Do barley cultivars differ in their phosphorus use efficiency (PUE)?

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Key messages

- Grain yield responses to applied phosphorus (P) of between 2 to 22% were observed at six sites where the surface (0-10cm) Colwell P levels ranged from 22 to 34 mg/kg and the phosphorus buffering index (PBI) from 3 to 36 mL/g.
- Phosphorus use efficiency (PUE) was assessed by two methods: (1) efficiency = yield with no added P (0 kg P/ha) and (2) responsiveness = difference in yield between high P (30 kg P/ha) and minus P (0 kg P/ha).
- Cultivars differed in their efficiency ($p<0.001$) but there was no significant cultivar effect on their responsiveness to applied P ($p=0.243$).
- We found no evidence that the commercial barley cultivars tested show consistent differences in their response to applied P when grown on Western Australian soils and as such cultivar specific P recommendations for the most popular cultivars grown (i.e. Bass, Hindmarsh and Scope CL) are not warranted at this stage.

Background and Aims

Growers, breeders and industry are increasingly focusing on getting more yield per unit of input. Improving the nutrient use efficiency (i.e. phosphorus (P) and nitrogen (N)) of crops is one way of improving productivity. Do barley cultivars differ in their ability to take up nutrients from the soil and to utilise nutrients for grain production?

This paper focuses on P and asks the question do barley cultivars differ in their ability to utilise native soil P and to respond to applied P? Studies in South Australia suggest that there are genetic differences in the P use efficiency (PUE) in barley (McDonald *et al* 2010, Bovill *et al* 2011). However, what do we mean by PUE?

Using the principles described by McDonald *et al* (2010) and Bovill *et al* (2011, 2013) PUE was defined by two methods: (1) efficiency = yield at low P and (2) responsiveness = difference in yield between high P and low P (Figure 1). Cultivars that are efficient have a high yield under low P supply whereas cultivars that are responsive show a high yield response with the addition of P. An ideal cultivar might be described as a being efficient and responsive. The aim of this paper was to compare the grain yield of thirty barley cultivars for their efficiency and responsiveness to applied P under Western Australian conditions.

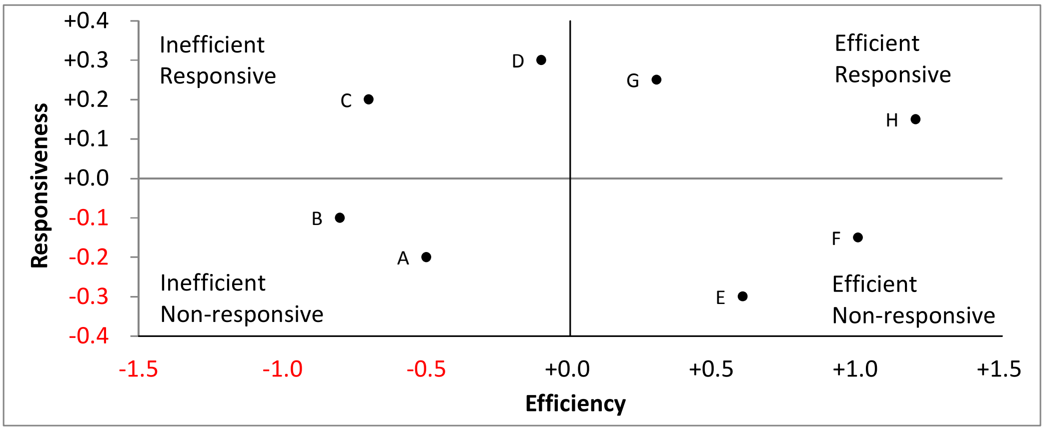

Figure 1. Characterising eight cultivars for their PUE based on two indicators of PUE: (1) efficiency = yield at low P (cultivars E, F, G and H) and (2) responsiveness = yield response to applied P (cultivars C, D, G and H).

Method

Thirty barley cultivars (including six un-released lines) were assessed for their field response to applied P (minus and plus) at six sites across Western Australia. The cultivars were selected to (1) reflect a range of the commercially available barley cultivars grown or being considered for release in Western Australia, (2) include a selection of lines carrying the *Alt1* gene for improved tolerance to high soil aluminium (Al) (WABAR2476, WABAR2481, WABAR2482, WABAR2518 and Litmus), and (3) include two mutations of Dash selected for their low phytate levels (Dash #34-1 and Dash #47-5). Ten of the cultivars (Buloke, Commander, Fleet, Gairdner, Hannan, Hindmarsh, Oxford, Roe, Stirling and Vlamingh) were common to the South Australian study (McDonald *et al* 2010 and Bovill *et al* 2011).

Three sites (Goomalling, Kojonup-West and Gibson) were chosen for their moderately low soil P status (Table 1). Small plot research trials were sown at each location in 2012 and 2013. Each trial was designed as a split-plot two-way randomised design with three replicates. Cultivar was sown as the main plot and applied P as the sub-plot (minus P = 0 kg P/ha and plus P = 30 kg P/ha). At seeding each plot was top dressed with 43 kg/ha urea, 120 kg/ha muriate of potash and 140 kg/ha crystalline sulphate of ammonia supplying 49 kg N/ha, 60 kg K/ha and 33 kg S/ha. For the plus P (30 kg P/ha) treatment, double superphosphate at 170 kg/ha was banded 3 cm below the seed. Each site was sprayed with a knockdown and IBS herbicide before seeding. Barley seed (target density of 150 plants/m^2) was direct drilled at 2-3 cm depth with a small plot air-seeder with press wheels. Post-emergent grass selective and broadleaf herbicides were used to control weeds. Grain was harvested with a small plot header and plot weights recorded.

Table 1. Location, soil type, previous crop, growing season rainfall (GSR, May-Oct) and Colwell soil test (0-10 cm) data.

Trial ID	Location	Soil type	Previous crop	GSR (mm)	Colwell P (mg/kg)	PBI (mL/g)	pH_{Ca} ($CaCl_2$)
12NO33	Goomalling	brown deep sand	canola	187	20	10.6	5.5
12GS34	Kojonup-W	brown shallow sandy duplex	canola	328	30	36.3	4.5
12ED22	Gibson	grey deep sandy duplex	canola	302	33	-	5.3
13NO45	Goomalling	yellow deep sand	canola	258	22	13.6	5.1
13GS36	Kojonup-W	brown duplex sandy gravel	canola	401	34	11.0	4.7
13ED25	Gibson	grey deep sandy duplex	canola	337	28	3.4	6.1

The grain yield data was analysed by fitting a mixed model using Residual Maximum Likelihood (REML) in Genstat with cultivar and applied P as fixed effects and components for spatial trend. Predicted means were generated for cultivar, applied P and their interaction, efficiency and responsiveness calculated for each cultivar. A combined site analysis was then done based on the standardised efficiency and responsiveness from the individual site analyses. Statistical analysis was in principle similar to Smith (2009) and Taylor (2012), who analysed South Australian cultivar by applied P experiments, except they had cultivar as a random effect and did a one stage combined site analysis.

Results

All six sites showed a significant grain yield response to applied P ($p<0.001$) despite surface soil (0-10 cm) Colwell P test results ranging between 20 to 34 mg/kg (Tables 1 and 2). The average grain yield response was 10% and ranged between 2 to 22%. There was a main effect of cultivar on grain yield ($p<0.001$) at all six sites (Table 2), but interactions between cultivar and applied P were only observed at three of the sites (12NO33, 13GS36 and 13ED25). At those three sites 20, 13 and 8 cultivars respectively had significant grain yield increases to applied P and only 0, 1 and 1 cultivars respectively had a significant grain yield decrease. Across 12NO33, 13GS36 and 13ED25 only three cultivars, Commander, Flinders and Granger, had a consistent significant increase in their grain yield with increasing applied P. Their average yield increase was 14% compared to the average of 10% for all 30 cultivars. Bovill *et al* (2011) also reported that Commander was generally responsive to P in South Australian trials.

Table 2. Grain yield (t/ha) response of barley to applied P and REML significance of applied P, cultivar and the interaction between cultivar and P.

Trial ID	Yield at 0P (t/ha)	Yield at 30P (t/ha)	Difference (t/ha)	Response (%)	REML significance of applied P	LSD (p=0.05)	REML significance of cultivar	REML significance of interaction
12NO33	0.48	0.57	0.08	17%	<0.001	0.01	<0.001	0.021
12GS34	2.75	3.36	0.61	22%	<0.001	0.10	<0.001	n.s.
12ED22	4.66	4.79	0.14	3%	<0.001	0.05	<0.001	n.s.
13NO45	2.67	2.88	0.21	8%	<0.001	0.03	<0.001	n.s.
13GS36	4.55	4.91	0.36	8%	<0.001	0.09	<0.001	<0.001
13ED25	4.98	5.09	0.11	2%	<0.001	0.05	<0.001	0.022

The combined site analysis of efficiency gave a highly significant cultivar effect ($p<0.001$) indicating there was a high correlation between experiments for cultivar efficiency (Figure 2). Compass, Lockyer and WABAR2518 were the highest yielding cultivars in the absence of applied P across the six sites. Dash #34-1, Hamelin and Stirling were the lowest yielding cultivars in the absence of applied P.

There was a high correlation (r = 0.88, p<0.001) between yield at 0P (minus P) and yield at 30P (plus P) (Figures, 2, 3 and 4). Generally cultivars that were high yielding with applied P are also high yielding without applied P, but there were some cultivar ranking changes due to P addition (Figures 2 and 3).

The data suggests that the *Alt1* gene may improve the efficiency of barley in scavenging native P in Western Australian soils. WABAR2476 (W92%794/4*Baudin) and WABAR2518 (W92%794/4*Baudin) are BC4 lines derived from Baudin carrying the *Alt1* gene from W92%794, whilst WABAR2481 (WB229/4*Hamelin) and WABAR482 (WB229/4*Hamelin) are BC4 lines derived from Hamelin but carrying the *Alt1* gene from WB229. Three of the four *Alt1* lines, except WABAR2476, were more efficient than their parental line (Figure 2). With 30P, however, the two Hamelin BC4s and Hamelin were the same yield as each other, whilst WABAR2476 and Baudin were the same as each other and WABAR2518 still higher yielding (Figure 3). Litmus (another acid tolerant cultivar) was also high yielding under 0P, but it had a lower overall ranking with 30P. It is important to note that three of the sites had acidic sub-soils (pH_{Ca}<4.8 at 15-30 cm), namely 12NO33, 12GS34 and 13NO45. A more detailed study is required to establish if there is a link between Al tolerance and improved P efficiency.

The mutation of Dash to develop lines with low phytate (improves feed efficiency of barley for pigs) appears to have reduced the efficiency to uptake soil P, but only Dash #34-1 was lower yielding than Dash (Figure 2). More lines would need to be evaluated to determine if there is an actual link between low phytate and P efficiency, but under 30P the two Dash mutants and Dash had the same grain yield (Figure 3).

Whilst the standardised analysis suggests that Dash #34-1, Fleet, Oxford and Wimmera were the most responsive to applied P across the six sites (Figures 5 and 6), the combined site analysis of responsiveness gave no significant effect of cultivar (p=0.243). Even within the three experiments with a significant cultivar by applied P interaction the cultivar response to applied P across sites was not significant (p=0.069). This indicates a lack of consistency in the cultivar response to applied P.

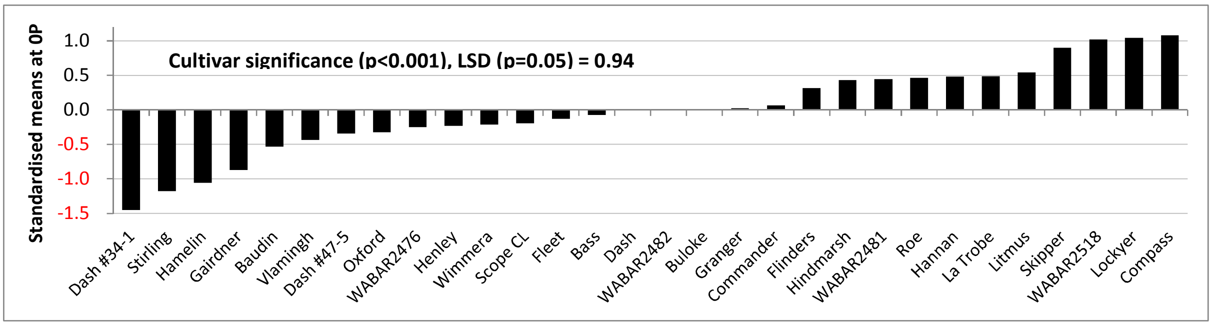

Figure 2. Standardised predicted means for grain yield at 0P averaged over the six sites.

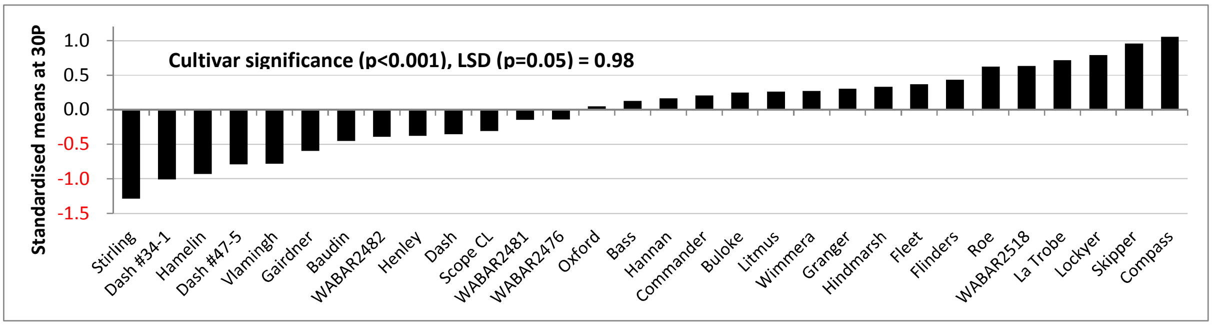

Figure 3. Standardised predicted means for grain yield at 30P averaged over the six sites.

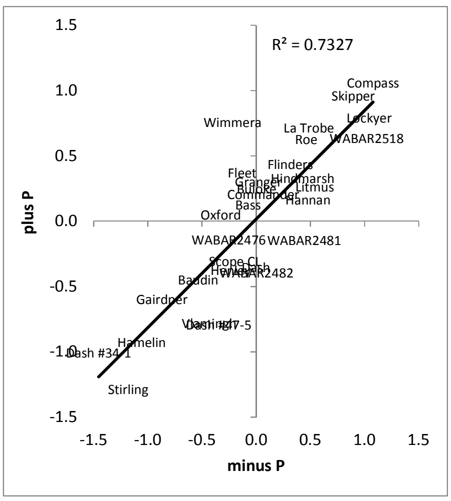

Figure 4. Relationship between standardised predicted means for yield at 0P (minus P) and 30P (plus P) averaged over the six sites.

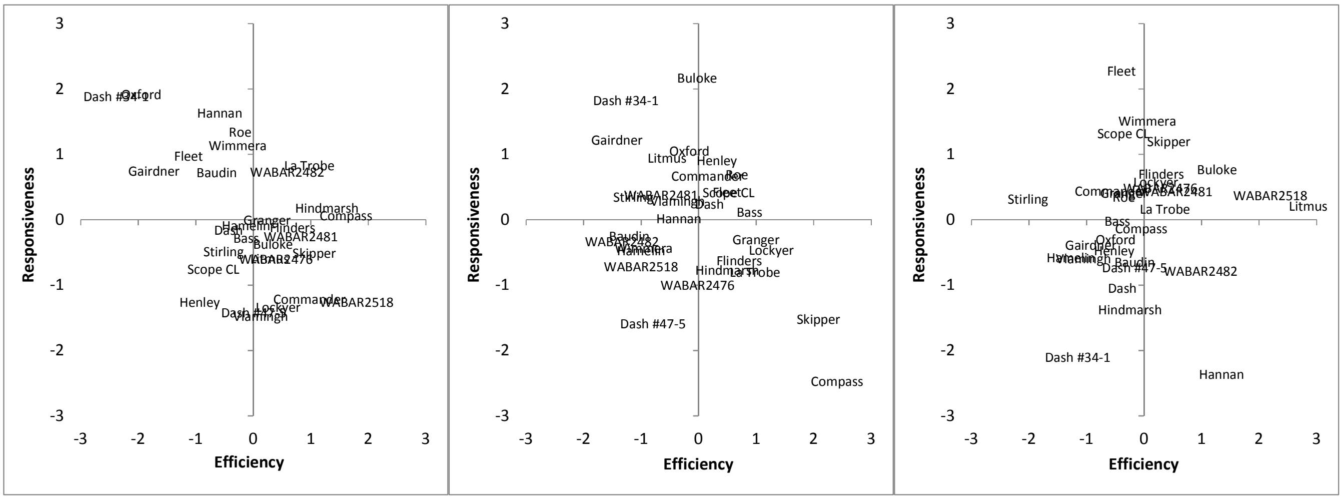

Figure 5. Relationship between standardised efficiency and standardised responsiveness at the three sites (left to right: 12GS34, 12ED22, 13NO45) with no cultivar x P interaction.

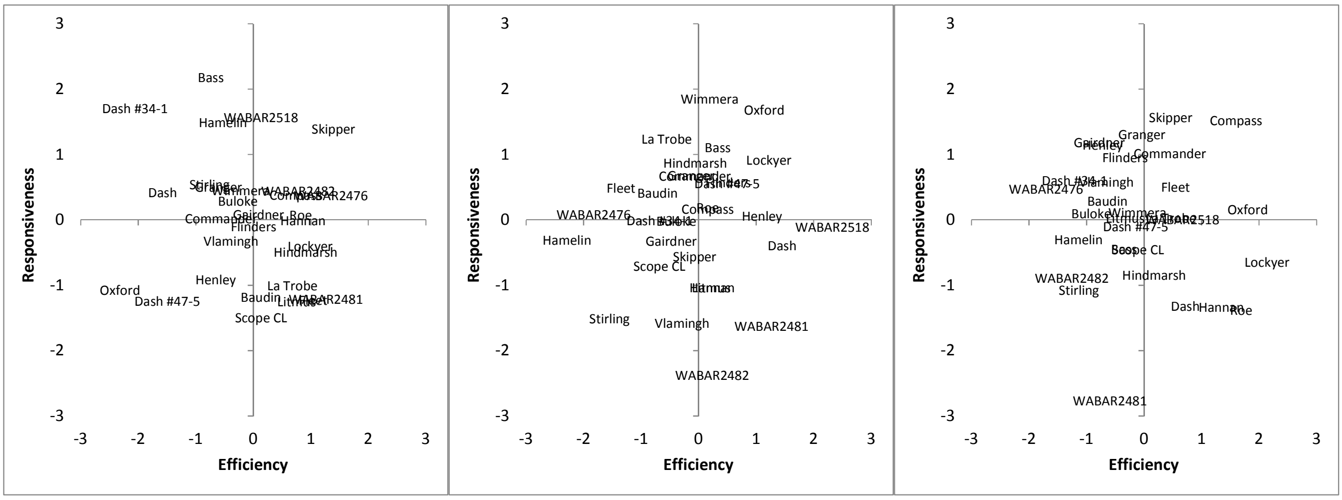

Figure 6. Relationship between standardised efficiency and standardised responsiveness at the three sites (left to right: 12NO33, 13GS36 and 13ED25) where there was a significant cultivar x P interaction (p<0.05).

Conclusion

Genetic variation in the response of 30 barley cultivars to applied P (0 or 30 kg P/ha) was assessed at six field sites in Western Australia. Grain yield responses (averaged over cultivars) ranged from 2% in 13ED25 to 22% in 12GS34, with significant responses observed at each site (Table 2). Yield at P0 (minus P) or efficiency showed a strong genetic correlation across sites (Figure 2) and with yield at P30 (plus P) (Figure 4). Genetic correlations for responsiveness to applied P were not consistent across sites (Figures 5 and 6).

A combined site analysis of seven comparable experiments in South Australia had similar findings to this study with large genetic differences in yield at low P supply, but not so with the response to applied P. Taylor (2012) concluded that the responsiveness to applied P in SA experiments did not show consistent patterns of correlation between trials, even at the same site between different years. This is despite several of the South Australian experiments were sown on much more P responsive sites and a wider range of genetic material assessed than in this study.

Within the commercial barley cultivars we tested (many of which are currently being grown or soon to be grown in Western Australia) we found no consistent differences in their responses to applied P on soils with a moderately low soil P status (by current Western Australian standards). For the most popular cultivars such as Bass, Hindmarsh, Scope CL, this means that cultivar specific P recommendations are not warranted at this stage. Bass, Hindmarsh and Scope CL are forecast to account for 70% of the Western Australian barley area in 2015 (Gupta *et al* 2015).

Our study followed the methodology of the GRDC funded project UA00115 (led by Dr Glen McDonald). Although the South Australian study had a wider range of cultivars, similar conclusions were made. In the South Australian study, however, several cultivars did respond more consistently to applied P. McDonald *et al* (2010) suggested the low genetic correlation between efficiency and responsiveness indicates it may be possible to select for cultivars with a high efficiency (high yield at low P) and are responsive to applied P (Figure 1). So like a number of genetic traits

associated with adaptation any improvements in PUE are likely to be incremental changes rather than major step changes.

A barley population derived from Commander and Fleet was selected for further investigation within UA00115 with an aim to develop genetic markers for PUE. Ultimately the goal of that project was to assist barley breeders develop barley cultivars that provide a greater economic return following the application of P fertiliser. A public summary of their findings is not yet available. Further evaluation of the PUE of barley on Western Australian soils may be warranted at some time in the future should lines become commercially available using any genetic markers developed. Further assessment of the potential positive effect of the *Alt1* gene on P scavenging and the potential negative effect of low phytate on P scavenging should or could also be considered.

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Key words

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