# Does optimum wheat phosphorus requirement change with sowing time and conditions in WA?

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## Key messages

- Early sowing is well associated with increased yield crop potential, but when soil moisture was adequate for crop emergence, optimum phosphorus applications at sowing for wheat yield varied with sowing time, from low in April-sown crops to high in June-sown crops.
- The effect was seen in early-mid and mid-late maturing wheats, in high and low rainfall years, in healthy and marginal P status soils and is somewhat counter-intuitive to common practice of increasing inputs to support a high yield potential.
- The results suggest opportunities for fine tuning on-farm management of P inputs for efficiency and improved yield outcomes and have implications for advisory and decision support systems based on P response data that have not factored sowing time into field trial interpretations.

## Aim

An investigation of the application of studies and methodologies from the eastern states to phosphorus supply in wheat crops at different times of sowing in Western Australia.

## Introduction

Logistical considerations due to increases in farm size and total land area under crop have largely been responsible for the trend to early sowing (Fletcher *et al* 2016). Resultant increases in production potential of early-sown wheat have been clearly shown when soil moisture is sufficient for effective germination and emergence (Cann *et al* 2020). However, in spite of potential yield differences we see little evidence in Western Australia that fertiliser applied at sowing, in-particular phosphorus (P), changes in response to the shifting sowing window or during a period of sowing that may stretch from early April to late June.

Fertiliser decisions are commonly based on an average previous crop P removal-replacement strategy, or by soil tests to determine a difference between soil supply and a yield requirement deficit that is to be filled by fertiliser sources. The soil test approach relies on historic datasets from field experiments predominantly sown in late May and June (Spiers *et al* 2013; Conyers *et al* 2020).

Work in New South Wales during the 1980s and 1990s found that winter wheat sown in April under high soil moisture achieved higher yields than later sown crops at equivalent applied P rates and could attain near maximum (90%) yield with less applied P regardless of soil test P status (Batten and Khan 1987; Batten *et al* 1993, 1999). More recently, similar results were found with both mid- and late-season maturing spring wheat cultivars on high P-fixing calcareous soils in South Australia with adequate April rainfall (Mason and McDonald 2021). To our knowledge, data detailing crop P response and requirement at different times of sowing in the Western Australian wheat belt are not readily available and, indeed, do not exist for popular contemporary wheat varieties. This study was designed to address this knowledge gap and provide a foundation for improving cereal crop P fertiliser advice and management.

## Method

Field experiments were conducted to examine the response to P fertiliser at a separate site in 2020 and 2021. While the sites lie in close proximity, 13 km apart near the Southern Brook locality of the M3 rainfall zone, the growing season rainfall profiles were vastly different between years (Figure 1). The aim of the experiments was to determine how time of sowing influences the response of wheat to P using spring wheat varieties differing in maturity.

*Table 1. Soil phosphorus analyses at the sites. Samples taken at T1 each year (± std deviation, n=10).*

| | 2020 | | | 2021 | | |
|---|---|---|---|---|---|---|
| Depth (cm) | Colwell P (mg/kg) | PBI | DGT (µg/L) | Colwell P mg/kg | PBI | DGT (µg/L) |
| 0-10 | 19 ±3 | 26 ±8 | 48 ±13 | 37 ±4 | 39 ±4 | 57 ±7 |
| 10-20 | 9 ±4 | 27 ±2 | 22 ±16 | 14 ±1 | 46 ±7 | 12 ±4 |
| 20-30 | 6 ±1 | 57 ±25 | 5 ±1 | 5 ±1 | 57 ±14 | 7 ±1 |

*Table 2. Time of sowing dates and growing season rainfall prior to sowing (1st of April to sowing date) for the experiments over two years.*

| Year | T1 | | T2 | | T3 | |
|---|---|---|---|---|---|---|
| 2020 | 28 April | 7 mm | 28 May | 32 mm | 15 June | 48 mm |
| 2021 | 21 April | 10 mm | 18 May | 79 mm | 11 June | 137 mm |

Soil analysis at both sites included Colwell P, phosphorus buffering index (PBI) and the diffusive gradients in thin film (DGT) test to assess soil P status (Table 1).

Experimental treatments were two wheat varieties (early-mid maturing Scepter and mid-late maturing RockStar), 5 P rates (0, 5, 10, 20 and 40 kg P/ha) as mono-ammonium phosphate (MAP) and 3 times of sowing (T1 April, T2 May & T3 June, Table 2) each year. Timings were intended to be approximately 4 weeks apart. Layout was a split-split plot design with 4 replications.

Phosphorus response curves were fitted to mean actual and relative yield data using a Mitscherlich function in the form $f(x) = a - be^{-cx}$ where $a$ is theoretical maximum yield (Ymax), $b$ is the trial yield response to P application (Ymax – Y at P0) and $c$ is the response curvature through the range of applied P, designated by variable $x$. Relative yields were calculated separately for Scepter and RockStar wheat at each P treatment relative to the maximum yield from that variety in the trial.

## Results

### *Growing season rainfall and crop emergence*

While similar April rainfall was received in both years prior to T1 sowing, rainfall for the remainder of the season was vastly different. Soil moisture was sufficient for T1 crop emergence in both years, but in 2020 T1 early crop growth was much slower than 2021 with 25 mm rain falling between T1 and T2 in 2020 compared with 69 mm in 2021. Ultimately, 2020 was a Decile 1 rainfall growing season characterised by a sharp and early season finish with only 22 mm rain after 20th of August whereas 2021 was Decile 10 (Figure 1).

Despite rainfall differences, number of emerged plants was consistent between years, varieties and time of sowing, averaging 170 & 165 plants/m$^2$ for Scepter and 183 & 154 plants/m$^2$ for RockStar for 2020 & 2021, respectively. Emergence in all treatments was above the threshold of 100 plants/m$^2$ that will limit yield (Zaicou-Kunesh *et al* 2019). Rate of P fertiliser did not affect seedling emergence.

### *Vegetative Growth*

In all times of sowing RockStar had a greater NDVI when compared with Scepter ($p<0.001$) typical of the more vegetative growth habit of this variety. Overall biomass significantly increased with increasing P rates ($p<0.02$) and the main effect of sowing time affected how biomass responded to increased P ($p<0.01$). Wheat sown in April and May showed a similar response with moderate increases in biomass up to 10 kg P/ha. Sowing in June showed a stronger biomass response to increasing P rates, with the greatest NDVI measured at 40 kg P/ha in all cases.

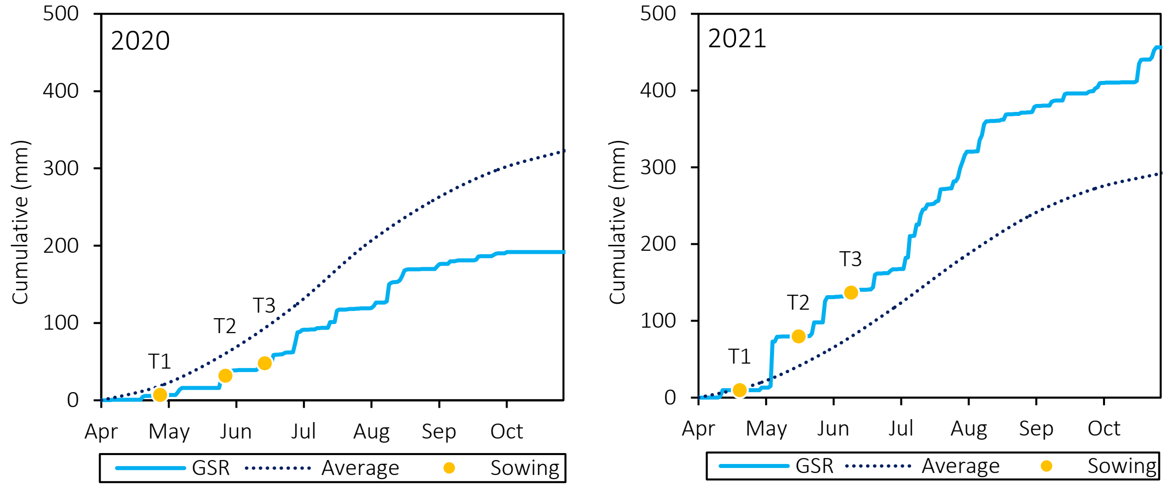


*Figure 1. Contrasting growing season rainfall for the 2020 (Decile 1, 131 mm below average) and 2021 (Decile 10, 164 mm above average) trial sites. 30-year average data from BOM Northam (10111) and Grass Valley (10150) stations.*

### *Grain Yield*

Site mean treatment yields ranged from 1.2 to 2.0 t/ha in 2020 and 2.3 to 4.4 t/ha in 2021. In 2020 there were no differences in yield between the varieties. However, in 2021 RockStar yields were higher than Scepter ($P<0.01$).

As a general observation, yields were greatest in April or May sown wheat, with significant yield penalties evident by delaying sowing until mid June. Yield increased in response to increasing P application rate ($P<0.01$). Yield increases were greater as the crop was sown later ($P<0.01$) and were observed for both varieties and in both years (Table 3). Despite the main effect differences, no two- or three-factor interactions (P rate X sowing time X variety) were significant.

Differences in the sowing time proportionate P responses were primarily due to depression of yield with nil P applied at later sowing times, indicating decrease in plant available soil P pool and/or decrease in capacity of plants to access, take up and utilise the P from the labile soil pool.

The P response differences with time of sowing were evident in fitted Mitscherlich curves (Figure 3). Shape and slope of the curves was different at the low applied end with shallow curvature in early sown wheat confirming a smaller response to P than late sowing times. The pattern of response was very similar between the wheat varieties with the exception of RockStar sown in June 2021 where response to 10 kg P/ha was less than expected, altering the response curve inflection and maximum yield regions. Taking the near-maximum yield point from each curve (90% or 95%) gave distinctly different optimum fertiliser P application requirements for each time of sowing (Figure 3, Table 4).

*Table 3. Wheat yields in response to changing P application rates at different times of sowing.*

| | | 2020 Yield (t/ha) | | | 2021 Yield (t/ha) | | |
|---|---|---|---|---|---|---|---|
| | P (kg/ha) | T1 April | T2 May | T3 June | T1 April | T2 May | T3 June |
| Scepter | 0 | 1.9 | 1.7 | 1.3 | 3.9 | 3.7 | 2.3 |
| | 5 | 1.9 | 1.8 | 1.5 | 3.9 | 3.8 | 2.7 |
| | 10 | 1.9 | 1.9 | 1.6 | 3.9 | 4.0 | 2.8 |
| | 20 | 2.0 | 2.0 | 1.7 | 3.9 | 4.1 | 2.8 |
| | 40 | 2.0 | 2.1 | 1.8 | 4.1 | 4.1 | 3.1 |
| Yield P response (t/ha) | | 0.1 | 0.4 | 0.5 | 0.2 | 0.4 | 0.8 |
| RockStar | 0 | 1.8 | 1.7 | 1.2 | 4.3 | 3.9 | 2.6 |
| | 5 | 1.9 | 1.8 | 1.4 | 4.4 | 4.2 | 3.1 |
| | 10 | 2.0 | 1.9 | 1.5 | 4.4 | 4.2 | 2.8 |
| | 20 | 2.0 | 2.0 | 1.5 | 4.4 | 4.3 | 3.3 |
| | 40 | 2.0 | 2.0 | 1.6 | 4.4 | 4.3 | 3.5 |
| Yield P response (t/ha) | | 0.2 | 0.3 | 0.4 | 0.1 | 0.4 | 0.9 |

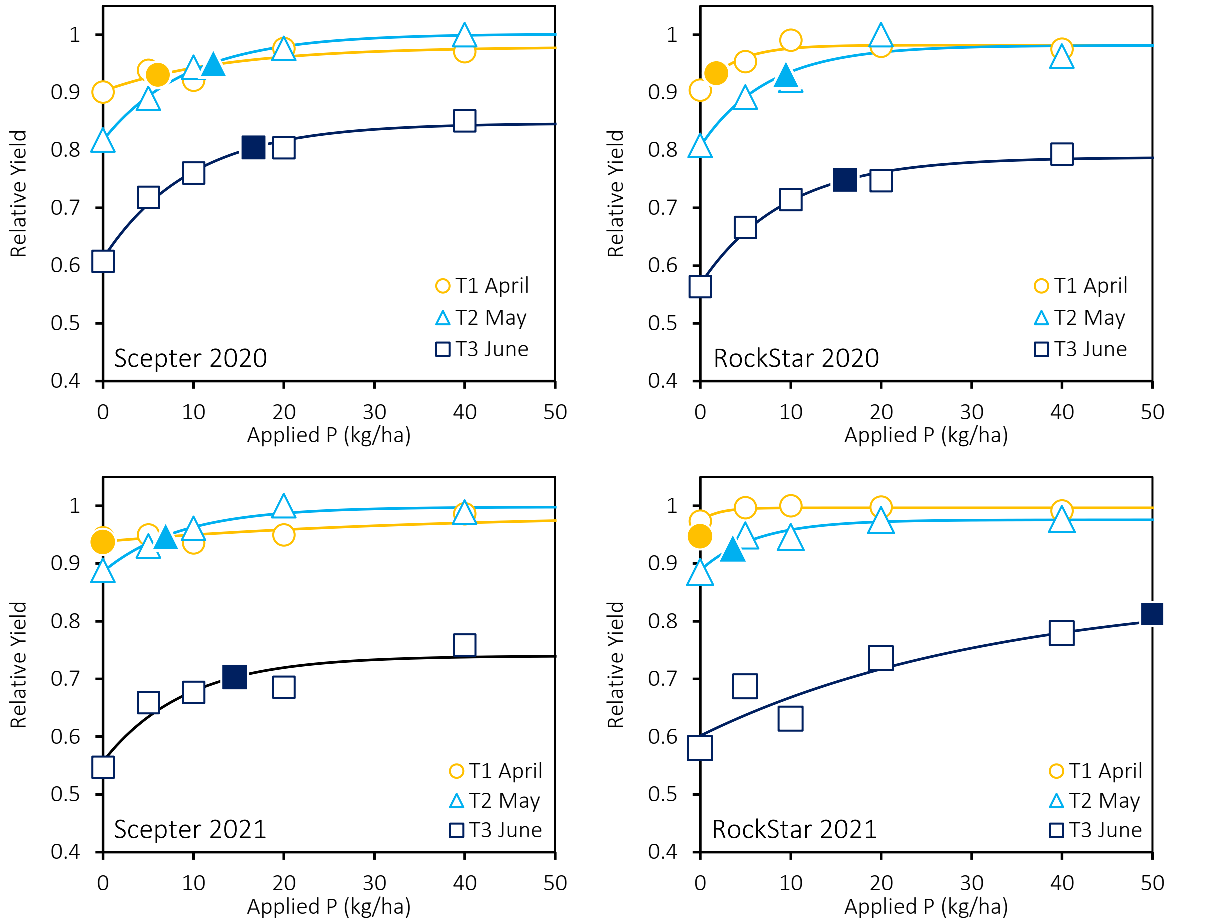


*Figure 3. Yield responses to P by wheat varieties sown at different times in two years. Open symbols are yield measurements relative to the whole-trial maximum. Closed symbols are near-maximum (95%) yield for each within-trial sowing time, indicating optimum P input requirement for yield.*

*Table 4. Requirement for applied P fertiliser at different sowing dates to achieve near-maximum yield.*

| | | 2020 Fertiliser requirement (kg P/ha) | | | 2021 Fertiliser requirement (kg P/ha) | | |
|---|---|---|---|---|---|---|---|
| | % of Max RY | T1 April | T2 May | T3 June | T1 April | T2 May | T3 June |
| Scepter | 95% | 6 | 12 | 17 | 0 | 7 | 15 |
| | 90% | 0 | 6 | 10 | 0 | 1 | 8 |
| RockStar | 95% | 2 | 9 | 16 | 0 | 4 | 58 |
| | 90% | 0 | 4 | 10 | 0 | 0 | 36 |

Ignoring the different curve for 2021 June-sown RockStar P calculation, the difference in optimum P requirement between the start and end of an 8-to-9 week April-June sowing program is in the order of 10-15 kg P/ha, and the requirement for applied P appears to be lower when the early sowing times correspond with a higher April monthly rainfall (Table 4). These optimum P requirements based on relative yield (RY) curves correspond well with the maximum on indicative return trendlines for each sowing time (Figure 4). For context, Harries *et al* (2021) found average farm paddock P application in the region to be 9.5 kg/ha with minimal variation (standard deviation 0.3 kg/ha).

Notably, finding lower required P input to achieve near-maximum yield occurred in Decile 1 and in Decile 10 rainfall seasons and in both healthy and marginal P status soil. Soils here were at the low end (2020) or above (2021) the 90% confidence interval range of Colwell P in 0-10cm for maximum yield in Tenosols (16-26 mg/kg, Bell *et al* 2013). It is most likely a combination of complex soil moisture interactions with other aspects of site conditions (e.g. temperature, complete nutrient fertility, total length of season light hours, etc.), crop morphology/ phenology, weather event timings and/or other associated factors such as alignment of crop demand with nitrogen mineralisation that influence the P nutrition and requirement of a growing crop.

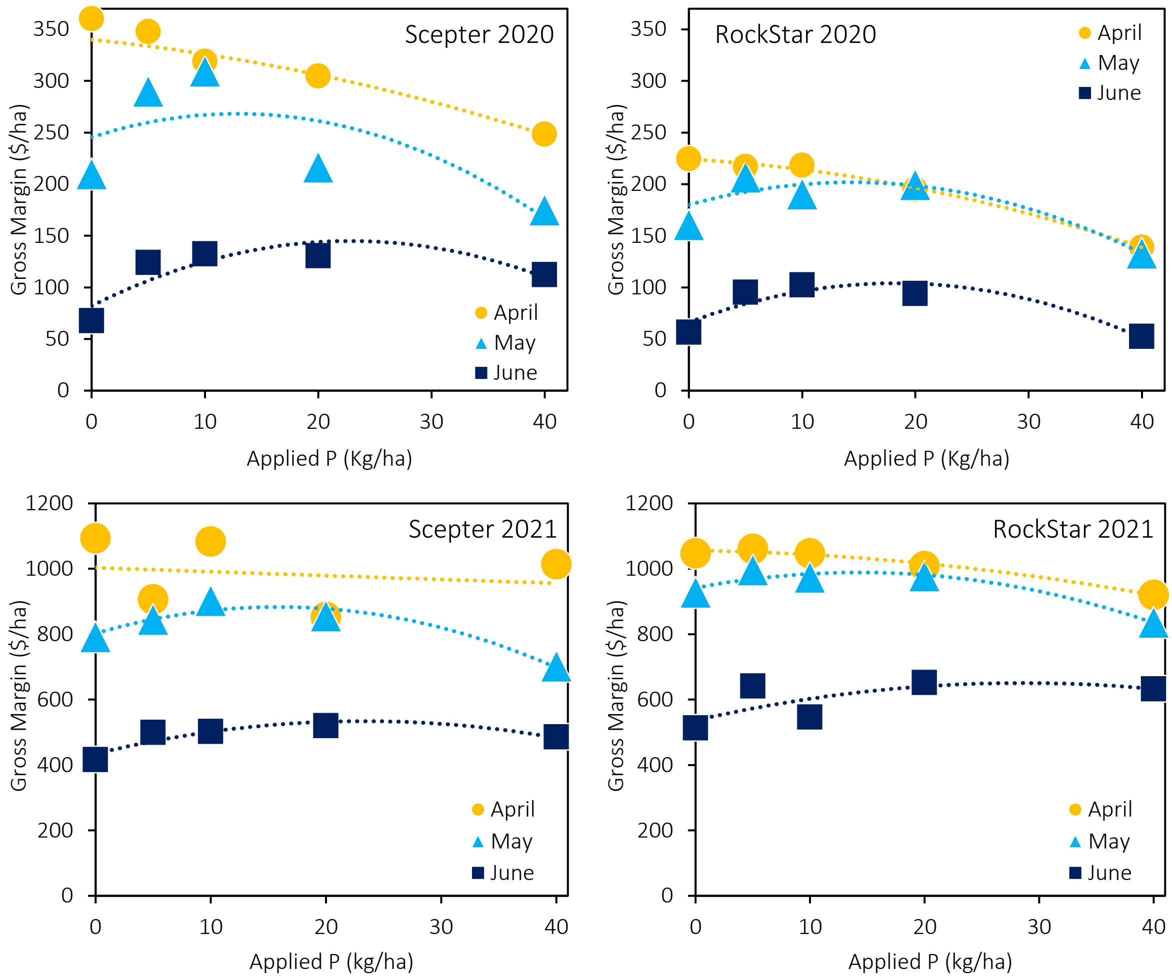


*Figure 4. While early sowing produced higher returns overall, achieving indicative optimum returns required increased P application with later sowing times in high (2021) and low (2020) rainfall seasons. Gross margins are a simple calculation of grain value for yield and delivery grade minus cost of all fertiliser inputs for P and basal nutrients. Simple 2nd order polynomial regression lines are fitted.*

Finding small yield responses to P and corresponding low optimum P requirements in early-sown wheat is somewhat counter-intuitive to the generally-accepted rule of thumb that increased yield potential needs to be supported by higher inputs. Nonetheless, the data is consistent and has implications for P fertiliser management. It is becoming clear, if soil moisture is sufficient for wheat emergence, that there is opportunity for growers to sow wheat early with a decreased rate of fertiliser P and still achieve yield potential. Conversely, consideration should be given to increasing fertiliser P supply to wheat crops as sowing dates extend into early June and beyond in order to optimise yield and returns from a late-sown crop.

Results of different studies (Batten *et al* 1999; Mason and McDonald 2021) have suggested that influences of temperature and soil moisture on optimal P rates is transferrable across different soil types. The trial sites and yield responses achieved in the current study support this suggestion. Although the precise mechanisms are open to speculation and deserve further research attention, it is possible they may include some or all of temperature and moisture effects on: simple dissolution and stoichiometry of plant available soil P forms; relative rates of crop root establishment and growth soon after germination; release to the rhizosphere of plant, fungus or microbial compounds that facilitate soil P solubility and transfer from adsorbed and tightly held forms.

### *Phosphorus uptake, concentration and export in harvested grain*

Grain P analysis was not available at the time of paper submission but we hope to include this data in the Research Updates 2022 conference presentation. It is important to note that previous work supporting decreased P fertiliser input with early sowing has cautioned that differences in P utilisation efficiency due to greater utilisation of residual soil P pools may mean that P export exceeds input, causing run down of P over time (Batten and Kahn 1987; Batten *et al* 1993; 1999) and this will require monitoring by appropriate soil testing (Mason and McDonald 2021).

## Conclusion

Opportunity may exist for wheat growers sowing in April and early May, when conditions of good soil moisture occur, to decrease P inputs while still achieving near-maximum growth and yield potential from these early-sown wheat crops. Coupled with shifting P resources to crops sown later in the season may have a proportionately greater impact on increasing yields and contribute to an overall improvement in yield and returns across a cropping program.

The opportunity relies on utilisation of the residual soil P pool and careful management and monitoring will be important due to risk of high P removal rates with early sowing.

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⦶ *Varieties displaying this symbol are protected under the Plant Breeders' Rights Act 1994.*

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