Starter phosphorus reduces the critical external phosphorus requirements of two tropical pasture legumes

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Abstract
Tropical pasture legumes are expected to improve pasture productivity and forage quality in the extensive grazing systems of northern Australia. However, highly productive C_4 grasses often outcompete these legumes, particularly in nutrient-deficient soils. A controlled-environment experiment was conducted to investigate the benefit of starter phosphorus (P) for tropical legume growth across a range of soil P supplies. A low-P soil was amended with basal nutrients and six rates of P fertiliser (0–80 mg P kg^{-1}, as KH_2PO_4 in the basal solution). The amended soils were then incubated for five weeks to prepare contrasting 'native' P treatments. Following incubation, micro-swards of Centro and Desmanthus were established in the six native P treatments, with or without an application of starter P fertiliser (6 kg P ha^{-1} equivalent, as KH_2PO_4 solution). The seed and starter P were applied together in a shallow row. The shoot yield and tissue P concentrations of both legumes increased in response to native P supply. The application of starter fertiliser generally increased shoot yields and reduced the critical external P requirements of both legumes (by 38% for Centro and 74% for Desmanthus). It is likely that the localised application of P fertiliser enabled the legumes to develop more root length so that the soil volume could be explored earlier. This would benefit early legume growth and establishment. These results suggest that starter P applications are likely appropriate for tropical pasture legumes, even in soils that have moderate levels of native P.

Keywords *Centrosema pubescens*, *Desmanthus pernambucanus*, fertiliser benefit, starter fertiliser

Introduction
Tropical pasture legumes are expected to improve pasture and animal performance in the extensive grazing systems of northern Australia (Clem and Hall 1994; Jones and Rees 1997). This is because the soils are generally nutrient deficient and fixation of atmospheric nitrogen by legumes is expected to increase soil fertility and livestock diet quality. However, legume persistence can be poor (Peck et al. 2012), with relative differences in palatability, growth rates and nutrient requirements between grasses and legumes likely to contribute to the higher competitiveness of grasses. Consequently, grazing management and soil fertility are two aspects of the grazing system that could be altered for better legume productivity and persistence.

Starter fertiliser is commonly applied when establishing crops and high-performance pastures. The fertiliser encourages early root development which leads to better establishment and exploration of the soil profile for nutrients. However, starter fertiliser is not commonly applied in extensive grazing systems, due to establishment risk and the cost associated with applying fertiliser over large areas, particularly when land values are relatively low. Nevertheless, the application of starter fertiliser, particularly P, is likely to be beneficial considering the inherent infertility of soils in northern Australia. Indeed, recent work has shown the benefit of applying starter P fertiliser for plants grown in three low-P soils that were collected from across central to northern QLD (McLachlan et al. 2023). However, little is known about how tropical pasture legumes respond to starter P across a range of soil fertilities. The objective of the present work was to therefore determine the effect of native soil P supply on the benefit of starter P applications for tropical pasture legumes and whether starter P benefits plants sown into high P soils.

Methods
Plant growth conditions
Centro (*Centrosema pubescens* cv. Cardillo) and Desmanthus (*Desmanthus pernambucanus* cv. JCU 9) were grown to determine shoot yield and tissue P concentrations in response to starter fertiliser applications.

A sandy loam soil was collected from a field at Kirby SMART Farm, Armidale, NSW, Australia. The soil had a Colwell extractable P concentration of 7 mg P kg^{-1}, a Phosphorus Buffering Index (PBI) of 51, and a

pH ($CaCl_2$) of ~4.6. The soil was passed through a 5 mm sieve and lime (1 g $CaCO_3$ kg^{-1}) was mixed through the soil. While mixing, a complete basal nutrient solution (without P) was applied to the soil. Six P-amended soils (0, 5, 10, 20, 40 and 80 mg P kg^{-1}, hereafter referred to as P0, P5, P10, P20, P40 and P80, respectively) were prepared by adding KH_2PO_4 to the nutrient solution. KCl was also applied to the P0–P20 treatments to balance the potassium to be equivalent to that of the P40 treatment. The P-amended soils were incubated for five weeks. After incubation, 1.3 kg (oven-dry equivalent) of the P-amended soils was added to cylindrical PVC pots (87 mm internal diameter; 200 mm height). The total depth of soil was ~190 mm and the bulk density was ~1.15 g cm^3.

Micro-swards of both legumes were established by sowing seed in a shallow row (~5 mm depth) to achieve a population of 4 plants pot^{-1}. Half of the pots received an application of starter P fertiliser (6 kg P ha^{-1} equivalent of KH_2PO_4 solution) with the seed in the row while the other half did not. Five replicate pots of each legume at each native soil P level and +/− starter fertiliser were prepared. After planting, the pots were watered and moved to a glasshouse (natural daylight, ~1800 mmol m^{-2} s^{-1} peak intensity; 30/25°C, day/night) in Armidale, NSW, Australia. Plants were grown between April and June 2020. Pots were arranged in a randomised complete block design (blocks comprised one replicate of each treatment) which was generated using DiGGer (Coombes 2006). Soil moisture was maintained between 80–100% field capacity by watering daily to a predetermined weight using distilled water.

Harvest and analysis

Plants were harvested after eight weeks' growth. Shoots were cut at the soil surface, oven-dried at 70°C for 72 h and weighed. Shoot samples were then finely cut before a ~50 mg subsample was pre-digested in a glass tube with 1 mL deionised water and 4 mL 70% (v/v) nitric acid for at least 4 h. Samples were then digested using a Milestone UltraWAVE 640 (Milestone Srl, Sorisole, Italy). The P concentration of the digested samples was determined colourimetrically at 630 nm using the malachite green method (Irving and McLaughlin 1990). Shoot P content was calculated by multiplying shoot P concentration and shoot dry mass. Measured parameters were analysed using R (R Core Team 2020).

Results

The shoot dry mass of both legumes increased in response to native soil P supply ($P < 0.001$; Fig. 1). The addition of starter fertiliser increased shoot yields significantly ($P < 0.001$), with the largest benefit generally observed between the P5–P20 treatments. The advantage of starter P was not observed in the P40 and P80 treatments. On average across the treatments, Desmanthus was more productive than Centro ($P < 0.001$).

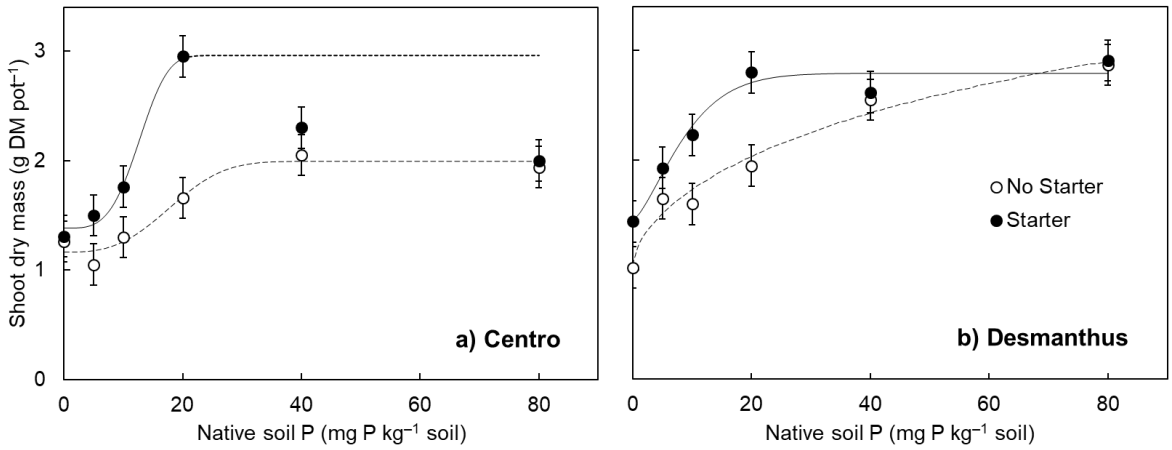

Figure 1. The shoot dry mass of Centro (a) and Desmanthus (b) when grown in response to six native soil P treatments, both with and without starter P fertiliser. Values show the mean ± se (n = 5). Fitted curves show Weibull growth functions. The shoot yield achieved by Centro with starter fertiliser in the P40 and P80 treatments was significantly lower than in the P20 treatment. To enable the Weibull growth function to be fitted, the shoot yield of the P40 and P80 treatments was assumed to be equivalent to that of the P20 treatment. The dotted line represents the assumed P response curve above the P20 treatment.

The critical external P requirements of both legumes decreased in response to starter P fertiliser (Table 1). Centro and Desmanthus were equally efficient when starter P was applied to the soil at planting.

Table 1. The critical external and internal P requirements of Centro and Desmanthus, both with and without starter fertiliser. Critical external P requirements were calculated as the amount of P applied to achieve 90% maximum yield, with 95% confidence intervals shown in parentheses. Critical internal P requirements were the shoot P concentrations that corresponded with the critical external P requirements. * shows the values that could not be calculated.

Species	Critical external P requirement (mg P kg^{-1} soil)	Critical internal P requirement (mg P g^{-1} DM)
Centro – no starter	**23.0** (15.8–56.8)	**2.21**
Centro – starter	**16.0** (12.6–22.9)	**2.13**
Desmanthus – no starter	**52.8** (36.3–*)	**2.52**
Desmanthus – starter	**13.5** (9.6–21.5)	**2.11**

Shoot P content increased with native soil P supply for both legumes ($P < 0.001$), and the addition of starter fertiliser had a positive effect on shoot P content ($P < 0.001$; Fig. 2). Nevertheless, shoot P content was, on average across the treatments, higher for Desmanthus than Centro ($P < 0.001$).

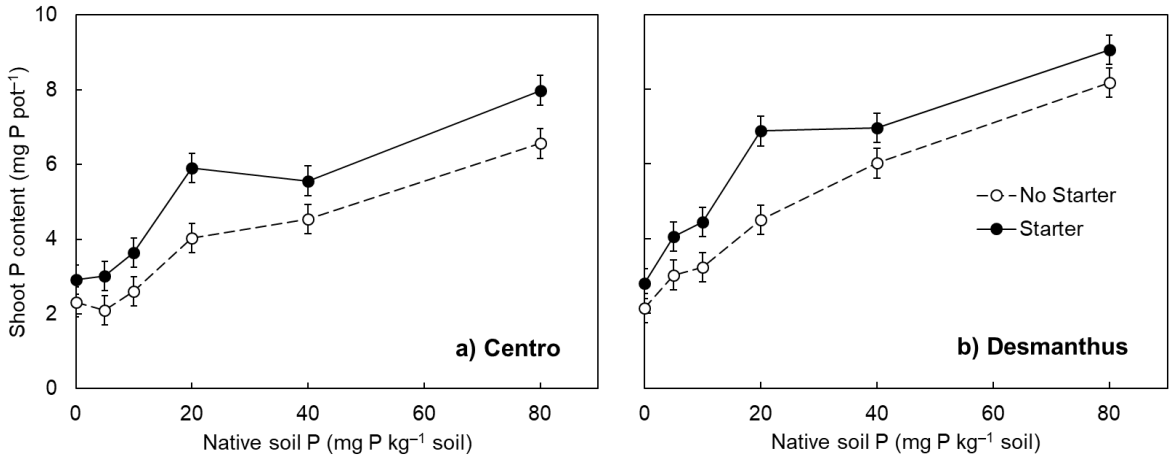

Figure 2. The shoot P content of Centro (a) and Desmanthus (b) when grown in response to six native soil P treatments, both with and without starter fertiliser. Values show the mean ± se (n = 5).

Shoot P-use efficiency declined in response to native soil P supply for both legumes ($P < 0.001$; Fig. 3). There was no difference between Centro and Desmanthus in how they responded to P availability ($P = 0.311$). On average across treatments, shoot-P use efficiency was higher when starter fertiliser was not applied at planting.

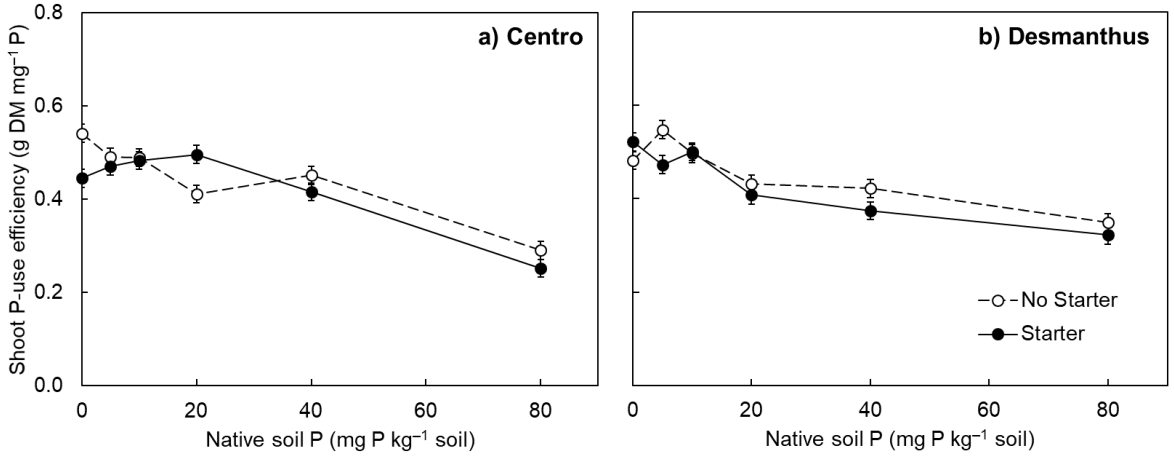

Figure 3. The shoot P-use efficiency of Centro (a) and Desmanthus (b) when grown in response to six native soil P treatments, both with and without starter fertiliser. Values show the mean ± se (n = 5).

Discussion

Centro and Desmanthus both responded to the increasing levels of available P in the six native soil P treatments. This indicates that although these tropical pasture legumes are commonly grown in nutrient deficient soil that receives little nutrient input, they are likely to be more productive if grown in higher fertility soil. However, there was a substantial difference in the critical external P requirements and maximum yields between the two species when starter fertiliser was not applied at planting. This is likely associated with differences in root traits, because both species were equally efficient at using acquired P to produce shoot dry mass.

Starter P fertiliser had a positive effect on shoot yield, particularly between the P5–P20 treatments. Indeed, the addition of starter P reduced the critical external P requirements of both species. This result suggests that both legumes responded to the banded application of starter P by proliferating roots that then enabled further exploration of the soil profile. Root traits were not assessed in the present experiment, nevertheless previous work has shown that these two species respond positively to banded applications of P fertiliser, by acquiring more P from the fertiliser fraction within the early stages of growth (McLachlan et al. 2024). We therefore suggest that starter fertiliser will likely be beneficial across a range of native soil P levels for tropical pasture legumes, but the benefit disappears when soil P supply exceeds critical requirements. These requirements will vary based on pasture species and soil type, but are expected to range between 15–20 mg P kg^{-1} soil in the field.

Conclusion

Centro and Desmanthus both responded positively to the banded application of starter P fertiliser when native soil P levels were low to moderate. This result suggests that starter fertiliser applications should be considered when establishing tropical pasture legumes where soil has lower P concentrations than the critical external P requirement. Further work could consider the longer-term benefit of starter P because, although plants will continue to forage the soil for nutrients, faster growth during establishment may help legumes produce a larger root system to acquire nutrients and stored water that enables better productivity and persistence, particularly under drying conditions.

Acknowledgements

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References

Clem RL, Hall TJ (1994) Persistence and productivity of tropical pasture legumes on three cracking clay soils (Vertisols) in north-eastern Queensland. Australian Journal of Experimental Agriculture 34: 161-171. doi: 10.1071/EA9940161.

Coombes NE (2006) DiGGer, a design generator. http://www.austatgen.org/files/software/downloads.

Irving GCJ, McLaughlin MJ (1990) A rapid and simple field test for phosphorus in Olsen and Bray No. 1 extracts of soil. Communications in Soil Science and Plant Analysis 21: 2245-2255. doi: 10.1080/00103629009368377.

Jones RM, Rees MC (1997) Evaluation of tropical legumes on clay soils at four sites in southern inland Queensland. Tropical Grasslands 31: 95-106.

McLachlan JW, Flavel RJ, Guppy CN (2024) Preferential phosphorus placement improves the productivity and competitiveness of tropical pasture legumes. Legume Science 6. doi: 10.1002/leg3.235.

McLachlan JW, Gunadasa SG, Guppy CN (2023) Emergence and early growth of four *Desmanthus* species in three alkaline clay soils. Agronomy 13: 2996. doi: 10.3390/agronomy13122996.

Peck G, Hall T, Silcock R, Clem B, Buck S, Kedzlie. G (2012) Persistence of pasture legumes in southern and central Queensland. Proceedings of the 16th Australian Society of Agronomy Conference. http://www.agronomyaustraliaproceedings.org/, Armidale, Australia.

R Core Team (2020) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.