The determinants of South Australian wheat yield increases

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Abstract

We used Oz-Wheat, APSIM, historical variety evaluation trials and a range of variables derived from longitudinal statistics to explore: (A) the drivers of improved SA wheat yield efficiency between 1977 and 2006 and (B) the systems component contributions to average annual efficiency improvements. Wheat yield efficiency improved by an estimated average 1.7 percent p.a. with a slight, but significant, negative curvilinearity towards the end of the period. Significant positive explanatory variables for improved yield efficiency were increased fertiliser use and an improvement in wheat price compared to canola. Significant negative explanatory variables included wheat terms of trade and wheat area. We separated the system components of annual wheat efficiency improvements into varietal yield gain (VG) and improved farming systems (FSI) plus the FSI-VG interaction; with farming systems further partitioned into earlier sowing times and "other" changes. Wheat varieties have contributed 0.5 percent p.a. to efficiency improvement and hence 1.2 percent p.a. is attributed to farming systems improvement and FSI-VG interaction. We suggest that the 'change in average sowing time over the period' component of the farming systems gain necessarily includes larger and more efficient machinery, more effective and efficient use of better herbicides, etc, and estimate it to have contributed 0.7 percent p.a. Hence other factors of improved systems (e.g. more effective crop nutrition, effective rotations, etc) have contributed 0.5 percent. The annual improvement due to farming systems comes at a cost of 0.1 percent p.a. annual increase in farm inputs.

Key Words

efficiency improvements, explanatory variables, genetic gain, farming systems

Introduction

This study explores explanatory variables that could contribute to an understanding of wheat yield improvements in SA at a farm management level, and separates improvements into varietal gain (VG) and components of farming systems improvements (FSI) plus the VG-FSI interaction.

Methods

SA wheat yields and longitudinal efficiency gains

We used Oz-Wheat (Potgieter et al. 2005) predictions over the 1977-2006 period to provide seasonal estimates of SA wheat yields based on amount and timing of rainfall. The program uses 1993 technology with a basket of then current varieties, depending on sowing date. Hence Oz-Wheat provides a reference point in terms of technology in use. ABS (2004 and back issues) and PIRSA (2008) data were used to provide actual seasonal wheat yields over time. We ensured that these data were from equivalent SA constituent regions to those used in Oz-Wheat. We divided the actual seasonal yields by the Oz-Wheat predictions, and then converted the estimates to a longitudinal series with 1977 yield = 100.

Estimating efficiency improvements through time.

An average estimate was achieved by logging the ratio of observed wheat yield to Oz-Wheat yield and fitting a linear relationship, with the slope thus representing the average efficiency gain. Curvilinearity was assessed through the use of orthogonal polynomials, representing year, year squared and year cubed, regressed against the logged efficiency longitudinal series. SHAZAM v 8.0 (1997) was used in this and other OLS regressions.

Deriving and assessing the impact of explanatory variables as drivers of yield improvement

ABARE (2000, 2008), ABS and PIRSA data were used to derive 1977 = 100 logged longitudinal series for wheat terms of trade, wheat/canola price ratio, wheat/grain legumes price ratio, (no. of crop specialist farms)/(no. of crop specialist + mixed crop & livestock farms), wheat area, total crop area, oilseeds area, grain legumes area, grain legumes & oilseeds area, crops other than wheat area, wheat/(wheat & oilseeds + grain legumes area), (wheat area)/(total crops area), proportion of cropping area containing herbicide resistant weeds, fertiliser per ha cropped quantity index (QI), chemicals per ha cropped QI, fertiliser plus chemicals per ha cropped QI. Ordinary least squares time series analysis, using second order autocorrelation, was applied in a stepwise fashion until all non-significant explanatory variables were eliminated. In addition to using the derived efficiency series, actual longitudinal wheat yields (1977 = 100, logged) was also used as the dependent variable, with the Oz-Wheat series included as an additional explanatory variable.

Modelling wheat yield increase component contributions as percent annual increases

The following equations represent our modelling assumptions.

(A) Wheat yield increase = genetic gain component + farming systems improvements component
(B) Farming systems improvements a n interaction with genetic gain = improvement due to earlier sowing + other sources of improvement
(C) Wheat enterprise total factor productivity increase per ha = output factor productivity increase per ha – input factor productivity increase per ha
= wheat yield increase – changes in farming systems inputs per ha

Estimating varietal yield gain (Table 2)

To estimate the contribution from cereal breeding for yield, annual comparisons in the same variety trials in SA among the better-performing ('reference') varieties that were released in different years establish relative yields in identical situations in the seasons in question. Because relative performance can vary under a range of climatic conditions, representative sites at which the comparisons were made were nominated to cover major regional differences and the comparisons are based on several years testing. The results from the relative experiments are reported in annual reports of SARDI's varietal testing (SARDI 2007 and back issues).

Estimating wheat growing input factor productivity per ha

A full accounting of the impact of farming systems changes on wheat yield efficiency includes an estimate of changes in factor inputs in growing wheat. These were estimated using ABARE data for 1977 to 2005 seasons. The Tornquist-Thiel approximation of a continuous input Divisia index was used to estimate changes to input factor productivity in wheat farming systems, relative to total value changes. We used pro rata changes in the value of the wheat industry contribution to the crop specialist and crop-livestock categories of the ABARE databases.

Estimating improvement in wheat yields due to earlier seasonal average sowing times

APSIM V5.3 (Keating et al. 2003) was used to simulate an historical sequence (1900-2007) of wheat yield at Minnipa Research Centre (a low rainfall cropping environment) and Turretfield Research Centre (a high rainfall cropping environment) for sowing on 15 May, 23 May and 15 June each year. The relationship between the yield estimates from different sowing times proved quite stable within years and second order polynomials were fitted to the results from each site. Our estimate of earlier annual sowing time was a change from a 15 June average to a 31 May average over the 1977-2006 period. There is no readily obtainable data on this variable so it therefore needs to be noted that our estimate is a guess. The Minnipa and Turretfield estimates were combined using the relative mean sowing area in high and low rainfall regions over the review period.

Results and discussion

Estimates of yield efficiency annual gain and longitudinal curvilinearity

Our estimate of SA wheat yield efficiency gain was 1.7 percent p.a. Longitudinal log regression analysis using orthogonal polynomials showed that the fitted curve had significant linear and third order polynomial trends, and hence a downward trend towards the end of the time series. Using 107-year APSIM runs with daily climate files we could not find any reason to suspect that this downward trend was due to long-term climate change.

Farm management drivers of wheat yield improvement

Table 1 presents the results of the final stepwise OLS longitudinal analyses for wheat yield efficiency improvement and wheat yield improvement. Elasticity provides a percentage measure of how far the dependent variable shifts for a 1 percent shift in the explanatory variable.

Table 1. Farm management drivers of SA wheat yield improvement 1977-2006

Explanatory variable	**Dependent variable (logged)**			
	1. Yield efficiency (1977 = 100)		**2. Yield** (1977 = 100)	
	t value	**elasticity**	**t value**	**elasticity**
(Oz-Wheat)	not used	not used	17.38***	1.34
Wheat area	-2.86**	-0.47	-2.09*	-0.29
Fertiliser per ha cropped quantity index	5.34***	0.48	5.61***	0.35
Wheat terms of trade	-4.11***	-0.87	-4.83***	-0.39
Wheat/canola price ratio	4.34***	0.90	2.15*	0.32
Model adjusted R^2	0.74		0.95	
Durbin-Watson autocorrelation statistic	2.56 (NS)		2.45 (NS)	

*, **, *** Statistically significant at < 0.05, 0.01, 0.001 respectively. NS: not significant

Table 1 shows that the models based on yield efficiency and yield show similar influences of explanatory variables. Despite the relative R^2, yield efficiency should be viewed as the more sensitive version because Oz-Wheat is embedded in the dependent variable measure, therefore allowing a greater role for other explanatory variables. The dominance of seasonal rainfall in predicting annual wheat yields is displayed by the very high t value and high elasticity for Oz-Wheat, which adjusts for seasonal rainfall in its predictions, in Model 2. We suggest the following explanations: Additional wheat area has a negative impact on efficiency increases because the expansion is onto less suitable cropping land on-farm. Chemicals (mainly herbicides) proved to be not significant, indicating that they have more of a "maintenance of yield" role. The negative effect of wheat terms of trade (TOT) may appear counter-intuitive. TOT shows a historically consistent negative trend, therefore as TOT get worse, wheat yields increase. The effect has been demonstrated before in a total factor productivity context (Mullen 1995, Black 2004) and may relate to farmers feeling less pressure to maximise yields when wheat prices are relatively higher and therefore wheat farming more profitable, or it could also be related to cost and price pressures increasing overall yield by forcing less efficient farmers and possibly less suitable paddocks out of production. An increase in wheat price compared to that of canola has a positive impact on wheat yield increases, probably because relatively more farm system inputs (fertiliser, chemicals, resources for more timely sowing) as well as better land are diverted to wheat relative to canola.

Contributions to increases in wheat yield efficiency

Table 2. Average contributions to increased SA wheat yield efficiency 1977-2006

Contributing factor	Average annual percent change
Estimated varietal yield gain (VG)	0.5
Farming systems improvement (FSI) and FSI-VG interaction[a] (Total – VG)	1.2
Estimated total annual improvement	1.7
Farming systems and FSI-VG interaction[a] contributions	
Estimated earlier average sowing times (EAS)	0.7
Other farming systems contributions (FSI – EAS)	0.5
Estimated input factor productivity growth (IFP)	- 0.1

[a] We are aware that some view all wheat growing systems as an FSI-VG interplay.

Estimated varietal yield gain has been constant over the period, therefore the flattening in the wheat yield efficiency fitted curve is attributed to a decreasing farming systems improvement effect. This may be due to the fact that the fitted curves to the time of sowing APSIM results showed slightly decreasing impacts on wheat yield as sowing becomes earlier. Also, the fertiliser volume index showed curvilinearity (as well as that for chemicals). It needs to be noted that the improvement from varietal gain is viewed as a conservative estimate. Some of the FSI-VG interaction can be awarded to genetic gain - for example the exhibition of varietal disease resistance/tolerance in a crop environment that has higher disease loads than in variety trials. Further, in recent years many variety trials have tended to be sown later that surrounding farmers' crops, thus probably underestimating VG (R Wheeler, pers. comm.). Evans (1993, pp 297-300, 317-364) provides examples of FSI-VG interactions and within FSI component interactions. An alternative approach is to consider the relative amount of R&D contributing to varietal yield gain compared to farming systems R&D. At least in SA in recent years, it is our observation that local R&D for wheat breeding and pre-breeding has increased considerably in public institutions compared to farming systems research. If we assume that there is a strong causal link between lagged R&D effort and productivity improvement, this relative change in public institution R&D resources may have caused the observed efficiency curvilinearity. The earlier average sowing time contribution is a proxy for all the farming systems components that have contributed to this effect, which was first demonstrated in SA by R Holloway on the Eyre Peninsula and then E Braunack-Mayer in the mid North, in the early to mid 1980s. These components include larger and more effective machinery, better use of more effective herbicides, etc. If our suggested estimate of average sowing time changes is reasonable these evolutionary innovations, derived mainly through commercial R&D for machinery and herbicides, have had the dominant impact on SA wheat yield improvements. Other farming systems contributions, such as increased fertiliser use, better disease control through rotational biofumigation and precision farming have had an impact similar in size to varietal yield gain.

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