National and regional assessments of crop yield trends and water use efficiencies

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Abstract
Low productivity increases and unsustainable farming systems have been a concern in the Australian grain industry. However, a crop modelling exercise found a dramatic improvement in recent cropping performance in many areas. National wheat yield trends during the 1980s/1990s increased three-fold over the previous 50-year period. Considerable regional variations were found with higher wheat yield trends found across Western Australia, in wetter areas of South Australia and southeastern and northern New South Wales. Higher trends occurred where farmers addressed a number of limiting soil factors, including chemical (nutrient, acidity), biological (root diseases, weeds) and physical (water storage, infiltration). The best performing shires consistently increased N fertiliser application and crop diversity (pulses, oilseeds, or sorghum), with the latter being important where N-fixation, and/or soil cleansing of root diseases, was beneficial. Climate variability dominates regional cropping performance through its impact on yield variability and the level of risk associated with a high-input, high-yield, farming system. The application of N fertiliser and the adoption of pulses and oilseeds decreased as yield variability increased. High water use efficiencies (WUE) were generally found in southern States where soils had good water-holding capacities, rainfall was reliable between June and September, and yield variability was low. Relative profitability of different crops was important as trends and WUE for barley and oats were lower than that for the more profitable wheat crop. The regional pattern of barley trends tended to match that for wheat, while oat yield trends tended to match the winter rainfall distribution. Sorghum yields increased steeply in the 1990s in northern NSW as farmers increased nitrogen inputs, while in Queensland very high yield variability discouraged increased fertiliser use.

Key Words
Yield trend, productivity, water use efficiency, variability, technology, nitrogen

Introduction
Hamblin and Kyneur (1) found low or static wheat yield trends across many drier areas of the Australian wheatbelt between 1950 and 1991. They attributed this to low soil fertility, largely related to nitrogen (N). The main factors limiting input of N were poor legume pastures, a low proportion of grain legumes in rotation and inadequate inputs of N fertiliser. Cornish et al*.* (2) also found low productivity growth in northern cropping regions between 1975 and 1993 and also attributed this to low N fertiliser use. In contrast, considerable improvements (up to 80 kg/ha/yr) were found in Western Australian between 1980 and 1994 (3) and wetter shires of South Australia prior to 1995 (4). For many shires, the early 1980s appears to be a break point where farmers began to increasingly switch to early sowing with herbicide control of weeds, use better tillage techniques, increase N inputs, and plant more grain legumes (3). The nation-wide transition to higher-yielding semi-dwarf varieties was also being completed, especially in Western and South Australia (5).

As a part of the National Land and Water Resources Audit (NLWRA), theme 5.1 (Land Use Change, Productivity and Diversification) commissioned a national study to examine productivity changes and production efficiency (6). This paper provides an overview of shire-level yield changes and Water Use Efficiencies (WUE) determined by the STIN crop model (3,7). Crops examined were the main winter crops: wheat, barley, oats (and other cereals), and the main summer crop, sorghum. Other data and maps produced by the NLWRA were used to analyse the STIN model outputs as a basis for determining what factors have been most influential in adjusting production efficiencies and trends.

Methods
The last 15 years of full agricultural census data (1982-96) was obtained from the Australian Bureau of Statistics (ABS). Where shire boundaries had changed, the NLWRA retrofitted data for the 1996 SLA boundary back in time. To properly examine yield trends, the Western Australian Department of Agriculture's STIN model (3,7) was used to remove the seasonal variation in rainfall through the audit

period. STIN calculates a weekly water balance and accumulates moisture stress (waterlogging, water deficit) experienced by the crop through the growing season. For each shire, STIN was calibrated on shire yields and a representative rainfall station for each shire. This model utilises a multiple regression approach to differentiate water supply variability and trends in technology. It assumes a linear increase in yields with time, with model predicted yields (Y) calculated by:

$$Y = b_0 + b_1*(SI) + b_2*(year) \quad (1)$$

where SI is the STIN moisture stress index and b_0, b_1, and b_2 are the population regression coefficients estimated by the method of least squares. By using this approach, the climate variability is removed via the stress index, leaving edaphic and technological factors contributing to the trend term (b_2). Actual yields were converted into de-trended yields using (b_2) and the variability of de-trended yields was examined through the coefficient of variation.
Water use efficiency is related to the amount of grain produced per millimetre of total water used in the crop growing period. To assess water use (or production) efficiency of shire yields, actual shire yields were divided by potential shire yields (Y_{pot}) defined by French and Schultz (8). However, instead of using a fixed 110 mm of rainfall as soil evaporation we assumed that a third of growing season rainfall was lost to soil evaporation. This assumption prevents the actual yield exceeding the potential yield in drought conditions (Tennant, personal communication).

Results and discussion

The output from the modelling and regression analysis showed considerable rates of winter crop yield improvement in Western Australia, and to a lesser extent in South Australia and New South Wales. The importance of N was confirmed, as regions with increased N supply to crops were most successful at raising productivity and had a positive N balance. The success of wheat/sorghum rotations in northern New South Wales was also a standout performer compared to earlier studies.

In relation to wheat it was found:

- A recent three-fold increase in national wheat yield trends compared to the previous 50-years. Regionally, highest wheat yield trends (> 60 kg/ha/yr) occurred in south-eastern and north-eastern areas of New South Wales, north-western and south-western Western Australia, wetter districts in South Australia and the south-eastern edge of the Darling Downs in Queensland. Negative yield trends were found in some of the most variable shires of Queensland and South Australia, along with shires in the Murray Mallee (New South Wales) and Hindmarsh shire in the northern Wimmera (Victoria).
- Higher yield trends occurred where farmers addressed a combination of soil constraints, including chemical (nutrient, acidity), biological (root diseases, weeds, nematodes) and physical (water storage, infiltration) factors. The best performing shires consistently increased N fertiliser application and crop diversity (pulses, oilseeds, or sorghum), with the latter being important where N-fixation, and/or soil cleansing of root diseases, was beneficial.
- Climate constraints dominated the performance of the Australian grain industry as unreliable rainfall across seasons resulted in yield variability and income risk adversion practises. High yield variability is a major constraint to increased crop productivity as it is deters:
    - (i) Adoption of non-cereals. If the coefficient of variation (CV) of wheat yields (across seasons) exceeded 0.35, there was a small increase (even decrease) in crop diversity, whereas a 10-25 per cent increase in diversity generally occurred when the CV was less than 0.2; and
    - (ii) High application rates of N fertiliser. Low to negative yield trends occurred over large areas of Queensland, northern Eyre Peninsula (South Australia), northern Victoria and central NSW where yield variability was very high and risk management kept N application rates very low.
- The most profitable farm businesses in the 1990s had high productivity increases, low yield variability and high cropping intensity. Higher cropping intensity did not seem to impact negatively on crop performance as higher trends have occurred in some of the most intensely cropped zones where cropping intensity has increased (more non-cereals in rotation). Farm business profits appear linked to the adoption of new farming technology and the amount of inputs applied.
- Highest percentage increases in wheat yields generally occurred across Western Australia and were related to widespread adoption of a new agronomy package, incorporating new varieties and better management. The change to a wheat/lupin rotation substantially increased wheat yields on infertile soils,

especially in the northwest cropping areas. Low yield variability and many good seasons (absence of major droughts) encouraged a high yielding cropping system.

- In South Australia, wheat yield trends were the most closely related to rainfall, with wetter districts (> 400 mm annual rainfall) consistently having yield increases greater than 45 kg/ha/yr, and drier districts consistently lower than 30 kg/ha/yr. Drier districts with greater yield variability were slower to adopt break crops, had greater root disease and applied little N.
- Victorian wheat yield trends were lower than other regions in southern Australia and coincided with a negative N balance across the main cropping areas. Despite a 10-35% increase in the proportion of pulses and oilseeds in rotation in southern Victoria, wheat yield trends suffered as grain legumes in this region leave little residual N, better land was planted to "cash" legume crops, and a decline in long fallowing reduced the amount of soil moisture carrying through to wheat crops.
- In south-eastern New South Wales, very large yield trends coincided with some of the largest application rates of lime and adoption of canola, better grass weed control, and use of higher yielding varieties in wetter areas. Very low wheat yield trends in northern New South Wales were reversed, as farmers:
  (i) substantially increased application of N fertilisers and reversed soil fertility decline;
  (ii) improved fallow and weed control management; and
  (iii) increased summer cropping (sorghum) which forms a break crop reducing root disease. Increased cash flow from successful summer crops (sorghum/cotton) meant farmers were able to spend more on inputs for winter crops. Also, the realisation that applied N can carry over from a low yielding crop to the next season has reduced the downside risk of high input costs and losses in dry seasons.
- Queensland wheat yield trends were severely affected by droughts of the early 1990s, low N inputs, low adoption of legumes and oilseeds and an increase in root diseases coinciding with increased stubble retention/ minimum tillage.
- High water use efficiencies (WUE) were generally found in southern States where soils had good water-holding capacities, rainfall was reliable between June and September, and yield variability was low. Subsoil restrictions to roots, root diseases, nutrient deficiencies and extreme climate variability appear to substantially reduce WUE in north-eastern regions. High amounts of drainage and waterlogging on duplex soils reduce WUE in wetter districts of Western Australia, while poor water-holding capacities, highly sodic subsoils, and water repellency appear to reduce WUE in the Eyre Peninsula and the upper south-east of South Australia.

In relation to the other winter cereals and the summer crop sorghum, this study finds:

- Barley yield trends were generally lower than wheat, attributable to less N fertiliser, as price premiums were offered for malting barley which required lower protein/N content in the grain. Trends showed the same regional patterns as wheat, but were better than wheat in southern Victoria and southern Western Australia where barley better handles waterlogging and frosts.
- Oats (and other cereals) had lower trends than wheat, but did better in wetter/cooler environments where special contracts for milling oats were offered. Trends were highest in southern Australia and negligible in northern areas where they are only grown in small amounts.
- Summer sorghum yields improved dramatically in northern NSW in the 1990s in conjunction with a large increase in N application, whilst serious droughts restricted trends in Queensland.
- The regional pattern of WUE for barley, and oats and other cereals tended to match wheat, but were mostly lower, especially in more northern and more arid regions. There was a steep decline in sorghum WUE as one moves inland from the Darling Downs and Liverpool Plains to regions in the western cropping areas of Queensland and northern New South Wales.

With Australian growers shifting to higher input farming, there is now a greater vulnerability to financial losses in poor seasons, and therefore a greater need for:

(i) accurate seasonal forecasts with good lead times and tactical decision support tools to assist in managing crop selection and inputs in relation to climate risks;
(ii) better allocative skill (mix of crops in relation to prices) in decision making; and
(iii) increased N use efficiency through tactical and targeted management (e.g. precision agriculture) and more nutrient responsive varieties.

Conclusion

Recently, productivity gains have increased at a greater rate as farmers have shifted to a higher input farming system in conjunction with higher yielding varieties and better management practices. High levels of agricultural R&D spending has brought big dividends as cropping business profits have improved and Australia has lifted its share of world wheat exports. To maintain this trend, improvements must continue in varieties, management, and nutrient use. However, future developments should focus on the unique regional pattern of climate and soil constraints highlighted in the NLWRA (6,9). Water-supply and N deficiencies appear to be the most limiting factors to crop production, but acidity, sodicity and diseases are also major limitations. All these factors and risks must be addressed systematically if relative production efficiencies are to improve further.

Acknowledgments

This research was funded by the National Land and Water Resources Audit and benefited from the generous advice of many district agronomists, consultants and researchers.

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