Legume competitiveness is improved by preferential fertiliser application at planting in mixed pasture swards

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Abstract: *Pasture legumes can be outcompeted by grasses in mixed pasture swards due to differences in nutrient requirements, growth rates and grazing preference. Ensuring adequate soil nutrition during establishment is one way of optimising legume competitiveness. A field trial was conducted to determine the benefit of preferentially fertilising the legume component of a mixed pasture sward at establishment. Tall fescue/lucerne and digit grass/desmanthus mixes were grown for three months to investigate shoot yield, tissue N and tissue P responses to mono-ammonium phosphate (MAP) fertiliser. The pasture species were planted in separate rows, with starter fertiliser applied either below the grass and legume (MAP at 3 kg P/ha equivalent in each row), or below the legume only (MAP at 6 kg P/ha in the legume rows). The grasses were highly productive and outyielded their companion legumes in both fertiliser treatments. Nevertheless, the preferential application of starter fertiliser below the legumes increased the shoot yield (avg. +63%) and shoot P content (avg. +87%) of this component while not impacting the productivity of the grasses. On average, the potential recovery of P fertiliser (shoot P content as a proportion of applied P fertiliser) was only 2.3% for lucerne and 0.4% for desmanthus. These results indicate that a preferential application of starter fertiliser below the legume component at planting can increase legume vigour, relative to the grass component, without having a detrimental impact on overall pasture production. Further research is required to determine if this difference in early growth influences longer-term legume productivity and persistence.*

Key words: banded application, *Festuca arundinacea, Medicago sativa, Digitaria eriantha, Desmanthus pernambucanus*

Introduction

Legumes are a valuable component of many pastures because they fix atmospheric nitrogen (N) and improve the diet quality of grazing livestock (Nichols and Crush 2014; Boschma *et al.* 2021). Indeed, there is a wide range of adapted legumes that have been successfully integrated into Australian pastures. However, legumes can be outcompeted by constituent pasture grasses, particularly in more extensive grazing systems. This may occur due to differences in nutrient requirements, growth rates and/or yield potential between grasses and legumes, whereby grasses generally forage more effectively for limited nutrients (Evans 1977) and their growth can eventually overwhelm that of the legumes (Haling *et al.* 2013). These differences are often exacerbated by the comparatively high palatability of legumes, meaning they are preferentially grazed and are further disadvantaged, especially if there is limited control of grazing. Ongoing management (including the addition of fertiliser and control of stocking rates) is therefore required to maintain the competitiveness of legumes, particularly if they are to remain productive in mixed pasture swards.

Fertiliser is normally broadcast onto the soil surface of pastures, due to the ease and cost of application (McLaughlin *et al.* 2011). However, this results in P stratification within the soil profile. Subsurface applications of banded P fertiliser have therefore been suggested as an alternative method of application because they allow for greater availability of P for plant growth, particularly during surface dry conditions. Previous research has demonstrated that a subsurface application of P fertiliser can increase P fertiliser recovery in a temperate pasture (McLachlan *et al.* 2019). This method of fertiliser application is most applicable at planting when seed and fertiliser can be placed together to maximise nutrient availability. Targeted fertiliser applications are likely to improve the success of pasture establishment, particularly that of legumes which often have a higher requirement for nutrients than grasses.

Strong growth in the first season improves the chance of plant persistence and for seed set which increases the potential for seedling recruitment in subsequent seasons, if this is required for ongoing productivity.

Preferential fertilisation of the legume component at planting may achieve these goals. Previous research has demonstrated that warm-season pasture species, including lucerne and desmanthus, acquired more P from the zone of P enrichment following a banded application of P fertiliser in the vicinity of establishing plants (McLachlan *et al.* 2023). Subsequent research has shown that legume productivity can be improved by preferentially fertilising this component when tropical grasses and legumes are sown in a P-responsive soil (McLachlan *et al.* 2024). These results indicate that a banded application of starter fertiliser at planting, placed preferentially below the legume component, may improve early plant vigour and competitive ability. However, this previous research has been conducted under controlled conditions. Field validation of these responses is therefore warranted. The objectives of the present experiment were to determine the; i) effect of spatial configuration (seed and fertiliser placement) on the competitive ability of the legume component in a mixed pasture sward, and ii) influence of native soil P supply on the benefit of a banded application of starter fertiliser.

Methods

Site preparation

A field trial was conducted at the Kirby SMART Farm, Armidale, NSW, Australia (30°25'59.2"S 151°37'30.0"E). The soil at the site was a sandy loam (Brown Chromosol; Isbell 1996) with a Phosphorus Buffering Index (PBI) of 109. Prior to any preparation, the soil had an average Colwell extractable P concentration of ~21 mg P/kg and an average pH_{Ca} of ~5.0. These averages were based on detailed grid sampling of the site.

Six 'native' P fertiliser treatments were prepared approximately two years prior to the establishment of the present field trial. There were five treatments where triple superphosphate (15.7% P, 4.6% S) was broadcast onto the soil surface at rates of 0, 15, 30, 45 and 90 kg P/ha. There was one treatment where triple superphosphate was applied ~2.5 cm below the soil surface as a banded application at a rate of 15 kg P/ha. Hereafter these treatments are referred to as P0, P15, P30, P45, P90 and B15, respectively. The sulfur that was applied to the P0–P30 treatments in the triple superphosphate was balanced with gypsum, to be equivalent to that of the P45 treatment. The site also received a basal application of 50 kg K/ha and 22 kg S/ ha (as Sulfate of Potash; 41% K, 18% S) and 1 kg/ha of micronutrients (Librel® BMX, which includes boron, copper, iron, manganese, molybdenum and zinc) applied as a solution. Following the addition of nutrients, the site was sown with *Trifolium subterraneum* L. Due to extreme drought conditions in 2019, there was minimal growth of the *T. subterraneum* within the first six months after planting. The site was therefore periodically grazed before weed control commenced in preparation for the establishment of the present experiment. In the four months prior to planting, there were three applications of Glyphosate 450 (2.5 L/ha) to maintain a fallow. The third application included Starane Advanced (0.9 L/ha) to ensure complete control of all grass and broadleaf weeds. Following this weed control, there was another application of 50 kg K/ha and 22 kg S/ha (as Sulfate of Potash).

Trial establishment

Two grass-legume mixes were established in the plots that had previously been prepared with the six native P fertiliser treatments and had been amended with basal nutrients. There was a temperate pasture mix that included tall fescue (*Festuca arundinacea* cv. Quantum II) and lucerne (*Medicago sativa* cv. Haymaster), and there was a tropical pasture mix that included digit grass (*Digitaria eriantha* cv. Premier) and desmanthus (*Desmanthus pernambucanus* cv. JCU 9). Sowing rates were equivalent to 15 kg/ha for tall fescue, 10 kg/ha for lucerne, 10 kg/ha for digit grass and 5 kg/ha for desmanthus. These sowing rates accounted for germination percentage and seed coating and aimed to achieve ~40% legume content based on plant population. The seed was sown using a double disc opener cone seeder that had eight discs, with alternating rows of grass and legume sown separately (four rows of each component) spaced at 12.5 cm. Mono-ammonium phosphate (MAP) fertiliser (10.0% N, 21.9% P) was applied in the rows with the seed, either at 3 kg P/ha equivalent with the grass and legume, or at 6 kg P/ha equivalent with the legume only. The treatments were arranged in a randomised complete block design (blocks comprised the different replicates) which was generated using DiGGer (Coombes 2009). There were five replicates of each treatment so there was a total of 120 plots, each 5 m long and 1 m wide. Plants were grown in January–April 2021, during which the site received 282 mm of rainfall (the January to April average for Armidale is 297 mm). Four days after planting and before the pasture species emerged, Glyphosate 450 (2.5 L/ha) was applied across the trial site to control weed seedlings.

Sampling and measurements

Plants were harvested three months after planting. Two rows of grass (4 m long) and two rows of legume (4 m long), excluding 0.5 m at either end of the plots, were harvested separately to allow the proportion of grass and legume to be calculated. Shoots were cut at the soil surface, oven-dried at 70°C for 7 days and weighed. The harvested biomass was multiplied by 2.5 to estimate the total amount of biomass that had been produced across the entire plot. Shoot samples were 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 12 h. All 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. Potential P fertiliser recovery was calculated as the percentage of shoot P content divided by applied P fertiliser. Shoot samples were also assessed for N concentration using a LECO Trumac Analyser. Shoot N content was calculated by multiplying shoot N concentration and shoot dry mass. Potential N fertiliser recovery was calculated as the percentage of shoot N content divided by applied N fertiliser.

Soil samples were also taken from each plot for the determination of soil P status. Five cores were randomly collected between the planted rows (to avoid the banded fertiliser) to a depth of 10 cm and bulked together so there was one sample per plot. The collected samples were then analysed for Colwell extractable P concentration by tumbling 0.4 g of air-dried soil for 16 h in 40 mL of 0.5 M $NaHCO_3$ and the supernatant was analysed colourimetrically at 630 nm using the malachite green method.

Statistical analyses

Measured parameters were analysed in R Version 4.5.1 (R Core Team 2025) by fitting linear models and using an analysis of variance with ‘species mix’ (tall fescue/lucerne and digit grass/desmanthus), ‘fertiliser placement’ (banded below both and banded below legume only) and ‘native P treatment’ (P0–P90 and B15) as predictor variables. When appropriate, the effect of ‘replicate’ and ‘column’ from the randomised complete block design was included in the most parsimonious model. Where significant, the effect of replicate and/or column accounted for the error associated with spatial variation. Means and standard errors were calculated from the fitted linear models (R Package: emmeans) (Lenth 2020) and means were compared using Tukey’s honest significant differences (HSD). Fourteen plots were removed from the analysis due to only one component (i.e. either the grass or the legume) being present in the plot due to poor establishment. Normal quantile-quantile plots and Shapiro-Wilk tests were used to test the normality of the residuals for all fitted models. When required, these models were log-transformed to meet the assumptions of normality. A 5% level of significance was applied for all statistical tests.

Results and discussion

Soil phosphorus status

Soil test Colwell P concentrations at the time of harvest reflected the amount of P fertiliser that had been broadcast two years prior to the establishment of the present experiment (Fig. 1). The P0 treatment had an average Colwell P concentration of 33 mg P/kg which increased significantly across the treatment range to a maximum of 82 mg P/kg in the P90 treatment (P < 0.001). The Colwell P concentration of 33 mg P/kg in the P0 treatment at the time of harvest was higher than the original Colwell P concentration of 21 mg P/kg, which could be attributed to the mineralisation of organic P following the extremely dry conditions (Lucci 2019) in 2019 and the fallowing that occurred in preparation for the present experiment. Given the relatively low PBI of 109, the soil P status across the trial was at or above the critical P requirements for mixed pasture swards (Gourley *et al.* 2019).

Shoot yield

Shoot yields were not influenced by native soil P supply (i.e. the P0–P90 and B15 treatments) (P = 0.451 and P = 0.614 for the grasses and legumes, respectively), but legume shoot yields were influenced by the placement of banded fertiliser (i.e. either below both components or below the legume only) (P = 0.010). The shoot yield results were therefore summarised according to species mix and fertiliser application (Fig. 2). On average, legume shoot yields were 63% higher when fertiliser was placed below this component only compared to when fertiliser was placed below both the grass and legume. By contrast, the shoot yields of the grasses were not influenced by the placement of banded fertiliser (P = 0.702) (Fig. 2). The advantage of applying starter fertiliser with the legume only, without any yield penalty on the grass, likely reflects the adequate fertility of the soil where the trial was conducted. By contrast, it is expected that starter fertiliser would have a positive effect on the yield of the grasses also if the soil was P responsive. Indeed, previous work under controlled conditions in a highly P-responsive soil showed that the shoot yield of desmanthus increased whereas that of digit grass decreased when the legume component was preferentially fertilised with a double rate of starter fertiliser compared to when both components received a standard rate of starter fertiliser (McLachlan *et al.* 2024). This meant that, even though the legume was benefited, the overall productivity of the sward declined.

On average across the treatments, the performance of the four species was as follows; digit grass > tall fescue > lucerne > desmanthus (Fig. 2). These differences in shoot yield meant that both pasture mixes were grass dominant (avg. 82% grass in the tall fescue/lucerne mix and avg. 98% grass in the digit grass/desmanthus mix), even though the sowing rates had targeted a legume proportion of ~40% on a plant population basis. It is possible that the soil type constrained the growth of both lucerne and desmanthus, given the sandy loam texture and the marginal soil pH_{Ca} of ~5.0.

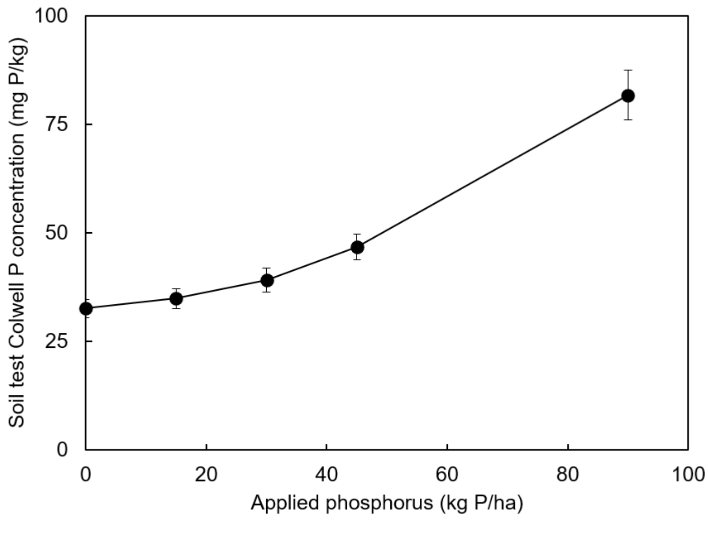

Figure 1. Soil test Colwell phosphorus (P) concentration at the time of harvest for the five native P treatments (0, 15, 30, 45 and 90 kg P/ha) that were prepared by broadcasting triple superphosphate (15.7% P, 4.6% S) approximately two years prior to the establishment of the present experiment. Values show the mean ± standard error (n = 20).

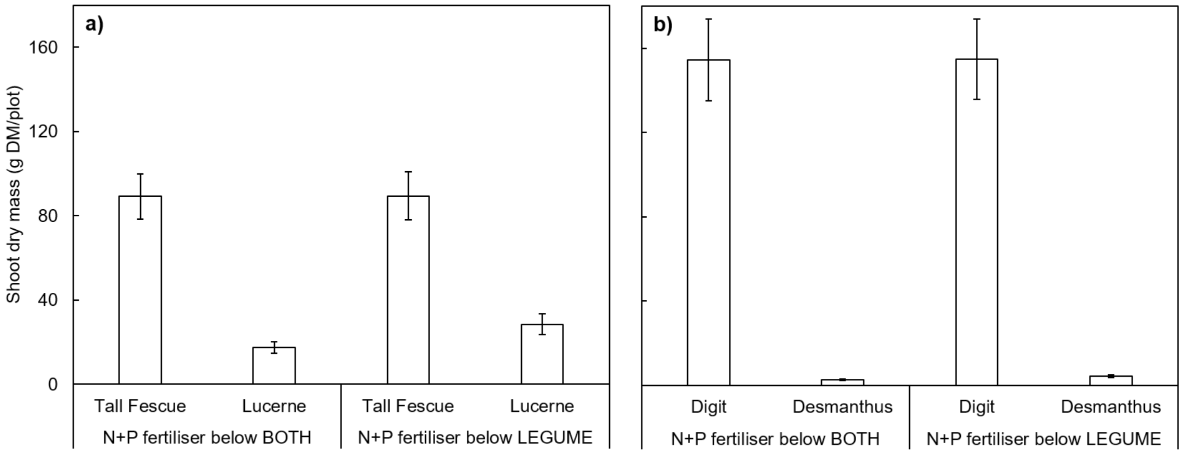

Figure 2. Shoot dry mass of a) tall fescue/lucerne and b) digit grass/desmanthus when grown in response to two starter fertiliser application treatments (N+P fertiliser applied below both the grass and legume at a rate equivalent to 3 kg P/ha, or below the legume only at a rate equivalent to 6 kg P/ha). Values show the mean ± standard error (n = 4).

Furthermore, the climatic conditions in Armidale would have limited the yield potential of desmanthus even though the trial occurred between January and April. Nevertheless, the preferential placement of starter fertiliser below the legumes increased the proportion of the legume biomass component by an average of 46%.

The shoot yield results suggest that preferentially fertilising the legume component at pasture establishment may be a viable method for increasing legume competitiveness, provided the grass and legume components can be sown in separate rows. The additional benefit of alternating rows of grass and legume is that there is more space for the plants to establish thus reducing interspecific competition. However, previous work with subterranean clover, lucerne and phalaris in southern Australia has shown that the value of alternative spatial configurations is highly site-specific and season-dependent (Hayes *et al.* 2017). Even if grasses and legumes are sown in separate rows, it is expected that the grasses will forage for the starter fertiliser and, over time, will capitalise on the improved soil nutrition below the legume. Indeed, previous research has shown that, within six weeks of growth, digit grass had acquired P that had been applied below desmanthus (when both components were fertilised with P and when only the legume had been fertilised with P) (McLachlan *et al.* 2024). These findings are consistent with our present work and indicate no great limitation to early grass productivity as a result of more spatially distant P placement. Nevertheless, the effect of preferential fertiliser application on the longer-term productivity and persistence of the legume component warrants further investigation.

Shoot nitrogen

Shoot N results were also summarised according to species mix and fertiliser application (Fig. 3). Shoot N concentrations were not influenced by fertiliser placement (P = 0.985 and P = 0.220 for the grasses and legumes, respectively). The average shoot N concentrations were 3.0, 1.9, 1.8 and 1.7 mg N/g DM for desmanthus, digit grass, lucerne and tall fescue, respectively. Except for desmanthus which produced a limited amount of biomass, the shoot N concentrations of the other pasture species were below critical internal requirements (Pinkerton *et al.* 1997), yet they did not respond to the banded application of N at planting. Shoot N contents reflected differences in shoot yield which meant that shoot N content was highest for digit grass, followed by tall fescue, lucerne and desmanthus (Fig. 3).

Potential N fertiliser recovery (i.e. shoot N content as a proportion of applied N fertiliser) was not influenced by the placement of starter fertiliser and was moderate for both legumes (avg. of 36% for lucerne and avg. of 11% for desmanthus) (data not shown). These potential recoveries, which do not account for fixed N or soil N, suggest that there was adequate N available for the two legumes.

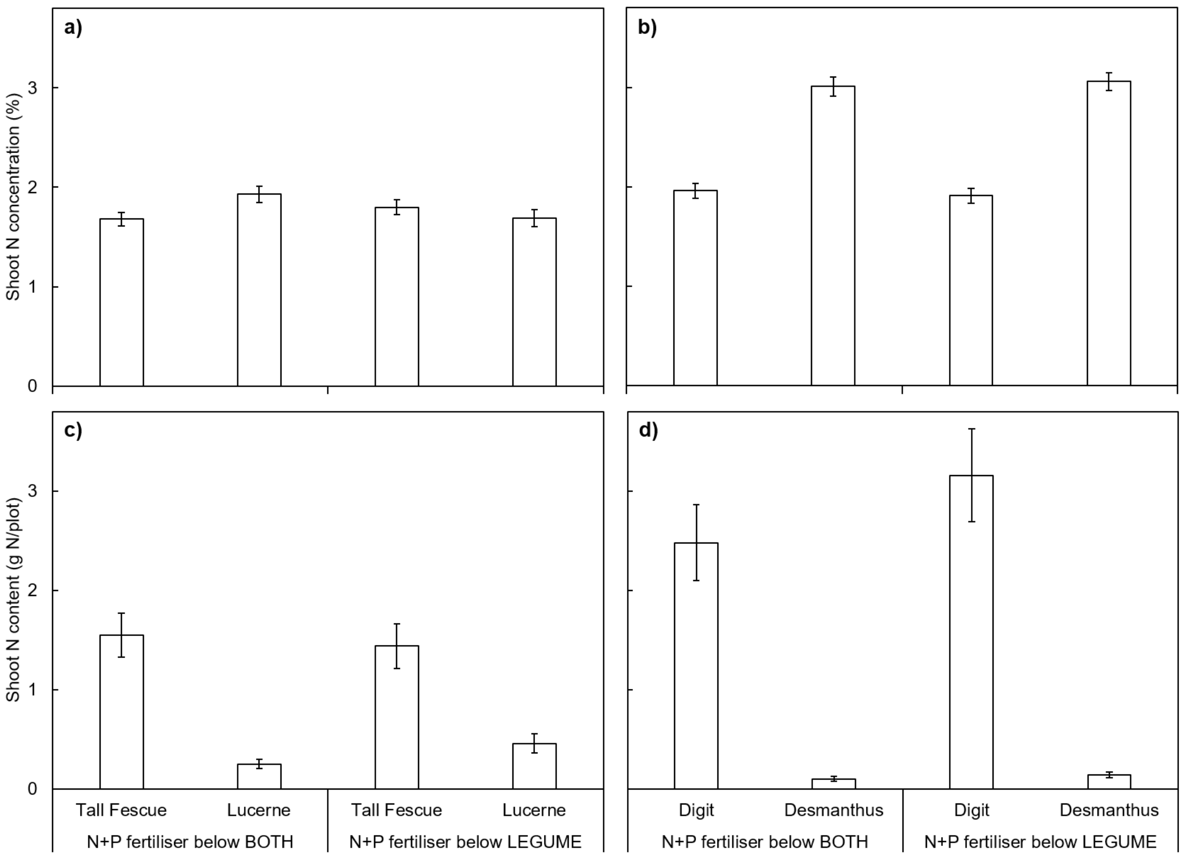

Figure 3. Shoot nitrogen (N) concentration (a, b) and shoot N content (c, d) of tall fescue/lucerne (a, c) and digit grass/desmanthus (b, d) when grown in response to two starter fertiliser application treatments (N+P fertiliser applied below both the grass and legume at a rate equivalent to 3 kg P/ha, or below the legume only at a rate equivalent to 6 kg P/ha). Values show the mean ± standard error (n = 4).

Shoot phosphorus

Grass and legume shoot P concentrations were influenced by native soil P supply ($P < 0.001$ and $P = 0.001$, respectively) but not by the placement of banded fertiliser ($P = 0.861$ and $P = 0.070$, respectively). Because of this, the shoot P concentration results were summarised according to species mix and native soil P supply treatment (Fig. 4). In general, shoot P concentrations were lowest in the P0 treatment and increased to be highest in the P90 treatment. Based on previously published results, the shoot P concentrations were above the critical internal requirements for digit grass and desmanthus (McLachlan *et al.* 2025) but were below for the tall fescue and lucerne (Pinkerton *et al.* 1997). Shoot P content reflected the differences in shoot yield and, to a lesser extent, the differences in shoot P concentration (Fig. 5). In particular, grass shoot P contents were not influenced by the placement of banded fertiliser ($P = 0.680$) whereas the shoot P contents of the legumes were ($P = 0.006$). On average, fertiliser placed below only the legume component increased the shoot P content of this component by 87%. Again, the advantage of preferential fertiliser placement on the legume, with no penalty on the grass, suggests that this may be an appropriate fertiliser application strategy in soil of moderate fertility.

Potential P fertiliser recovery (i.e. shoot P content as a proportion of applied P fertiliser) was not influenced by the placement of starter fertiliser or the native soil P supply and was relatively low for both legumes (avg. of 2.3% for lucerne and avg. of 0.4% for desmanthus) (data not shown). These low recoveries indicate that there was ample starter fertiliser available for plant uptake and growth, and that the benefit of the starter fertiliser was not fully realised within the relatively short three-month period. This corresponds with previous work that showed the total recovery of applied P was relatively low (≤7% of applied P) for pasture mixes that included digit grass and desmanthus (McLachlan *et al.* 2024). It is expected that the benefit of starter fertiliser will increase in soils of lower fertility and that recoveries will also increase with time. Nevertheless, the low potential fertiliser recoveries across the establishment period indicate that starter fertiliser applications should remain beneficial for the duration of the first growing season.

Conclusions

Preferential fertiliser application below the legume component at planting increased the productivity of the legume component without having a detrimental impact on overall pasture production. This method of fertiliser application may be an appropriate way to increase the success of legume establishment, particularly when legumes are planted with highly productive grasses which compete more effectively for soil nutrients. Further research is required to determine if any difference in early growth influences longer-term legume productivity and persistence. The low potential recovery of applied P fertiliser indicates that any application of starter fertiliser will likely remain available for the duration of the first growing season.

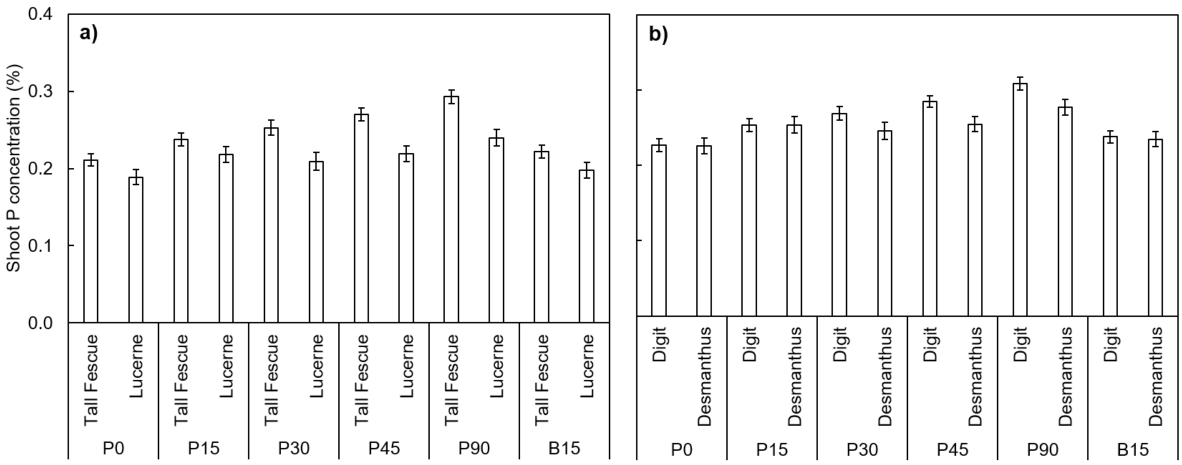

Figure 4. Shoot phosphorus (P) concentration of a) tall fescue/lucerne and b) digit grass/desmanthus when grown in response to six native soil P supply treatments (0, 15, 30, 45 and 90 kg P/ha broadcast and 15 kg P/ha banded, labelled as P0, P15, P30, P45, P90 and B15, respectively). Values show the mean ± standard error (n = 4).

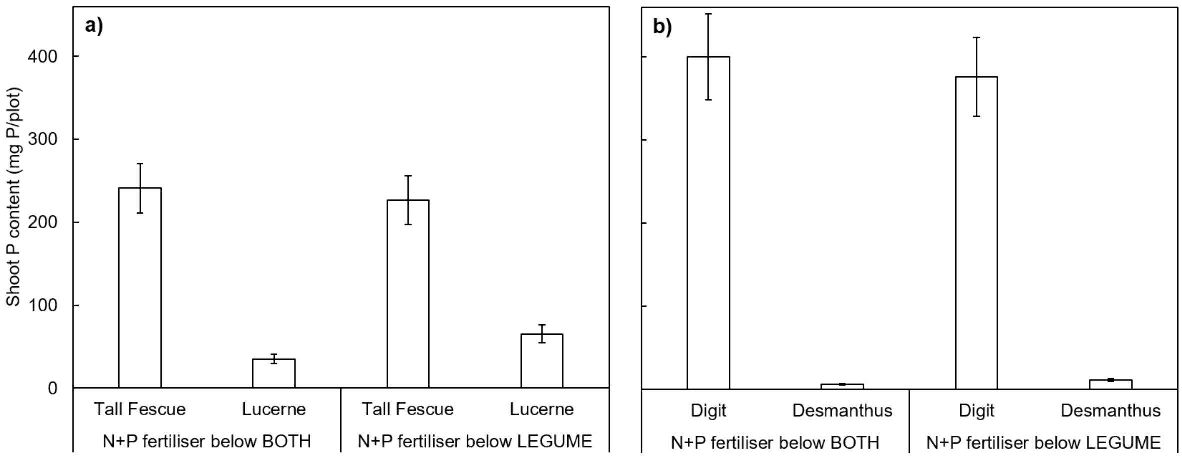

Figure 5. Shoot phosphorus (P) content of a) tall fescue/lucerne and b) digit grass/desmanthus when grown in response to two starter fertiliser application treatments (N+P fertiliser applied below both the grass and legume at a rate equivalent to 3 kg P/ha, or below the legume only at a rate equivalent to 6 kg P/ha). Values show the mean ± standard error (n = 4).

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References

Boschma SP, Harris CA, Brennan MA, Harden S (2021) *Medicago sativa* and *Desmanthus virgatus*: suitable perennial legumes in mixes with *Digitaria eriantha* in Australia during drought. *Crop & Pasture Science* **72**, 692–706.

Coombes NE (2009) 'DiGGer, a spatial design program.' Biometric Bulletin. (NSW Department of Primary Industries: Orange, Australia)

Evans PS (1977) Comparative root morphology of some pasture grasses and clovers. *New Zealand Journal of Agricultural Research* **20**, 331–335.

Gourley CJP, Weaver DM, Simpson RJ, Aarons SR, Hannah MM, Peverill KI (2019) The development and application of functions describing pasture yield responses to phosphorus, potassium and sulfur in Australia using meta-data analysis and derived soil-test calibration relationships. *Crop & Pasture Science* **70**, 1065–1079.

Haling RE, Campbell CD, Tighe MK, Guppy CN (2013) Effect of competition from a C_4 grass on the phosphorus response of a subtropical legume. *Crop & Pasture Science* **64**, 985–992.

Hayes RC, Li GD, Sandral GA, Swan TD, Price A, Hildebrand S, Goward L, Fuller C, Peoples MB (2017) Enhancing composition and persistence of mixed pasture swards in southern New South Wales through alternative spatial configurations and improved legume performance. *Crop & Pasture Science* **68**, 1112–1130.

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.

Isbell RF (1996) 'The Australian soil classification'. (CSIRO Publishing: Melbourne, Australia)

Lenth R (2020) 'emmeans: estimated marginal means, aka least-squares means.' https://CRAN.R-project.org/package=emmeans. Accessed 30 June 2026.

Lucci GM (2019) Pastures and drought: a review of processes and implications for nitrogen and phosphorus cycling in grassland systems. *Soil Research* **57**, 101–112.

McLachlan JW, Flavel RJ, Guppy CN (2024) Preferential phosphorus placement improves the productivity and competitiveness of tropical pasture legumes. *Legume Science* **6**, e235.

McLachlan JW, Flavel RJ, Guppy CN (2025) Root morphology and phosphorus requirements of 12 tropical pasture species grown in a controlled environment. *Crop & Pasture Science* **76**, CP25049.

McLachlan JW, Guppy CN, Flavel RJ (2019) Banded application improves the recovery of phosphorus fertiliser in a temperate pasture sward containing red clover. In 'Proceedings of the 19th Australian Society of Agronomy Conference, 25–29 August 2019, Wagga Wagga, NSW, Australia'.

McLachlan JW, Staker BJ, Flavel RJ, Guppy CN (2023) Warm-season pasture species respond to subsurface placement of phosphorus fertiliser. *Agronomy* **13**, 2524.

McLaughlin MJ, McBeath TM, Smernik R, Stacey SP, Ajiboye B, Guppy C (2011) The chemical nature of P accumulation in agricultural soils – implications for fertiliser management and design: an Australian perspective. *Plant and Soil* **349**, 69–87.

Nichols SN, Crush JR (2014) Novel approaches to improving growth of pasture legumes at low phosphorus levels. In 'Proceedings of the New Zealand Grassland Association'. Volume 76, pp. 197-201. Alexandra, New Zealand.

Pinkerton A, Smith FW, Lewis DC (1997) Pasture species. In 'Plant Analysis – An Interpretation Manual.' (Eds DJ Reuter, JB Robinson.) pp. 287-346. (CSIRO Publishing: Melbourne, Australia).

R Core Team (2025) 'R: a language and environment for statistical computing.' (R Foundation for Statistical Computing: Vienna, Austria).