Phenotyping radiation interception in chickpea

Cossani, C.M.[123*], Gimenez, R.[4], Dron, N.[5], Lake, L.[123], and Sadras, V.O.[123]

[1] SARDI, 2C Hartley Grove, Urrbrae, SA, 5064. mariano.cossani@sa.gov.au
[2] School of Agriculture, Food and Wine, The University of Adelaide, Urrbrae, SA, 5064.
[3]College of Science and Engineering, Flinders University.
[4]School of Natural Sciences, University of Tasmania, Sandy Bay Campus, Hobart, Tasmania, Australia
[5]Tamworth Agricultural Institute, Department of Regional NSW, Calala, NSW, 2340

Abstract
Capture and efficiency in the use of radiation are commonly used to estimate crop biomass and yield. The fraction of photosynthetically active radiation absorbed by the canopy (*f*APAR) correlates with Normalised Difference Vegetation Index (NDVI), therefore remote sensors can be used to monitor *f*APAR. In this work, we calibrated a phenotyping method for estimating *f*APAR with NDVI in chickpea. We simultaneously measured NDVI and *f*APAR in 272 experimental plots in Kapunda (SA) from early vegetative to advanced reproductive stages during 2022 and 2023. *f*APAR ranged from 4% to 99.8% and NDVI ranged from 0.12 to 0.82. A lineal *f*APAR-NDVI model returned $r^2 = 0.87$, with a marginal improvement using an exponential model accounting for the saturation of NDVI. Phenotypic differences in *f*APAR were detected in a sample of 25 chickpea cultivars. Our results could be upscaled to remote sensors to phenotyping radiation capture and radiation use efficiency with complementary measurements of biomass or photosynthesis-related traits.

Keywords
NDVI, Radiation use efficiency, RUE, Radiation, High throughput

Introduction

The modern model of crop growth and yield for grain crops is based on resource capture and resource use efficiency (Monteith, 1972; Monteith, 1994). Grain yield, in most cases, can be defined as the product of the incident Photosynthetic Accumulated Radiation (*i*PAR), the fraction of iPAR absorbed by the crop (*f*APAR), the radiation use efficiency (RUE), and the harvest index (HI).
The fraction of photosynthetically active radiation absorbed by the canopy *f*APAR (fAPAR) can be estimated from remote and proximal sensors through NDVI (Pellegrini et al. 2021) and correlates with growth rate, grain yield and biomass (Gallagher and Biscoe, 1978, Andrade et al., 2005; Fischer, 1985; Lake and Sadras, 2016).
Australia has become the second largest producer of chickpea (*Cicer arietinum L.*) with around 600,000 ha and 873,000 t per year (FAOSTAT, 2019), contributing significantly to the sustainability and economy of national farming systems. Desi-type cultivars are grown in 90% of chickpea area, mostly in northern and central Queensland and northern NSW, with kabuli-type grown in the southern regions.
Estimating *f*APAR from remote sensors is key to estimating yield from the conceptual model of resource capture and resource use efficiency. This could also contribute to providing a phenotyping tool to breeding programs for complementary selection for traits related to yield potential and heat adaptation.
In this work, we developed calibrated a phenotyping method for estimating *f*APAR and related traits based on NDVI for chickpea.

Methods

Step 1 Data acquisition for model calibration
We created a database from field trials where sources of variation were season, sowing date, cultivar and crop ontogeny. In total, we simultaneously measured NDVI and fAPAR in 272 plots in Kapnda (SA) from early vegetative to advanced reproductive stages during 2022 and 2023. In 2023 we used a set of 25 historical cultivars including 19 desi type and 6 kabuli type lines adapted to the North and South areas, and different focus of release representing the history of chickpeas in Australia to test the relationship between the estimated APAR and the productivity of chickpea. Field experiments were carried out using conventional farming practices, with seeds treated with P-Pickel -T (thiram 360g/L & thiabendazole 200g/L) before sowing, and starting nutrition, rhizobial inoculation, herbicide, insecticide, and fungicide to control pests and disease when required.
Sowing times for plots measured during 2022 were 10 May, 14 June and 15 July 2022; and 20 June and 22 July in 2023 all grown in Kapunda, SA. Experimental design was a randomized complete block design with 3 repetitions for the trial of historical cultivars.

Step 2- Assessment of *f*APAR, and RUE from proximal sensing.
For the historical set of cultivars assessed in 2023, we measured NDVI from plant emergence till 135 days after emergence, measuring a total of 13 days during the growing season. We used a tri-lineal model (Acreche et al. 2009) for estimating daily NDVI for each plot, setting NDVI = 0 at emergence. Once daily NDVI was estimated, we used the calibration developed in Step 1 to estimate the *f*APAR for each day. Lastly, we calculated the APAR for each plot by multiplying the daily *f*APAR by the Incident radiation obtained from the BOM.
Yield and yield components data were measured in 2 lineal m samples, measuring total seed weight, and above-ground biomass after drying samples for 48 hs at 70˚C. Model II regression were used to evaluate the relationship between the estimated *f*APAR and aboveground biomass of each type of cultivar.

Results and discussion

We measured the intercepted radiation in chickpeas growing at pre-flowering, flowering, podding, and grain-filling stages covering most of the stages of canopy development. After measuring the 272 plots, *f*APAR measured with the ceptometer ranged from 4% to 99.8%, and NDVI ranged from 0.12 to 0.82. This allowed us to capture a wide range of variability in intercepted radiation and *f*APAR within the calibration set, covering most possible conditions of intercepted radiation. We fitted a model II regression to simplify the calibration model which returned R^2 = 0.87 (*p*-=0.0001) and an RMSE of 0.106, and a slope of 1.279±0.02464. The x-intercept for y=0 had a value of 0.1311. We also tested an exponential model accounting for the saturation of NDVI but it only produced a marginal improvement.

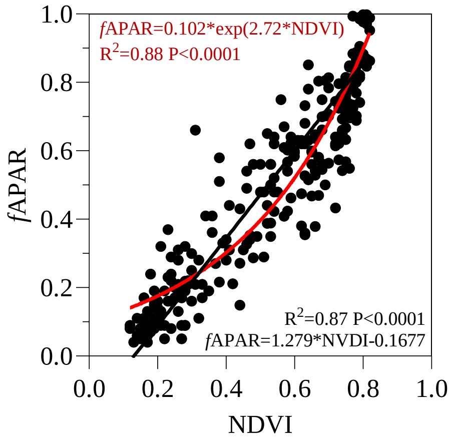

Figure 1. Relationship between *f*APAR and NDVI measured in the calibration set during 2022 and 2023 growing seasons at Kapunda, SA. Black line indicates the regression line for the lineal model while the red line was used for the exponential model.

The tri-lineal model fitted for the historical set of cultivars had an average R^2 of 0.97 P<0.001 and RMSE=0.05 (Figure 2). The estimated accumulated APAR (ΣAPAR) for the historical set of cultivars ranged from 380 MJ m^2 to 548 MJ m^2. Aside from the estimated ΣAPAR, this model could be used to estimate useful growth traits such as the rates of canopy cover, time to maximum intercepted radiation, maximum APAR, beginning of senescence, canopy senescence rate, and duration of maximum canopy cover.

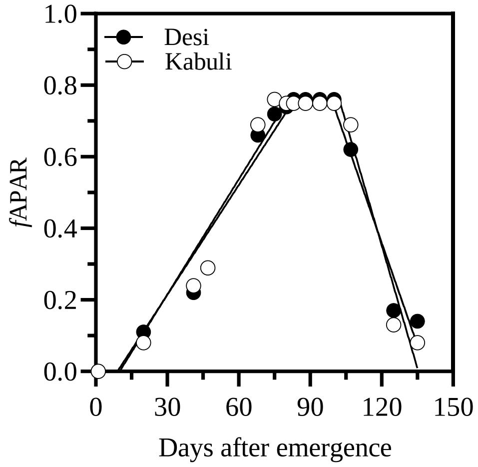

Figure 2. Example of the fitted tri-lineal model for estimating daily *f*APAR through the 2023 growing season for desi (closed symbols) and kabuli (open symbols) Line indicates the regression line for tri-lineal model.

The ΣAPAR had a positive relationship with the aboveground at maturity and allowed to estimate the radiation use efficiency (RUE) for the different types of cultivars as the slope of its regression. The average estimated RUE was 2.30 g MJ^{-1} for the desi cultivars and 2.74 g MJ^{-1} for the kabuli ones (Figure 3).

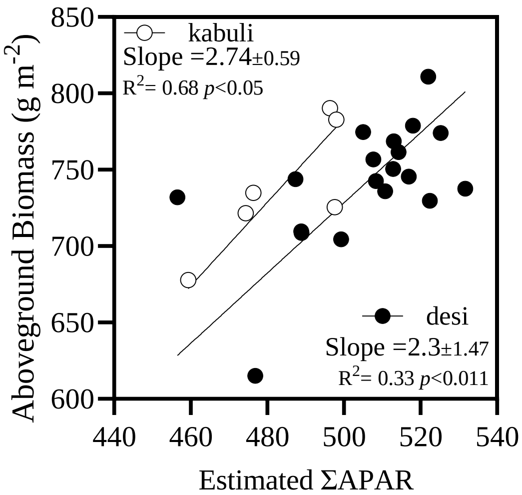

Figure 3. Relationship between estimated ΣAPAR and aboveground biomass at maturity for the historical set of cultivars grown during 2023 growing seasons at Kapunda, SA. Black line indicates the model II regression lines. Closed symbols were used for desi and open symbols were used for kabuli cultivars.

Conclusion

Our method allowed us to quantify intercepted radiation during the growing season and estimate relative physiological traits of importance for yield potential and heat stress adaptation such as ΣAPAR and RUE. Phenotypic differences in *f*APAR were detected in a sample of 25 chickpea cultivars. Our results could be upscaled to remote sensors and contribute to phenotyping radiation use efficiency in breeding programs and monitor intercepted radiation and biomass productivity at a regional scale.

References

Acreche, M., Briceño-Felix, G.,Martin Sanchez, J.A., Slafer, G.A. (2009). Radiation interception and use efficiency as affected by breeding in Mediterranean wheat. Field Crops Research. 110. 91-97. 10.1016/j.fcr.2008.07.005.

Andrade, F H, V O Sadras, C R C Vega, and L Echarte. 2005. “Physiological Determinants of Crop

Growth and Yield in Maize, Sunflower and Soybean: Their Application to Crop Management, Modeling and Breeding.” Journal of Crop Improvement 14 (1–2): 51–101. https://doi.org/10.1300/J411v14n01_05.

Gallagher, J N, and P V Biscoe. 1978. “Radiation Absorption, Growth and Yield of Cereals.” The Journal of Agricultural Science 91 (1): 47–60. https://doi.org/10.1017/S0021859600056616.

FAO (2019) FAOSTAT. United Nation Food and Agriculture Organization (FAO) statistical division Rome, Italy: http://www.fao.org/faostat/.

Fischer, R A. 1985. “Number of Kernels in Wheat Crops and the Influence of Solar Radiation and Temperature.” The Journal of Agricultural Science 105 (2): 447–61. https://doi.org/10.1017/S0021859600056495

Lake, L, and V O Sadras. 2016. “Screening Chickpea for Adaptation to Water Stress: Associations between Yield and Crop Growth Rate.” European Journal of Agronomy 81: 86–91. https://doi.org/10.1016/j.eja.2016.09.003.

Monteith, J. 1972. Solar radiation and productivity in tropical ecosystems. Journal of Applied Ecology 9, 747–766.

Monteith, J.L. 1994. Principles of resource capture by crop stands. In: Monteith, J.L., Scott, R.K., Unsworth, M.H. (Eds.), Resource capture by crops. Nottingham University Press, Nottingham, 1-15.