Yields of *Trifolium* pasture cultivars, but not *Ornithopus* cultivars, are increased by addition of N, S and K to a dairy farm soil high in P on the Peel Harvey coastal plain, Western Australia

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Abstract
Pasture soils of the Peel Harvey coastal plain of Western Australia have been greatly enriched in phosphorus (P), but less so in nitrogen (N), sulphur (S) and potassium (K). To determine whether pasture legume cultivars differ in susceptibility to deficiencies of N, S and K when grown on soils high in P, we grew six annual and one perennial pasture legume cultivar, as well as annual ryegrass (*Lolium rigidum*), on a dairy farm. Six nutrient treatments were established (Nil, +P, +N, +SK, +NSK, All). Shoot dry weights (DWs) did not differ between the Nil treatment and the +P, +N, and +SK treatments for any cultivar. However, while shoot DWs of *Trifolium* cultivars were 2–3 fold higher in the +NSK and All treatments compared with the Nil treatment, shoot DWs of *Ornithopus* cultivars did not differ among treatments, despite having similar DWs to the highest yielding treatments for the *Trifolium* cultivars. Forage quality parameters (dry matter digestibility and crude protein) were high for all legume cultivars and were slightly improved in the All treatment compared with the Nil treatment. We conclude that many pastures in the Peel Harvey region may not require P fertiliser to maximise yields, but instead may respond to the addition together of N, S and K. Further, we suggest that the root systems of *Ornithopus* genoptypes are better at accessing limiting soil nutrients than current commonly grown pasture legumes, likely due to a greater ability to explore soil.

Keywords
Phosphorus, nutrition, serradella, forage quality, sulfur, potassium.

Introduction
The coastal plain of the Peel Harvey catchment south of Perth, supports areas of irrigated horticulture and many small-sized dryland farms where beef and dairy production dominate. Pasture soils in this catchment have been enriched in phosphorus (P) due to many years of P fertiliser additions, but may be relatively less enriched in potassium (K) and sulfur (S) (Ryan et al. 2017; Weaver and Reed 1998) which may limit pasture growth (Christy et al. 2015). The traditional annual pasture legume grown in this region is subterranean clover (*Trifolium subterraneum* L.*)*, a species known for its high fertility requirement. For instance, subterranean clover has a higher P requirement than serradella (*Ornithopus*) species (Haling et al. 2016a; b). Serradellas have a root system superior for exploring the topsoil, where P is normally concentrated in pastures (Ryan et al. 2017), at a minimal carbon cost; that is, long thin roots and long root hairs (Haling et al. 2016a; b). It is not known whether this morphology also confers a superior ability to access other soil nutrients. This experiment was therefore designed to determine whether pasture legume cultivars differ in susceptibility to deficiencies of N, S and K when grown on a soil high in P and relatively low in N, S and K. We also report the nutritional value of the legumes, as there is little available information on alternative legumes such as *Ornithopus* species.

Methods
A paddock was chosen on a commercial dairy farm in the Peel Harvey coastal plain, Western Australia, in 2015. The first significant rainfall occurred on 10 April (47 mm) and the total rainfall for the year was 513 mm, which was below the long term average of 689 mm due to lower than average rainfall in each month between May and September. The soil was a Coolup sand, that is, an acidic grey shallow sandy duplex (Moore et al. 2004). Twelve cores to 10 cm depth were taken diagonally across the site prior to sowing and the results are presented in Table 1. Many soil characters were highly variable. For instance, Colwell P varied from 46–161 mg kg^{-1}, but was always high. Mineral N, Colwell K and S were each low enough to potentially limit pasture growth (Table 1).

Eight pasture cultivars were sown with a trial seeder on 15 May 2015: *Lolium rigidum* L. cv. Winter star (annual ryegrass), *Trifolium subterraneum* L. subspecies *yanninicum* cv. Trikkala (subclover), *Trifolium repens* L.cvs. Kopu II and Bounty (mixed together) (white clover), *Trifolium vesiculosum* Savi. cv. Cefalu (arrowleaf clover), *Ornithopus compressus* L. cvs. Santorini and Avila (yellow serradella), *O. pinnatus* (Mill.) Druce cv. Jebala (slender serradella) and *O. sativus* cv. Margurita (French serradella). There was a post-sowing, pre-emergent application of Tryquat (Paraquat 125 g L^{-1} + Diquat 75 g L^{-1}) at a rate of 2 L ha^{-1}. Three weeks after sowing Fusilade Forte © (800 mL ha^{-1}) was applied to all legumes for grass control and Kerb © (1.5 L ha^{-1}) was applied to all legumes to control winter grass and wireweed. The experiment was a randomised block design with three blocks and each cultivar present in each block as a 2.4 × 40 m strip. Appropriate rhizobia were added to all legumes at planting. Chlorpyrifos (200 mL ha^{-1}) was applied for control of insects post-sowing; no further insect control occurred. The site was not grazed. Large weeds were removed by hand. There was no irrigation.

Table 1. Soil characters at the field site, 0–10 cm: mean (s.e.), n=10.

Mineral N (mg kg^{-1})	Colwell P (mg kg^{-1})	Total P (mg kg^{-1})	PBI	Colwell K (mg kg^{-1})	Sulfur (mg kg^{-1})	pH ($CaCl_2$)	Organic C (%)
40 (4)	115 (13)	457 (52)	57 (6)	66 (5)	26 (5)	5.7 (0.2)	3.9 (0.4)

On 15 July 2015 (61 days after germination), fertiliser treatments were applied by hand in strips of 2.4 m across the strips of cultivar. The treatments that were sampled were: 1) nil fertiliser applied (Nil), 2) 20 kg ha^{-1} of P as triple superphosphate (+P), 3) 100 kg ha^{-1} of K and 41 kg ha^{-1} of S as K_2SO_4 (+KS), 4) 25 kg ha^{-1} of N as liquid urea and ammonium nitrate (+N), 5) treatments 3+4 (+NKS) and 6) treatments 2+5 (All). The treatments containing P, K and S were spread by hand, while the liquid N was sprayed onto the foliage. Rain then fell on 19 July (28 mm).

We decided to assess forage quality before the swards, which were not grazed, accumulated high biomass and/or commenced flowering, as the quality of pastures can decline with advancing maturity and senescence. Hence, on 12 August, a 0.5 × 0.5 m quadrat was randomly placed in each plot in the Nil and All treatments and all shoot material removed, dried at 70°C for 7 days, weighed and forage quality assessed by near infrared reflectance spectroscopy (NIRS) (Norman et al. 2015). Additional nitrogen (50 kg ha^{-1}) was then applied immediately to the ryegrass (all fertiliser treatments) as urea: rain fell 5 days later (60 mm over 6 days). On 22 September, shoots were again removed as described above, dried at 70°C for 7 days and weighed. By this harvest, all serradella cultivars had commenced flowering and early seed set.

Shoot forage characters were analysed using a two-way ANOVA (Genstat version 18) with the factors Cultivar (8 cultivars) and Fertiliser treatment (Nil, All). Shoot dry weight data from each cultivar were analysed with a one-way ANOVA with the factor Fertiliser treatment (Nil, +P, +N, +SK, +NSK, All).

Results

Forage quality results are shown in Table 2. For both dry matter digestibility (DMD) and crude protein (CP) there were significant effects of fertiliser and cultivar, but no interaction. The effects of fertiliser were small, with the estimated means being DMD (Nil 68%, All 70%, *lsd* at P=0.05, 1) and CP (Nil 20, All 23, *lsd* at P=0.05, 1). The effects of cultivar were also generally small with the serradella cultivars similar to the traditional legumes. The only exception was the ryegrass, which had around half the CP in the Nil treatment of the legumes and although CP greatly increased in the All treatment, it remained lower than for the legumes.

Shoot dry weight in September is presented in Figure 1. In the Nil treatment, the greatest shoot DW occurred for yellow serradella cv. Santorini, followed closely by the other three serradella cultivars; the smallest shoot DW occurred for white clover and subterranean clover. There was no difference between the Nil treatment and the +P treatment for any cultivar; although ryegrass showed a strong trend. There was also no difference between the Nil treatment and the +KS and +N treatments for any cultivar. However, the +NKS treatment and the All treatment had 2–3 fold greater shoot DW than the Nil treatment for white clover, arrowleaf clover and ryegrass (P<0.05) and subterranean clover (P=0.076). In contrast, all four serradella cultivars were not affected by the fertiliser treatment (P>0.05).

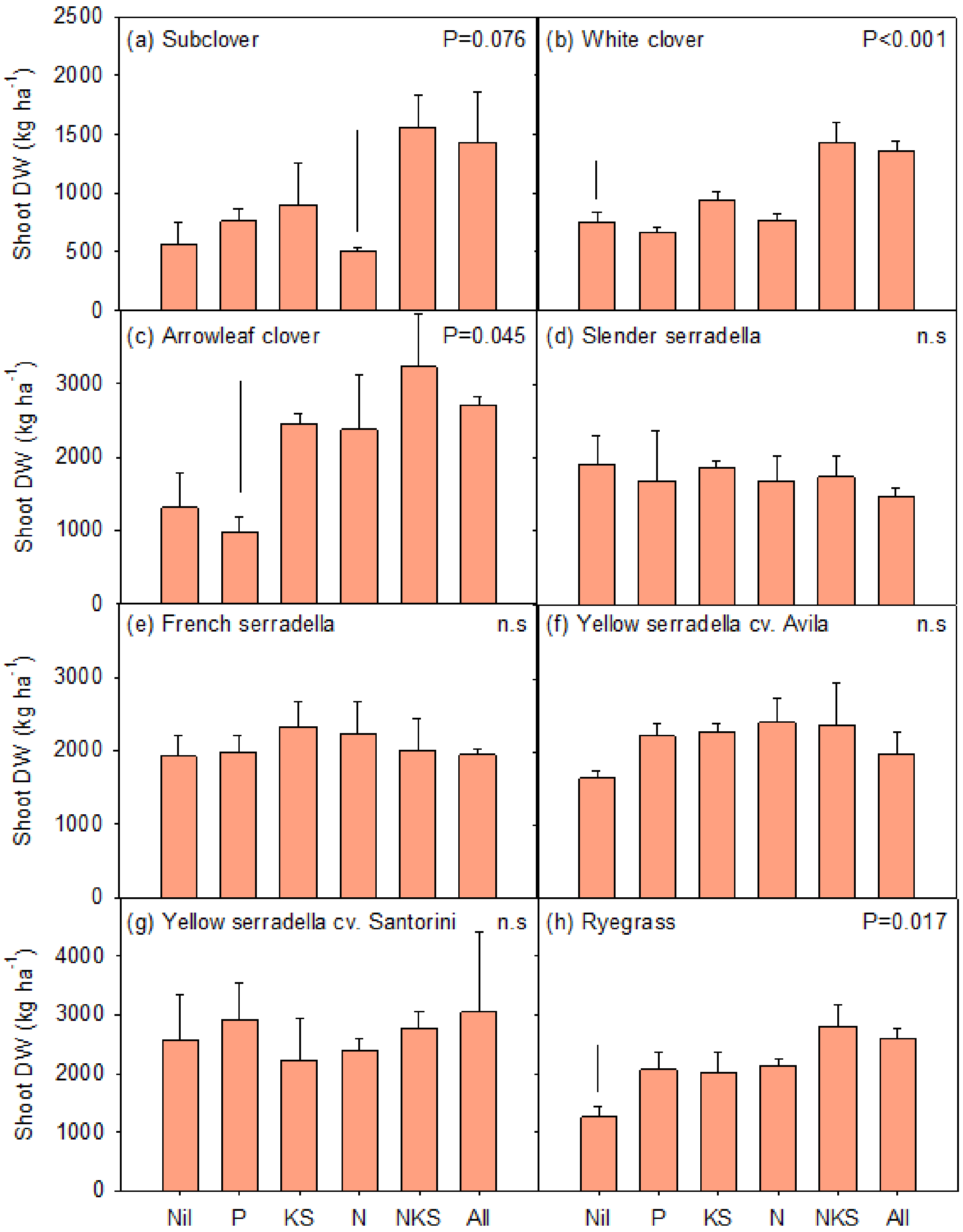

Figure 1. Shoot dry weight on 22 September for ungrazed swards of eight pasture cultivars grown with six fertiliser treatments on a high phosphorus soil. The *lsd* at *P* = 0.05 and P-value is shown for those cultivars where there was a significant effect of fertiliser treatment.

Table 2. Forage quality on 12 August for ungrazed swards of eight pasture cultivars grown with two fertiliser treatments on a high phosphorus soil.

Cultivar	Dry matter digestibility (DMD %)		Crude protein (CP %)	
	Nil	All	Nil	All
Subterranean clover	67	70	22	25
White clover	70	73	21	23
Arrowleaf clover	69	71	22	23
Slender serradella	67	68	23	25
French serradella	67	70	19	23
Yellow serradella cv. Avila	67	69	23	25
Yellow serradella cv. Santorini	67	69	22	24
Ryegrass	71	73	10	17
Fertiliser treatment	$P<0.001$		$P<0.001$	
Cultivar	$P<0.001$		$P<0.001$	

Conclusion

Shoot DW did not increase for any cultivar in response to the addition of P, presumably due to the high concentration of Colwell extractable P in the soil. However, traditional pasture legumes and ryegrass responded to N, K and S, when applied together, but not to application of N alone or K and S together. This suggested co-limitation by N, K and S. The high yields and lack of response to fertiliser treatments by the *Ornithopus* cultivars suggests a superior ability to access all soil nutrients, presumably due to a root system morphology that confers a superior ability to explore the soil, as shown by Haling et al. (2016a; b) for serradella cultivars in relation to P uptake.

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