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# Leading farmers in South East Australia have closed the exploitable wheat yield gap: Prospects for further improvement

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ABSTRACT

Australian dry-land crop producers farm in regions with highly variable climate and soils. Farmers have responded to the pressures of rising costs by pioneering and adapting new technologies to narrow the gap between actual and water-limited yield. With yields reaching a plateau in many of the developed world's cropping areas, it is possible that Australia's leading farmers have similarly closed the exploitable yield gap and require technological breakthroughs to sustainably push the production frontier to new and higher levels. To assess the potential for Australian farmers to continue closing the yield gap, and possibly increase water-limited yield, the long-term farm production records of individual wheat fields of three leading farmers in South East Australia were used to ascertain the applicability of modelling to develop new and innovative practices. The cropping systems simulator APSIM was used to establish the attainable simulated yield based on the farmers' chosen management inputs for wheat crops over a period of 16–20 years. A strong relationship ($r^2 = 0.89$, RMSD = 508 kg ha$^{-1}$) was found between actual and simulated yields. This relationship indicates that yield-reducing factors not simulated by APSIM (weeds, disease etc.) were largely controlled on these farms and confirms APSIM's suitability for this analysis. Over the 16–20 year study period, the average yield gaps on the three farms ranged from 480 to 770 kg ha$^{-1}$; representing between 74 and 82% of their water-limited yield potential. For these leading farmers, the yield gap is only small and unlikely to be economically exploitable under current management practices. Consequently, three tactical management innovations with potential to improve farm wheat yield and reduce risk were evaluated. One innovation investigated whether farmers practicing no-till crop establishment, who were able to control weeds prior to sowing, could benefit from sowing current cultivars earlier than present-day practice. It was found that leading farmers are already sowing at the optimum time and sowing earlier would not increase yield because of greater risk of frost damage. Two other innovations were found to have practical application. The first used Yield Prophet® to assist farmers decide when to apply in-crop nitrogen fertiliser based on a more complete understanding of nitrogen and water requirements of crops in variable growing seasons. The second innovation involved sowing slow maturing wheat cultivars earlier than current practice but only in years with adequate stored soil water and early season rainfall. Both innovations were found to increase grain yield and reduce risk of over- or under-application of nitrogen fertiliser. Investigation of strategic and tactical management options to increase yield using simulation modelling for subsequent evaluation in the field has the potential to keep Australian farmers at the forefront of innovations in crop production.



## 1. Introduction

To keep pace with global population growth and food consumption patterns, future global food security will require agricultural production in 2050 to be 60% more than it was in 2010 (Alexandratos and Bruinsma, 2012). As a net exporter of grains,

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Australia's wheat producers can contribute to this goal but this cannot be taken for granted given that over the last decade a number of the world's major cropping zones have reached production plateaux (van Ittersum and Cassman, 2013). One promising pathway for increasing grain production is by bridging the gap between yields currently achieved on farms and those that can be achieved by using the best adapted crop cultivars and production practices (van Ittersum et al., 2013).

Farming in dry regions with highly variable climate, such as South East (SE) Australia (Nicholls et al., 1997), is inherently a highly risky enterprise (Connor, 2004) and production of high yield is uncertain. Leading grain farmers have led the way in adopting new technologies and therefore provide insights into future trends in productivity growth. Over the last 20–30 years, these grain farmers initiated and participated in the rapid development and adoption of new and improved crop management practices. They have made significant changes to production systems, leaving behind traditional farming practices in which cereal crops were sown into cultivated soil, often after a long fallow period. No-till farming, where crops are now sown every year into standing stubble left from the previous crop, is now the norm for leading farmers. Sequences of cereals, oilseeds and pulses, which avoid the same type of crop on the same land in consecutive years, have reduced disease levels and improved weed control (Kirkegaard and Hunt, 2010). Nutrient supply and timing of operations have also improved markedly (Kirkegaard et al., 2013). It is significant, therefore, that leading farmers in SE Australia are concerned that their crop yields have reached a plateau and are asking the question 'Where are the next production gains coming from?'

In discussing yield potential and possible new management practices that may help increase farm production it is important to define the terms that are used to benchmark production:

- Ya = Actual yield: yields achieved in commercial fields. Reflecting farmers' natural endowment, access to technology, and their skill and exposure to real market economics (Evans and Fischer, 1999 as adapted by Hochman et al., 2009a).
- Ysim = Simulated yield: simulated yield for the same conditions, climatic and crop management, as practiced by farmers to achieve Ya. Ya will fall below Ysim when factors such as weeds and diseases have an impact on yield.
- Yw = Water-limited yield: simulated yield for the same conditions, climatic and crop management, as for Ysim, but with non-limiting N supply (Hochman et al., 2012). Yw, as defined here, applies to current best practice. New technology or innovative practices can increase Yw and so redefine the production frontier.
- Yg = Yield gap for rain-fed crops: the difference between Yw and Ya.
- Y% = Relative yield: calculated as 100 × Ya/Yw (Lobell et al., 2009).
- Exploitable yield gap: difference between 80% Yw and Ya. Based on observations that farmers' yields generally plateau at 80% of Yw, probably due to diminishing returns to investment and aversion to risk (Lobell et al., 2009; van Ittersum et al., 2013).

One solution to the challenge of future yield gains is to close the current yield gap (Yg) between water-limited yield (Yw) and actual farm yield (Ya) (van Ittersum et al., 2013). An average yield gap of 2000 kg $ha^{-1}$ (average Y% = 53%) was estimated for wheat (*Triticum aestivum* L.) grown in one of the higher rainfall regions of SE Australia (Hochman et al., 2012). Clearly there is an exploitable yield gap for many farmers and it is important that appropriate management strategies to increase Ya are identified and communicated to these farmers (Keating and Carberry, 2010). Farmers with no exploitable yield gap will need to investigate opportunities to increase Ya and Yw through new and improved crop management practices or wait for a technological breakthrough. Without such action, productivity gains in the Australian grains industry will slow down.

The first issue raised in this paper is whether leading farmers in SE Australia are consistently producing crops at or near their water-limited yield. Farmers have been able to compare their actual wheat yields against the theoretical potential in a water-limited environment since French and Schultz (1984a) developed an empirical water use efficiency (WUE) model. This model estimates potential water-limited wheat yield (Yw) from crop water use calculated as the change in soil water content between sowing and maturity plus rainfall during the same period by assuming evaporative losses from soil of 110 mm and a maximum transpiration efficiency for grain yield of 20 kg $ha^{-1}$ $mm^{-1}$. Based on this benchmark, weeds, diseases, sowing time and nitrogen deficiency were identified as the main reasons for yields levelling at 2000 kg $ha^{-1}$ in seasons with above average rainfall (French and Schultz, 1984b; Cornish and Murray, 1989). The WUE methodology for calculating Yw allowed farmers and advisers to quantitatively assess crop performance in variable, low rainfall environments and begin to identify why individual crops did or did not reach Yw. In the two decades since French and Schultz published their seminal work, atmospheric $CO_2$ levels have increased, semi-dwarf wheat cultivars with higher harvest index became available, and together with genetic gain, wheat yield steadily increased by 0.5% p.a. (Fischer, 2009) such that by 2006 the WUE benchmark has been re-evaluated at 22 kg $ha^{-1}$ $mm^{-1}$ with a minimum evaporation of 60 mm (Sadras and Angus, 2006) and more recently, by assuming that the ratio of evaporation to transpiration in cultivars has not changed with year of release, at 25 kg $ha^{-1}$ $mm^{-1}$ (Sadras and Lawson, 2013). Extensive application of WUE for calculating water-limited yield also revealed limitations in the method, especially in relation to the impact on yield of: (i) distribution of rainfall during the cropping season; and (ii) differential ability of individual soils to hold and supply water to the crop (Hochman et al., 2009a; Oliver et al., 2009). It became clear that a more dynamic model was required to improve the determination of Yw and Ysim and to show how yield gaps (Yg) may be exploited.

Simulation modelling offers the possibility to combine the understanding of many individual complex processes and interactions when crops are grown in water- and nitrogen-limited environments (O'Leary and Connor, 1996; Probert et al., 1998). Grain farmers in Australia now have access, by means of the internet, to the latest developments in the cropping systems model APSIM (Keating et al., 2003) through the Yield Prophet® program (www.yieldprophet.com.au) (Hunt et al., 2006; Hochman et al., 2009b).

Yield Prophet® was first tested off-line in 2002 and since 2004 is nationally available on-line as a user-pay service supporting crop management. It was created through collaboration between farmers, researchers, the Birchip Cropping Group (BCG) and a private consulting agronomist (Hunt et al., 2006; Hochman et al., 2009b). Extensive testing of APSIM simulations in explaining wheat field yield variations has been conducted and reported by Carberry et al. (2009) and Hochman et al. (2009a). Australian grain farmers can now run interactive APSIM simulations, using Yield Prophet®, over the internet (Hochman et al., 2009b). This paper will further test the accuracy of APSIM simulation of wheat grain yields of individual fields over a period of 16–20 years and water storage during the summer fallow period to establish the local credibility of this modelling approach to determining Ysim and Yw.

The objective of the paper is to demonstrate how simulation modelling can assist farmers and their advisers to identify:

i. how close crops, grown under current management, are to their water-limited yield.