Rainfall before sowing is an important factor in wheat response to phosphorus fertiliser

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Abstract
The context for phosphorus (P) fertiliser decisions has changed since most of the field-based research for P was done in Western Australia (WA). Long term positive P balances in WA cropping systems have led to a decrease in acute deficiency in soil P supply. Also, cropping intensity has increased, the percentage of cropped area as legumes has decreased, and near-complete adoption of no-till has occurred in the last three decades. We assessed which soil and rainfall properties had the greatest influence on wheat yield response to fertiliser P using a recent (2018-2021) set of 40 field trials in WA. The sliding window approach was used to examine whether total rainfall within time-based windows was related to wheat response to P fertiliser. Relationships between soil properties, rainfall and yield response were also assessed using regression tree modelling. Our analysis revealed that for soils where P buffering index (PBI) (0-10 cm) was less than 50, grain yield response to P fertiliser was related to rainfall in a 4-week period before sowing. Overall, the greatest yield responses occurred where less than 8 mm of rain fell in this period. However, when rainfall was greater than 8 mm, pH was an important factor; relative yield was lower when soil pH_{CaCl2} (0-10 cm) was <5.1, compared to sites where soil pH_{CaCl2} was ≥5.1. The rainfall-to-relative yield relationship identified in this work provides a basis for a tactical response of P application at sowing to rainfall conditions leading up to this operation. Future decision support systems should include the effect of rainfall prior to sowing on low-PBI soils to optimise the economic payoffs from different strategies.

Keywords
Phosphorus fertiliser, wheat, rainfall, phosphorus buffering index, DGT P

Introduction
Long-term changes to grain production systems in Western Australia have led to changes in crop demand for, and soil supply of, phosphorus (P), which may have implications for P fertiliser management. The knowledge base used to guide P fertiliser management in grain production in WA is mostly derived from field trials from the 1960s to 2000s (Bell *et al.* 2013), but there are some important differences between current systems and those in the historical research. Crop demand for P has increased, and water use efficiency for wheat in WA has nearly doubled in the last two decades (Planfarm 2023). However, in most soils used for grain production, soil P supply has also increased due to long-term positive P balances (Weaver and Wong 2011; Harries *et al.* 2021). In addition, there have been some important changes to agronomic management; long-term adoption of no-till (Llewellyn and Ouzman 2019) leading to less mixing of soil, reduced crop and pasture legume area (Seymour *et al.* 2013) potentially reducing the supply of organic P, and a shift to earlier sowing (Flohr *et al.* 2018).

Previous research on P management in grain production has been heavily focused on soil-test calibrations. The aim of the previous research was to develop empirical models that relate grain yield response from fertiliser P to a measurement of soil P and has mostly focused on Colwell extractable P. However, incomplete reporting of P buffering index (PBI) in the previous research limited the ability to quantify if, or how, calibration curves differ for different levels of PBI. The impact of climate, particularly rainfall, on crop response to fertiliser P has not been investigated in WA. The aim of this work was to examine how rainfall and soil properties influence wheat response to P fertiliser in current cropping system and examine if these factors have an interactive effect.

Methods

Field experiments

Forty field experiments were conducted with wheat over 2018 to 2021. The same experimental design was used at each site; five levels of P applied as monoammonium-phosphate (MAP): 0, 5, 10, 20, 40 kg P/ha, with three or four replicates. The same protocol for soil sampling and analysis was used at each site. Soil analysis was performed using standard soil testing methods (Mason *et al.* 2010; Rayment and Lyons 2011). Rainfall data were collected at each site using a logging rain gauge.

Climate analysis

The sliding window method was used to examine whether rainfall has an impact on wheat response to fertiliser P. The aim of the sliding window approach is to examine whether there are relationships between climate variables and a response variable within a time-based window (Pol *et al.* 2016). In our case, we examined whether there were relationships between rainfall within time-based windows (from 20 weeks before to 20 weeks after sowing) and relative yield for the field trials. A program was written in R to calculate total rainfall and fit a linear and quadratic model to the rainfall-to-relative yield data for each time-based window.

Statistical analysis

Regression tree modelling was done to investigate whether interactions between the soil chemical and physical properties measured influenced relative yield (RY = grain yield at 0P/grain yield at max P). Soil test calibration curves were assessed using the arcsine-log calibration curve (ALCC) method (Dyson and Conyers 2013; Correndo *et al.* 2017; Correndo *et al.* 2023). The ALCC method quantifies the goodness of fit using the Pearson correlation coefficient of the transformed relative yield and soil test data (r-value).

Results and Discussion

There were no interactions between soil properties influencing relative yield. The best tree from the regression modelling had one split only based on DGT-P (0-10 cm). For sites below 36 $\mu g\ L^{-1}$ DGT- P 0-10 cm, mean relative yield was 64%, whereas for sites ≥36 $\mu g\ L^{-1}$ mean relative yield was 83%.

Our analysis of relative yield and soil test data showed that PBI was an important factor. Overall, relative yield was not closely related to Colwell P (0-10 cm). The r-value for the whole data set was 0.07, and was 0.02 and -0.1 when the data were split into, respectively, PBI groups 0-35 and >35 [based on groups from Moody (2007)]. Relative yield was more closely related to DGT-P (0-10 cm); with r-value of was 0.44 for all data, 0.33 for PBI 0-35 and 0.61 for PBI >35. Further examination of the influence of PBI on soil test calibration curves showed the calibration curve for DGT-P was best when a breakpoint of PBI 50 was used. For sites where PBI (0-10 cm) was ≥50, relative yield was closely related to DGT-P (0-10 cm); the r-value for the calibration curve was 0.95. For sites where PBI <50, relative yield was not related to Colwell P or DGT-P. There is some evidence to support the breakpoint at around PBI 50; previous work in WA showed that calibration curves above and below PBI 55 differed (Neuhaus *et al.* 2015).

The calibration curve identified for DGT-P (0-10 cm) is close to those in previous work. The critical value for 90% relative yield in this study was 48 $\mu g\ L^{-1}$, and was 34 $\mu g\ L^{-1}$ for soils other than calcarosols (Speirs *et al.* 2013). While the calibration curve we have identified here is useful for identifying P sufficiency of soils with PBI >50 at a coarse level, e.g. as sufficient or deficient, a larger data set is required to develop a calibration curve to provide a more robust prediction of relative yield based on soil test DGT-P results.

The sliding window analysis showed that rainfall near sowing had an impact on relative yield for sites where PBI 0-10 cm was <50. The lowest values for relative yield occurred when there was little to no rain in the window from 2-5 weeks prior to sowing. Where there was greater than 8 mm in this window, pH_{CaCl2} influenced relative yield; mean relative yield was 81% and 88% for sites where pH (pH_{CaCl2} 0-10) cm was <5.1 and ≥5.1, respectively. The impact of rain in this period before sowing may be due to a combination of decreased soil water repellence, triggered mineralisation of soil organic P, or improved root growth during establishment facilitating crop access to soil P.

Conclusion

Our analysis revealed that rainfall prior to sowing and soil pH were important factors for wheat yield response to fertiliser on soils with PBI <50, which is attributed to the impact of these parameters on the availability of residual soil P. For sites where PBI 0-10 cm was ≥50, yield response was most closely related to DGT-P 0-10 cm. Future decision support systems should include the effect of rainfall prior to sowing on low PBI soils to allow the economic payoffs from different strategies to be assessed.

References

Bell, R *et al.* (2013) Soil phosphorus-crop response calibration relationships and criteria for winter cereal crops grown in Australia. Crop and Pasture Science 64, 480-498. (http://dx.doi.org/10.1071/CP13016)

Correndo, AA *et al.* (2023) The soiltestcorr R package: An accessible framework for reproducible correlation analysis of crop yield and soil test data. SoftwareX 21, 101275. (https://doi.org/10.1016/j.softx.2022.101275)

Correndo, AA *et al.* (2017) A modification of the arcsine–log calibration curve for analysing soil test value–relative yield relationships. Crop and Pasture Science 68, 297-304. (https://doi.org/10.1071/CP16444)

Dyson, CB, Conyers, MK (2013) Methodology for online biometric analysis of soil test-crop response datasets. Crop and Pasture Science 64, 435-441. (http://dx.doi.org/10.1071/CP13009)

Flohr, BM *et al.* (2018) Fast winter wheat phenology can stabilise flowering date and maximise grain yield in semi-arid Mediterranean and temperate environments. Field Crops Research 223, 12-25. (https://doi.org/10.1016/j.fcr.2018.03.021)

Harries, M *et al.* (2021) Sustainability of nutrient management in grain production systems of south-west Australia. Crop and Pasture Science 72, 197-212. (https://doi.org/10.1071/CP20403)

Llewellyn, R, Ouzman, J (2019) Conservation agriculture in Australia: 30 years on. In 'Australian agriculture in 2020: From Conservation to Automation.' (Eds J Pratley, J Kirkegaard.) pp. 21-33. (Agronomy Australia and Charles Sturt University: Wagga Wagga) (https://agronomyaustraliaproceedings.org/index.php/2-uncategorised/774-special-publications)

Mason, S *et al.* (2010) Prediction of wheat response to an application of phosphorus under field conditions using diffusive gradients in thin-films (DGT) and extraction methods. Plant and Soil 337, 243-258. (http://dx.doi.org/10.1007/s11104-010-0521-0)

Moody, PW (2007) Interpretation of a single-point P buffering index for adjusting critical levels of the Colwell soil P test. Soil Research 45, 55-62. (http://dx.doi.org/10.1071/SR06056)

Neuhaus, A *et al.* (2015) 'Phosphorus requirements for cereals: what role does crop rotation play?, 17th Australian Agronomy Conference.' Hobart, Tasmania. Australian Society of Agronomy. Available at http://agronomyaustraliaproceedings.org/images/sampledata/2015_Conference/pdf/agronomy2015final00333.pdf

Planfarm (2023) Planfarm Benchmarks 2022 Season. Planfarm, Perth.

Pol, M *et al.* (2016) Identifying the best climatic predictors in ecology and evolution. Methods in Ecology and Evolution 7, 1246-1257. (https://doi.org/10.1111/2041-210X.12590)

Rayment, GE, Lyons, DJ (2011) 'Soil chemical methods: Australasia.' (CSIRO Publishing: Collingwood, Australia)

Seymour, M *et al.* (2013) Break-crop benefits to wheat in Western Australia - insights from over three decades of research. Crop and Pasture Science 63, 1-16. (http://dx.doi.org/10.1071/CP11320)

Speirs, S *et al.* (2013) Soil phosphorus tests II: A comparison of soil test–crop response relationships for different soil tests and wheat. Crop and Pasture Science 64, 469-479. (https://doi.org/10.1071/CP13111)

Weaver, DM, Wong, MTF (2011) Scope to improve phosphorus (P) management and balance efficiency of crop and pasture soils with contrasting P status and buffering indices. Plant and Soil 349, 37-54. (http://dx.doi.org/10.1007/s11104-011-0996-3)