MEAT & LIVESTOCK AUSTRALIA

final report

Project code:	**DAQ.093**
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Date published:	**October 1997**
ISBN:	**1 7403 6962 9**

PUBLISHED BY
Meat & Livestock Australia Limited
Locked Bag 991
NORTH SYDNEY NSW 2059

Phosphorus management for breeding cattle in northern Australia

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Abstract

Phosphorus deficiency in cattle is widespread in northern Australia and results in much production foregone. For the first time in the tropics, the effects and their amelioration have been determined for growing heifers and young breeding cows.

Phosphorus deficiency stunts growth and depresses reproduction in growing heifers and first-calf cows. Milk yields and consequent calf growth are depressed. Older cows are less affected. Phosphorus requirements have been measured and found to be much lower than in published feeding tables. New diagnostic techniques have been pioneered. Commercial supplementation should target heifers and first-calf cows to maximise returns.

DAQ.093 Phosphorus management for breeding cattle in northern Australia

Executive Summary

Opportunity

Most of the cattle in Australia north of about 21°S graze phosphorus-deficient native pastures growing on phosphorus-deficient soils. Cattle grazing these pastures often suffer sub-clinical phosphorus deficiency, leading to slow growth and poor fertility. Across northern Australia, the losses might total $80 million annually. Where no clinical symptoms of phosphorus deficiency are apparent, producers are often reluctant, for reasons of cost, to feed supplementary phosphorus. Furthermore, there is no reliable means of accurately diagnosing phosphorus deficiency in cattle. In summary, phosphorus deficiency is widespread, causes large losses, is not adequately corrected by current producer practice and represents a large R&D opportunity.

Achievements

We have demonstrated conclusively that phosphorus deficiency has dramatic effects on young cows in the form of poorer body condition, lowered milk yield, lighter calves and very low reproductive fertility. To avoid growth being depressed, growing heifers were shown to require adequate dietary phosphorus at all times during liveweight gain. More mature cows had greater resilience in the face of inadequate phosphorus.

We have shown that previous preliminary estimates of phosphorus requirements for three-year-old first-calf heifers by Ternouth and Coates are valid for three, four and five-year-old Brahman cross cows grazing native tropical pastures with or without oversown legume. These are the first comprehensive estimates for breeding cows in the tropics.

We have refined the concept of blood phosphorus as an indicator of phosphorus status to the extent of nominating the conditions under which it is valid and that the values are different for growing heifers, three-year-old cows and older cows. We have extensively tested and calibrated *in vivo* measurement of tail-bone mineral density and concluded it to be an unreliable indicator of phosphorus status. We have begun development of a dynamic system of assessing phosphorus status based on bone turnover, potentially a very sensitive and reliable indicator of phosphorus status.

We have continually, and in a whole property context, promoted our findings widely amongst producers, agribusiness and extension agencies. We have test-driven an integrated diagnostic flow chart with several audiences.

Industry benefits

We gauge that there has been a large uptake of phosphorus management systems in northern Australia over the last five years. Much of this adoption has been as part of an overall herd management package stimulated by the use of whole-herd decision support systems in producer groups. This sort of activity has, for the first time, highlighted where gross inefficiencies were occurring in breeder herd management. Additional factors in this uptake have been tightening market specifications, a realisation that phosphorus deficiency was perhaps the last major physical impediment to efficient beef production, and the availability of more tailored supplementation products. In the next five years, impacts from this project could arise from more certain diagnosis of phosphorus status; tailoring phosphorus management to variations in season, class of cattle, and type of country; planned nutritional health monitoring.

We believe most producers in northern Australia would benefit by targeting growing heifers and first-calf cows for aggressive and comprehensive phosphorus management. Concentrating phosphorus supplementation on young females will, on properties with adequate segregation, greatly reduce costs and effort compared to supplementing a larger fraction of the herd. Feed and supplement manufacturers and suppliers could benefit by more rational tailoring of products. Many landscapes could benefit from a more efficient but less numerous breeding herd.

Conclusions and Recommendations

Concentrating phosphorus supplementation on young females would, on properties with adequate segregation, greatly reduce costs and effort compared to supplementing a larger fraction of the herd.

Growing heifers and first-calf cows should be targeted for aggressive and comprehensive phosphorus management.

Blood phosphorus is a useful diagnostic indicator of phosphorus deficiency when used with care. Indicators of bone turnover are potentially very sensitive and reliable indicators of phosphorus status. Tail-bone mineral density is an unreliable assay of phosphorus status.

Blood phosphorus and bone turnover indicators for different cow classes should be tested and validated. Sources of variation in bone turnover indicators need to be located and the assays simplified.

Phosphorus requirements of grazing, breeding cows are quite modest by published standards. The indicative requirements published by Ternouth and Coates in 1997 are valid for use in northern Australia in the pasture growing season. We still have no good estimates of dry season/pregnancy/out-of-season lactation requirements for cows.

There needs to be published an addendum to the McCosker and Winks manual detailing new wet season phosphorus requirements and revised blood diagnostic levels.

The requirements should estimate supplementation requirements for different pasture zones, taking account of phosphorus supplied from forage.

Cow phosphorus requirements for dry season growth, pregnancy, and out-of-season lactation need to be determined.

All of these conclusions are drawn from small numbers of cows under a limited set of conditions.

The conclusions need to be validated at a commercial scale, over longer time periods and in a wider range of circumstances.

Project personnel

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Ron Hendricksen, DPI, Rockhampton.

Acknowledgment

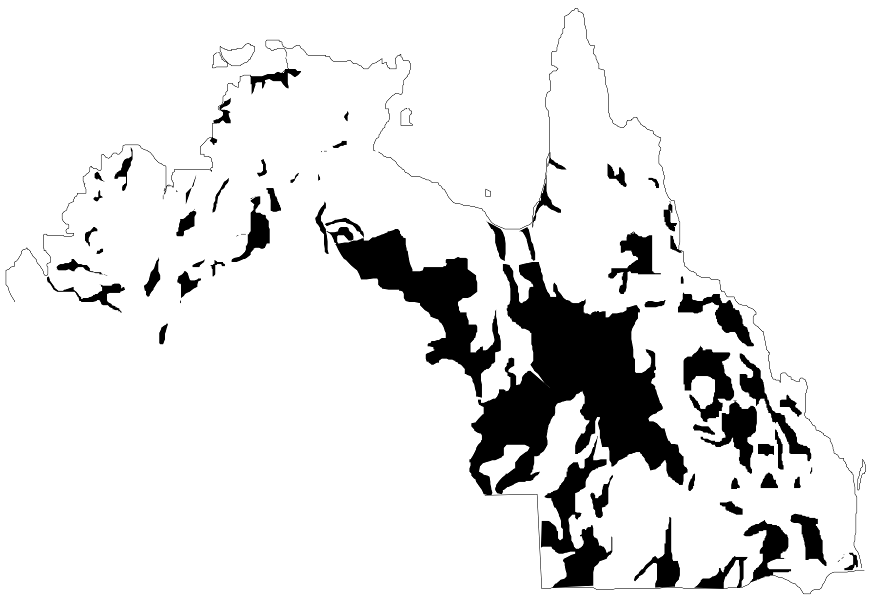
This project made extraordinary demands on staff in terms of weekend work, dark starts and finishes, patience and commitment. It is a pleasure to record the willingness and devotion shown. Particular thanks are due to Col Webb and Bob Drury who carried the burden of bizarre requests and sudden changes, while trying to give our cows a normal life, with fortitude and good humour. Special thanks go also to those from bases remote from Mareeba who gave up their normal lives for weeks at a time.

Background

Industry

Of the 4.7 million cattle run in Australia north of about 21°S (Proserpine - Mt Isa - Karratha), about 4 million graze phosphorus deficient native pastures growing on phosphorus deficient soils (Figure 1; Kerridge *et al.* 1990). The extent of production loss varies but on indications from Producer Demonstration Sites and experimental work is of the order of 10-20 percentage units in branding rates, 5-10 percentage units in death rates and 30-50 kg liveweight in annual growth rates. On a whole herd basis, the economic losses range from $6.00 to $43.00 per adult equivalent or $16 000 to $107 000 for an average property (Holmes 1990). Across northern Australia, these losses might total $80 million annually, with few visible symptoms other than those associated with general, dry-season malnutrition.

Figure 1. Soils in northern Australia with less than 10 ppm extractable phosphorus are not shaded.



Where phosphorus deficiency is visible in the form of peg-leg, producers normally supplement cattle with phosphorus. Where no clinical symptoms of phosphorus deficiency are apparent, producers are often reluctant, for reasons of cost, to supplement. Nevertheless, losses due to sub-clinical phosphorus deficiency far exceed those caused by overt deficiency.

Effective supplementation in areas of sub-clinical phosphorus deficiency across northern Australia was estimated (informed person survey by Coates, 1989) to be carried out by only 7% of producers (45% feed phosphorus, 15% of them feed in wet season).

The North Australia Beef Producer Survey estimated 72% of producers in the four northern regions of Northern Speargrass, Northern Aristida, Gulf/Peninsula and NT/WA Speargrass fed phosphorus supplements with 64% feeding year-round or in the wet season. This suggests 46% of those producers are feeding phosphorus effectively but the estimate needs to be discounted because (a) respondents (33% of eligible producers) might be more likely to supplement than non-respondents, (b) a producer nominating that supplement was fed in a particular season is not necessarily effective feeding and (c) it applies to all properties, whether deficient or not.

Reluctance by producers to supplement effectively is due to:

1. Uncertainty about the potential benefits. Because there is no unequivocal test of phosphorus status, only in extreme situations can producers and their advisers predict benefits in productivity or profitability terms. Although it is possible to predict responses by growing cattle in small areas based on soil phosphorus levels (Miller *et al*. 1990), the response by breeding cattle cannot be inferred nor can soil tests usefully assess phosphorus status across the variations in landscapes grazed by most breeding cattle.

2. Unwillingness to bear the cost. At present, phosphorus requirements for various livestock classes are unclear. Blanket recommendations for supplementation result in annual material costs of $11.70 per breeder or $12 000 for an average property together with the costs of feeding out. Capital costs can amount to $70 000 and despite analyses showing it to be a very profitable investment in some circumstances, it "requires a large financial commitment from the grazier" (Holmes 1990).

3. Extra cost and difficulty in wet season compared with dry season supplementation. Although supplementation is known to be more effective in the wet season there are extra costs in protecting supplements from weather and difficulty in moving around the property at that time.

4. At the same time, there are no guidelines on the costs and benefits of various patterns of strategic, seasonal supplementation.

If 50% of producers were to feed effectively, the gross benefit could amount to $32 million annually. Net of present costs, that could amount to $8 million annually. If supplementation costs could be reduced by $5 per head those same 50% of producers would save a further $8 million annually.

In summary, phosphorus deficiency is widespread, causes large losses, is not adequately corrected by current producer practice and represents a large R&D opportunity.

Research and development

In a MRC-commissioned review of research and development in phosphorus nutrition, Dr R.G. Holroyd (1992) found that producers, extension personnel and researchers all listed as their first question about phosphorus nutrition "Will the response be big enough to cover the costs?" although each expressed that question in a different way. Holroyd went on to make the following recommendations, among others:

- MRC funding over the next 5 years should concentrate on animal, particularly the breeding female, rather than plant or soil responses with additional P as a supplement rather than as a fertilizer source.

- a high priority is given to providing financial support for continued field studies into simultaneous work with breeders determining the P requirements of different classes and for the further development of diagnostic technology based on both blood metabolites and tail bone density measurements.

- the provision of financial support for the establishment of additional or enhancement of existing herd management demonstrations in varying P deficient situations, of which P supplementation is one input, is supported as a medium priority. These sites must be involved with the more detailed research aspects outlined above to enable verification/modification of breeder P requirements and diagnostic methodology.

- MRC funding for additional work on better P delivery systems and case studies was not supported.

Several developments over the few years leading up to this project greatly raised the probability of resolving the technical constraints.

The first was that a series of techniques had been developed and refined to give, for the first time, good estimates of the forage, phosphorus and nitrogen intakes, excretions and absorptions of grazing cattle (Ternouth *et al.* 1990; Coates and Ternouth 1992; Hendricksen *et al.* 1993; McLean and Ternouth 1993).

Secondly, this work and related animal house studies (Bortolussi *et al.* 1992) indicated that the published requirements for phosphorus are substantially overestimated, raising the promise of cheaper and more efficient supplementation.

The third was the development and refinement of techniques for the diagnosis of dietary phosphorus deficiency using plasma inorganic phosphorus alone (Wadsworth *et al.* 1990), plasma inorganic phosphorus and plasma urea nitrogen together to differentiate between phosphorus and nitrogen deficiencies (Bortolussi *et al.* 1994), or by non-surgical bone densitometry (Murray, Coates, Hopkins, Ryan; unpublished).

The fourth development, partly facilitated by MRC, has been the willingness of personnel in several R&D organizations to pool resources, expertise and data in the interests of integrated outcomes (for example in the projects CS.PO.19 (Mineral nutrition of legume based cattle production systems, DPI, CSIRO and UQ), CS.148 (Effect of phosphorus status on phosphorus kinetics and reproductive function in pregnant and lactating beef heifers, CSIRO and UQ).

The time was right to capitalize on these developments in developing phosphorus management systems for breeding cattle on native pastures, following the success of a team approach in rationalizing phosphorus management systems for growing cattle on sown pastures (Miller *et al*. 1990; Partridge and Miller 1991).

Objectives

1. To determine phosphorus requirements for breeding cattle grazing native pastures, by June 1996.

2. To develop, calibrate and refine diagnostic techniques for assessing dietary intake and body reserves (together defining status) of phosphorus and nitrogen in breeding cattle grazing native pasture, by June 1996.

3. To validate these findings and calibrate them against herd productivity on a commercial scale, by June 1996.

4. To demonstrate the benefits of phosphorus supplementation, according to the new model, as part of an improved management package, in situations of varying phosphorus deficiency, beginning by December 1995.

5. To integrate and promote findings in a way that enables producers and their advisers to make optimal decisions about supplementation, by June 1996.

Methodology

Strategy

A combination of formal experimentation, monitoring of Producer Demonstration Sites and technology transfer is required to achieve the objectives, taking into account other management practices such as early weaning, urea and protein supplementation, pasture grazing and burning, and automated cattle management.

The essential components of a decision about supplementing breeding cows with phosphorus are:

DECISION	KNOWLEDGE NEEDED
Whether to feed supplementary P	1. Existing P status of cow 2. Benefits from increasing P supply
How much supplementary P to feed	3. Cow requirements for P

Formal experimentation at the scale proposed can provide estimates of cow phosphorus requirements (3) and develop methods for determining existing phosphorus status (1) but only large scale comparisons of the type undertaken at Producer Demonstration Sites can estimate the cumulative and aggregate benefits from increasing phosphorus supply (2) to cows of known status.

Formal experimentation

Objectives. The primary purpose of formal experimentation is to make accurate estimates of phosphorus requirements for cows in various reproductive and lactation states. At the same time, it provides a unique opportunity to calibrate dietary phosphorus and body reserve (status) diagnostic techniques (blood phosphorus and nitrogen parameters, as well as bone density) with breeding cows of known phosphorus status across a wide range of phosphorus supply.

Design. The experimentation involved breeding cows and heifers in various reproductive phases (post-weaning, pre-conception, pregnancy, lactation) in treatments of varying phosphorus supply and protein availability. While the objectives of this research were concentrated on phosphorus deficiency, the universal, often overriding, nitrogen deficiency in northern Australia made it essential to control and monitor nitrogen intake of cattle at the same time. There were two experiments:

In the first, cows pregnant with their first or second calf grazed, continuously, the following six combinations at Springmount, near Mareeba:

Very Low P pasture (2 ppm soil P)	**Low P pasture** (3-4 ppm soil P)	**Moderate P pasture** (6-10 ppm soil P)
1. No supplement	2. No supplement	6. No supplement
	3. N supplement	
	4. P supplement	
	5. P+N supplement	

Supplements were fed year-round at 10 g P/cow/day as Kynofos and 28 g N/cow/day as urea. Supplements were mixed with 50 g salt /cow/day and was delivered twice weekly. Treatment 6 area was fertilized with superphosphate in September 1993 to maintain a moderate level of soil phosphorus.

In the second experiment, growing heifers grazed Low P pasture or Moderate P pasture, without phosphorus or nitrogen supplementation.

The formal experiments were conducted at Springmount, near Mareeba, where the natural level of soil and pasture phosphorus is very low.

Experiment 1. Eight (1994-95) or ten (1993-94) cows grazed each treatment at a stocking rate of 8 or 6 ha, respectively, per breeder. A fresh batch of pregnant females with a history of marginal phosphorus supply was necessary each year to ensure these limited numbers were all reproductive. Three-year-old, first-calf cows were used in 1993-94. In 1994-95, first-calf cows were 5 years old while second-calf cows were 4 years old. While an ideal situation would have cows at all physiological stages in all seasons of the year, thereby testing all combinations of phosphorus (and nitrogen) supply and demand, logistic considerations limited the variation to the supply side of P and N nutrition with all cows at a similar stage of reproduction and lactation.

*Measurements***.** On three occasions annually, phosphorus kinetic measurements were undertaken using 4 resident cows from each treatment together with some non-resident, oesophageally-fistulated steers. The procedures are given in Ternouth *et al.* (1990).

N and P intake: Residents were dosed with intraruminal, calibrated, chromic oxide capsules (Captec) at Day -7. The concentration of Cr in faecal grab samples, collected daily for a minimum of nine days, were used to estimate faecal dry matter (DM) output. The DM digestibility of diet available to cows was estimated on oesophageal extrusa from the fistulated steers by *in vitro* digestibility analysis. DM intake was estimated from faecal output and digestibility estimates. Concentration of P in the diet was estimated using 4 oesophageally-fistulated steers injected subcutaneously with 8-10 MBq ^{32}P.

N and P losses: Endogenous faecal losses of P and P absorption coefficients were measured in resident females infused, via jugular vein, on Day 0 with a known dose (80-120 MBq) of ^{32}P. Blood and faecal samples were collected for 10 days after infusion for determination of P and N concentration and specific activity.

Body P reserves: Tail bone density was measured on all females by photon absorption at the time of kinetics measurements. Tails were removed from the first draft of cows for tail bone density measured by the dual-energy X-Ray (DEXA) technique in Perth.

Cow growth and production: Cow and calf liveweight was measured monthly, and cow ovarian activity about monthly after calving. Ovarian activity was monitored by ultrasonography of ovaries and progesterone analyses.

Other measurements included pasture yield, botanical and chemical composition (to coincide with P kinetics measurement periods).

Experiment 2. Four groups, each comprising eight growing heifers, grazed one of two paddocks at a stocking rate of 4 ha per heifer. One paddock was low (L) soil phosphorus (3-4 ppm), the other moderate (M) soil phosphorus (7-9 ppm). Heifers grazed continuously (LL and MM) or rotated between paddocks each eight weeks (LH and HL). During a two month spell in November-January, the rotating groups grazed a paddock intermediate between L and M.

Measurements. At ten day intervals, heifers were weighed and samples of urine, faeces and jugular blood taken. Urine was analysed for deoxypyridinoline and creatinine; faeces for nitrogen and phosphorus; and blood for osteocalcin, parathyroid hormone, urea nitrogen and plasma inorganic phosphorus. At eight week intervals, four heifers from each group were dosed with intraruminal chromic oxide capsules to measure faecal output. Digestibility and nitrogen and phosphorus concentration of pasture were measured on samples plucked to simulate forage being grazed.

Producer Demonstration Sites and commercial herd monitoring

Blood samples collected from PDS and commercial properties were analysed for plasma inorganic P and faecal samples for nitrogen and P.

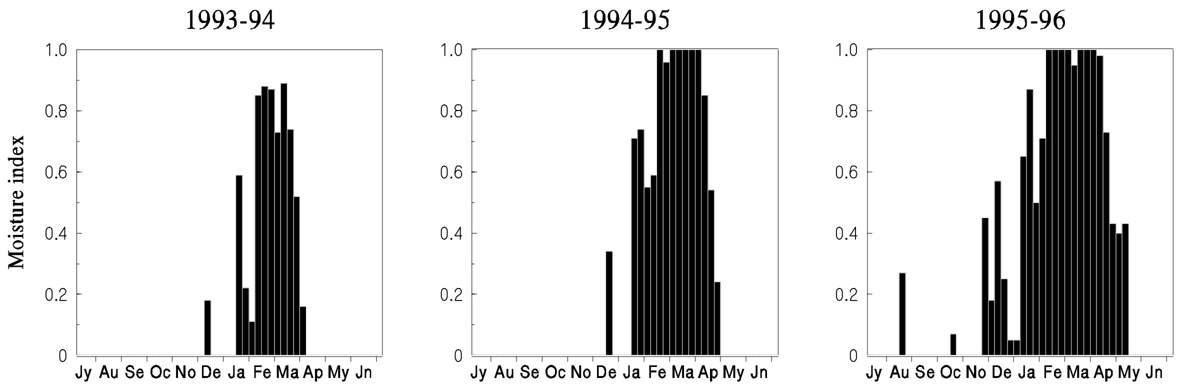
We were not very successful in getting useful blood or faecal samples from PD sites or commercial properties. We lost our cooperator, Dr Bill Ryan, in Western Australia and got no samples from there. Drought and changing management prejudiced sampling in Queensland (e.g. in 1994 at Kangaroo Hills, rain fell in the unsupplemented paddock but not in the supplemented one) whereas three successive, extraordinarily good seasons in the Northern Territory, rendered many comparisons invalid. In general, comparisons between supplemented and unsupplemented cattle at the one site are becoming increasingly difficult, with progressive producers being reluctant to leave any cattle unsupplemented.

Results and discussion

Seasonal conditions

Rainfall of 451 mm and 462 mm in 1993-94 and 1994-95, respectively, was well below the median 800 mm. Both seasons began in late January instead of the more usual November (Figure 2). In 1993-94 there was a further dry spell in early February, and the season ended in late March. The third year, 1995-96, was an exceptionally good one. Though rainfall of 775 mm was only near median, the season extended from late November until early May, with some dry spells in December and January. The differences and patterns are clear in Figure 2 where moisture index is calculated as in McCown (1980), except on a daily basis, with soil moisture store set at 150 mm, Penman evaporation calculated from Mareeba temperatures, and the crop factor set at 0.8.

Figure 2. Soil moisture index at Springmount.

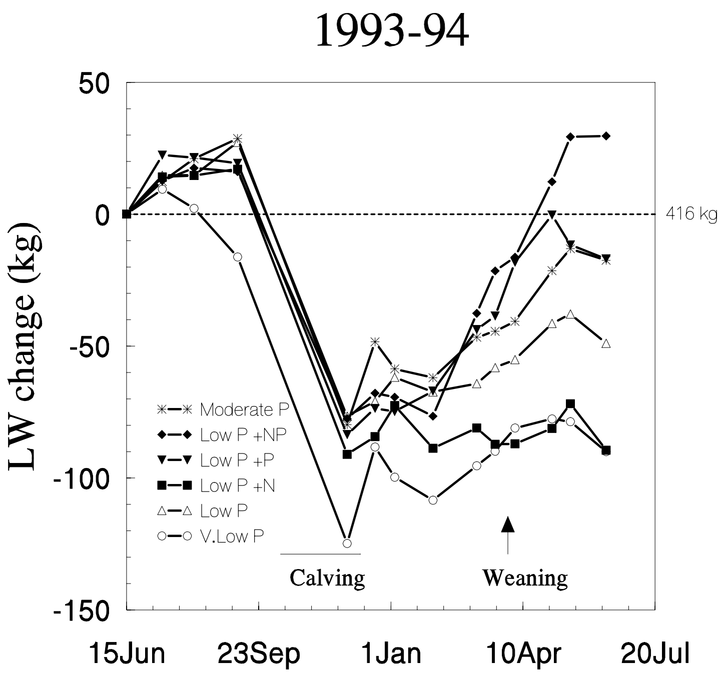


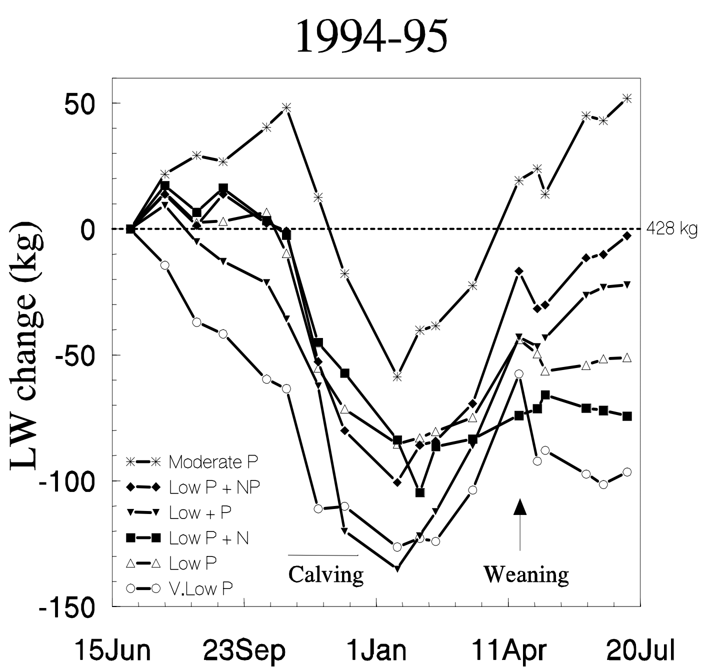
Cow and heifer liveweight

Cow liveweight reflected seasonal conditions with liveweight losses in the dry season and gains in the wet season (Figure 3). In 1993-94, cows lost weight from September until the end of November. Treatment differences (75 kg between Moderate P and V.Low P) were probably related to quantity of legume available rather than to differences in dietary phosphorus. Weights were then static until early February when rapid weight gains began in treatments supplemented with phosphorus. Cows not supplemented with phosphorus grew slowly until May and then began losing weight again. Cows in treatments with P supplement or Moderate P regained their starting weights, whereas cows in low phosphorus treatments were 40-80 kg lighter after 12 months.

In 1994-95, the dry season pattern was similar with an even greater separation than in 1993-94 between treatments (up to 150 kg) prior to calving. By the time the season broke in January, differences were reduced to 60 kg. P-supplemented treatments and moderate P grew rapidly until June whereas other treatments stopped growing by early May. Moderate P treatment performed better after the paddock was fertilized in September 1993.

Figure 3. Seasonal liveweight change of cows





Cows lost 60-130 kg liveweight during the dry season (Tables 1 and 2) of which some 60 kg could be ascribed to foetus and accompanying tissues.

Table 1. Liveweight changes of cows in 1993-94

	V.Low P	Low P	Low P +N	Low P+P	Low P+NP	Moder. P
Dry Jun-Sep	-16	27	17	19	16	29
Calv Sep-Dec	-109	-104	-108	-103	-94	-108
Drought Dec-Jan	16	9	2	16	1	18
Pre-wean Jan-Mar	19	9	2	28	55	18
Post-wean Mar-May	11	20	15	50	51	31
Early dry May-Jun	-11	-11	-17	-28	0	-4
June to min LW	-125	-76	-91	-84	-78	-80
Min to max LW	47	39	19	95	107	67
YEAR	-78	-37	-72	11	29	-13

Table 2. Liveweight changes of cows in 1994-95

	V.Low P	Low P	Low P +N	Low P + P	Low P+NP	Moder. P
Dry Jun-Sep	-60	7	3	-21	2	40
Calv Sep-Dec	-67	-92	-87	-114	-103	-99
Pre-wean Jan-Mar	69	41	10	92	84	78
Post-wean Mar-May	-44	-8	2	20	6	24
June to min LW	-126	-85	-105	-135	-101	-59
Min to max LW	69	41	39	113	98	110
YEAR	-57	-44	-66	-22	-3	51

The depression of liveweight from feeding P supplement alone in the dry season, relative to other groups with extra P, repeats a common observation and is presumably due to some imbalance.

In 1994-95, half the cows were first calf, half second calf. Although numbers are small, it is worth noting that performance was quite different between the two (Table 3). This cannot be an age effect since the first calf cows were older than the second calf cows.

Table 3. Liveweight changes (and SE of mean) by number of calves (parity) 1994-95

	Calf No.	LW loss	LW gain (kg)	Year
Unsupplemented	1 (n=12)	-135 (10.6)	51 (7.7)	-83 (7.3)
	2 (n=9)	-83 (12.0)	54 (4.7)	-28 (11.0)
P-Supplemented	1 (n=12)	-115 (13.0)	96 (5.6)	-18 (12.1)
	2 (n=11)	-79 (9.8)	114 (5.8)	36 (9.3)
All cows	1 (n=24)	-125 (8.5)	74 (6.6)	-51 (9.7)
	2 (n=20)	-80 (7.5)	87 (7.8)	6 (10.1)

After 10 months, and an exceptionally good season when cattle growth was continuous, heifers on moderate phosphorus pasture had grown at an average 580 g/d (196 kg) whereas heifers confined to low phosphorus pasture grew at less than two thirds that rate at 380 g/d (122 kg). Heifers that rotated between low and moderate phosphorus pasture had intermediate growth rates (Table 4).

In a dry season where growth never stopped, there were small growth responses to phosphorus treatment. From November to January, MM heifers grew faster than those on paddocks with lower phosphorus and, in fact, there was no further response by MM over LM or ML after January. Heifers on low phosphorus continuously (LL), on the other hand, continued to grow more slowly than other groups throughout the wet season. Taking the whole November to May period (181 days) as the growing season, heifers grew at 514, 635, 691 and 780 g/d respectively for LL, LM, ML, and MM.

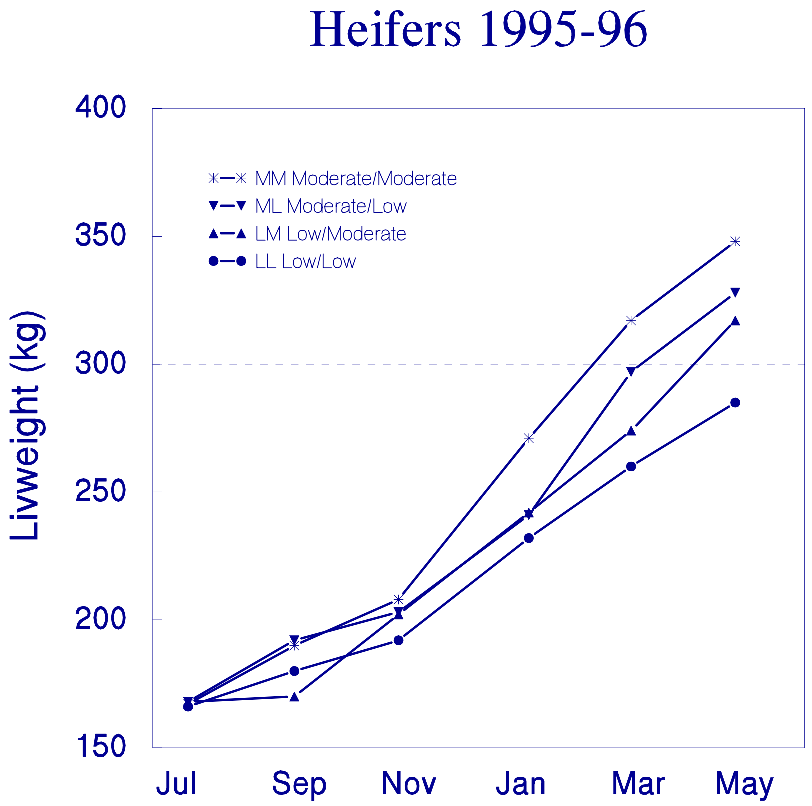
Table 4. Liveweight changes of heifers in 1995-96

	LL	LM	ML	MM
Dry Jul-Sep	14	11	24	23
Dry Sep-Nov	12	23	11	18
TOTAL DRY	26	34	35	41
Spell Nov-Jan	40	(40)	(38)	64
Wet Jan-Mar	29	32	56	46
Wet Mar-May	24	43	31	31
TOTAL WET	53	75	87	77
YEAR	119	149	160	182

L = low phosphorus paddock
M = moderate phosphorus paddock
( ) = heifers in intermediate paddock

These differences, significant enough in themselves in terms of growth rate, could have dramatic consequences in promoting or inhibiting puberty and consequent time of first conception. Assuming 300 kg as a threshold for puberty, HH heifers would reach it in February, ML and LM in March and April respectively, while LL would be unlikely to reach puberty until the following wet season (Figure 4).

Figure 4. Seasonal liveweight change in heifers.

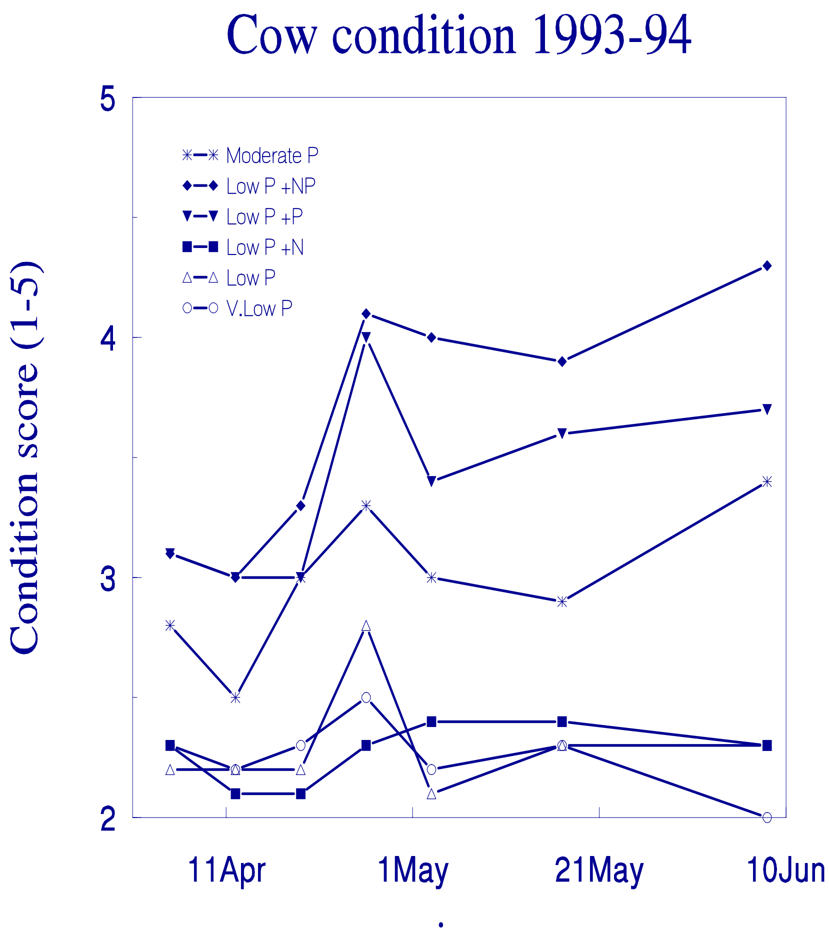


Condition scores

Scoring only commenced in March 1994. Condition of 1993-94 groups unsupplemented with phosphorus hardly changed from backward store after March weaning whereas groups supplemented with phosphorus or on Moderate P increased by 0.5 to 1.0 units to store or forward store from weaning to June (Figure 5).

Groups separated quickly in 1994-95 in the early dry season, although most groups converged towards 2.5 at dry season end. The exception was Moderate P where condition never fell below 3.0. Groups supplemented with phosphorus or on Moderate P increased condition rapidly after break of season but others increased condition only slowly and never reached store condition.

Figure 5. Cow condition changes



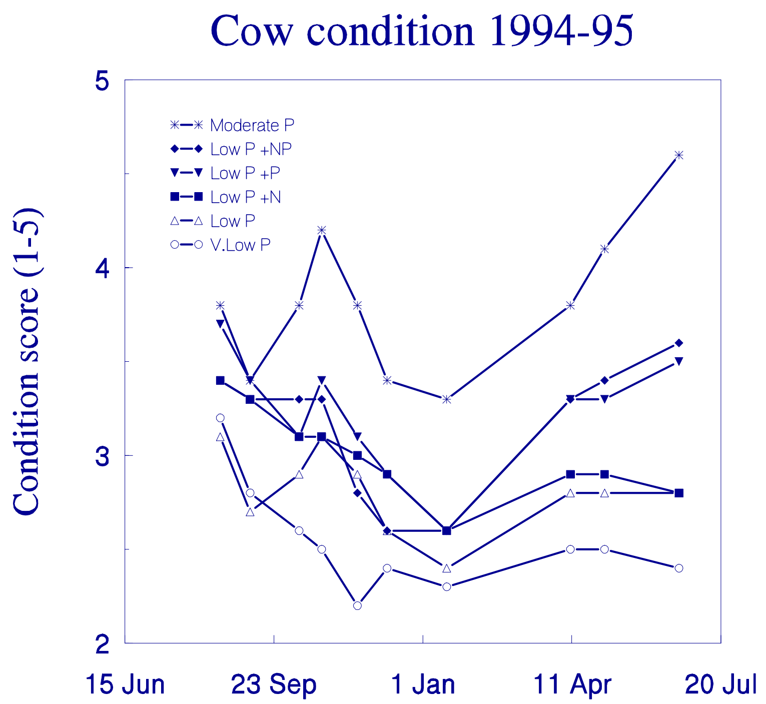


Table 5. Cow condition scores at weaning

	V.Low P	Low P	Low P + N	Low P + P	Low P+NP	Moder. P
5 April 1994						
Mean condition score	2.3	2.2	2.2	3.1	3.1	2.8
SE of mean	0.15	0.15	0.13	0.10	0.18	0.08
19 April 1995						
Mean condition score	2.5	2.8	2.9	3.2	3.2	3.8
SE of mean	0.13	0.16	0.22	0.16	0.16	0.21

Ovulation

Differences in number of cows ovulating were much larger in 1993-94 than 1994-95 (Table 6). This is most likely due to 1993-94 cows being three years old and 1994-95 cows being four and five years old. Most supplemented cows and cows in Moderate P ovulated in both years whereas few unsupplemented cows ovulated in 1993-94.

Calving to ovulation intervals as calculated were long, covered a similar range in each year and did not vary among treatments to the same extent as numbers ovulating. On the other hand, the measure is not particularly sensitive, since the latest assumed date of ovulation was in early June when the last scans and progesterone assays were done. In reality, cows that had not ovulated by early June were unlikely to do so before the next wet season.

On a group basis, the fastest possible calving to calving interval was 416 days, implying that of the calves possible, many would be born out of season.

Table 6. Ovulation observations

	V.Low P	Low P	Low P + N	Low P + P	Low P+NP	Moder. P
1993-94						
No. ovulated by March 31	0	1	0	1	1	0
No. ovulated by April 30	0	1	2	9	10	5
No. ovulated by June 7 [a]	0	1 [b]	4	10	10	7 [b]
Calving to ovul. (days) [c]	224	214	202	175	167	177
1994-95						
No. ovulated by March 31	0	0	2	0	0	3
No. ovulated by April 30	3	1	4	2	7	6
No. ovulated by June 9th [d]	6	5	6 [e]	6	8	7 [e]
Calving to ovul. days [f]	183	210	176	190	165	134

[a] June 7th was the last examination for ovulation.
[b] Nine cows. There were ten cows in other groups.
[c] For cows that did not ovulate, June 7th assumed.
[d] June 9th was the last examination for ovulation.
[e] Seven cows. There were eight cows in other groups.
[f] For cows that did not ovulate, June 9th assumed.

Lactation

Differences between treatments in milk production in 1993-94 were large (Table 7). Treatments supplemented with phosphorus produced an average 5.8 kg/d while those without P supplement produced an average 3.5 kg/d. Differences in milk phosphorus were small.

In 1994-95, the range of milk production was smaller with no obvious treatment effect. These were older cows than in 1993-94 and presumably were better able to use body reserves to maintain milk production despite experimental treatment. Again, differences in milk phosphorus were small.

Table 7. Milk production and milk phosphorus

	V.Low P	Low P	Low P +N	Low P + P	Low P+NP	Moder. P
1993-94						
Milk production (kg)	3.4	3.6	3.5	5.1	4.8	7.4
SE of mean	0.24	0.43	1.24	0.24	1.23	1.12
Milk phosphorus (g/L)	1.05	0.87	1.11	1.09	1.16	1.10
SE of mean	0.02	0.04	0.04	0.03	0.01	0.08
1994-95						
Milk production (kg)	6.6	4.5	5.9	6.2	7.0	5.4
SE of mean	0.66	0.59	0.80	0.66	1.80	0.47
Milk phosphorus (g/L)	1.03	1.08	1.04	1.03	0.97	1.04
SE of mean	0.04	0.04	0.08	0.04	0.12	0.07

Calf growth

Calves on V. Low P grew slower than other groups in 1993-94 (Table 8). There were no clear-cut differences in calf growth in 1994-95, reflecting the uniformity of milk production in that year. Weaner production per cow followed a similar trend, with an extra advantage to Moderate P in 1993-94 where 10 cows raised 11 calves.

Table 8. Calf growth and weaner production

	V.Low P	Low P	Low P +N	Low P + P	Low P+NP	Moder. P
1993-94						
LW 20 Dec 93	63	71	66	68	66	69
LW at wean 21 Mar (SE)	134 (5.6)	162(5.6)	148(8.3)	160(6.2)	156(7.3)	163(7.5)
LW gain Dec-wean	71	91	82	92	90	94
Weaner LW per cow	134	146	148	160	156	190
LW 4 May 94	140	172	151	167	164	173
LW gain wean-May	6	10	3	7	8	10
1994-95						
LW 17 Jan 95	62	64	68	63	65	75
LW at wean 19 Apr (SE)	155(9.7)	153(4.2)	162(7.0)	165(5.2)	166(4.8)	181(11.5)
LW gain Jan-wean	93	89	94	102	101	106
Weaner LW per cow	174	153	141	165	166	158

Phosphorus kinetics

Cows ate more forage in the wet season (2.1-2.8 % liveweight) than in the dry season (1.1-1.5 %) (Table 9). Treatment effects were smaller. Dry matter intake of the V. Low P group was probably restricted by lack of forage (due to drought) in September 1993 and February 1994.

Dietary phosphorus was lowest in the V. Low P group and highest in the Moderate P group. Except in the Low P+NP group, which had unaccountably low diet P, other low P groups had similar and intermediate dietary P.

Phosphorus intake varied over a much larger range than did forage intake, because of the multiplying effect of phosphorus concentration being higher at the same time as forage intake was at a maximum.

Retention of phosphorus was almost always negative in groups with P intakes below 10 g/d whereas other groups had either positive balance or very small negative balance.

Absorption coefficients (efficiency of absorption of dietary phosphorus) were mostly high, above 0.7, except in groups with low dietary phosphorus in February of both years. We have no explanation for this beyond noting that phosphorus absorption efficiency is often low where P intake is below 10 g/d (Ternouth 1990). Presumably, absorption mechanisms are deranged under severe deficiency.

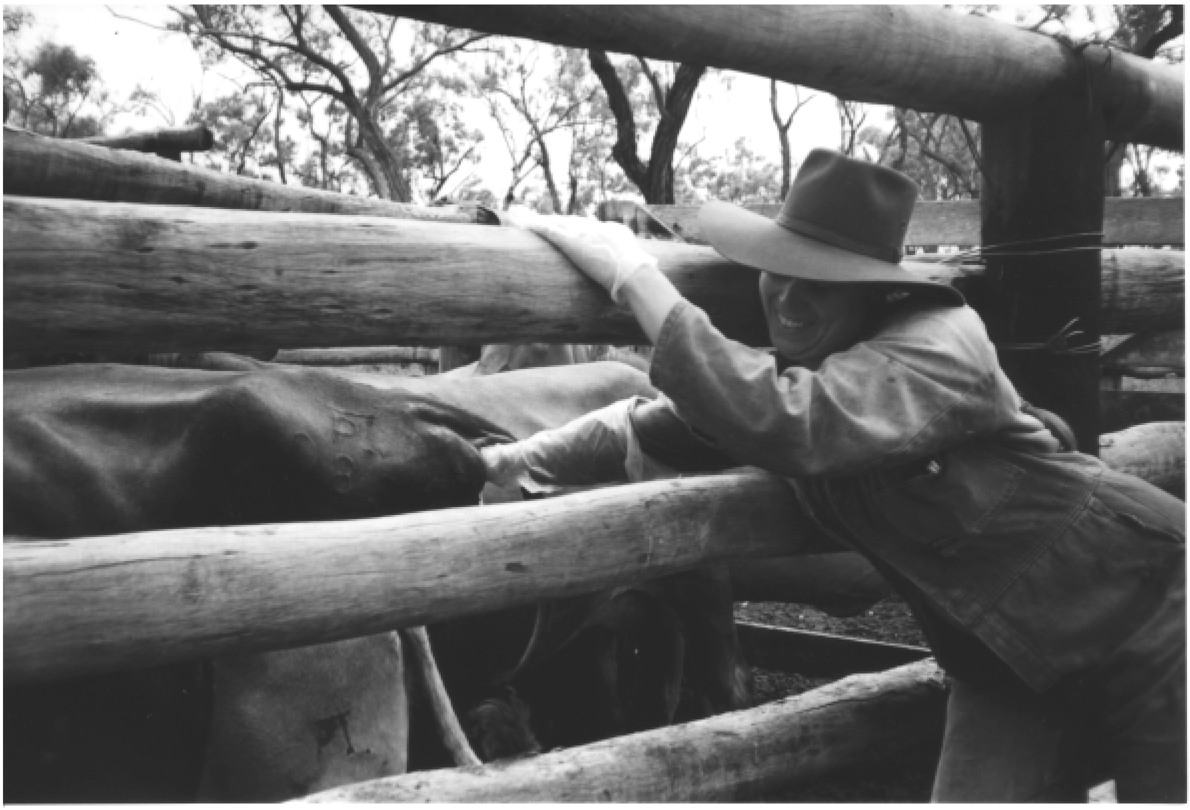


Table 9. Forage and phosphorus intake and phosphorus absorption and balance.

	V. Low P	Low P	Low P +N	Low P + P	Low P+NP	Moder. P
Dry matter intake (kg/d)						
Sep 93	4.37	6.54	4.62	5.14	5.96	5.50
Feb 94	6.74	8.70	7.62	8.89	9.62	8.02
May 94	6.38	7.10	6.23	8.92	7.03	8.28
Sep 94	4.86	6.18	6.74	6.70	6.41	6.64
Feb 95	9.72	7.64	8.26	9.43	10.45	9.80
May 95	7.04	6.72	6.02	10.93	8.46	9.05
Diet P concen. (g/kg)						
Sep 93	0.31	0.35	0.34	0.29	0.40	0.64
Feb 94	0.83	1.05	1.11	1.35	0.96	1.75
May 94	0.42	0.48	0.46	0.56	0.44	1.00
Sep 94	0.36	0.50	0.46	0.53	0.36	0.80
Feb 95	0.80	1.26	1.14	1.34	0.97	2.16
May 95	0.32	0.56	0.41	0.66	0.98	1.36
P intake (g/d)						
Sep 93	1.33	2.28	1.55	1.49	2.36	3.54
Feb 94	5.59	9.17	8.42	30.40	27.85	14.04
May 94	2.68	3.43	2.88	23.18	21.39	8.27
Sep 94	1.76	3.06	3.11	22.44	22.14	5.30
Feb 95	7.78	9.66	9.44	18.73	17.57	21.15
May 95	2.28	3.80	2.49	13.93	15.19	12.29
P balance (g/d)						
Sep 93	-1.50	-1.67	1.10	-2.01	-2.04	-0.15
Feb 94	-5.21	-3.24	-2.93	16.00	12.96	-2.69
May 94	-2.29	-1.80	-2.57	10.24	12.76	0.83
Sep 94	-0.92	0.11	-0.25	13.14	15.01	1.03
Feb 95	-8.98	-2.21	-6.28	-0.95	-0.76	-0.36
May 95	-2.64	-0.94	-2.06	3.16	7.05	4.10
P absorption coeff.						
Sep 93	0.76	0.88	0.80	0.88	0.96	0.88
Feb 94	0.50	0.50	0.59	0.86	0.87	0.67
May 94	0.76	0.84	1.00	0.94	0.94	0.80
Sep 94	0.83	0.86	0.82	0.91	0.99	0.82
Feb 95	0.62	0.63	0.56	0.79	0.80	0.78
May 95	0.88	0.83	0.73	0.86	0.90	0.88

Phosphorus requirements

Estimations of phosphorus requirements have been made in two ways in Table 10. As previously noted by Ternouth *et al.* (1996), their equation gives requirement estimates of about 60% of those of AFRC (1991) when absorption coefficients of 0.75 and 0.58 are used in their respective equations.

Observed P intakes met AFRC requirements on only 3 occasions and met Ternouth *et al.* requirements in only 9 of 36 cases, only in P-supplemented or moderate P groups. P balance in those cases was positive or nearly so, as it was in 4 other cases, including 2 in groups without P supplement. Other indicators of cow performance (and P status – see later) also suggest that P requirement was being met more often than these discrepancies between calculated requirements and observed balances imply.

Table 10. Estimated requirements for and observed intakes of phosphorus (g/day).

	V.Low P	Low P	Low P +N	Low P + P	Low P+NP	Moder. P
September 1993						
Ternouth *et al.*[1]	9.2	14.2	10.1	9.9	10.3	12.2
AFRC [2]	13.6	22.2	14.9	15.1	16.6	18.4
Observed intake	1.3	2.3	1.6	1.5	2.4	3.5
February 1994						
Ternouth *et al.*	10.8	11.8	12.2	17.6	15.5	17.8
AFRC	18.8	21.9	21.3	29.6	27.7	29.1
Observed	5.6	9.2	8.4	30.4	27.8	14.0
May 1994						
Ternouth *et al.*	6.0	9.0	12.2	15.8	17.8	13.0
AFRC	12.0	16.5	19.8	26.9	27.3	22.6
Observed	2.7	3.4	2.9	23.2	21.4	8.3
September 1994						
Ternouth *et al.*	9.5	10.7	15.3	10.9	16.3	10.8
AFRC	14.5	17.3	23.7	18.1	24.8	17.9
Observed	1.8	3.1	3.1	22.4	22.1	5.3
February 1995						
Ternouth *et al.*	17.5	15.3	29.3	24.1	19.2	17.4
AFRC	30.2	25.3	44.1	38.4	33.0	30.0
Observed	7.8	9.7	9.4	18.7	17.6	21.2
May 1995						
Ternouth *et al.*	13.2	6.3	14.4	14.8	9.8	8.2
AFRC	21.7	12.7	22.4	27.5	18.7	17.1
Observed	2.3	3.8	2.5	13.9	15.2	12.3

[1] P requirement (g/day) = (0.51 DMI + 0.0037 LW + GAIN + PREG + MILK) / 0.75
Ternouth *et al.* 1996.

[2] P requirement (g/day) = (1.6(0.693 DMI - 0.06) + GAIN + PREG + MILK) / 0.58
AFRC 1991.

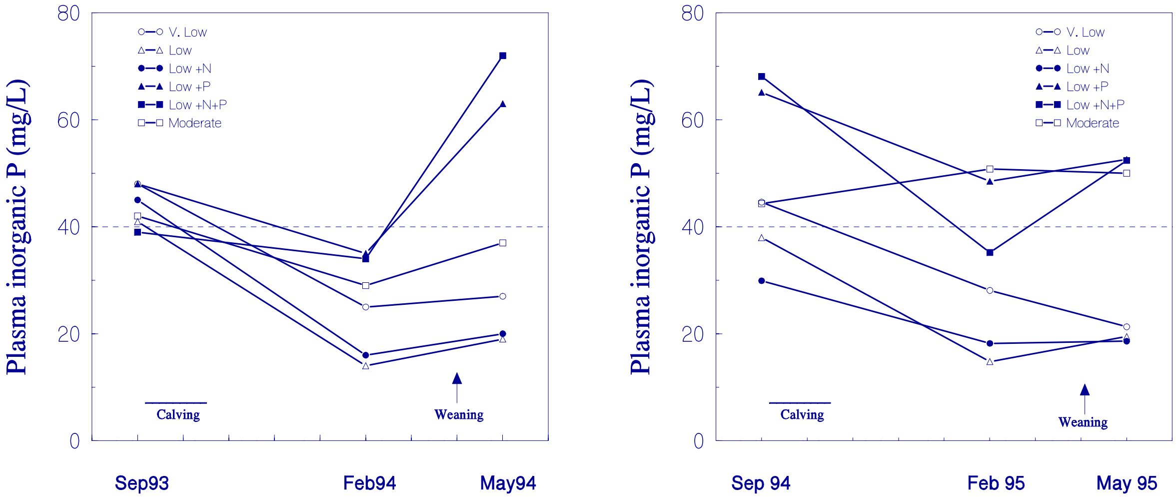
where DMI = dry matter intake in kg/day,
LW = liveweight in kg,
GAIN = LWG (1.2 + 4.635.$A^{0.22}$.$LW^{-0.22}$) where LWG = LW gain in kg/day, A=mature LW(960 kg)
PREG = 3.14 g/day (AFRC 1991)
MILK = observed P in milk.

Phosphorus diagnostics

Blood phosphorus

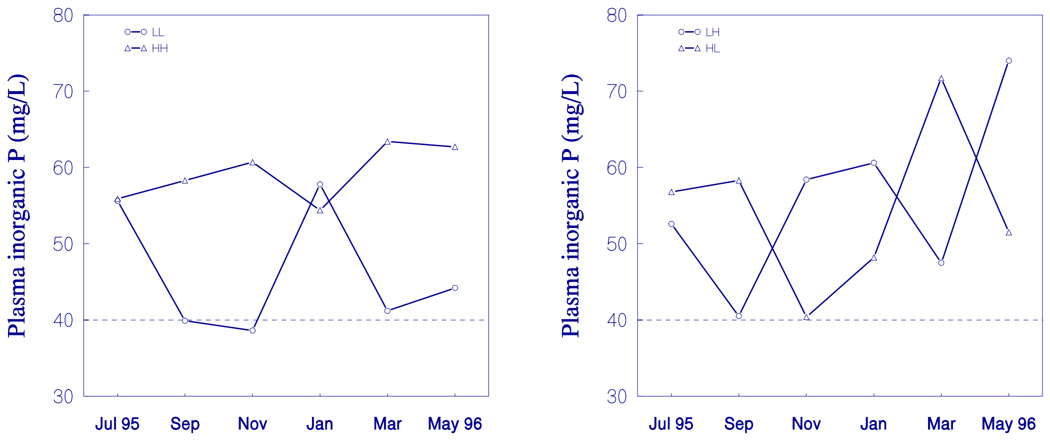
Plasma inorganic phosphorus levels in cows generally fell from mid-dry season to mid-wet season (Figure 6). Levels in unsupplemented groups then changed only marginally by late wet season, whereas in supplemented groups, levels tended to rise more sharply in late wet season. Using the conventional level of 40 mg/L as an indication of adequate status gives reasonably good agreement with P balance measurements, where only supplemented and moderate P cows had positive P balance.

Figure 6. Blood phosphorus concentrations in cows.



In heifers, seasonal fluctuation in plasma inorganic phosphorus (Figure 7) was much greater at low P (LL) than at moderate P (HH). Blood phosphorus responded rapidly to change of paddock (LH and HL) and can be considered a sensitive measure of P nutrition in heifers. As with cows, heifers with plasma inorganic phosphorus significantly above 40 mg/L also were in positive P balance.

Figure 7. Blood phosphorus concentrations in heifers.



Rib bone biopsy

Cortical bone thickness (CBT) was 3mm or greater in supplemented cows or cows on moderate P. Deficiency has usually been associated with CBT of less than 2 mm, with an indeterminate diagnosis for thicknesses between 2mm and 3 mm. Most measurements made on these cows suggest that unsupplemented cows on low or very low P were deficient for much of the time. We conclude, on the basis of very few measurements, that 12th rib CBT below 3mm in young cows indicates previous deficiency.

Table 11. Compact bone thickness (mm) of 12th rib.

	V. Low P	Low P	Low P +N	Low P + P	Low P+NP	Moder. P
June 1994	2.35	2.25	2.40	3.42	3.57	2.92
June 1995	2.00	2.81	2.68	3.50	3.58	3.99

Tail bone density

Results of tail-bone density measurements on 7 separate occasions gave inconsistent results. Only example measurements of tail bone density made with the single photon absorptio-meter (densitometer) are presented in Table 12.

	V. Low P	Low P	Low P +N	Low P + P	Low P+NP	Moder. P
May 1994	0.373	0.308	0.361	0.368	0.369	0.346
February 1995	0.273	0.233	0.270	0.312	0.284	0.309

The reasons for inconsistency were explored by David Coates in a study of resected tails from the 1993-94 cows. His conclusions were that:-

- Mineral density of the 9th coccygeal vertebra (the target of tail-bone densitometry) was not, however measured, a sensitive indicator of dietary P status or cow P status.
- *In vivo* estimates of bone mineral density were poorly related to estimates made on dissected tails.

Better results have been obtained by Coates at Lansdown and is the subject of a separate project.

Bone turnover estimates

Dynamic indices of bone accretion and resorption ought to provide sensitive estimates of current animal P status. The two most promising indices, as tested in heifers, are plasma osteocalcin (OC; accretion) and urinary deoxypyridinoline (DPD; resorption). Alone, OC seems to discriminate between low and moderate P heifer background whereas DPD does not (Table 12). When the two indices are combined as Net Bone Metabolism (OC/DPD), the combined index discriminates between cow P background in the dry season (22 *vs* 38) but not in the wet season (18.6 *vs* 18.2).

Table 12. Indicators of bone turnover.

Osteocalcin (ng/ml plasma)		Deoxypyridinoline (nM/nM creatinine)	
Low P	High P	Low P	High P
134.0	143.5	4.5	4.5
86.0	67.9	4.2	4.6
115.7	170.1	5.8	4.3
91.8	116.9	7.4	4.4
102.2	167.1	6.9	5.0
84.2	156.5	5.4	6.7
109.5	118.6	4.3	5.2
110.8	115.9	5.0	4.3
75.5	83.5	3.3	4.5
75.7	96.3	3.3	4.7
66.6	70.8	6.0	4.6
68.8	98.4	5.5	4.2
Paired t = -3.01 (P<0.05)		Paired t = 0.91 NS	

General Discussion

Treatment groups were exposed to a wide range of dietary phosphorus (and nitrogen) regimes, representative of the range that cows might be exposed to across northern Australia.

Effects of phosphorus deficiency

Cows in the low phosphorus groups never had their apparent dietary phosphorus needs met. The consequences of dietary deficiency in three-year-old cows were multiple and serious:

> Dietary phosphorus intake in the dry season (September) and the transition season (May) was sometimes below endogenous faecal excretion, the minimum level of excretion. In these circumstances, phosphorus balance must be negative and to continue functioning, a cow must withdraw phosphorus from bone. Indeed, these cows in low phosphorus situations were nearly always in negative phosphorus balance. In a young, growing cow, this is an untenable situation and if continued over a period longer than the twelve months cows spent on this experiment, will result in stunting, bone malformations and the like, to say nothing of infertility.
>
> Liveweight change of cows on low phosphorus averaged -120 kg in the dry season and around 60 kg in the wet season. For a growing cow, a net weight loss of 60 kg can only be recouped by shutting down reproduction for a year.
>
> As estimated by ovulation, cows on low phosphorus would not conceive in the twelve months following their first or second calf. Three-year-old, first-calf cows in any phosphorus regime showed ovulation only after March 30th, meaning that calving could not begin until January the following year, presenting further problems with late conceptions in their third pregnancy.
>
> Milk production and consequent calf growth were depressed by low phosphorus.

In four and five-year-old cows, none of the consequences of phosphorus deficiency were as serious as for young cows. Cow condition, ovulation, and milk production were all less affected than in younger cows.

Phosphorus supplement fed alone in the dry season accelerated liveweight loss in older cows as it has done in steers in several studies. It may be that younger, pregnant cows making skeletal growth had higher requirements for phosphorus than the older cows and therefore suffered no ill effects.

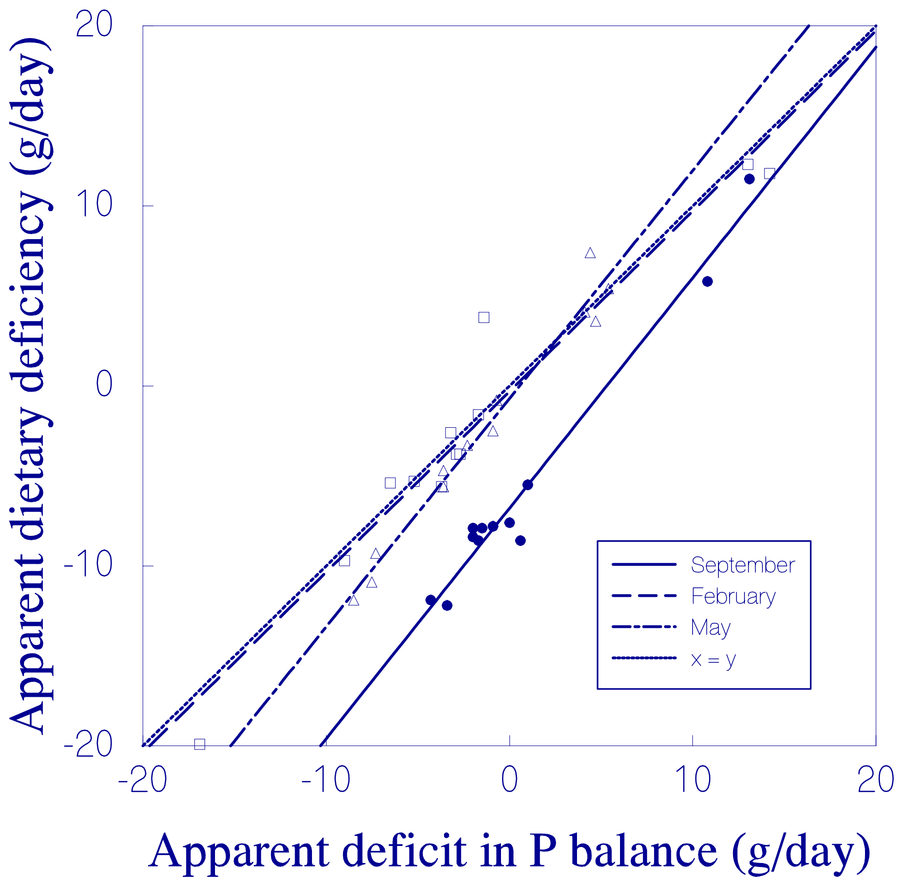
Phosphorus requirements

These results confirm the findings of Ternouth and Coates (1997) and Ternouth *et al.* (1996) that dietary phosphorus requirements of young cows in grazing situations are much lower than the most conservative estimates published in feeding tables.

For example, the cows on moderate phosphorus consumed half to two-thirds of AFRC (1991) requirements yet performed very well by northern Australian standards. One reason for this apparent efficiency is that the efficiency of absorption of dietary phosphorus under grazing in low phosphorus situations was very high (80-90%), except in lactation. Low (< 0.7) efficiency of phosphorus absorption in February was associated with treatment groups where plasma inorganic phosphorus was at or below 30 mg/L, a value below which efficiency of phosphorus absorption is depressed (Ternouth *et al.* 1996; Ternouth and Coates 1997).

In Figure 8, we have plotted the difference between observed phosphorus intake and Ternouth *et al.* requirements (apparent dietary deficiency) against the difference between observed phosphorus balance and P balance required for observed liveweight gain (apparent deficit in P balance.) These strong relationships lend strength to the methods we used to measure P fluxes and confirm the validity of requirements as calculated by Ternouth *et al.* (1996) and Ternouth and Coates (1997). The overestimation of dietary deficiency in September is probably due to mobilisation of body P during liveweight loss, for which no allowance is made in the requirement calculations.

Figure 8. Relationship between apparent dietary deficiency and apparent deficit in P balance.



The high efficiency of absorption of phosphorus by four and five-year-old cows in this project means that the lower phosphorus requirements now confirmed for younger cows are valid for cows of all ages.

Diagnosis of phosphorus deficiency

Plasma inorganic phosphorus was a sensitive indicator of dietary phosphorus supply when cows and heifers were growing or lactating. Different levels may be applicable to different cow classes. For breeding cows more than 3 years old, levels of 30 mg/L discriminated between sufficiency and deficiency and we have reports from elsewhere of plasma levels below 30 mg/L with satisfactory cow fertility. A level of 40 mg/L was more appropriate to three-year-old cows and a value of 50 mg/L was appropriate for growing heifers 6-18 months old. All these values assume a diet with at least moderate nitrogen content (faecal N > 1.5%) There is a suggestion in our data that under low dietary nitrogen conditions, blood phosphorus does not fall as low as where dietary nitrogen is higher. This supports the suggestion in McCosker and Winks (1994) that higher dietary nitrogen exacerbates phosphorus deficiency.

Extensive measurements of bone density brought disappointment in terms of developing new diagnostic indices, not because it measures only the net history of bone accretion and resorption without explaining the course of that history, but because neither is the tail bone a sensitive indicator of cow phosphorus status nor can its bone mineral density be measured accurately *in vivo.*

Bone turnover measurement is, conceptually, a sounder means of assessing phosphorus status than any previous method. It is a measure of the integration of phosphorus supply and demand dynamics and, unlike blood phosphorus, is relatively independent of other aspects of dietary and metabolic environment. Preliminary work with dynamic indices of bone accretion (osteocalcin) and bone resorption (deoxypyridinoline) give promise that the techniques are worth further development.

Success in meeting objectives

1. **To determine phosphorus requirements for breeding cattle grazing native pastures, by June 1996.**
   We have shown that previous preliminary estimates of phosphorus requirements for three-year-old first-calf heifers (Ternouth and Coates 1997) are valid for three, four and five-year-old Brahman cross cows grazing native tropical pastures with or without oversown legume. These are the first comprehensive results for breeding cows in the tropics.

2. **To develop, calibrate and refine diagnostic techniques for assessing dietary intake and body reserves (together defining status) of phosphorus and nitrogen in breeding cattle grazing native pasture, by June 1996.**

We have refined the concept of blood phosphorus as an indicator of phosphorus status to the extent of nominating the conditions under which it is valid and that the values are different for growing heifers, three-year-old cows and older cows. We have extensively tested and calibrated *in vivo* measurement of tail-bone mineral density and concluded it to be an unreliable indicator of phosphorus status. We have begun development of a dynamic system of assessing phosphorus status based on bone turnover.

3. **To validate these findings and calibrate them against herd productivity on a commercial scale, by June 1996.**
   We were unable to make any useful progress on this front. Seasons were unsuitable, cooperators vanished and our own personnel resources were fully stretched in coping with the main experiments.

4. **To demonstrate the benefits of phosphorus supplementation, according to the new model, as part of an improved management package, in situations of varying phosphorus deficiency, beginning by December 1995.**
   We made no progress in this area, although we had input into demonstrations organized by others in Western Australia, Northern Territory and Queensland.

5. **To integrate and promote findings in a way that enables producers and their advisers to make optimal decisions about supplementation, by June 1996.**
   We have continually, and in a whole property context, promoted our findings widely amongst producers, agribusiness and extension agencies. We have test-driven an integrated diagnostic flow chart with several audiences.

Impact on meat and livestock industry

We gauge that there has been a large uptake of phosphorus management systems in northern Australia. Much of this adoption has been as part of an overall herd management package stimulated by the use of whole-herd decision support systems in producer groups. This sort of activity has, for the first time, highlighted where gross inefficiencies were occurring in breeder herd management. Additional factors in this uptake have been tightening market specifications, a realization that phosphorus deficiency was perhaps the last major physical impediment to efficient beef production, and the availability of more tailored supplementation products. Fairly consistent publicity about this project must have helped in the process of adoption although there is no way of isolating the effect of individual factors.

In the future, impacts from this project could arise from more certain diagnosis of phosphorus status; tailoring phosphorus management to variations in season, class of cattle, and type of country; planned nutritional health monitoring.

Conclusions and recommendations

Phosphorus deficiency has dramatic effects on young cows in the form of poorer body condition, lowered milk yield, lighter calves and very low reproductive fertility. Much of the oft-reported appalling fertility of first-calf heifers in northern Australia could be due to phosphorus deficiency. To avoid growth being depressed, growing heifers require adequate dietary phosphorus at all times during liveweight gain. More mature cows had greater resilience in the face of inadequate phosphorus.

Concentrating phosphorus supplementation on young females would, on properties with adequate segregation, greatly reduce costs and effort compared to supplementing a larger fraction of the herd.

Recommendation

Growing heifers and first-calf cows should be targeted for aggressive and comprehensive phosphorus management.

Blood phosphorus is a useful diagnostic indicator of phosphorus deficiency when used with care. *In vivo* bone density is an unreliable assay of phosphorus status. Indicators of bone turnover are potentially very sensitive and reliable indicators of phosphorus status.

Recommendation:

Test blood P indicators for different cow classes

Recommendation:

Validate and develop bone turnover indicators, locating sources of variation and simplifying the assays.

Phosphorus requirements of grazing, breeding cows are quite modest by published standards. The indicative requirements published by Ternouth and Coates (1997) are valid for use in northern Australia in the pasture growing season. We still have no good estimates of dry season/pregnancy/out-of-season lactation requirements for cows.

Recommendation:

Publish an addendum to McCosker and Winks (1994) detailing new wet season P requirements and revised blood diagnostic levels. The requirements should estimate supplementation requirements for different pasture zones, taking account of P supplied from forage.

Recommendation:

Determine cow P requirements for dry season growth, pregnancy, and out-of-season lactation.

Recommendation:

Validate conclusions at a commercial scale, over longer time periods, and in a wider range of circumstances.

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Proposed publications arising from the project

Coates, D.B. *et al.* Sources of variation in rib-bone biopsy to assess phosphorus status of cattle .

Coates, D.B. *et al.* Tail-bone mineral density as a diagnosis of phosphorus status in cattle.

Miller, C.P. *et al*. Phosphorus management for young beef cattle in northern Australia.

Miller, C.P. *et al*. Stability in native pastures oversown with stylo and grazed leniently.

Ternouth, J.H. *et al.* Phosphorus dynamics in young breeding cattle grazing native pastures.

White, S.J. *et al*. Bone turnover as an assessment of phosphorus status in growing heifers.

Associated extension and publicity

1993	February	Poster at 17th International Grassland Congress, Rockhampton.
	July	Spoke at Dagworth Field Day, Georgetown.
	October	Spoke at Millungera Field Day.
1994	May	Spoke to DPI NQ Beef Industry Group, Wairuna.
	June	Spoke to several visiting producers, Springmount.
	October	Session at Meat Profit Day, Townsville.
	October	Release of Stylo and Phosphorus Video, “Meating the Market”, MPD.
	October	Spoke to DPI NQ Beef Industry Group.
	November	Spoke to Mt Aberdeen Field Day, Collinsville.
	December	Spoke to GLADA Meat Profit Seminar, Normanton.
1995	April	Spoke to Jap Ox Competition Field Day, Utchee Creek.
	May	Spoke to MSc students from James Cook University, Mareeba.
	June	Spoke to Koolatah Field Day, lower Mitchell River.
	June	Mounted poster display at Mareeba saleyards.
	June	Mounted poster display at FNQ Field Day, Lotus Glen.
	August	Spoke to Mt Sanford Field Day, Northern Territory.
	November	Mounted poster display at Kairi Production Feeding Field Day, Tolga.
1996	March	Participated in northern Australia Phosphorus Workshop, Mareeba.

	April	Spoke to NQ Beef Research Committee meeting, Cairns.
	July	Posters at Aust. Soc. of Anim. Prod. Biennial Conference, Brisbane.
1998	April	Poster display at Meat Profit Day, Emerald.

Several articles in “NAP news”.