The effect of pH and PBI on the critical phosphorus requirements of two tropical pasture species

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Abstract
Tropical pasture species are often grown in soils with available phosphorus (P) concentrations below their critical P requirements. However, little is known about how key soil traits such as pH and Phosphorus Buffering Index (PBI) influence the critical P requirements of these species. Two controlled-environment experiments were conducted to investigate the effect of different starting pH and PBI on the shoot yield and P acquisition of Digit and Desmanthus. In the first experiment, the two species were grown in low-P soil that was amended to achieve five soil pH treatments (4, 5, 6, 7 and 8). In the second experiment, the two species were grown in a low-P soil mix that contained varying combinations of a low-PBI soil and a high-PBI soil to achieve five soil PBI treatments (65, 145, 225, 305 and 385). Ten soil P treatments (0–120 mg P kg^{-1}) were prepared by adding KH_2PO_4 solution to the soil surface. The shoot yields of Digit and Desmanthus increased in response to the higher application rates of P in both experiments. In the soil pH experiment, both species were most productive in the pH 5–8 treatments. Critical external P requirements were lowest in the pH 7 treatment and increased at lower and higher pH levels. In the soil PBI experiment, critical external P requirements increased significantly with PBI. Nevertheless, critical internal P requirements remained relatively stable. Tissue P tests may therefore be a useful way to determine likely responses of tropical pasture species to P fertiliser application across a range of soil types.

Keywords
C_4 grass, *Desmanthus pernambucanus*, *Digitaria eriantha*, tissue P values, tropical legume

Introduction
Tropical pasture species are often grown in nutrient deficient soils that receive little fertiliser input. As a result, little is known about the nutrient requirements of many tropical grasses and legumes. Recent work has shown that there are differences in critical P requirements and maximum yield potential among a range of tropical grasses and legumes, which will have implications for species selection and pasture management (McLachlan et al. 2024). This prior work demonstrated the potential for additional biomass production if tropical pasture species were to be fertilised, but was conducted using a sandy loam soil for ease of assessment. That soil type is generally not representative of the soils found throughout northern Australia, so further work is required to understand the critical P requirements of tropical pasture species across a broader range of soils with different characteristics. The present work considers the role of soil pH and PBI in influencing nutrient availability and plant growth, and therefore the critical external P requirements of common tropical pasture species

Soil pH and PBI have a direct influence on nutrient availability, with the availability of P being highest at a neutral pH and in soil with a low PBI. Availability generally decreases as pH moves away from neutral or PBI increases (Burkitt et al. 2008; Penn and Camberato 2019). The range of different soils across northern Australia necessitates a greater understanding of how critical P requirements vary with these soil characteristics. The objective of this study was to determine the effect of pH and PBI on the critical P requirements of two tropical pasture species, allowing agronomists and pastoralists to make more informed decisions about the P status of pastures across a range of soil types.

Methods
Plant growth conditions
Digit (*Digitaria eriantha* cv. Premier) and Desmanthus (*Desmanthus pernambucanus* cv. JCU 9) were grown to determine shoot yield and tissue P concentrations in response to soil pH and PBI. There were two components of this study.

Soil pH: A clay loam soil was collected from Gregory Downs Station, Gregory, QLD, Australia. The soil had a Colwell extractable P concentration of 3 mg kg^{-1}, a Phosphorus Buffering Index (PBI) of 65, and a pH ($CaCl_2$) of ~7.0. The soil was crushed and amended with a basal nutrient solution that included 34 mg kg^{-1} soil $MgSO_4.7H_2O$, 36 mg kg^{-1} $CaSO_4.2H_2O$, 141 mg kg^{-1} KNO_3, 23 mg kg^{-1} $(NH_4)_2SO_4$, 14 mg kg^{-1} NH_4NO_3, 99 µg kg^{-1} H_3BO_3, 635 µg kg^{-1} $MnCl_2.4H_2O$, 301 µg kg^{-1} $ZnSO_4.7H_2O$, 28 µg kg^{-1} $CuSO_4.5H_2O$, 60 µg kg^{-1} $(NH_4)_2MoO_4$, 17 µg kg^{-1} $CoCl_2 \cdot 6H_2O$ and 1283 µg kg^{-1} FeNa-EDTA. Based on previous soil incubations, five soil pH treatments (4, 5, 6, 7 and 8) were prepared by either adding sulfuric acid (2M H_2SO_4, to reduce the pH to 4–6) or lime ($CaCO_3$, to increase the pH to 8). Cylindrical PVC pots (50 mm internal diameter, 115 mm height) were filled with 300 g (oven-dry basis) of the five amended soils. Ten P solutions were prepared using KH_2PO_4 (K was balanced with KCl) which were applied to the soil surface, resulting in ten different soil P treatments: 0, 2.5, 5, 10, 15, 20, 40, 60, 80 and 120 mg P kg^{-1} (hereafter referred to as P0, P2.5, P5 etc.). The soil was watered, dried and homogenised to distribute the applied P within the top ~5 cm of the profile.

Soil PBI: A clay soil was collected from Kingaroy, QLD, Australia. The soil had a Colwell extractable P concentration of 14 mg kg^{-1}, a PBI of 385, and a pH ($CaCl_2$) of ~5.0. The soil was amended with the basal nutrient solution outlined above and lime (5 g $CaCO_3$ kg^{-1} soil) was added to raise the pH ($CaCl_2$) to ~6.0. Five soil PBI treatments (65, 145, 225, 305 and 385) were prepared by mixing different amounts of the amended Kingaroy soil with different amounts of the amended Gregory Downs soil described above.

Micro-swards of Digit and Desmanthus were established in the pots prepared in the 'pH' and 'PBI' components, by sowing seed (~5 mm depth) to achieve a population of 3 plants pot^{-1}. Two replicate pots of each species at each pH/PBI level and P application rate 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. The pH component of the study occurred in October–November 2022 while the PBI component occurred in November–December 2022. Pots were arranged in a randomised complete block design (blocks comprised one replicate of each treatment). 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 four 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). Critical external P requirements were calculated as the amount of P required to achieve 90% of maximum yield based on a Weibull growth function, with the 95% confidence intervals determined by bootstrapping the residuals. Critical internal P requirements were calculated as the shoot P concentrations that corresponded with the critical external P requirements.

Results

Shoot yield and critical external P requirements

The shoot dry mass of Digit and Desmanthus increased in response to soil P supply ($P < 0.001$; Fig. 1). In the soil pH experiment (Fig. 1a,b), both species were most productive in the pH 5–8 treatments (Digit produced much less biomass in the pH 4 treatment while Desmanthus did not grow at all). In general, the critical external P requirements of Digit and Desmanthus were lowest in the pH 7 treatment and increased at lower (i.e. pH 4–6 treatments) or higher (i.e. pH 8 treatment) pH levels (Table 1). In the soil PBI experiment (Fig. 1c,d), the species had the lowest critical external P requirements when soil PBI was lowest (i.e. PBI 65 treatment) (Table 1). The critical external P requirements of the species increased with soil PBI. In both the pH and PBI components, Digit consistently out-yielded Desmanthus and had lower critical external P requirements.

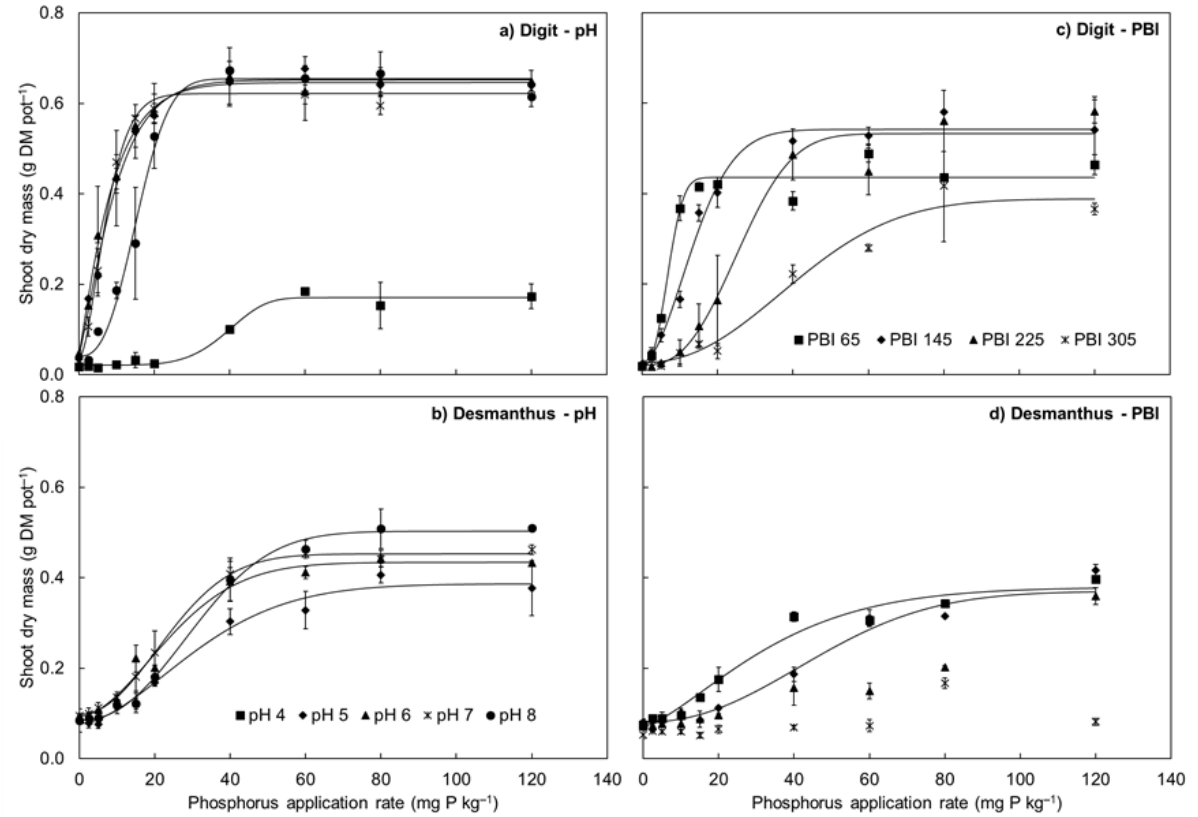

Figure 1. The shoot dry mass of Digit (a, c) and Desmanthus (b, d) when grown in soils with different pH (a, b) and PBI (c, d) levels. Values show the mean ± s.e. (n = 2). Fitted curves show Weibull growth functions. Curves could not be fitted for Desmanthus in the PBI 225–385 treatments due to limited but highly variable growth.

Table 1. The critical external and internal P requirements of Digit and Desmanthus, grown in soils with different pH and PBI levels. 95% confidence intervals are shown in parentheses. * denotes the values that could not be calculated.

Species pH or PBI	Critical external P requirement (mg P kg^{-1} soil)	Critical internal P requirement (mg P g^{-1} DM)
Digit – pH		
pH 4	48.6 (44.7–68.7)	1.74
pH 5	20.1 (17.0–24.7)	1.02
pH 6	18.7 (14.7–25.5)	0.98
pH 7	14.3 (12.4–16.8)	1.14
pH 8	24.0 (20.8–32.5)	0.93
Desmanthus – pH		
pH 4	*	*
pH 5	56.3 (44.8–75.3)	1.33
pH 6	42.6 (33.6–50.0)	1.54
pH 7	39.9 (33.0–46.7)	1.28
pH 8	50.2 (44.3–56.1)	1.42
Digit – PBI		
PBI 65	11.0 (9.5–12.9)	0.97
PBI 145	25.7 (22.0–31.6)	0.86
PBI 225	40.1 (25.9–54.4)	1.22
PBI 305	68.9 (50.0–*)	1.20
PBI 385	*	*
Desmanthus – PBI		
PBI 65	62.7 (52.2–74.8)	1.81
PBI 145	75.4 (68.3–83.5)	1.49
PBI 225	*	*
PBI 305	*	*
PBI 385	*	*

Shoot P concentration and critical internal P requirements

Shoot P concentrations increased in response to soil P supply for both Digit and Desmanthus ($P < 0.001$; data not shown). Although there were some differences in shoot P across treatments, shoot P concentrations were generally not influenced strongly by either pH or PBI level, as demonstrated by the relatively consistent critical internal P requirements of the species (Table 1).

Discussion

The results of the two experiments suggest that soil pH and PBI are likely to influence the response of tropical pasture species to soil P supply. In both species, the lowest critical external P requirements occurred in soil with pH of 7, with lower and higher pH soils resulting in higher critical external P requirements. This may be due to the impact of soil pH on nutrient availability and P sorption. However, it may also be due to species differences in preferred soil type (including root development) that would similarly influence P uptake dynamics. For example, Desmanthus is suited to neutral to alkaline clay soils, which have a medium to heavy texture (Gardiner et al. 2004). It is therefore expected that this species would perform poorly in lighter soils that have a relatively low pH. Furthermore, lack of growth at low pH is common among legume species and largely driven by lack of root function. In terms of soil PBI, Desmanthus emergence and growth were severely limited at higher levels, primarily because the higher PBI red ferrosol dried quickly which resulted in a hard-setting surface. This again highlights that factors other than nutrient availability influence species suitability. Regardless of species differences, higher critical external P requirements mean that extra P is required for optimum production.

The critical external P requirements of both tropical pasture species were generally quite high in the two experiments. This is largely attributable to the small soil volume and relatively short growth period. However, excluding the pH 4 treatment, critical internal P requirements were relatively consistent regardless of soil pH and PBI (Digit = 0.86–1.22 mg P g^{-1} DM, and Desmanthus = 1.28–1.81 mg P g^{-1} DM) and much closer to what would be expected under field conditions. Tissue P tests may therefore be a useful way to determine likely responses of tropical pasture species to P fertiliser application across a range of soil types.

Conclusion

The critical external P requirements of the two tropical pasture species responded as expected to different starting soil pH and soil PBI levels, which means that the critical value of a species should be increased in soils with a pH that is more distant from 7 or soils with higher PBIs. However, tissue P concentrations were relatively stable which means that they are likely to be an informative way of determining the need for P fertiliser application across a range of soil types.

Acknowledgements

This work was made possible by MLA funding: 'P.PSH.1050 – Phosphorus management and requirements of tropical legume pasture swards'. Emma Flavel is thanked for technical assistance.

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