Yield gap of winter pulses in South Eastern Australia

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Abstract

Pulses are a vital component in the rain-fed farming systems in South Eastern Australia and the pulse yields are highly dependent on the seasonal water supply. As a result, pulses show a wide variability of yields across seasons and agroecological zones in South Eastern Australia. Our work quantified the water limited yield potentials, actual yields achieved by growers, and defined the yield gap for lentil, chickpea, faba bean and wheat in South Eastern Australia during 2009-2016. Results indicate average yield gaps of 42% for lentil, 50% for chickpea, 26% for faba bean and 31% for wheat. The yield gaps can be overcome through research, development and extension that identifies the underlying issues and develops genetic and agronomic solutions to increase productivity, profitability, and sustainability of farming systems in the region.

Keywords

Lentil, chickpea, faba bean, wheat

Introduction

Pulses are an integral component of South Eastern Australian rainfed farming systems. However, the average yield fluctuated between 0.8 and 2.2t/ha over 2009-2016, which is strongly linked to seasonal rainfall (ABARES 2018). There is a considerable yield gap (Y_g) between the water limited yield (Y_w) and the actual yield (Y_a) achieved by the growers. Here, Y_w is the yield of a well-adapted cultivar grown under rainfed condition when pests, diseases and other stresses are well managed and nutrients are non-limiting (Van Ittersum et al. 2013).

Causes for yield gaps (Y_gS) have been quantified and identified for wheat but not for pulses in south eastern Australia (Van Ittersum et al. 2013). Quantification of Y_g at field, regional or national levels is vital to generate baseline information to identify the main causes driving the Y_gS and, identify research and development goals and recommend improved agronomic strategies to close the gap (Van Ittersum et al. 2013). Therefore, the aim of this study was to quantify the Y_a produced by the growers in different agroecological zones in Victoria and South Australia and the Y_w that is achieved in the given agroecological zone for lentil, chickpea and faba bean, and estimate Y_g, and finally compare those gaps with the performance of wheat in the given environment.

Methods

Study area: The actual yield (Y_a) of lentil, chickpea, faba bean and wheat were collated from a survey conducted among growers and agronomists in Victoria and South Australia during 2009 – 2016. Historical and current grain yield data from research trials, 2002- 2016, were also used to estimate the Y_a of crops in the region.

A modified French and Schultz model (1984) was used to calculate Water limited yield (Y_w) = (SWS-E) x TE, where Y_w is water limited potential yield, SWS is seasonal water supply, E is soil evaporation and TE is the maximum transpiration efficiency for grain production. The SWS was calculated as the total rainfall received during April-October growing season (from on-farm monthly rainfall records or the data from the closest Bureau of Meteorology weather station) plus the plant-available soil moisture content at sowing (French & Schultz 1984). Plant available soil moisture at sowing was estimated as 30% the rainfall received during January to March. Evaporation was estimated as 30% of the growing season rainfall or 60 mm, whichever that was higher. TE for pulses was considered as 15 kg/ha/mm and 22 kg/ha/mm for wheat (Sadras & Rodriguez, 2007; Siddique et al., 2001).

The Yield Gap (Y_g) was calculated for each crop as the difference between the Y_w and Y_a during 2009 – 2016. %Y_g was calculated as %Y_g/Y_w. The Y_g data was analysed where comparisons were made between different rainfall zones, growing season water supply, states, local government areas (not discussed here), and farm and, experimental trials.

Results

Study area: Overall, 1261 data points for lentil, faba bean, chickpea and wheat were collected from over 45 locations representing the key pulse production areas of which 17% were in the high-rainfall zone (HRZ), 41% in the medium-rainfall zone (MRZ) and 42% in the low-rainfall zone (LRZ) of South Eastern Australia during 2002 – 2016.

Variation of yields and yield gap in different rainfall zones

All crops produced higher Y_w and Y_a in HRZ compared to MRZ and the LRZ (Figure 1). However, in all rainfall zones wheat produced 36 – 45% greater Y_w and 63 – 70% more Y_a than those produced by pulses. The average Y_gS of all crops were in the range of 1.17 – 1.51 t/ha across all rainfall zones. All crops had higher %Y_g in the LRZ compared to MRZ and the HRZ. Further, on average faba bean %YgS were similar to wheat while lentils and chickpeas had higher %YgS compared to wheat at LRZ, MRZ and HRZ zones (Figure 1). This indicates the greater degree of yield constraints other than water affecting pulses compared to wheat, especially in the LRZ.

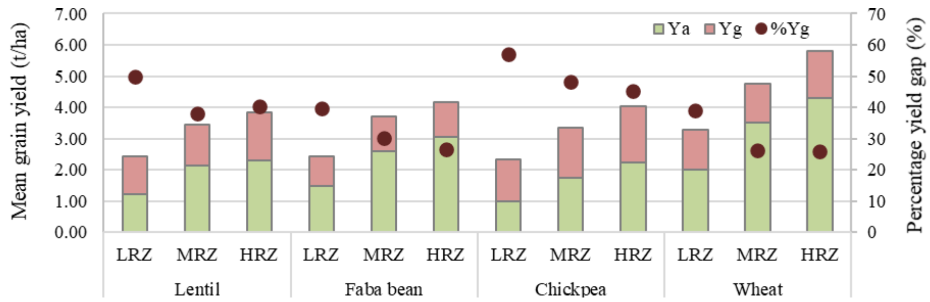

Figure 1 Actual yield (Y_a), yield gap (Y_g) and percentage yield gap (%Y_g) of lentil, chickpea, faba bean and wheat grown in low (LRZ), medium (MRZ) and high rainfall zones (HRZ) in South Eastern Australia during during 2009 – 2016. %Y_g is yield gap (Y_g) as a percentage of water limited yield (Y_w).

Effect of water supply during the growing season on yields and yield gap

For all crops the average Y_w and Y_a increased when growing season rainfall increased (Figure 2): The Y_a of lentil increased from 0.60 t/ha to 3.21 t/ha, chickpea from 0.38 to 3.09 t/ha, faba bean from 0.36 to 3.95 t/ha and wheat from 1.06 to 5.18 t/ha as SWS increased from 100-150 mm to 450-500 mm.

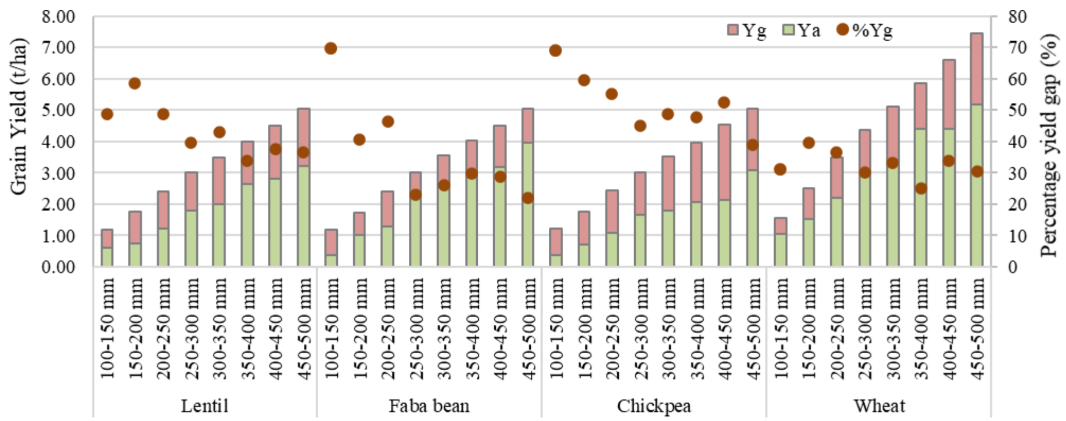

Figure 2 Average actual yield (Y_a), yield gap (Y_g) and percentage yield gap (%Y_g) of lentil, chickpea, faba bean and wheat grown under different seasonal water supply ranges in South Eastern Australia during 2009 – 2016. %Y_g is yield gap (Y_g) expressed as a percentage of water limited yield (Y_w).

The %Y_g of pulses generally decreased with increasing seasonal water: An increase in SWS from 100 – 150 mm to 450 – 500 mm decreased the %Y_g by 25% in lentil, 68% in faba bean and 44% in chickpea. However, for wheat the %Y_g only decreased by 2% when SWS increased from lowest to highest level. This indicates the presence of more production constraints in pulses especially in low rainfall areas and dry seasons compared to wheat (Figure 2). Generally, pulses had higher %Y_g compared to wheat at each SWS indicating potential of R&D strategies for bridging pulse Y_gS (Figure 2).

Variation of yields and yield gaps in Victoria and South Australia during 2009 – 2016

All the crops showed considerable annual variation of Y_a and Y_g during 2009 - 2016 reflecting the variability of seasonal conditions in Victoria and South Australia (Figure 3). The average Victorian $\%Y_g$ for pulses were 42% and 36% in South Australia reflecting the potential for improved agronomy to overcome subsoil constraints, diseases, weeds, waterlogging, frost, and reproductive heat stress, especially in Victoria (Nuttall et al. 2004; Delahunty et al. 2018).

In both states, chickpea had the highest average $\%Y_g$ (up to 50%) possibly due to ascochyta blight causing high yield losses (Murray & Brennan 2012). Faba beans had the lowest $\%Y_g$ averaged across years in both states (22% in Victoria and 29% in South Australia) indicating less production constraints and higher proportion of data from the HRZ where Y_gS are lower. The $\%Y_g$ for wheat was about 30% in both states again showing less constraints in wheat compared to pulses in South East Australia.

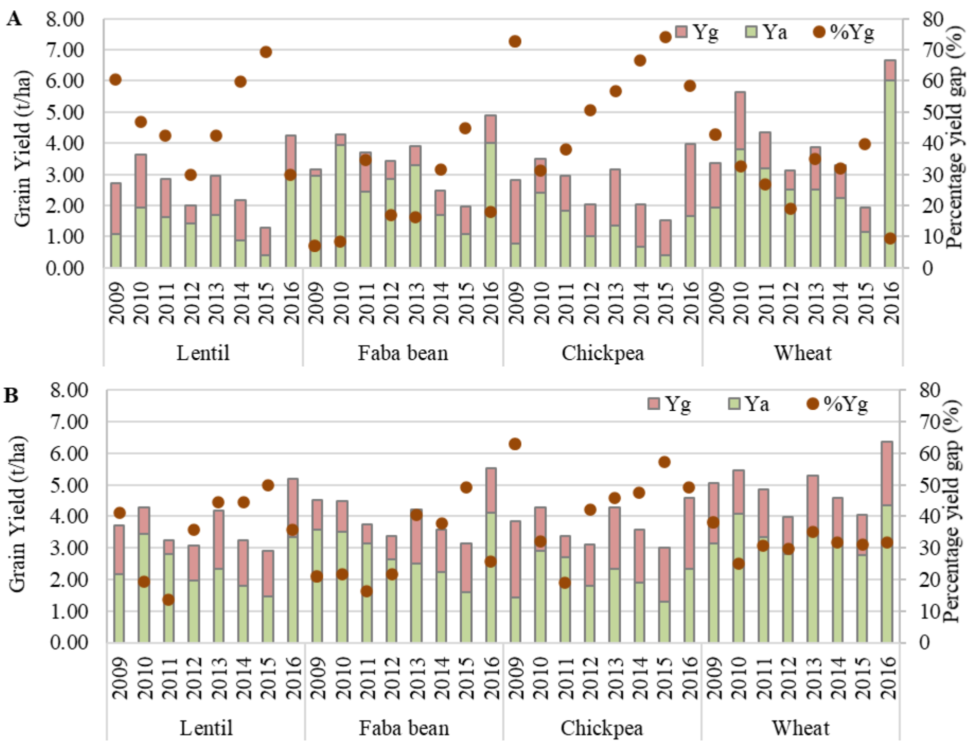

Figure 3 Average actual yield (Y_a), yield gap (Y_g) and percentage yield gap ($\%Y_g$) of lentil, faba bean, chickpea and wheat grown in (A) Victoria and (B) South Australia between 2009 and 2016. $\%Y_g$ is yield gap (Y_g) expressed as a percentage of water limited yield (Y_w).

Farm vs experimental yields

The Y_a of trials compared to farms were 24%, 33%, 37% and 116% more for wheat, faba bean, lentil and chickpea, respectively (Figure 4). This is because trials are normally located in more favourable soils and topography, being representative of the higher yielding parts of farmer paddocks and are managed to eliminate pests, diseases, and nutrient deficiencies.

On average $\%Y_g$ for pulses at farm and trial sites were 51% and 38%, respectively, which were higher than those for wheat, which was 38% at farms and 30% at trials (Figure 4). This indicates higher degree constraints at farm scale with pulses in contrast to wheat, where farms yield considerably closer to trials. Further, lower $\%Y_g$ for pulses (38%) at trial sites reflect optimal trial site positioning and that research programs are effectively addressing the constraints to narrow the Y_g in pulses.

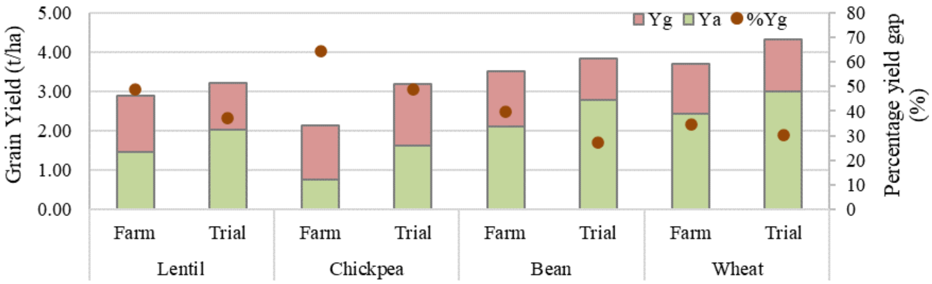

Figure 4 Average actual yield (Y_a), yield gap (Y_g) and percentage yield gap (%Y_g) of lentil, chickpea, faba bean and wheat in farms versus trial sites in South Eastern Australia during during 2009 – 2016. %Y_g is Yield gap (Y_g) expressed as a percentage of water limited yield (Y_w).

Seasonal water supply is a key determinant of the yields of lentil, chickpea, faba bean and wheat in Victoria and South Australia. Lentil and chickpea have larger Y_g than wheat. The Y_g in faba bean is comparable to wheat except under the lowest seasonal water supply (100-150 mm). Research trials generally show a lower Y_g than farmer trials indicating both the optimal site selection and that research is progressing to address the Y_g. However, further research is needed to identify the underlying issues limiting yield and to develop genetic and agronomic solutions for areas with larger Y_gS to increase productivity, profitability, and sustainability of farming systems.

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References

ABARES. (2018). Australian Crop Report: December 2019 No. 192 (No. 187; p. 33). Australian Bureau of Agricultural Resource Economics and Sciences (ABARES).

Delahunty, A., Nuttall, J., Nicolas, M., & Brand, J. (2018). Response of lentil to high temperature under variable water supply and carbon dioxide enrichment. Crop and Pasture Science, 69(11), 1103–1112.

French, R. J., & Schultz, J. E. (1984). Water use efficiency of wheat in a Mediterranean-type environment. I. The relation between yield, water use and climate. Australian Journal of Agricultural Research, 35(6), 743–764.

Murray, G. M., & Brennan, J. P. (2012). The Current and potential costs from diseases of pulse crops in Australia. (p. 208). Grains Research and Development Corporation. https://grdc.com.au/_data/assets/pdf_file/0021/82263/grdcreportdiseasecostpulsespdf.pdf

Nuttall, J., Armstrong, R., Imhof, M., Abuzar, M., & Belford, R. (2004). Subsoil constraints to dryland crop production on the low rainfall alkaline soils of Southeastern Australia. Challenges and Strategies of Dryland Agriculture, *32*, 373–387.

Robertson, M., Kirkegaard, J., Peake, A., Creelman, Z., Bell, L., Lilley, J., Midwood, J., Zhang, H., Kleven, S., & Duff, C. (2016). Trends in grain production and yield gaps in the high-rainfall zone of southern Australia. Crop and Pasture Science, 67(9), 921–937.

Sadras, V. O., & Rodriguez, D. (2007). The limit to wheat water-use efficiency in eastern Australia. II. Influence of rainfall patterns. Australian Journal of Agricultural Research, 58(7), 657–669.

Siddique, K. H. M., Regan, K. L., Tennant, D., & Thomson, B. D. (2001). Water use and water use efficiency of cool season grain legumes in low rainfall Mediterranean-type environments. European Journal of Agronomy, 15(4), 267–280.

Van Ittersum, M. K., Cassman, K. G., Grassini, P., Wolf, J., Tittonell, P., & Hochman, Z. (2013). Yield gap analysis with local to global relevance—A review. Field Crops Research, 143, 4–17.