Nitrogen supply, rotation and variety are critical predictors of the water use efficiency of wheat in grower's paddocks in Victoria

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Abstract

Victorian grain crops rarely reach their water limited yield potential. Few Australian studies have systematically ranked the relative importance of various genetic, environmental and grower management attributes on this gap under commercial conditions. Wheat crops growing in 136 paddocks in the Victorian Mallee, Wimmera and High Rainfall Zone were monitored from 2013 to 2016 to assess the relative importance of 53 environmental, genetic/cultivar and grower management attributes on water use efficiency (WUE). Growing season rainfall ranged from Decile 1 to 10 and grain yields from 0 to nearly 10 t/ha in the study and WUE averaged 11.5 kg grain/mm/ha. Conditional forest analysis identified grower management as the key determinant of WUE, with N supply, previous crop rotation and variety as the most important factors. The results indicate the need to focus future extension messages and research priorities on N management, rotation and variety selection to maximise WUE.

Key Words

Water use efficiency, nitrogen, rotation, Genetics, Environment and Management

Introduction

Using a framework based on statistical yield and cropping area data, simulation modelling and GIS mapping, Hochman et al (2012) estimated that grain growers were on average only achieving 53% of the physiological water-limited yield potential of wheat, although van Rees et al. (2014) suggested that some growers at least achieve close to 80% of the potential. The magnitude of this gap in commercial crops can be demonstrated between widely differing grain yields between adjacent paddocks, where rainfall is presumed to be comparable. Anecdotally these differences were attributed to different soils, disease, poor nutrition, late sowing, weed competition better varieties or simply 'good luck'. Studies based on designed experiments in Western Australia suggest that most of the yield gap in wheat can be attributed to 'environmental' (E) factors rather than management (M) or genetics (G). The full productivity potential of the Victorian grains industry will be difficult to achieve until the specific underlying causes and their relative effect on this unrealised potential are determined.

In designed experiments, resource limitations inevitably limit the number of factors that can be controlled. In contrast survey techniques undertaken in grower's paddocks can simultaneously account for multiple factors providing the sample size is sufficient. This paper reports on a study which examined factors contributing to grain of wheat in farmers paddocks sown to wheat. Because water supply is the key determinant of yield in these environments, we use water-use-efficiency (WUE) as the key metric. The effects of a range of factors including different factors broadly classified as **G**enetics, **E**nvironment and **M**anagement on WUE were measured. This large data set was then analysed using a range of 'traditional' statistical procedures, as well as recently developed multivariate and machine learning procedures to identify the relative importance of these different factors on the WUE of wheat in growers' paddocks.

Methods

Paddocks sown to wheat were monitored from 2013 to 2016. Most paddocks (> 80%) were in the Wimmera (390 to 430 mm annual rainfall) but paddocks from the Victorian High Rainfall Zone (>550 mm) and Mallee (325 to 365 mm) regions of Victoria were also included. In each paddock, 3 datum points were selected based on known differences in yields (e.g. obtained from yields maps or grower knowledge) or visual differences in topography or soil type where maps were not available. A total 138 paddocks and 408 datum points were measured.

A total of 53 different factors broadly classified as Environmental (including soil physicochemical properties throughout the soil profile (0-120 cm) such as pH, electrical conductivity, Sodicity, Colwell P, mineral N prior to sowing, soil classification, organic C and disease risk as measured by PredictaB), grass and broadleaf weed infestation and rainfall and temperature, Management (sowing date and rate and fertiliser application) and Genetics (variety, maturity class) were assessed.

Water use efficiency (WUE), rather than grain yield, was used as the key response variate to account for the known, overriding effect of growing season rainfall on grain yield. In contrast to other approaches based purely on rainfall, account was made of water stored in the profile prior to sowing (e.g. following a long fallow) or unused at maturity (due to soil constraints on root growth). This was calculated as:

WUE (kg grain/mm water) = Grain Yield (kg/ha)/WU (mm water) …Eq. 1., where
WU (mm water) = (Wv (mm) at sowing – Wv (mm) at Maturity) + GSR (mm) …Eq. 2 and

Wv is volumetric water calculated on a soil profile basis (0-120cm) and adjusted for estimated bulk density and GSR is growing season rainfall (April-November).

Data analysis
A variety of statistical methods was used to account for the inclusion of both categorical and continuous variables in this multivariate dataset when explaining variation in WUE. Procedures used included univariate statistical comparisons (analysis of variance (ANOVA)), multiple linear regression, Regression Trees (Breiman et al. 1984) and Random Forests (Strobl et al 2008; Breiman 2001) between a variable and WUE.

Results and Discussion

Rainfall during the four-year study period ranged from Decile 1 to Decile 10 for annual and growing season rainfall (data not presented).

Grain yields of wheat averaged 3.37t/ha (range: 0.01 to 8.83t/ha), WUE averaged 10.6kg/mm/ha (0.06-29.6kg/mm/ha), grain protein averaged 12.1% (7.3%-20.6%) and GSR 285mm (121-672). The frequency distribution of grain yields was skewed towards < 3t/ha, while for WUE this average was more normally distributed, but with a small number of outliers at the high (>24kg/mm/ha) end.

Canola was the most common crop preceding wheat in the rotation (43%), followed by the pulses faba beans, lentils, chickpeas and field peas (data not presented). Few wheat crops followed either fallow or pastures (reflecting the dominance of Wimmera paddocks in the dataset). Twelve percent of the wheat crops surveyed were preceded by a wheat crop. More than 60% of the wheat paddocks survey had been planted to either wheat or barley within the previous two seasons. A total of 22 different varieties were grown, including Scout (19.2 % of total), Wallup (12.5%), Yipti (10.3%), Correl (8.8%), Derrimut (7.4%) and Trojan (5.2%).

Water use efficiency
The WUE of wheat averaged across all paddocks and seasons was 11.5 kg grain/mm/ha (Figure 1), well below the theoretical potential of 24 kg/mm/ha recently suggested by Sadras & Lawson (2013). As expected, there was marked variation between paddocks in WUE but notably, a sizable proportion of paddocks recorded WUE above the French & Schultz (1984) frontier of 20 kg grain/mm/ha.

An assessment of factors contributing to WUE using Conditional Inference Forest Analysis (Figure 2) indicated that three out of the top five influential factors were classified as Management with a total of 34% of the variation explained. The rate of N fertiliser applied was clearly the most influential factor, followed by crop rotation in the previous year, variety, sowing date, and soil manganese concentration. A range of other factors, most classified as environment were rated as significant and included profile mineral N prior to sowing, available soil (Colwell) P concentration, soil type and risk of diseases such as crown rot (*Fusarium pseudograminearum*), yellow leaf spot (*Pyrenophora tritici-repentis)* and root nematodes (*Pratlynthus thornie)*. Whereas these factors individually did not make a major contribution, collectively they did, indicating the need for growers to account for them if the difference between actual and potential WUE d is to be narrowed.

The importance of N rate on WUE can be judged by the partial dependence plots. For example, WUE increased rapidly from less than 9kg /mm/ha at low rates of N before plateauing at 12kg /mm/ha at rates of 50kg N/ha or greater (Figure 3).

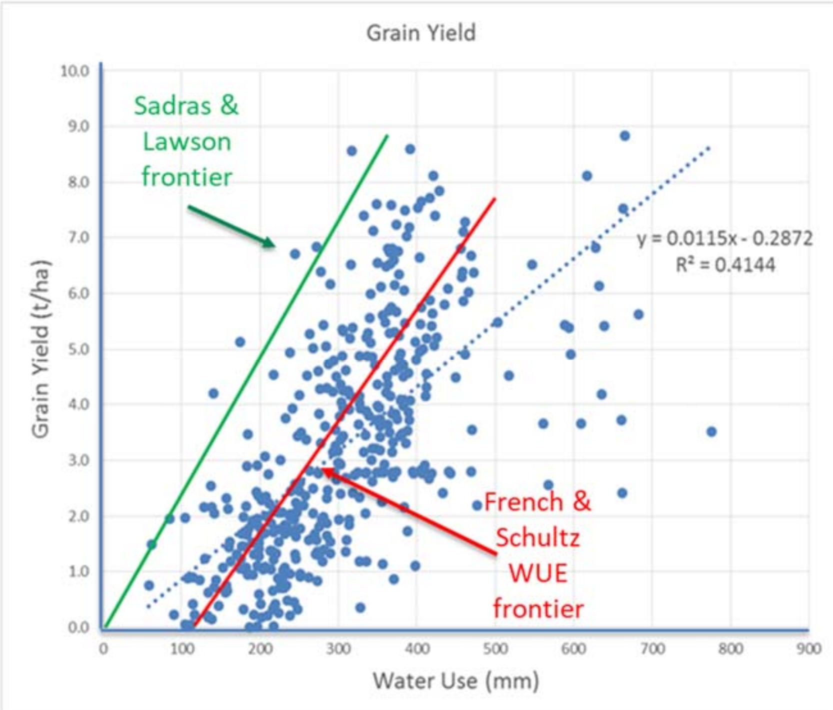

Figure 1: Relationship between water use (mm) and grain yield (t/ha) of wheat across all survey points. The green line represents the theoretical frontier (Sadras & Lawson 2013) of 24 kg grain /mm/ha, whereas the French & Schultz WUE frontier line represents French & Schultz (1984) benchmark (20kg/mm/ha).

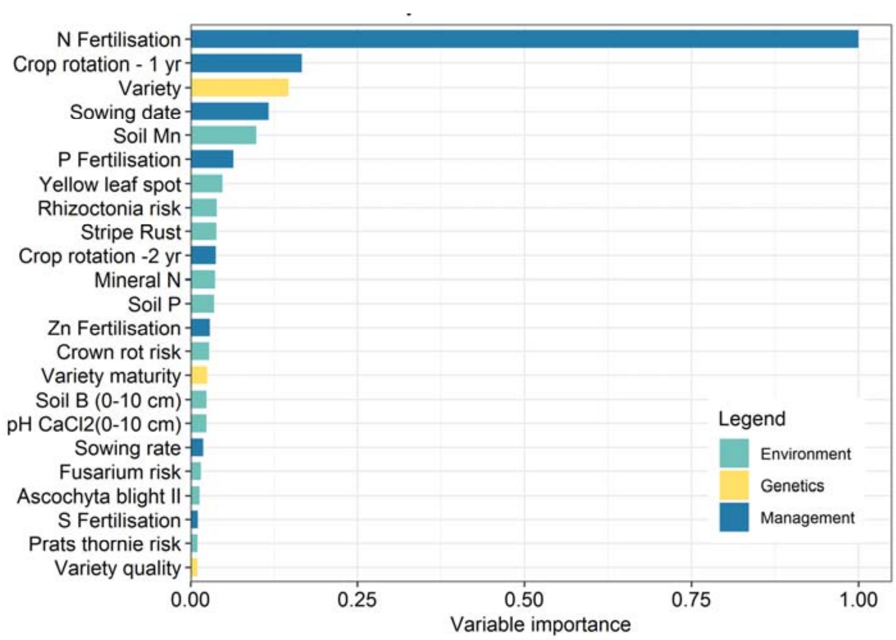

Figure 2. Relative importance of different environmental, genetic and management factors contribution to the WUE of wheat in growers' paddocks (2013-2016) based on Conditional Forest Analysis.

The conditional forest analysis explained 33.7% of the variation in WUE, suggesting other factors such as heat shock during grain filling and frost (e.g. Barlow et al 2015), both of which were not accounted for in this current analysis, and are most likely to make an important contribution to the yield gap.

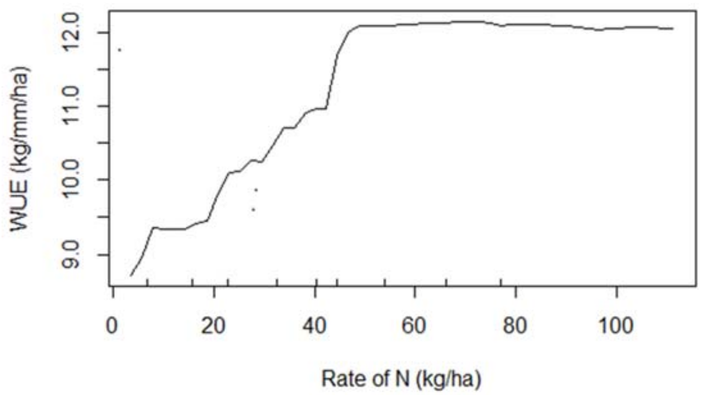

Figure 3: Partial dependence of WUE (kg/mm/ha) and rate of N fertiliser (kg/ha) applied to wheat.

Conclusions

This study aimed to generate an evidence-based 'hierarchy' of factors (biophysical, genetic and management) that influence WUE of wheat in growers' paddocks. In contrast to other studies with similar aims e.g. Anderson et al. (2010) in which factorial designed 'white peg' experimentation was used, the results in the current study were based on current grower management practices where both logistical and cost pressures strongly influence decisions.

Grower management, particularly N management, rotation and sowing time, along with variety choice, are key drivers of the water limited yield potential of wheat in grower's paddocks in western Victoria. Whereas grain growers have achieved significant improvements in WUE in recent decades, water limited grain yields remain well below the yield potential. A significant proportion of the variability in WUE remains unexplained, but the effect of heat shock and frost are likely to be important contributors.

Acknowledgements

This study was co-funded by Agriculture Victoria and the GRDC (Project CSA00055). We wish to thank Grant Hollaway and Josh Fanning for assistance with plant pathology analysis and Mark Imhoff and David Rees for soil classification. We are particularly indebted to the 45 Victorian farmers who participated in the study.

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