Residual benefits from dual phosphorus placement to crops in south-eastern Australia

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Abstract

Phosphorus (P) stratification in soils is a common phenomenon in no-till or minimum-till systems due to the minimal mixing of near surface-applied fertilisers, the retention of stubbles and the limited vertical movement of P. Due to dry conditions in this zone, both surface-applied fertiliser P and this stratified P can be unavailable to crops. Therefore, we tested the effectiveness of deep-banded P over the current practice of applying P at or just below seeding depth.

We conducted a field trial using a combination of P rates and placement strategies. Different rates of P were either applied as a dual placement strategy (some under every seed row and some banded at approximately 20 cm below the surface in 50 cm spacings) or it was all placed under every seed row. These two strategies are described as dual P or shallow P, respectively. P was applied as MAP and balanced for nitrogen.

Our results demonstrated a significant increase in grain yield to P fertilisation, with the increases continuing to the fourth season. Dual-banded P was only beneficial with very low rates of shallow-banded P and disappeared with a higher or similar rate of shallow P. This suggests that higher rates of shallow-banded P might overcome subsoil P limitations in south-eastern Australia. Higher rates of P are also advisable to maintain a positive P balance and soil P reserves above the critical range in the long run.

Keywords

Deep-banded P, shallow-banded P, dual-banded P, residual P, P balance, cumulative effect.

Introduction

Deep banding of P in the subsurface layer has been reported to increase grain yield of winter and summer crops in the northern growing regions (northern NSW and QLD), where rainfall is summer dominant and topsoils with stratified P can remain dry for extended periods of time during the growing season (Bell et al. 2022). P stratification is also common in the southern growing regions (southern NSW, Victoria and South Australia) (Armstrong et al. 2017). Sandral et al. (2019) highlighted the possible reasons for P stratification and the potential opportunities for deep P responses in these regions.

Soils and climate factors can directly affect P availability and, thereby, the conditions favourable for deep P responses (Verburg et al. 2024). Despite similarities in P stratification, there are some fundamental differences in soil types, climate factors and cropping systems between northern and southern growing regions. Contrasting to the north, cropping in the south is dominated by winter rainfall with low evaporative demands during the growing season. Here the topsoil can remain wet for considerable lengths of time following sowing, but some periodic drying can occur in seasons with intermittent rain. Therefore, it is unclear whether crops will be as responsive to deep P in the southern regions.

This paper will report experimental findings from southern NSW, where a comprehensive study was conducted to test the effectiveness of different combinations of dual placement of shallow (~5 cm) and deep (~20 cm) banded P. It will present the effect of P placement on grain yield and the residual P benefit on different crops and P balance over four seasons.

Methods

A field trial was conducted from 2020 to 2023 in a grower's paddock at French Park in southern NSW. Soil physicochemical properties of the experimental site are reported in Table 1. The soil has a neutral pH in the top 10 cm (pH (1:5 water) = 6.7) which increases with depth, reaching 9.0 at 30 cm. The changes in soil exchangeable sodium percentage (ESP) followed a similar trend with a value of 4.4% at the topsoil, 12.1% at 10 – 30 cm and more than 22% below 60 cm depth. The site has a Colwell P of 35 mg/kg at 0 – 10 cm but only 4 mg/kg at 10 – 30 cm.

The shallow-banded P treatments consisted of 0, 10, 20 or 40 kg P/ha applied at ~5 cm depth in bands 0.25 m apart prior to seeding but aligned with the seeding rows (shallow band). For each shallow P treatment (except nil), P was also applied in the subsoil (~20 cm depth) at 0, 20, 30 or 40 kg P/ha in bands 0.5 m apart (deep band). A very high rate of shallow-banded P (80 kg P/ha) was included to measure the severity of P deficiency. Another treatment had 30 kg P/ha applied annually (referred to as 30 P). Phosphorus was applied as MAP and balanced for nitrogen (using urea) in all treatments. All treatments were disturbed to ~20 cm depths to account for any ripping effect and an additional control 0/0 undisturbed (no ripping) was included. The total trial consisted of 16 P treatments arranged in a row-column orientation with four replicates. Each plot was 12 m long, 1.5 m wide and consisted of six rows of 0.25 m spacing.

In 2021, all plots received a blanket application of 5 kg P/ha to replace P exported the previous year. In 2022, the original undisturbed 0/0 treatment (0 UD/0) was treated with a shallow band of P at the maximum rate used in the initial experiment year (i.e., 80 kg P/ha) to examine fresh versus residual P benefits. In 2023, only the 30 P treatment received 30 kg P/ha. P supplementation was done using MAP and all plots were balanced for N.

The crop sequence during the four seasons was wheat (2020), lentils (2021), wheat (2022), and faba beans (2023). Header harvested grain yield is reported as t/ha. Grain P content is estimated from grain P concentration (ICP-MS analysis) multiplied by grain yield. Annual P balance is calculated as fertiliser P input minus P content in grain as crop stubbles were returned to the systems. Annual grain yield and P balance were summed over the four seasons for cumulative responses.

Table 1. Physicochemical properties at different soil depths at French Park, southern NSW. Values are means ± SE of n = 4.

Soil depth (cm)	pH (1:5 water)	Organic C (%)	EC (1:5) dS/m	CEC (cmol($^+$)/kg)	ESP (%)	Colwell P (mg/kg)	PBI
0-10	6.7±0.2	1.6±0.08	0.2±0.04	13.5±1.8	4.4±0.6	34.7±8.0	80.8±1.6
10-30	7.9±0.2	0.6±0.04	0.1±0.01	21.3±2.0	12.1±2.1	3.8±1.6	83.0±7.3
30-60	9.0±0.1	0.2±0.02	0.5±0.15	33.5±2.8	19.1±3.6	1.1±0.2	90.0±12.1
60-90	9.0±0.1	0.2±0.03	1.0±0.13	42.3±2.5	22.0±2.4	0.8±0.3	80.8±12.0

Results

Wheat 2020: Wheat grain yield in 2020 was increased by 25% (to an average of 8.3 t/ha) for 20/40, 40/20, 40/40 (shallow/deep kg P/ha) compared to the 0/0 control (6.6 t/ha, Figure 1). Surface only P of 40/0 and 80/0 kg P/ha provided an average yield of 8.0 t/ha, which was also significantly greater than the control 0/0 (6.6 t/ha). In addition, shallow and dual (shallow+deep) placed P treatments were not significantly different and consequently, there were no extra benefits from deep P.

Lentils 2021: P did not consistently increase yield of lentils and consequently, there were no statistical differences.

Wheat 2022: Fresh application of 80 kg P/ha doubled (6 t/ha) grain yield of wheat compared to the 0/0 control (3.1 t/ha; Figure 1). The historical and dual application of 10/30 (4.5 t/ha) yielded higher than the corresponding comparison of 40/0 (3.6 t/ha) indicating an advantage for dual placement. However, the 40/40 (4.4 t/ha) treatment did not yield significantly higher than its corresponding comparison of 80/0 (4.1 t/ha).

Faba beans 2023: Faba beans yield was increased by P strategies. Compared with the 0/0 control, applying 30 kg/ha shallow P annually (30 P treatment) increased grain yield from 2 t/ha to 2.9 t/ha. Residual P (either from the 2020 or 2022 seasons) increased yield in 2023. When compared with the 0/0 control, faba beans treated with 80/0 kg P/ha in the 2020 and 2022 seasons yielded 30% and 59% higher, respectively. However, these residual P responses were not significantly (P>0.05) different from the annual supplementation of 30 kg P/ha.

Cumulative yield: The effect of P strategies on the cumulative grain yield of different crops was significant (P<0.001) over four seasons (Figure 1). Compared with the 0/0 control, different P rates increased cumulative grain yield by up to 39%. The cumulative residual benefit of higher P rates (i.e., 40 kg P/ha or higher) resulted in 30% more grain yield than the 0/0 control over four seasons.

Any residual benefit of deep-banded P was evident only with low rates of shallow-banded P. For example, with 10 kg P/ha shallow-banded P, deep banding of 30 and 40 kg P/ha resulted in significantly higher yields than the 10/0 (shallow/deep kg P/ha) treatment. However, these differences disappeared with higher rates of shallow-banded P i.e., 20 or 40 kg P/ha. The residual and cumulative yield responses were rate-dependent but were not affected by the placement depths.

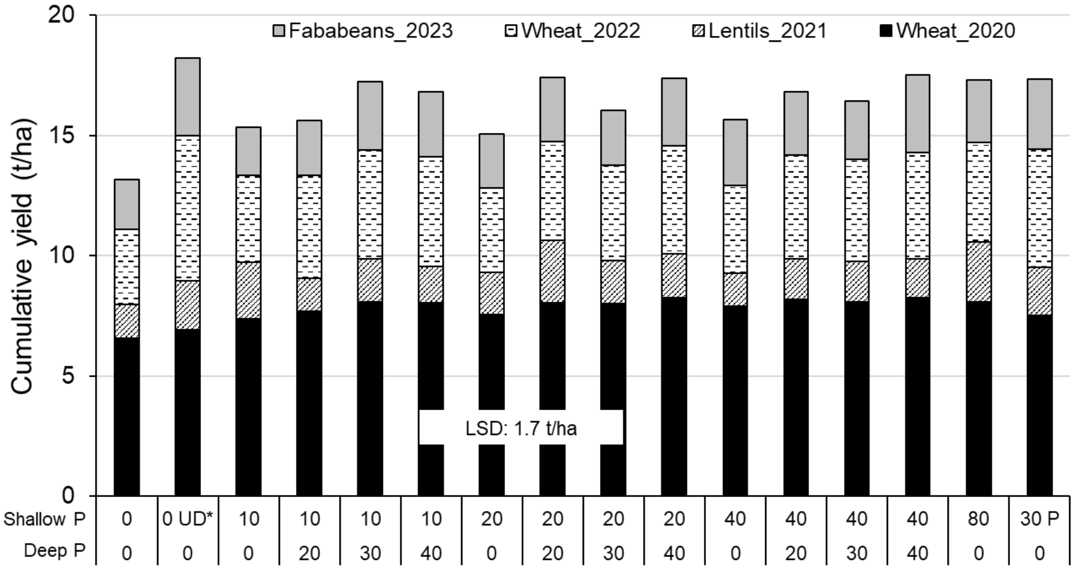

Figure 1. Cumulative grain yield responses of different crops to shallow and dual (shallow+deep) banded P (kg/ha) over four seasons from 2020 to 2023 at French Park, New South Wales. LSD indicates a significant difference between treatment means at P=0.05. The x-axis reads shallow-banded P (top row), then deep-banded P (bottom row). [*]UD: 0 UD/0 plots were treated with 80 kg P/ha as shallow bands in 2022 to compare with the residual benefits of other treatments from 2020.

P balance: Cumulative grain P removal over the four seasons ranged from 29.5 (0/0 control) to 49.1 kg/ha (40/40; shallow/deep P kg/ha; data not shown). This resulted in a negative P balance for all the treatments receiving at or below 40 kg P/ha over four seasons (Figure 2). Annual application of 30 kg P/ha resulted in the highest P balance. Like cumulative yield, P balance was rate-dependent, except for 10/30 (shallow/deep kg P/ha) where P balance was much lower than its corresponding comparison of shallow-banded P i.e., 40/0.

Discussion

Despite having a high background of plant-available P, this site was responsive to both fresh P applied annually and residual P applied up to four years previously. This suggests there may be an opportunity to improve farming productivity and profitability through better P management.

In line with earlier findings from the northern growing regions (Sands et al. 2022), the residual benefit of higher rates of deep-banded P still influenced grain yield after four crops following the initial application. The relative yield responses to deep-banded P observed in this experiment were much higher than the earlier reported values from the northern growing regions. However, this observed trend was evident only at low rates of shallow P and disappeared with a higher or corresponding comparison of shallow P rates (Bell et al. 2012). This suggests that applying higher rates of shallow-banded P can overcome low concentrations of subsoil P in south-eastern Australia.

In this experiment, there was little evidence of a yield advantage of dual-banded P when compared with the same total P placed shallow (i.e., 10/30 vs 40/0 in 2022 and 40/40 vs 80/0 in 2023; shallow/deep kg P/ha) but this trend was not consistent across other treatments and years. Even the cumulative yield response over the four seasons did not demonstrate any yield advantage from dual-banded P compared to its corresponding comparison of shallow-banded P only.

Grain P removal approximated 10.3 kg P/yr across different P treatments and crop rotations, leading to a negative P balance for treatments receiving at or below 40 kg/ha total P over the four seasons. This may result in a reduction of soil Colwell P (Laycock et al. 2022), which needs to be assessed in the context of averaged yields. In a long-term trial, an annual application of 10 kg P/ha maintained the same Colwell P from 2007 to 2021 (Laycock et al. 2022). The average annual yield in our study was higher than this long-term study, indicating a higher starter P is needed to maintain the positive P balance and soil P reserve above the critical range.

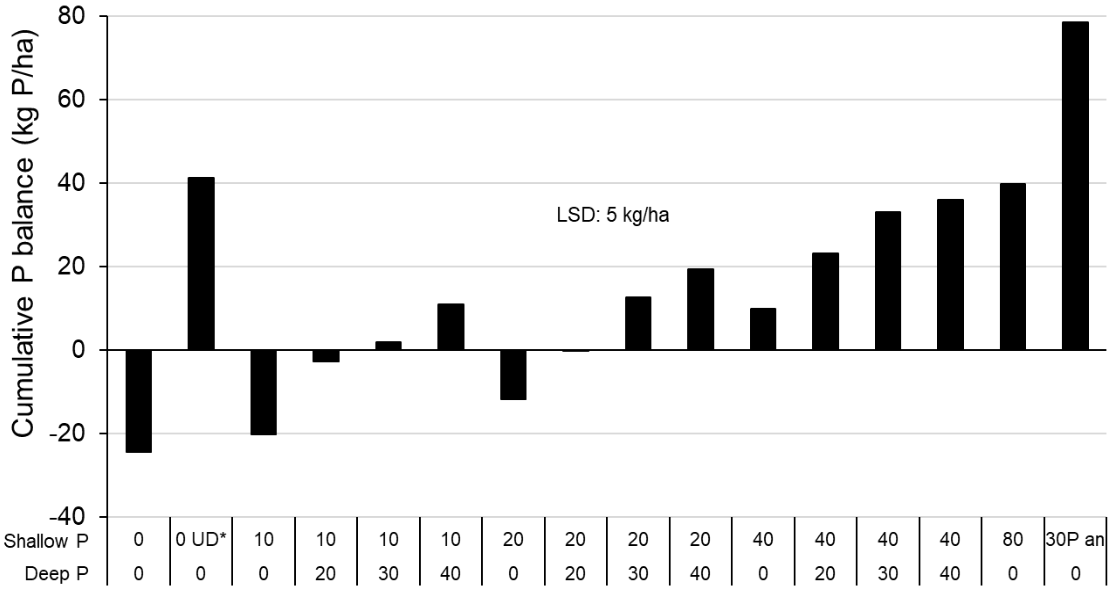

Figure 2. The Cumulative P balance responses to shallow and dual (shallow+deep) banded P (kg/ha) over four seasons from 2020 to 2023 at French Park, New South Wales. LSD indicates a significant difference between treatment means at P=0.05. The x-axis reads shallow-banded P (top row), then deep-banded P (bottom row). *UD: 0 UD/0 plots were treated with 80 kg P/ha as shallow bands in 2022 to compare with the residual benefits of other treatments from 2020.

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