Estimating yield gaps in rainfed wheat caused by a nitrogen fertiliser deficiency in Western Australia in 2015

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Abstract
The size of the yield gap, defined as the difference between water-limited potential yield and farm yield, is often a result of a combination of management activities. A small yield gap implies that management is near optimum. Nitrogen (N) deficiency often limits crop yields and it is essential to understand its effect of N fertiliser on yield gap. This study assessed whether N fertiliser was deficient and limited dryland wheat yield in Western Australia in 2015, using the APSIM model and agronomic practices surveyed from 47 paddocks. The farm survey indicated that the N fertiliser applications ranged from 0 to 98 kg/ha, with 80% of surveyed paddocks applying less than 45 kg/ha. The simulated yield with N fertiliser applied on farm (farm yield) ranged from 1.9 to 5.7 t/ha with an average of 3.2 t/ha. The yield gaps due to N fertiliser deficiency ranged from 0 to 1.6 t/ha, with an interquartile range of just 0.6 t/ha. The range of the relative yield gap (expressed as yield gap % of water-limited potential yield) was from 0 to 34%, with only 2 out 47 paddocks having a relative yield gap > 30%. We concluded that wheat yield was not limited by N deficiency in the majority of surveyed farms in Western Australia in 2015 due high soil mineral N at sowing and mineralised N. However, there is still a potential to increase yield for paddocks that had higher potential yield through improved N fertiliser management.

Keywords
Wheat, APSIM model.

Introduction
To overcome the challenge of feeding more than 9 billion people by 2050, it is critical to identify pathways to close yield gaps defined as the difference between (water-limited) potential yield and actual yield (Evans 1996). To achieve this target, there is a need to identify the factors that limit crop yields. Many studies have been conducted to explore yield potentials, yield gaps and their limiting factors (Hochman et al. 2016; van Ittersum et al. 2013) and provide useful information on the scope for improving yield. However, most of these studies examined yield gaps at the region or agro-climatic zone scale, using aggregated data for actual yield; while farmers' decision-making takes place at the farm level.

Rainfed agriculture covers 80% of the world's cultivated land and produces 60% of total crop production. Nitrogen (N) is often considered as the most important factor to affect crop growth and yield in dryland farming system (Dawson and Hilton 2011). A sufficient N fertiliser supply for crops might at least partially contribute to improve yield and reduce yield gaps. However, our quantitative understanding of the constrains of N availability on yield gap in key crops in Australian agriculture is still limited by the lack of necessary data on-farm measurements such as soil variation and soil constraints (Oliver and Robertson 2013). Thus, there is a need to analyse yield constraints caused by N fertiliser in a farmer's field to identify N management strategies for Australian rainfed agriculture.

Crop simulation models including the APSIM model, combined with farming practices on soil properties and agronomic practices, have been widely used in yield gap analysis (Calviño and Sadras 2002; Oliver and Robertson 2013). APSIM was used in this study to estimate water-limited potential yield and yield with N fertiliser applied on farm (farm yield). The aim of this study was to determine the size and distribution of yield gaps of dryland wheat associated with N deficiency in Western Australia.

Methods

Farm survey and data collection

47 paddocks, where wheat was grown, were monitored for the growing season of 2015 (Figure 1). These farms were selected on the basis that they were owned by leading farmers and cover the range of prevailing rainfall and soil conditions across Western Australian grainbelt.

Collaborating consultants supplied agronomic management details such as the management of previous crop residues and tillage, cultivar, sowing date, seeding rate and fertiliser management (type, application rate and date). The variation in soil conditions within a paddock may affect crop performance. To consider such an effect, soil types were identified and soil water and mineral N before sowing were measured in two transects (zones) selected across each paddock. Cores were subdivided into depth increments to estimate the water and N availability down to a depth of 1 m.

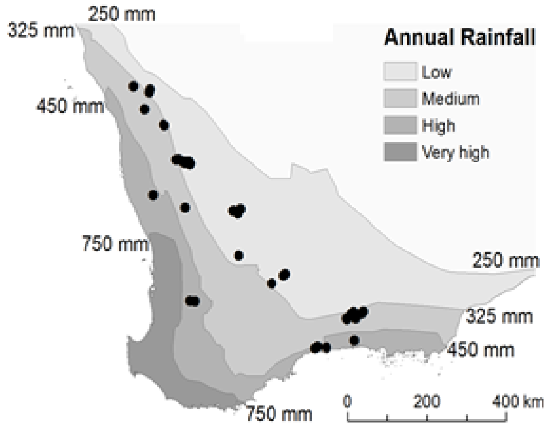

Figure 1. Location of the paddocks surveyed in Western Australia.

The APSIM model

The agricultural production systems simulator APSIM (Holzworth et al. 2014) was used to simulate water-limited yield potential and farm yield (see below). APSIM is a component based simulation framework with modules for simulating a crop (e.g. wheat) growth and development, soil water and nitrogen dynamics.

APSIM combines weather data, soil data, crop varieties and crop management rules to simulate crop production. The primary objective of this study is to assess wheat yield gap driven by N deficiency, not to simulate crop phenological development. Therefore the default cultivar parameters for surveyed wheat cultivars were adopted from APSIM v7.8. The farmers' other agronomic practices (sowing date, plant density, residue and fertiliser) were used as model inputs. For the simulations, soil parameter values for the identified soil types in the surveyed paddocks were sourced from APSoil. Weather data were sourced from SILO from meteorological stations located adjacent to the farms.

Estimating Yield gap in farmers' fields caused by N fertiliser deficiency

Yield gaps were estimated as the difference between water-limited potential yield and simulated farm yield. To assess the yield gap solely caused by N fertiliser deficiency, the farm yields were simulated with the N fertiliser applied on-farm in 2015 across the 47 surveyed paddocks, and were assumed to be free of weeds, pests or diseases. Water-limited potential yields were simulated with soil nitrate-N being topped up by 50 kg/ha whenever soil nitrate in the top 60 cm was less than 50 kg/ha up to anthesis. Both water-limited potential yield and farm yield were simulated at the two zones for each paddock, which were then averaged to obtain the two levels of yield on farm.

Results

Assessing applied N fertiliser on farms and attainable farm yield

The On-farm survey showed that the major fertilisers used for wheat were flexi-N (32%N) and urea (46%N) (Data not shown). The amount of N fertiliser applied for wheat in 2015 varied between 0 and 98.4 kg/ha, with 25% of farms having applying <25 kg/ha and 75% of farms applying <45 kg/ha (Figure 2). For a specific season, the variations of both N fertiliser application and N demand could be explained by soil texture, the amount of initial soil N, soil moisture, crop residue and farmers' experience (Anderson et al. 2005). Simulated farm yields with N fertiliser applied ranged from 1.9 to 5.7 t/ha for 2015, with an average of 3.2 t/ha (Figure 2). The cumulative distribution function showed the yield with 75% probability was less than 3.7 t/ha and with 25% probability was less than 2.5 t/ha.

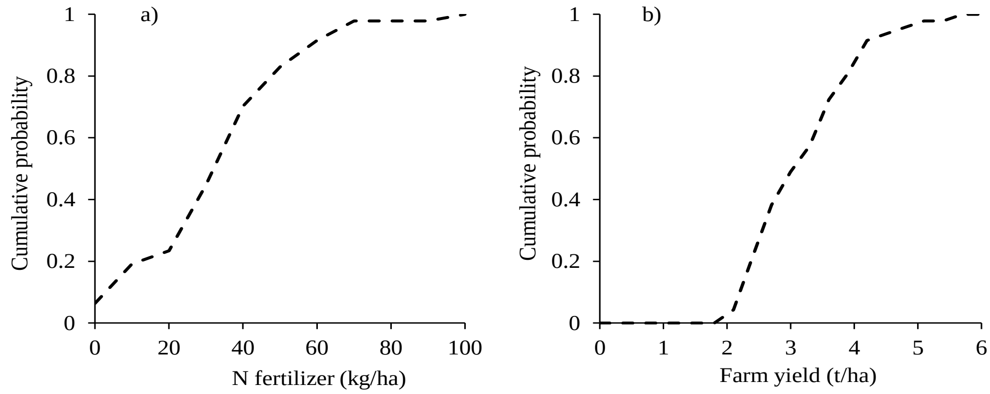

Figure 2. Cumulative probability distributions of N fertiliser application (a) and simulated farm yields (b) across 47 paddocks surveyed in Western Australia in 2015.

Yield gap analysis

Considering heterogeneity in soil nutrients, soil organic matter, available water capacity and climate in space, in this study, the yield gap was evaluated at a field scale to investigate the N fertiliser as a strategy in bridging the rainfed wheat yield gaps under farmer's management. Simulated water-limited potential yield ranged from 2.0 to 6.0 t/ha, with interquartile range of 2 t/ha (Figure 3a). The gap between water-limited potential yield and farm yield ranged from 0 to 1.6 t/ha, with 75% probability being less than 0.3 t/ha and 25% probability was less than 0.8 t/ha (Figure 3b). A relative yield gap, calculated as yield gap/water-limited potential yield × 100, ranged from 0 to 34% with 4 out of 47 paddocks being close or larger than 30%. Wheat did not suffer from N deficiency in more than 90% of paddocks surveyed. This was because 2015 had medium-low crop season rainfall for the wheatbelt of Western Australia (from http://www.bom.gov.au/climate/current/annual/aus/2015/), and soil mineral N at sowing was high for this season, ranging from 50 to 220 kg/ha (data not shown). Both yield gap and relative yield gap obviously related to the size of potential yield (Figure 4), indicating there was a potential to increase wheat yield for paddocks that had higher potential yield through improved fertiliser management. This result agreed with the reports of Gobbett et al. (2017) and Hochman et al. (2016), who found that gains in closing yield gaps were most likely to be made where yields were higher.

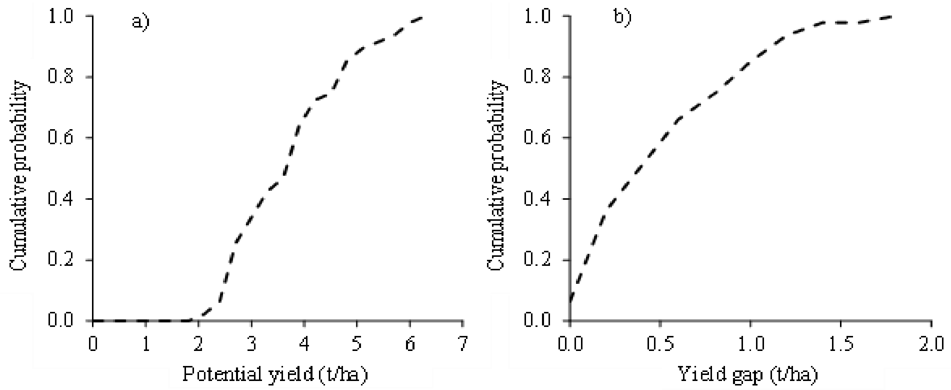

Figure 3. Cumulative probability distributions of water-limited potential yield (a) and yield gap (b) across 47 paddocks surveyed in Western Australia in 2015.

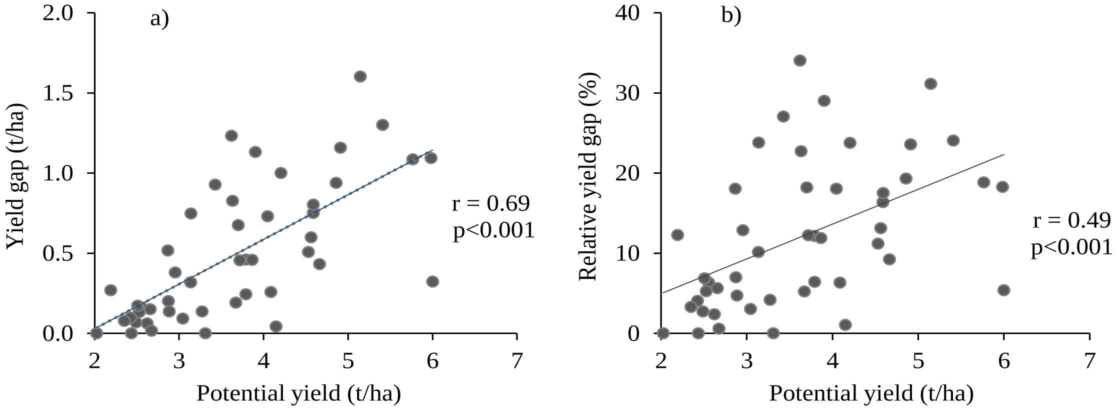

Figure 4. The relationship between water-limited potential yield and yield gap (a) and water-limited potential yield and relative yield gap (b).

Conclusions

This study integrated paddock survey and simulation modelling tools to quantify the dryland wheat yield gap caused by N fertiliser deficiency. The simulation results showed that wheat yield was not widely limited by deficiencies in N fertiliser application in most of paddocks owned by leading farmers in the wheatbelt of Western Australia in 2015, thanks to the high N from mineral N at sowing. However, there is still a potential to increase yield for paddocks that had higher potential yield through improved fertiliser management. More work is required to identify other factors that contribute to yield gaps. Work is also needed to identify yield gaps and limiting factors for below-average farms.

Acknowledgement

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