD $2.

PARdot quantum sensor.

Our work and future directions

We recently used these tools to phenotype field grown wheat (*Triticum aestivum*) in Narrabri, NSW, Australia. Over the course of two weeks we measured A_{max} of over 1300 leaves with OCTOflux (flag and second leaves of 160 genotypes with n = 4) and the light environment of 320 plots with PARbars (at two canopy heights for 160 genotypes with n = 2). This phenotypic data, together with genome mapping and analytical chemistry, will allow us to identify genetic markers that optimize the vertical distribution of photosynthetic nitrogen with regards to light. We plan to develop and improve our phenotyping tools, particularly for use in the field. We also hope to use them together with remote sensing technologies to improve how data from these is interpreted.

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