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Re-alimentation of phosphorus deficient cattle

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Abstract

Steers that were previously fed diets with different phosphorus (P) content for six months were fed a diet of approximately 11% crude protein, 63% dry matter digestibility and 0.1% P, with supplementary P supplied to provide a total dietary P content of approximately 0.25% P/kg DM intake for three months. Total dry matter intake of steers that previously had a low P intake was increased to the intake of steers that previously had a high P intake within one week of starting the re-alimentation period (and after a two week adaptation period). Steers that were previously fed a low P (0.09% P) diet increased their liveweight gain (1.33 kg/d) and rate of hip height change (57 mm/100 days) to a higher level than steers that were previously fed a high P diet (0.24% P) (0.70 kg/d and 34 mm/100 days, respectively) during re-alimentation. The concentration of P in the faeces and plasma responded to the high P diet within the first week of feeding, with little difference in concentration between steers, regardless of previous P intake. After three months of re-alimentation on a high P diet, steers that previously had a low P intake had lighter and leaner carcasses with lower dressing percentages than steers that previously had a high P intake, with no differences in ossification score, fat colour or meat pH. This just reflected that, although compensatory growth was occurring, the period of re-alimentation was not long enough for previously P deficient animals to catch up to the control animals. There were no differences in carcass characteristics when data was adjusted to a common carcass weight. In conclusion, steers that are fed on a low P diet will respond immediately to a high P diet, in terms of feed intake and liveweight gain, and the increased P intake will be reflected in increased concentration of P in the plasma and faeces, regardless of the P content of the diet previously consumed by the steers.

Executive summary

Large areas of grazing land across northern Australia have phosphorus (P) deficient soils, and hence forages, resulting in low P intake by animals. Feed intake is affected by phosphorus (P) content of the diet, which has consequences for liveweight (LW) gain and skeletal growth. Steers fed a P deficient diet had reduced feed intake, LW gain and hip height (HH) growth over a six month period (MLA Project NBP.537), compared to steers fed a P adequate diet. However, it is unknown how quickly P deficient cattle respond when offered a P supplement and the magnitude of this response. This project examined the response of steers, previously fed diets of different P content and then fed a diet representative of early wet season pasture (~11% crude protein and ~63% digestibility) supplemented with P to provide ~0.25% P/kg DM, over three months. Feed intake, LW gain, HH, bone density, plasma inorganic P (PiP), faecal P (FaecP) and carcass data were collected.

The main findings of this project were:

- After adaptation to a high P diet (two weeks), total dry matter (DM) intake was similar between steers within one week of feeding new treatment diets (the exception was two steers that had low P supplement and DM intakes).
- Steers that were previously offered a low P diet had higher LW gain (1.33 kg/d) and HH change (57 mm/100 days) than steers previously offered a high P diet (0.70 kg/d and 34 mm/100 days) during the re-alimentation period. The slower growth rates of steers previously offered a high P diet during the re-alimentation phase was attributed to those animals approaching mature size. The LW gain for the re-alimenting animals was 0.2 kg/d higher, while change in HH was similar, to animals fed a high P diet over the previous 6 months.
- The concentration of P in the faeces and plasma reflected changes in P intake and did not differ between steers that were previously fed diets of different P content.
- Steers that were previously fed a low P diet had lighter and leaner carcasses than steers that were previously fed a high P diet. However, there were no differences in carcass traits when adjusted to a common carcass weight.

The results indicate that feed intake and LW gain of growing cattle that previously had low P intakes, responded immediately to a high P diet. This contrasted to the earlier experiment (P depletion phase) where it took six to eight weeks for a P deficiency to depress feed intake and LW gain. The concentration of P in the plasma and faeces of growing steers responded immediately to P intake and were similar for all animals, regardless of previous P intake (or P status). The results suggest that FaecP:DMD is not indicative of P status (repletion vs. non-repletion) of growing animals but is a good indicator of P intake, regardless of previous P intake.

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1 Background

Phosphorus is the second most abundant mineral in the body of cattle, with 80-85% of body P stored in the skeleton (ARC, 1980). Phosphorus is required for skeletal growth (and strength), energy metabolism, DNA and protein synthesis, lactation and rumen microbe function in ruminants. Soils, and hence forages, across large areas of northern Australia are acutely P deficient (<5 ppm P), which is often associated with low crude protein (CP) content in the dry season. Forage P content increases during the wet season but a P deficiency still occurs, as CP and ME intake are much higher in the wet season and P becomes the first limiting nutrient and is unable to meet the requirements of rapidly growing young animals at this time when CP and ME are adequate for growth. Young cattle grazing these areas have low LW gain, and show a positive response in LW to wet season P supplementation. As such, wet season P supplementation of growing animals is recommended in areas where P deficiencies occur.

The P requirements of ruminants at maintenance can often be met by a moderate P content diet. It is when the requirements for P increase (growth, late pregnancy, lactation) that a P deficiency will occur unless additional P is supplied, either through fertilizer application to forages or, more commonly in extensive grazing systems, through supplementation with an inorganic source of P. Over the short-term ruminants can cope with dietary P deficiency, with P requirements met from P recycling and absorption from bone, however once these reserves are depleted a deficiency will occur. The initial response of ruminants to a P deficiency is a reduction in feed intake (reviewed by Ternouth, 1990; Quigley *et al*., unpublished). A reduction in feed intake due to a P deficiency is not associated with any changes in rumen microbial digestibility (Milton and Ternouth, 1985) but is more likely to be a function of cellular metabolism in the soft-tissues. A P deficiency induced reduction in feed intake will reduce LW gain of sheep (Ternouth and Sevilla, 1990a) and cattle in individual pens (Quigley *et al*., unpublished), finishing in feedlots (Geisert *et al*., 2010) and grazing tropical forages on P deficient soils across northern Australia (Winter *et al*., 1990).

In northern Australia, unsupplemented cattle typically experience a CP and P deficiency in the dry season, followed by a P deficiency in the wet season. Bortolussi *et al*. (1996) demonstrated that while the effects of a CP deficiency were more immediate than a P deficiency an increase in CP intake did not increase feed intake and LW gain for cattle when the diet remained deficient in P, stating that an increase in the N content exacerbated the P deficiency, with similar results reported for sheep (Ternouth *et al*., 1993). Despite the potential benefits of providing both N and P supplements to ruminants grazing P deficient pastures during the dry season, N supplements are commonly used in the dry season to address the first limiting nutrient (N), with P supplements provided in the wet season. It is therefore common for growing animals in northern Australia to experience a P deficiency during the dry season, which has only a minor effect on productivity relative to N, followed by a period of P deficiency and further reduced LW gain in the wet season, if a P supplement is not provided. In scenarios where adequate wet season P supplements are provided, positive LW and intake responses are expected, with a greater response evident when animals were previously fed sub-optimal amounts of N and P (Bortolussi *et al*., 1999). In addition, Ternouth and Sevilla (1990b) demonstrated that both Ca and P were required in repletion diets to give maximum responses in feed intake and LW gain of sheep that were P deficient.

Despite large areas of land used for cattle production in northern Australia being based on P deficient soils, uptake of P supplementation remains low. One potential reason for the low uptake of P supplementation is the lack of a reliable diagnostic tool to determine the P status of the diet consumed by cattle. Plasma inorganic P reflects P intake, particularly at low P intakes (Bravo *et al*., 2003), and has a good relationship with LW gain (Wadsworth *et al*., 1990). While PiP has been advocated by some as a useful indicator of P status, results can

be confounded by mobilisation of P from body reserves and the timing of sampling relative to other aspects (for example N content) of the diet. Cortical bone measurements for thickness (Little, 1984), P content and specific gravity (Little, 1972) have also been used to describe P status of ruminants. However, the technique lacks standardisation and is invasive and not practical under commercial conditions. The major route of excretion of P is via the faeces and the FaecP concentration typically reflects DM (and P) intake (Holecheck *et al*., 1985) and has been associated with LW gain during the wet season in cattle (Wadsworth *et al*., 1990). The majority of the P in the faeces is endogenous in origin, mainly from saliva. Faecal P on its own has generally been rejected as a diagnostic tool for P deficiency in cattle (Read *et al*., 1986; Wadsworth *et al*., 1990). The faecal P:N or its associated DMD:P provide a ratio of dietary P to CP or diet dry matter digestibility (DMD) and have been suggested to provide a better indicator of P intake of animals than FaecP alone (Dixon and Coates, unpublished). It is known that only weaners getting adequate energy or CP will exhibit a response to P in line with the first limiting nutrient concept. The P requirement at maintenance is much lower than for growth. Phosphorus requirements are usually expressed as a %DM or g/d but neither expression takes into account the P required/unit available energy or CP which is a better physiological expression. Very little P is excreted in the urine except in unusual circumstances, such as when grain based rations or high P diets are fed. Hence the FaecP:dietary N (CP) or DMD:FaecP has a physiological rationale. Faecal P can be measured chemically and dietary N and DMD can be predicted by faecal NIRS on the same sample. Unpublished results demonstrated a similar relationship between FaecP:dietary N and DMD:FaecP and P intake for growing steers fed similar diets (adequate in CP and with a high ME content) with an increasing P content (from 0.09 to 0.24% P), suggesting that either descriptors may be useful in determining the P content of diets consumed by cattle. However, it is unknown if the FaecP to dietary N or DMD ratios are useful indicators of dietary P content when cattle of differing P status are consuming a high P diet, conditions under which it could be expected that animals are utilizing P for compensatory LW gain and skeletal growth, rather than excretion of endogenous P in the faeces.

The hypothesis of this experiment was that growing steers that previously had low P intakes and low LW gain would have increased feed intake and LW gain compared to steers that previously had high P intakes in response to a high P diet, and that there will be differences in FaecP between steers that had different P intakes prior to commencement of this experiment.

2 Project objectives

1. Determine the response (in terms of feed intake, liveweight gain, faecal and plasma P, hip height and bone density) of P deficient cattle to a high P diet.
2. Determine if relationships between faecal P:dietary DMD and P intake exist in animals that are P deficient and are fed a high P diet.
3. Examine allometric growth in P deficient animals undergoing compensatory liveweight gain.

3 Methodology

The experiment was conducted at the Centre for Advanced Animal Science (CAAS) at the University of Queensland (Gatton, QLD) in accordance with the Australian Code of Practice for the Care and Use of Animals for Scientific Purposes and was approved by the University of Queensland Animal Ethics Committee.

Experimental design and animals

Thirty *Bos indicus* crossbred steers [227.8 ± 1.9 kg LW; mean ± standard error of the mean (sem)] were blocked on LW and randomly allocated to pens and one of five dietary P treatments in a completely randomized block design. Steers were fed pelleted diets that provided approximately 0.09% (P-1), 0.13% (P-2), 0.18% (P-3), 0.21% (P-4) and 0.25% (P-5) P, and were between 60 to 65% DMD with a CP content of between 10 to 12% (i.e. typical of early wet season tropical pastures). Steers were fed treatment diets for 24 weeks (*Phase 1*). Upon completion of the *Phase 1* feeding period, bone biopsies were collected from the 12th rib of all steers. All steers were then introduced to the P-1 pellet (106 g CP, 914 g OM, 400 g NDF, 270 g ADF and 1 g P/kg DM) and a supplementary P source [Biofos, 21% P; and monosodium phosphate (MSP), 24% P, were both used in the experiment] over two weeks, to allow recovery from the biopsies and adaptation to the new feeding regimen. *In vivo* DMD of the P-1 pellet used in *Phase 2* was determined in *Phase 1* of the experiment and was assumed to be the same (63% DMD) as the same batch of pellets were used in both phases of the experiment. Steers were then fed the P-1 pellet *ad libitum* (previous days intake + 1 kg), with MSP/Biofos offered at 6 or 7 g/kg DM, respectively, to supply a dietary P content of approximately 0.25% P/kg DM intake (*Phase 2*). The supplementary P source was mixed in equal proportion with sugar (w/w) to improve palatability and encourage consumption of the total allocation of supplementary P and was fed before the pellets each morning. Steers remained in individual pens for five weeks, with intake measured daily, and were then moved to feedlot pens (n=5/pen) with each pen containing one of the original animal blocks, such that animals of each of the original five P dietary treatments (P-1, P-2, P-3, P-4 and P-5) were represented in each feedlot pen. In the feedlot pens, the P supplement was offered first each morning (at the same rate as in the individual pens) and was spread out along the feed trough, allowing access by all animals, with pellets offered *ad libitum* (previous days intake + approximately 5 kg) after the daily allowance of P supplement was consumed. After a total of 12 weeks, steers were slaughtered (Marcelford Meats, Churchill Abattoir; Churchill, QLD) after an overnight curfew, with carcass measurements and Meat Standards Australia grading conducted.

Liveweight was measured before feeding, once each week. Hip height and faecal and blood samples were collected every three weeks, at the same time as LW measurements. X-ray images of the near side cannon bone (metacarpal) were conducted at the start and end of the experiment. Bone samples were collected from the 12th rib at the start of the experiment by biopsy and the alternate 12th rib was collected from carcasses 24 h after slaughter. Bone samples were hydrated in 0.9% NaCl until analysed.

Analytical

Sub-samples of feed and residues were dried to a constant weight at 65^{o}C to determine DM content. Residual DM content was determined by drying samples at 105^{o}C for 24 h, prior to combustion in a muffle furnace (Modutemp) at 550^{o}C for 8 h to determine organic matter (OM) content. Nitrogen content of feed offered was determined by the Kjeldahl method (Kjeltec 8400, FOSS). Ash-free neutral detergent fibre (NDF) and ash-free acid detergent fibre (ADF) content of the feed were determined using the Ankom 220 system. Phosphorus content of faecal and feed samples was determined on an inductively coupled plasma spectrometer (ICP; Optima 7300 DV, Perkin Elmer; Wellesley, MA, USA) after digestion in nitric and perchloric acid (3:1) at 150^{o}C. Plasma inorganic P concentration was determined on an Olympus AU400 auto-analyser (Beckman Coulter Diagnostic Systems Division; Melville, NYC, USA) using a Beckman Coulter Diagnostic Systems kit. Osteocalcin [undercarboxylated osteocalcin (Glu-OC) and osteocalcin (Gla-OC)] were determined by an *in vitro* enzyme immunoassay according to the manufacturer's instructions (Takara Bio Inc., Japan). Bone (outer core) biopsies and samples collected at slaughter were cleaned of trabecular bone and cortical bone thickness (CBT) measured using vernier calipers. Outer cortical bone samples were blotted dried and weighed in air and then suspended in water

and specific gravity (SG) was determined. Mineral content of bone biopsies are yet to be determined.

Statistical analysis
Change in LW and HH during the experiment was determined by linear regression, and analysed using the GLM procedure in SAS (SAS v9.2). Differences in PiP and FaecP between steers were determined at each sampling interval throughout the experiment and between sampling intervals. Osteocalcin and CBT, SG and x-ray data at the start and end of the experiment and change over the experiment were also analysed using the GLM model in SAS. The initial model included previous P treatment and allocation block, however for all variables allocation block was not significant and was subsequently removed from the model.

4 Results

Cumulative changes in LW, HH, PiP and FaecP over *Phase 1* and *Phase 2* of this experiment are presented in Appendix 1. The results presented in this section refer specifically to the re-alimentation phase of the experiment (*Phase 2*).

Body dimensions
Steers previously fed a diet low in P (P-1) had a lower LW than steers fed a diet high in P (P-5) at both the start and end of the experiment (Table 1). Steers that were of a low P status (P-1) at the commencement of the experiment had a higher LW and HH change than steers that were of a high P status (P-5) at the commencement of the experiment when fed a high P diet (Figures 1 and 2). If the experiment had run for longer it is likely that the low P steers would have eventually attained a similar LW and HH to the high P steers (Appendix Figures A1 and A2). The lower LW gain of high P steers is attributed to those steers approaching mature LW and HH during *Phase 2*, rather than any specific effects of the P content of the diet. It is interesting to note that differences in LW change between treatment groups became more apparent when animals were moved from the individual pens to the feedlot pens. Individual animal intakes could not be recorded during the seven week feedlot period but it is possible that feed and supplement intake of steers that previously had low P intakes was greater than that of steers that previously had high P intakes during the re-alimentation period in the feedlot pens. Subjective observations would support this, with P-1 steers often the first to come to the feed trough to consume P supplement when fed each morning.

Liveweight gain was positively related with increasing HH (as an indicator of skeletal size) in *Phase 1* and *Phase 2* of the experiment (Appendix Figure A3), although the relationships were different between the two phases. There was a significant quadratic relationship between LW gain and HH change in *Phase 1* (LW gain (kg/day)=0.049HHchange (mm/100 days)-0.0035HHchange^2-0.922; P<0.0001; R^2=0.65; CV%=40.7), in contrast there was a linear relationship between the two parameters in *Phase 2* (LW gain=0.01HHchange+0.41; P=0.16; R^2=0.19; CV%=38.4).

Feed and supplement intake
Dry matter intake of steers that were previously fed a low P diet responded immediately to supplementary P, with steers that were previously fed the P-1, P-3, P-4 and P-5 diets having a similar DM intake (g DM/kg LW.d) within the first week of the experimental period and throughout the five week individual intake measurement period, after a two week period to adapt to the new feeding regimen. Steers that were previously fed the P-2 treatment had lower DM intake than all other steers over the first four weeks of the individual feeding period (Table 1). There was no difference in P supplement intake or total daily P intake between steers that were previously fed the P-1, P-3, P-4 and P-5 diets, with average supplement intakes for these four treatments been 47, 56, 55, 59 and 66 g/day, in weeks one to five,

respectively. Steers that were previously fed the P-2 treatment, had lower P supplement intakes in weeks 2 and 3 of the individual feeding period (27 g/day in both weeks). Steers previously fed the P-2 treatment had lower P supplement intakes than P-1 and P-3 steers. This was due to low acceptability of the P supplement by two steers within the treatment group. If those two steers were omitted from the data prior to analysis then P supplement intake of P-2 steers would be similar to that of P-1 and P-3 steers.

Table 1. Liveweight (LW), LW change, hip height (HH), HH change and pellet and P supplement (P Supp.) dry matter (DM) intake over the five week individual measurement period of steers previously fed diets of different P content[1].

Parameter	Previous dietary P content (%)					SEM
	0.09	0.13	0.18	0.21	0.24	
Number per treatment (n)	6	6	6	6	6	.
Initial LW (kg)	314.0^{a}	333.8^{a}	380.8^{b}	428.8^{c}	447.2^{c}	9.9
Final LW (kg)	427.5^{ab}	417.3^{a}	453.8^{bc}	468.5^{cd}	501.5^{d}	12.2
LW change (kg/d)[2]	1.33^{d}	1.03^{c}	0.86^{bc}	0.47^{a}	0.70^{ab}	0.10
LW change (kg/d)[3]	1.41^{b}	1.09^{ab}	0.86^{ab}	0.41^{a}	0.61^{ab}	0.15
Initial HH (mm)	1311^{a}	1293^{a}	1286^{a}	1296^{a}	1346^{b}	10
Final HH (mm)	1366^{bc}	1333^{ab}	1336^{ab}	1332^{a}	1374^{c}	12
HH change (mm/100 days)[1]	57^{b}	46^{ab}	56^{b}	38^{a}	36^{a}	6
HH change (mm/100 days)[2]	56	46	57	38	34	7
Pellet intake (g DM/kg LW.d)	18.9^{b}	14.7^{a}	19.0^{b}	18.6^{b}	18.8^{b}	0.6
P Supp. intake (g DM/kg pellet DM)	8.9^{c}	7.0^{ab}	7.8^{b}	6.6^{a}	6.1^{a}	0.4
P Supp. intake (g DM/kg LW.d)	0.17^{b}	0.11^{a}	0.15^{b}	0.13^{a}	0.12^{a}	0.01
P intake (g/day)	20.1^{b}	13.8^{a}	22.0^{b}	21.2^{b}	21.4^{b}	1.8
P intake (g/kg LW.d)	0.059^{b}	0.040^{a}	0.055^{b}	0.049^{ab}	0.047^{ab}	0.004

[1]Data are least-squares means with pooled standard error of the mean (SEM). Different alphabetical superscripts across each row indicate a significant difference between previous P diets (P<0.05).
[2]Unadjusted data.
[3]Data adjusted to a common initial LW and HH.

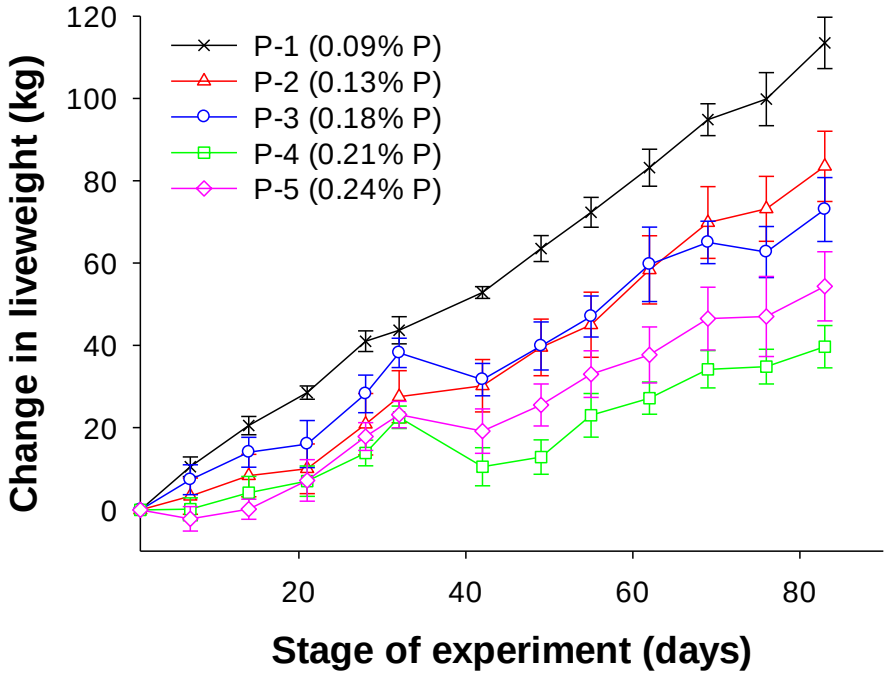


Figure 1. Cumulative change in liveweight of steers fed a diet containing 0.25% P, after being previously fed diets of different P content (P-1, P-2, P-3, P-4 and P-5).

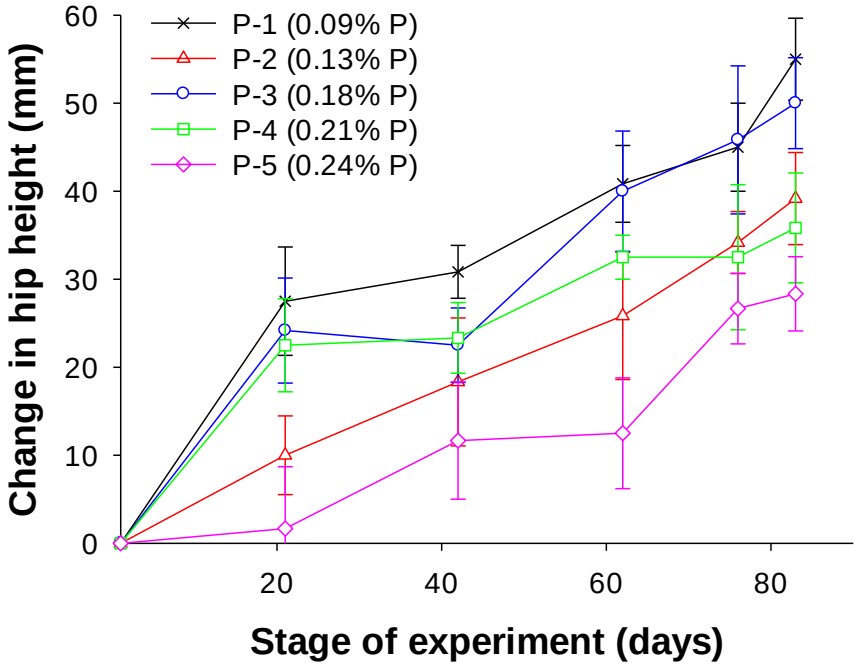


Figure 2. Cumulative change in hip height of steers fed a diet containing 0.25% P, after being previously fed diets of different P content (P-1, P-2, P-3, P-4 and P-5).

Plasma inorganic P and faecal P

The PiP concentration of steers was similar on days 1, 21 and 63 of the experiment, regardless of the P content of the previous diet. Steers that previously received a low P diet had a higher PiP concentration than steers that received high P diets (P-4 and P-5) on days 42 and 76 of the experiment ($P<0.05$). Plasma inorganic P increased significantly over the

first 42 days of the experiment (P<0.05) with no significant change in concentration over the remainder of the experiment (Figure 3).

The FaecP concentration of steers was similar at each stage of the experiment, regardless of the P content of the previous diet (P>0.05) (Figure 4). Faecal P concentration was significantly higher on day 76 of the experiment compared to the other stages of the experiment (P<0.05), with no differences between the other times during the experiment. There was a significant linear relationship between average P intake (weeks one to five) and average DMD:FaecP (entire *Phase 2* period) (DMD:FaecP = 168.8 - 1.37 P intake (g/d); P=0.004; R^2=0.27; CV%=8.4) (Figure 5 a.). The DMD:FaecP was similar over the *Phase 2* period, although the value was slightly but significantly lower at the end of the experiment (134) compared to the start of the experiment (149), indicative of stable P intake across the experiment (Figure 5 b.).

The differences in PiP and FaecP evident in *Phase 1* of the experiment were not present at the start of *Phase 2* (Appendix Figures A3 and A4). For two weeks prior to the commencement of *Phase 2*, all steers were offered a similar amount of P supplement (20 to 30 g supplement/d) to adapt to the new form of supplement and to ensure as complete intake as possible once *Phase 2* commenced. It is evident that PiP and FaecP responded to P intake even over this short two week adaptation period.

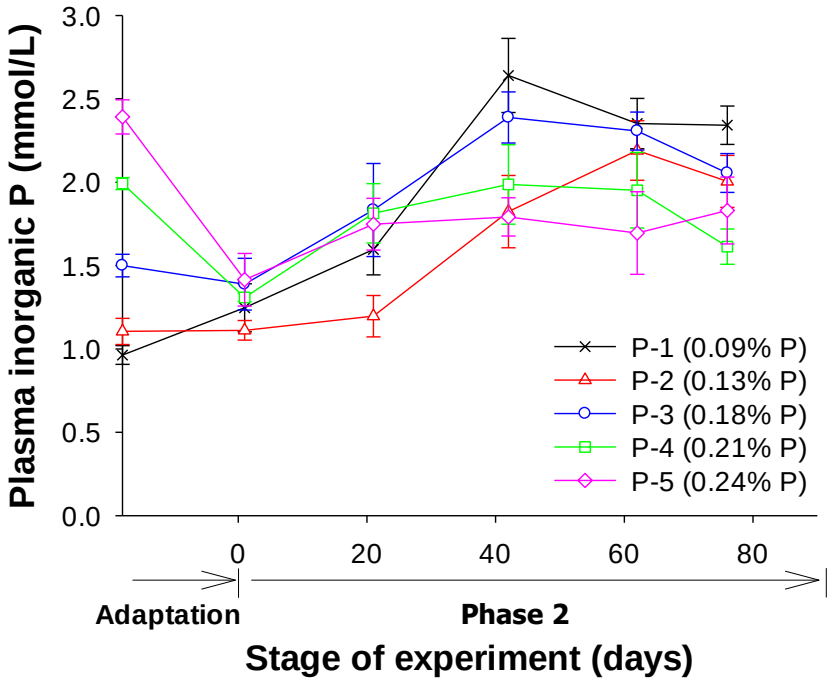


Figure 3. Change in plasma inorganic Phosphorus (P) concentration of steers fed a diet containing 0.25% P, after being previously fed diets of different P content (P-1, P-2, P-3, P-4 and P-5).

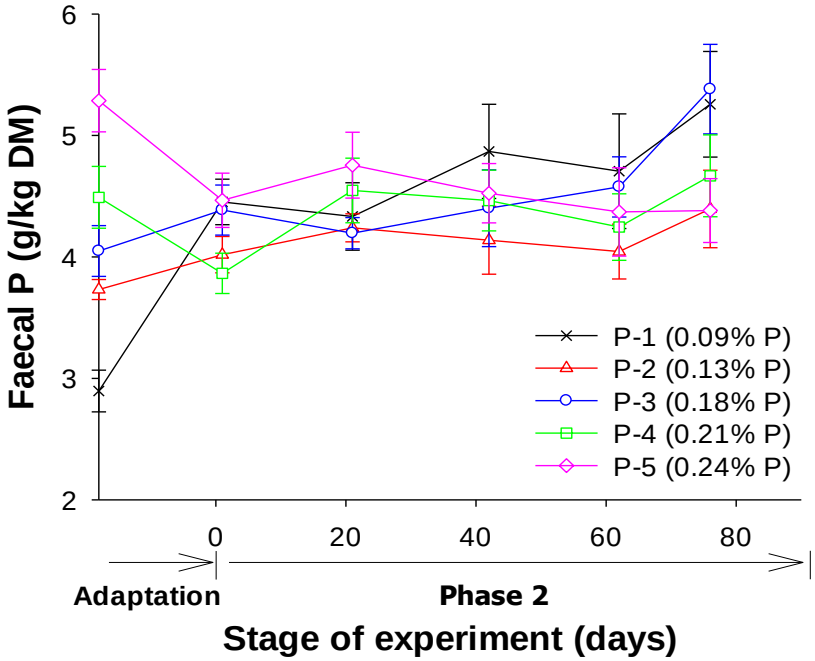
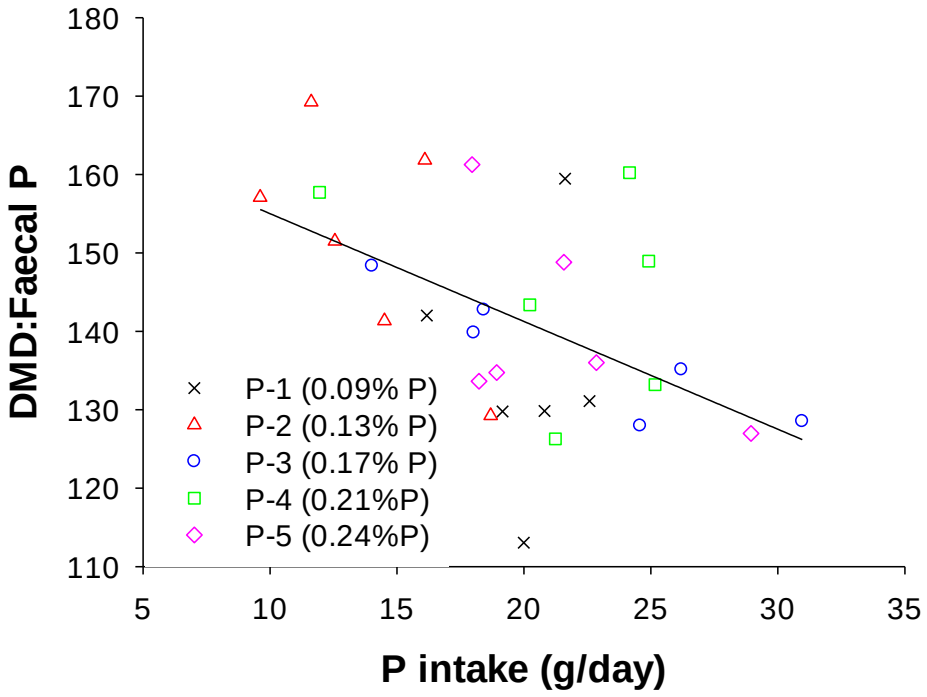


Figure 4. Change in faecal Phosphorus (P) concentration of steers fed a diet containing 0.25% P, after being previously fed diets of different P content (P-1, P-2, P-3, P-4 and P-5).

a.



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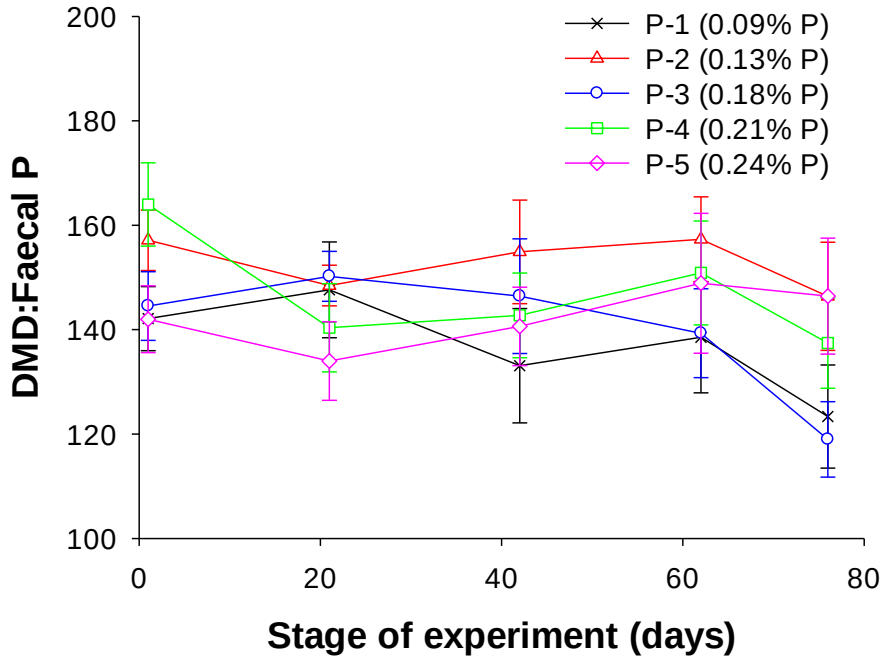

Figure 5. Relationship between average P intake and digestibility (DMD):Faecal P (FaecP) (a.) and change in DMD:FaecP over the duration of the experiment (b.) of steers fed a diet containing 0.25% P, after being previously fed diets of different P content (P-1, P-2, P-3, P-4 and P-5).

Bone and osteocalcin

Specific gravity of outer cortical bone from the 12th rib was similar at the start and end of *Phase 2* of the experiment (Table 3). Cortical bone thickness was different between animals that were previously fed diets with different P content at the start of *Phase 2* but similar at the end of *Phase 2*. This indicates that the thickness but not the density of cortical bone is influenced by a sudden change in dietary P content in growing cattle. There were no significant differences in Gla-OC or Glu-OC at the start or end of Phase 2 (Table 3) and no significant differences between previous treatments and Total OC and the proportion of Glu to Gla-OC.

Table 2. Specific gravity and thickness of the outer cortical bone collected from the 12th rib of steers fed a diet providing 0.25% P, after being previously fed diets with different P content[1].

	Previous dietary P content (%)					SEM
	0.09	0.13	0.18	0.21	0.24	
Number per treatment (n)	6	6	6	6	6	.
			Specific gravity			
Start	1.64	1.61	1.66	1.62	1.64	0.03
End	1.63	1.65	1.68	1.65	1.66	0.02
Change	-0.01	0.04	0.03	0.03	0.02	0.03
			Cortical bone thickness (mm)			
Start	2.54[a]	2.62[a]	3.24[b]	3.29[b]	3.65[b]	0.21
End	3.55	3.83	3.71	3.97	3.30	0.31
Change	1.02[b]	1.20[b]	0.47[ab]	0.67[b]	-0.35[a]	0.30

[1]Data are least-squares means with pooled standard error of the mean (SEM). Different alphabetical superscripts across each row indicate a significant difference between previous P diets (P<0.05).

Table 3. Concentration of osteocalcin (Gla-OC) and undercarboxylated osteocalcin (Glu-OC) of steers fed a diet providing 0.25% P, after previously being fed diets with different P content[1].

	Previous dietary P content (%)					SEM
	0.09	0.13	0.18	0.21	0.24	
Number per treatment (n)	6	6	6	6	6	.
			Gla-OC (ng/mL)			
Start	204.2	192.8	223.6	198.8	209.7	29.9
End	256.7	365.8	201.9	298.9	241.2	63.1
Change	52.6	173.0	-21.8	100.0	31.4	56.9
			Glu-OC (ng/mL)			
Start	24.0	34.4	21.2	57.3	51.9	15.5
End	36.4	35.9	31.3	45.4	50.0	13.8
Change	12.5	1.5	10.1	-11.8	-2.0	8.5

[1]Data are least-squares means with pooled standard error of the mean (SEM). Different alphabetical superscripts across each row indicate a significant difference between previous P diets (P<0.05).

Cannon bone imagery data

Changes in cannon bone dimensions during re-alimentation of steers that were previously fed a low P diet was similar to changes in steers that were previously fed a high P diet (Table 4). There was no significant correlation between change in cannon bone length and change in HH over the re-alimentation period. In addition, there was no significant correlation between the change in rib and cannon bone cortical bone thickness over the re-alimentation period.

Table 4. Length, cortical bone thickness, physeal width and epiphyseal height of the near cannon bone of steers fed a diet providing 0.25% P, after being previously fed diets with different P content[1].

	Previous dietary P content (%)					SEM
	0.09	0.13	0.18	0.21	0.24	
Number per treatment (n)	6	6	6	6	6	.
			Cannon bone length (mm)			
Start	233.0^{b}	227.2^{ab}	221.0^{a}	223.3^{ab}	231.5^{b}	3.0
End	240.8^{b}	232.0^{ab}	226.7^{a}	228.8^{a}	235.8^{ab}	3.6
Change	7.8	4.8	5.7	5.5	4.3	2.5
			Cortical bone thickness (mm)[2]			
Start	5.65^{a}	5.90^{ab}	6.42^{ab}	7.03^{c}	6.43^{bc}	0.21
End	6.88^{a}	6.73^{a}	7.38^{ab}	7.65^{b}	7.25^{ab}	0.26
Change	1.23^{b}	0.83^{ab}	0.97^{ab}	0.62^{a}	0.82^{ab}	0.18
			Physeal width (mm)			
Start	45.2^{ab}	47.2^{b}	42.2^{a}	45.8^{ab}	44.7^{ab}	1.3
End	49.2	49.0	47.8	48.0	47.2	1.2
Change	4.0	1.8	5.7	2.2	2.5	1.4
			Epipyseal height (mm)			
Start	39.2^{ab}	38.7^{ab}	36.3^{a}	38.2^{ab}	39.5^{b}	1.0
End	42.3	40.8	40.3	40.7	42.0	1.3
Change	3.2	2.2	4.0	2.5	2.5	1.2

[1]Data are least-squares means with pooled standard error of the mean (SEM). Different alphabetical superscripts across each row indicate a significant difference between previous P diets (P<0.05).

[2]Cortical bone thickness of the dorsal cannon bone 50% of the length.

Carcass composition

Steers that were previously fed a low P diet (P-1) had lighter and leaner carcasses, with a lower dressing percentage than steers that were fed a high P diet (P-5) during *Phase 1* of the experiment (Table 5). There was no difference in ossification score, fat colour or meat pH between steers that previously consumed different diets of different P content. Differences in eye muscle area (R=0.45; P<0.05) and P8 fat depth (R=0.49; P<0.01) between steers previously fed diets with different P content were related to hot carcass weight, regardless of previous diet. There was no significant effect of previous P diet on any of the traits measured when data was adjusted to a common carcass weight (244 kg) (data not presented).

Table 5. Carcass characteristics and Meat Standards Australia grading measurements of steers fed a diet providing 0.25% P, after being previously fed diets with different P content[1,2].

Parameter	Previous dietary P content (%)					SEM
	0.09	0.13	0.18	0.21	0.24	
Number per treatment (n)	6	6	6	6	6	.
Dentition	0.00^{a}	1.33^{b}	1.33^{b}	0.67^{ab}	1.00^{ab}	0.38
Hot carcass weight (kg/d)	224.6^{ab}	220.7^{a}	243.1^{bc}	255.6^{c}	275.0^{d}	6.7
P8 Fat depth (mm)	6.0^{a}	7.7^{ab}	5.2^{a}	8.2^{ab}	11.7^{b}	1.5
Hump height (mm)	85.0	80.8	80	85.8	83.3	3.3
Ossification score	115.0	125.0	116.7	116.7	120.0	4.0
AUSMB score	0.17^{a}	0.33^{ab}	0.33^{ab}	0.83^{ab}	1.00^{b}	0.24
MSAMB score	225.0^{a}	255.0^{ab}	253.3^{ab}	291.7^{ab}	336.7^{b}	34.4
Loin Temperature (^{o}C)	7.2^{a}	7.6^{a}	9.0^{b}	8.9^{b}	9.8^{b}	0.4
Loin pH	5.51	5.58	5.51	5.56	5.48	0.04
Fat colour score	0.67	0.33	0.33	0.33	1.67	0.26
Meat colour score	2.17^{ab}	2.50^{b}	1.83^{ab}	2.33^{ab}	1.67^{a}	0.28
Rib fat (mm)	3.0^{a}	3.3^{a}	4.3^{ab}	4.5^{ab}	6.2^{b}	0.8
Eye muscle area (cm^{2})	65.7^{a}	64.5^{a}	66.7^{a}	78.8^{b}	72.7^{ab}	4.0
Dressing %	52.5^{a}	52.9^{a}	53.5^{ab}	54.4^{b}	54.9^{b}	0.5

[1]Data are not adjusted for carcass weight.
[2]Data are least-squares means with pooled standard error of the mean (SEM). Different alphabetical superscripts across each row indicate a significant difference between previous P diets (P<0.05).

5 Discussion

The current recommendation for supplementation of growing cattle in northern Australia is to provide supplementary N in the dry season and P in the wet season. Growing cattle managed under the above supplementation strategy therefore experience a P deficiency in the dry season, followed by a period of adequate P intakes over the wet season. In addition cattle may be moved from areas where no supplementation is used, to areas where supplementation is used. Under both these scenarios, animals will have undergone P depletion followed by P repletion. The objective of this experiment was to examine the response of growing steers of variable P status to a high P diet.

The results of this experiment indicate that steers that have previously been fed a low P diet respond immediately to increased dietary P, in terms of feed and supplement intake, LW gain and HH change. The immediate increase in P intake by these animals was reflected in an increase in PiP and FaecP. The concentration of P in the faeces was similar for all steers, regardless of previous P intake, and was comparable to that evident in cattle fed a similar P content diet in *Phase 1* of this experiment. The immediate response of FaecP to an increase in dietary P content (and DM and P intake) supports its use as an indicator of P intake by cattle, as it appears not to be influenced by the longer-term P status and requirements of the growing animal and is mainly related to P intake, at least when the diet is providing adequate CP and ME for growth.

Steers that previously had a low P intake underwent some compensatory LW gain during the re-alimentation period when fed a high P diet. While the low P intake steers were growing much faster (1.33 kg/d) than high P intake steers (0.70 kg/d) fed the same diet during the re-alimentation period, the LW gain was only marginally (~0.2 kg/d) greater than high P intake

steers at a comparable LW over *Phase 1* of the experiment. The extent of compensation of low P intake steers was not sufficient for those steers to reach the same final LW as the high P intake steers, this was due to the short length of the re-alimentation period (three months) compared to the initial P depletion period (six months). If the repletion period was extended it is likely that full compensation in LW would have occurred, particularly as growth rates of the high P steers were slowing as they approached maturity. Similarly, during the re-alimentation period, steers that previously had a low P intake had greater increases in HH than steers previously fed a high P diet. The compensatory LW gain of low P intake steers was not related to any compensatory increase in skeletal size (inferred from HH changes) which was similar for steers that previously had low P intakes and were undergoing compensatory LW gain (57 mm/100 days) and steers that had high P intakes during *Phase 1* of the experiment (59 mm/100 days). The relationship between LW gain and HH change evident in *Phase 1* of the experiment was not apparent in *Phase 2* of the experiment. This uncoupling of the relationship between LW gain and HH change in *Phase 2* may be attributed to the compensatory gain in LW but not HH of animals that previously had low P intakes and the approaching mature LW and HH of steers that previously had high P intakes, and higher growth rates during *Phase 1*. Nevertheless, while the results from the two phases of the experiment demonstrate the important relationship between LW gain and HH change, it remains unclear if enhancing skeletal growth during periods of P depletion (or nutrient restriction) will enhance compensatory growth during periods of repletion; presumably the duration of any repletion or recovery period will have the ultimate influence on the extent of compensation achieved regardless of the LW and HH relationships. Interestingly, change in cannon bone dimensions over the re-alimentation period, including length and cortical bone thickness, were not related to changes in HH or changes in CBT of the rib. While CBT of the cannon bone did respond to the re-alimentation, the length of cannon bone appears relatively insensitive to changes in nutrient supply (P and total DM intake) and as such may not be a useful indicator of change in skeletal elongation rates in growing cattle.

Three months of re-alimentation was insufficient to fully compensate for LW losses attributed to low P and DM intakes in *Phase 1* of the experiment. Those steers that had low P and DM intakes during *Phase 1* of the experiment had lighter and leaner carcasses at slaughter, compared to steers that had high P and DM intakes during *Phase 1*. The low P intakes in *Phase 1* had no effect on carcass characteristics at a similar carcass weight, suggesting that low P intakes, followed by repletion, will result in a longer time to turn-off and slaughter without adversely affecting carcass composition (depending on the duration of the re-alimentation period), suggesting that overall proportions of muscle, fat and bone are not significantly altered in scenarios of P depletion and repletion, typical of that in northern Australia. Ossification is the accretion of bone, or conversion of cartilage to bone, which increases as maturity approaches. Ossification scores are associated with growth rates and meat eating quality (carcasses of the same weight but different ossification scores come from cattle of different physiological maturity). In the current experiment, ossification scores for all animals were low (<130) and there was no differences in ossification scores after re-alimentation, either adjusted or unadjusted for carcass weight. This suggests that re-alimentation after a period of restricted growth, due to a P deficiency, was able to produce animals of a similar physiological state to those that were not subjected to a P deficiency. This is consistent with the changes in CBT, where by the end of the re-alimentation period, steers that had low P intakes were able to form bone to have a comparable CBT to steers that had high P intakes throughout the experiment.

Plasma inorganic P of steers that were previously fed a low P diet responded immediately to the increased P intake and increased to a maximum 42 days after commencement of the re-alimentation period, consistent with *Phase 1* of this experiment and previous studies (Wadsworth *et al*., 1990; Bortolussi *et al*., 1999). Cortical bone thickness increased over the repletion period in animals that previously had low P intakes, followed by high P intakes, further demonstrating a repletion of P status of the steers. Interestingly, while Bortolussi *et*

al. (1999) reported a similar response in CBT during repletion, those workers did not report any change in bone P content. Faecal P displayed a similar response to an increase in P intake to that of PiP, with a similar response apparent for the DMD:FaecP. This confirms that endogenous P excretion is a function of DM and P intake and is not influenced by the longer-term P status of the animal and supports the use of FaecP (or the related DMD:FaecP) as an indicator of P intake by growing animals.

In conclusion, steers that were previously fed a low P diet for a six month period, responded immediately in terms of DM intake, LW gain, PiP and FaecP to a high P diet. Rates of skeletal elongation (HH change) and CBT had returned to normal after a 12 week repletion period. After the 12 week repletion period the carcasses of steers that previously had low P intakes were lighter and leaner than non-depleted steers but there were no differences in carcass composition when adjusted to a common carcass weight. The use of DMD:FaecP appears to be a reasonable indicator of P intake of steers, regardless of whether they are undergoing repletion or not.

6 Conclusions

1. Steers that were previously fed a low P diet (0.09% P) respond immediately (within two weeks) to a high P diet (0.25% P) in terms of DM intake and LW gain.
2. LW gain of steers previously fed a low P diet was 1.33 kg/d when fed a high P diet in *Phase 2*, which was higher than the 1.1 kg/d measured for steers fed a similar high P diet across the entire *Phase 1* period. In contrast, HH change of steers previously fed a low P diet in *Phase 1* was 57 mm/100 days when fed a high P diet in *Phase 2*, which was comparable to the 59 mm/100 days measured for steers previously fed a similar high P diet across the entire *Phase 1* period. This suggests that P deficient animals will undergo modest compensatory LW gain when offered a high P diet, and this compensatory gain is related to accretion of soft tissue rather than any compensatory increases in skeletal growth.
3. An increase in P intake will result in, and is reflected by, an increase in PiP and FaecP, regardless of the P content of the diet consumed previously. Therefore, PiP and FaecP are good indicators of P intake, regardless of the P status or requirements of growing animals fed high CP and ME (typical of early wet season tropical pastures.
4. Cortical bone thickness may be a more sensitive indicator of P status than specific gravity (or density) of bone.
5. Three months of re-alimentation on a high P diet was not sufficient time to recover the lower LW that resulted from the previous six months of low P intake. Steers that were previously fed a low P diet for six months prior to a high P diet for three months had lighter and leaner carcasses at slaughter than steers that received a high P diet over the entire nine month period. When adjusted to a common carcass weight, carcass composition was similar between steers regardless of previous P diet. This suggests that while low P intake will depress growth rates and delay turn-off, it will not affect carcass composition or overall allometric growth, as these animals would have achieved a similar carcass composition had they been allowed to reach the same carcass weight.

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Matt Callaghan (Technical Manager, Cattle and Sheep)

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9 Appendix 1

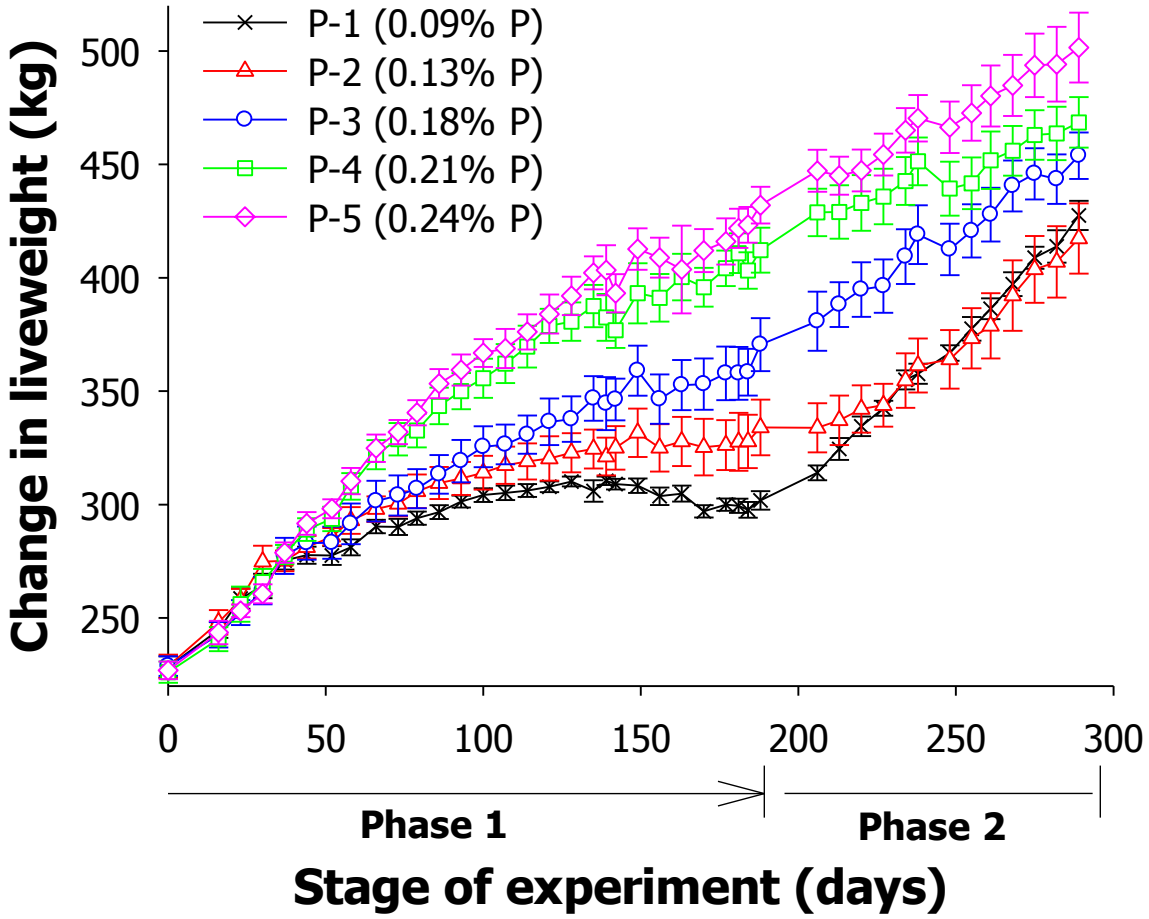

Figure A1. Change in liveweight of steers offered a diet with similar energy and protein content with increasing P content (*Phase 1*) followed by the same high P diet (~0.25% P/kg DM) (*Phase 2*).

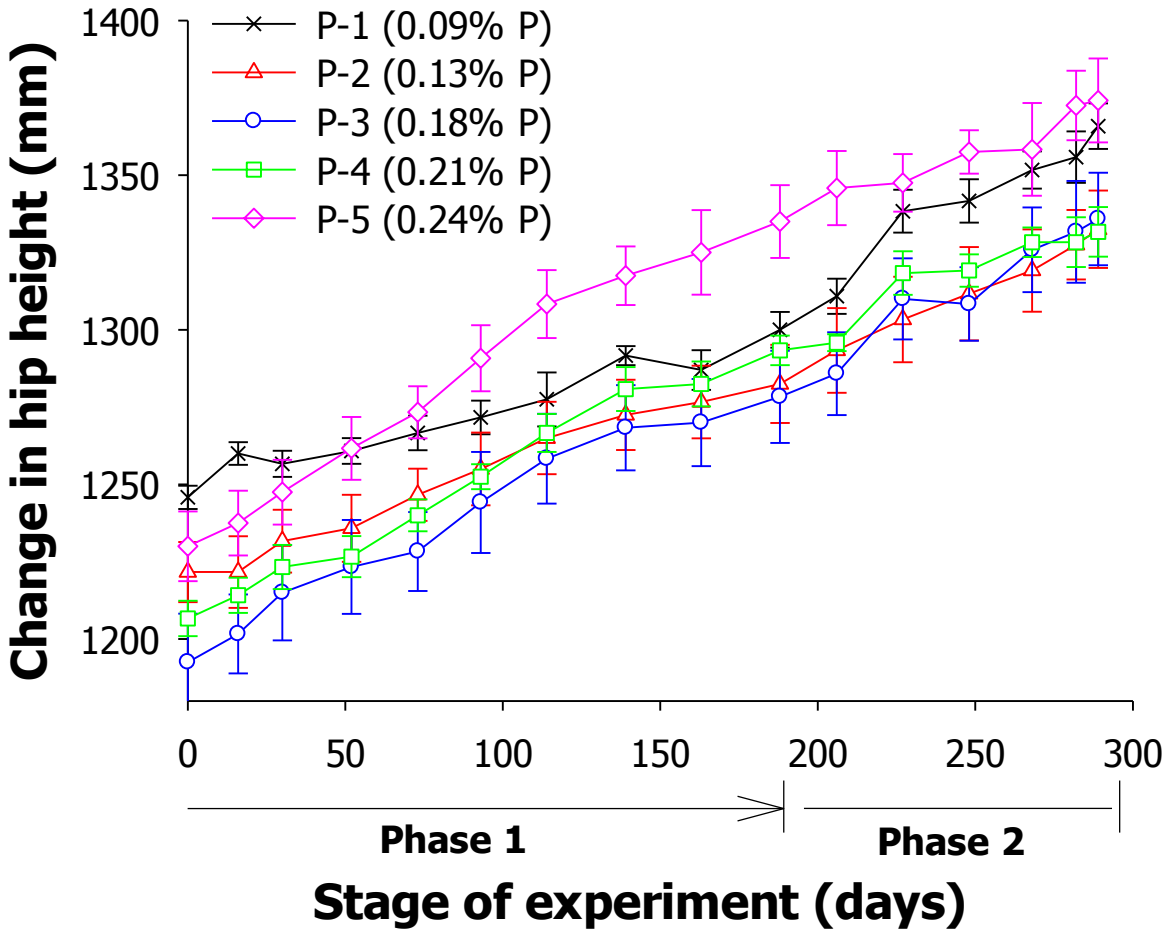

Figure A2. Change in hip height of steers offered a diet with similar energy and protein content with increasing P content (*Phase 1*) followed by the same high P diet (~0.25% P/kg DM) (*Phase 2*).

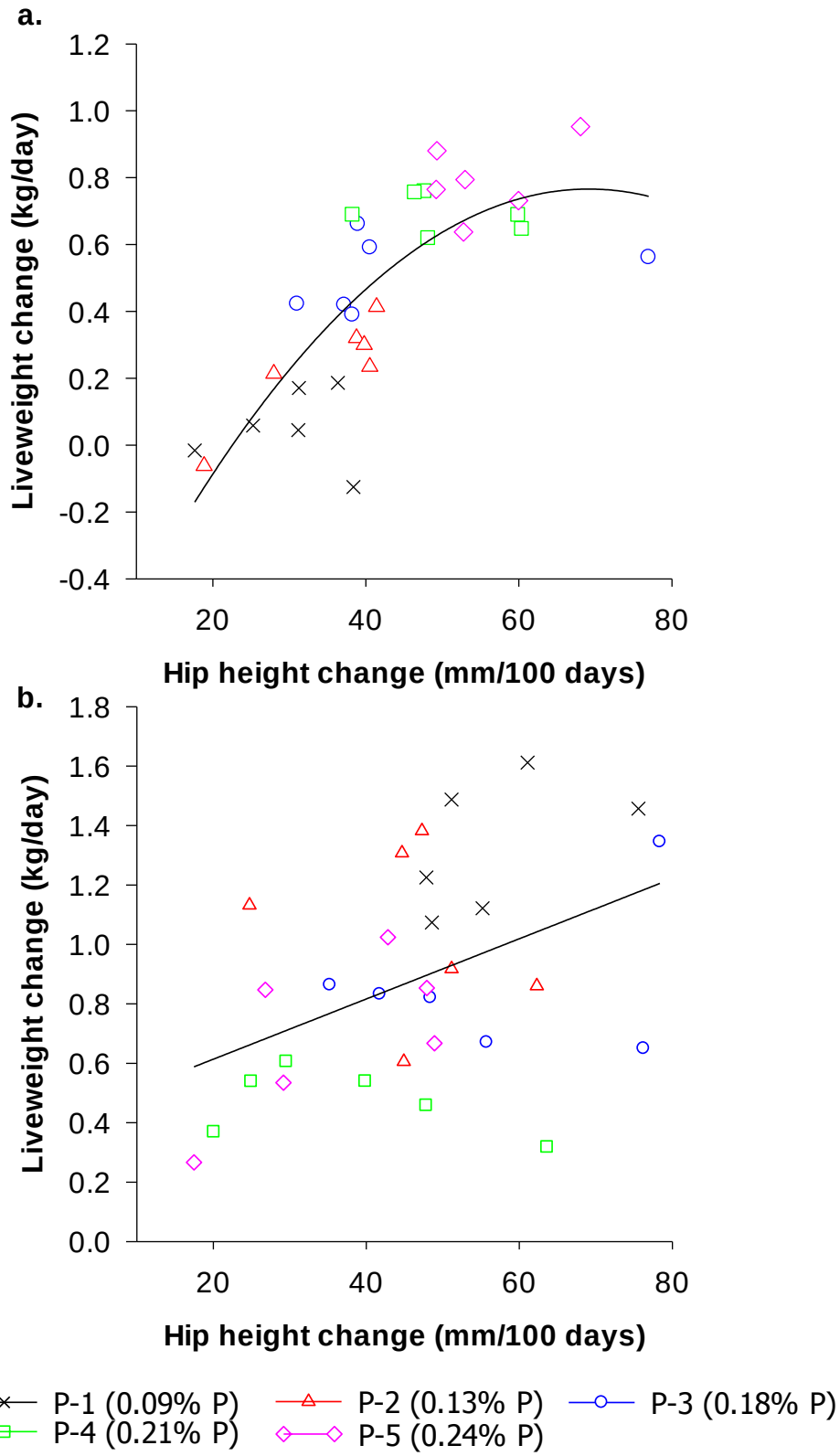

Figure A3. Relationship between liveweight and hip height change of steers fed diets with increasing P content (*Phase 1*; a) and undergoing re-alimentation on a high P diet after previously fed diets with different P content (*Phase 2*; b).

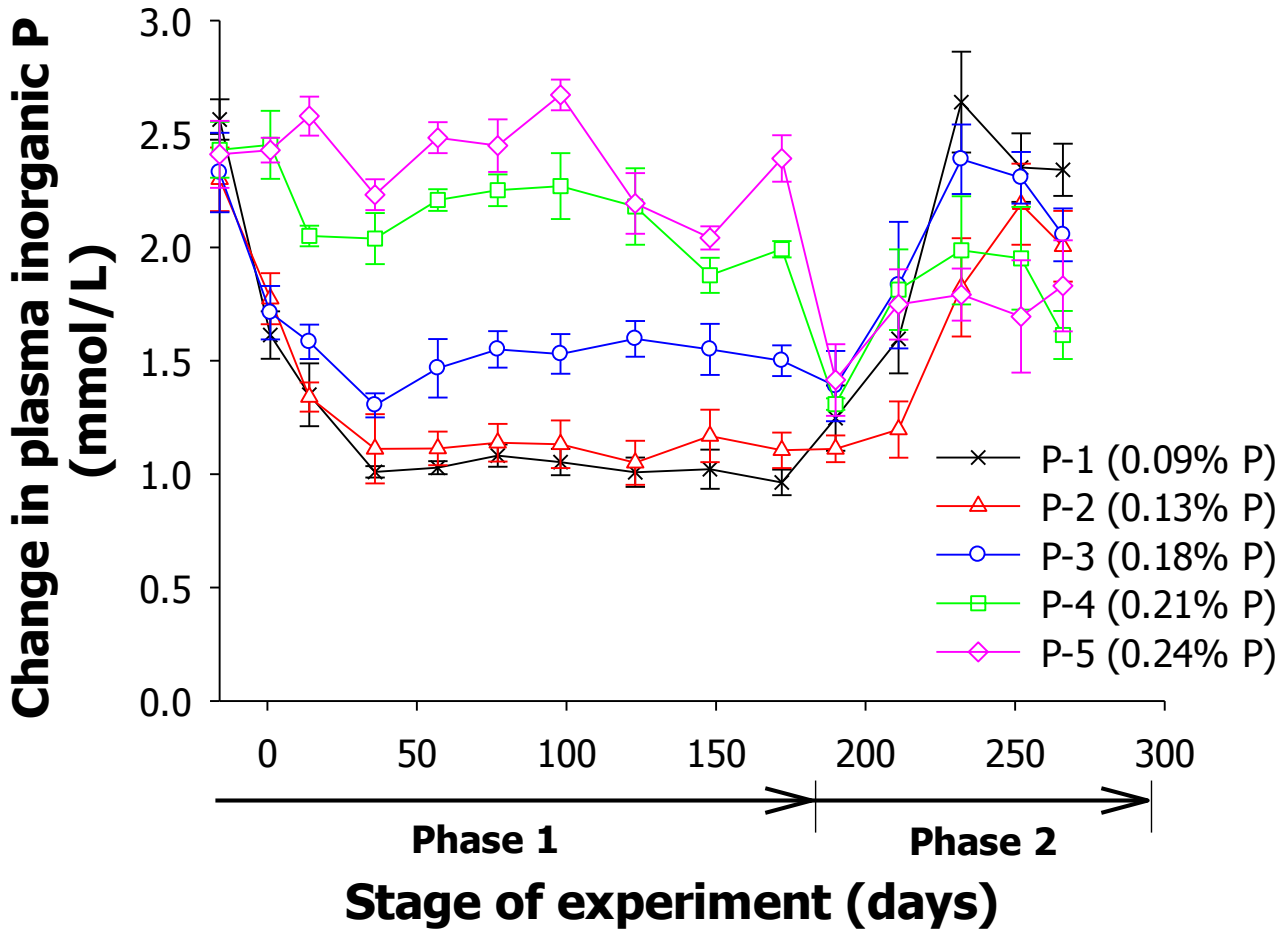

Figure A4. Change in the concentration of inorganic P in the plasma of steers offered a diet with similar energy and protein content with increasing P content (*Phase 1*) followed by the same high P diet (~0.25% P/kg DM) (*Phase 2*).

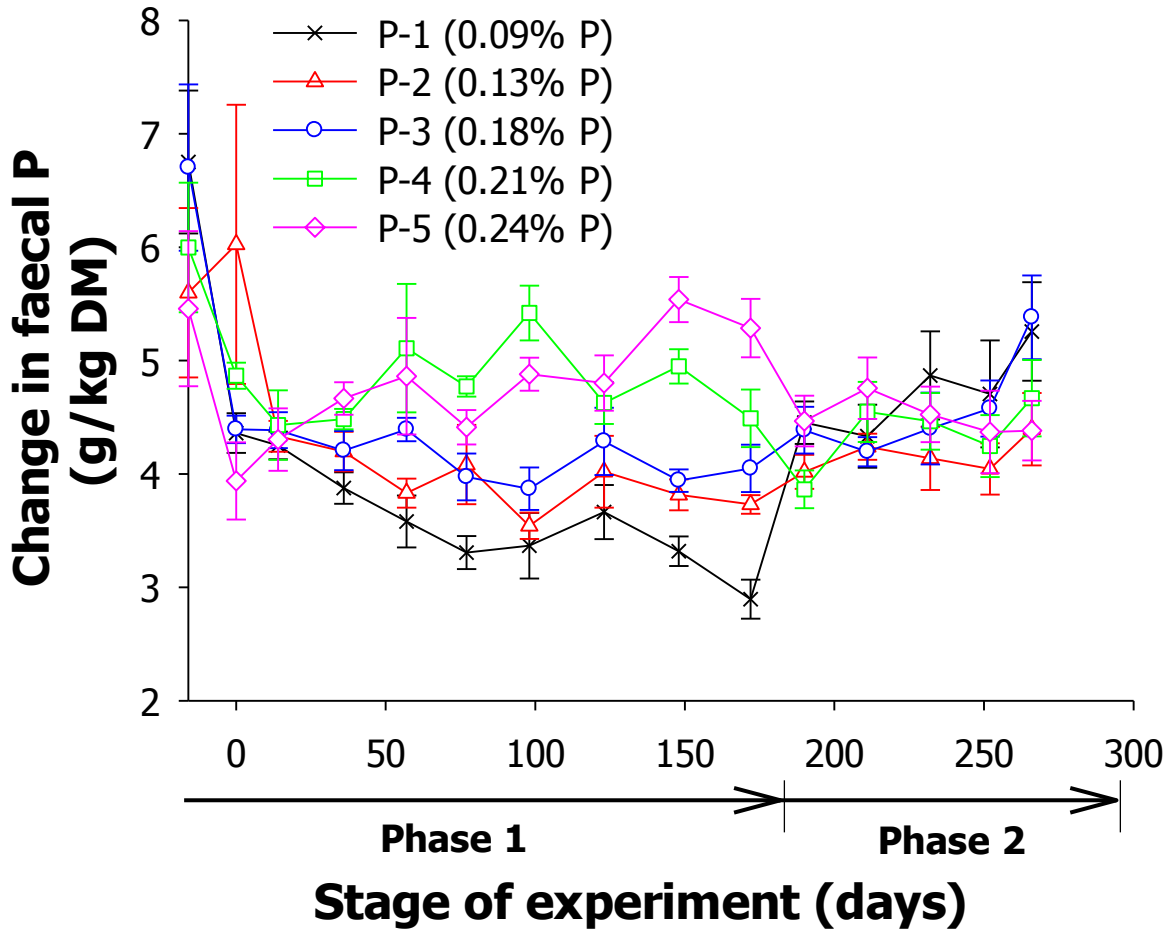

Figure A5. Change in the concentration of P in the faeces of steers offered a diet with similar energy and protein content with increasing P content (*Phase 1*) followed by the same high P diet (~0.25% P/kg DM) (*Phase 2*).