Phosphorus and the grazing ruminant. 2. The effects of supplementary P on cattle at Glen and Armoedsvlakte

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The effects of supplementary P (phosphorus) on the performance of cattle at two distinctly different experimental sites: one notorious for its P-deficient pastures (Armoedsvlakte), the other (Glen) suspected of being deficient in P, were compared over 5,5 years. The acuteness of the deficiency differed vastly between the two sites. At Glen no differences were observed in either bodymass or reproductive performance between supplemented (+P) and unsupplemented (−P) cattle, whereas at Armoedsvlakte the cumulative mortality rate of −P cattle was twice that of +P (58,3 vs 27,3%). The −P group weighed on average 121 kg less and their reproductive performance was severely impaired. Calves of −P dams averaged 9,8% lighter at birth (34,0 vs 37,7 kg) and 21,6% lighter at weaning (181,8 vs 231,8 kg) than the +P group. Financial advantages of supplementation are discussed. Possibly the most serious effect of the deficiency is the depression of feed intake, especially during late lactation and early pregnancy: e.g. in 1979 the digestible organic matter intakes per day were 2 752 and 4 925 g for −P and +P cattle, respectively. No such differences were observed at Glen. The +P cattle at both sites satisfied their ME and crude protein needs. A P deficiency uncomplicated by a protein deficiency was identified in the pasture of Armoedsvlakte.
S. Afr. J. Anim. Sci. 1986, 16: 7 – 12

Die effek van aanvullende P (fosfor) op die prestasie van beeste is oor 5,5 jaar op twee proefpersele (Armoedsvlakte en Glen) ondersoek. Terwyl eersgenoemde wêreldbekend is vir sy P-gebrekkige weiding, word vermoed dat by Glen ook 'n P-tekort bestaan. Die twee proefpersele het egter grootliks verskil in die graad van die P-tekort soos aangetoon by beeste. Geen verskille in óf liggaamsmassa óf reproduksie is by Glen waargeneem nie. Die kumulatiewe mortaliteitsyfer van −P-beeste te Armoedsvlakte was dubbel die van die +P-groep (58,3 vs 27,3%); die −P-groep het ook gemiddeld 121 kg laer liggaamsmassas gehad en hul reproduktiewe vermoëns is ernstig benadeel. Die −P-kalwers was gemiddeld 9,8% ligter by geboorte (34,0 vs 37,7 kg) en het ook gemiddeld 21,6% ligter (181,8 vs 231,8 kg) as die +P-groep gespeen. Die finansiële voordele van aanvullende P word bespreek. Die mees nadelige effek van 'n P-tekort is waarskynlik die verlaagde voerinname wat veral gedurende laat-laktasie en vroeë-dragtigheid waargeneem is; in 1979 was die verteerbare organiese materiaalinname byvoorbeeld 2 752 en 4 925 g per dag onderskeidelik vir −P en +P-beeste by Armoedsvlakte. Weer eens is geen verskille ten opsigte van inname by Glen waargeneem nie. Die ME- en ruproteïeninnames van +P-beeste op beide proefpersele het aan hulle behoeftes voldoen. 'n P-tekort sonder 'n ruproteïentekort is dus in Armoedsvlakte se weiding geïdentifiseer.
S.-Afr. Tydskr. Veek. 1986, 16: 7 – 12

Keywords: Phosphorus, phosphorus deficiency, phosphorus supplementation, grazing cattle, bodymass, reproduction.

Extract from a M.Sc.(Agric) thesis submitted by the senior author to the University of Stellenbosch

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Received 15 January 1985

Introduction

Before providing the animal with any supplementary nutrients, it is necessary to identify those nutrients which may possibly limit animal production. South African natural pastures and especially the grassland areas (like those of the central Orange Free State, OFS) are considered low in phosphorus (P) for at least part of the year (Du Toit, Louw & Malan, 1940), and the dramatic improvements in animal production resulting from P supplementation of cattle at Armoedsvlakte (e.g. Theiler, Green & Du Toit, 1927) are legendary. Phosphorus was therefore suspected as being the first limiting nutrient at the two experimental sites (i.e. Glen, in the central OFS and Armoedsvlakte) where these trials were conducted. The critical test of such a limiting nutrient would, however, be an improved animal performance, following its supplementation. Murray, Graham, Round & Bond (1978) provided evidence that responses do not always occur. A major reason for this is likely to be the occurrence of multiple nutrient deficiencies: especially a combined inadequacy of P and protein and possibly energy (Little, 1970), although both the calcium, Ca (Cohen, 1973) and sulphur, S (Playne, 1969) contents of the pasture have also been implicated. Besides these co-existing deficiencies, the chemical form of the P supplement may also explain the lack of response (Poppi & Ternouth, 1979).

Accordingly, a comparison of the effects of supplementary P on the performance of cattle at these two sites was conducted to indicate whether the degree of deficiency differs between these sites and feed intake was determined to indicate whether deficiencies of protein and/or digestible energy also occurred.

Experimental procedures

Two experimental sites were used in this study. Glen, situated in the central OFS, approximately 22 km north-east of Bloemfontein, and Armoedsvlakte, in the Northern Cape, approximately 10 km west of Vryburg. Hand-cut pasture samples do not represent the diet selected by grazing ruminants at these two experimental sites (Read, 1984) and salivary contamination makes samples collected by oesophageally fistulated (OF) ruminants unsuitable for P analyses. Even following grazing animals and hand plucking samples of what they consumed may produce erroneous results (Langlands, 1974). Forage P levels were therefore not estimated in the present trials although previous work (Lombard, 1966) suggested that levels between 0,16 and 0,06% P may be encountered at Glen. The P levels at Armoedsvlakte may vary between 0,03 and 0,15%. These figures were found in hand-cut samples. The P levels in the soils of Glen and Armoedsvlakte are 1 – 2 ppm and 0 – 0,5 ppm, respectively. The 96 cattle used in these trials were Bonsmara type crossbred heifers, all bred and raised at the Vaalharts Research Station, where, until the start of the present trials (at approximately 18 months of age) they had had free access to a salt/dicalcium phosphate lick. The cattle were randomly allotted to the different treatment groups (Table 1) and the PR group at Glen, which received their supplemental P via rumen fistulae, were fitted with rumen cannulae according to Engels (personal communication).

Table 1 Description of the treatments at the two experimental sites

Treatment groups[a]		Description of treatment
Glen	Armoedsvlakte	
– P (16)	– P (24)	– P: access to salt (NaCl) lick only
+ P (16)	+ P (24)	+ P: access to lick consisting of 44% salt; 44% diCaP and 12% molasses powder[b]
PR (16)	–	PR: access to salt lick in addition to daily dose[c] of P via rumen fistula (12 g P during late pregnancy and lactation otherwise 8 g P)

[a]Numbers in group at start of trial given in parenthesis
[b]Kalori 3000, Kynoch Feeds (Reg No V2809; Act 36 1947)
[c]P given in the form of diCaP (dicalcium phosphate)

Besides the mineral licks, the cattle received no supplementary nutrients and were therefore entirely dependent on the natural pasture to satisfy their requirements. Over the experimental period (November 1977 – June 1983) mean stocking rates applied at Glen and Armoedsvlakte were 7,3 and 7,4 ha/LSU respectively. The cattle were weighed each month, feed and water not being withheld prior to weighing. The mating season extended from 15 January to 15 March at Glen and from 15 December to 28 February at Armoedsvlakte. All calves were weaned at 210 days of age. Feed intake was determined using the same method as described by Read, Engels & Smith (1984a) except that one gelatin capsule containing 10 g Cr_2O_3 was administered twice daily to the cattle and pasture organic matter digestibility was determined on samples collected by OF cattle.

Data were analysed as a split plot design with repeated measurements over years, this procedure being an approximation of more appropriate multivariate analyses (Winer, 1962).

Results and Discussion

Feed intake

The depression in feed intake resulting from a P deficiency has been well demonstrated (e.g. Theiler & Green, 1932; Little, 1968, 1980). This is once again illustrated in Table 2, by comparing the intakes of the – P group at Armoedsvlakte with those of their + P contemporaries, especially during late pregnancy/early lactation (P) when the two groups differed significantly ($P < 0,01$) each year, although during late lactation/early pregnancy (L) these differences were not always significant (i.e. during 1980 and 1982). This may have resulted from relatively poor pasture availability which coincided with this stage of the reproductive cycle. The very low conception rates of the – P group during the 1979/80 and 1981/82 calving seasons (Table 5) may, however, have biased the comparison, because the mean intake of the – P group, represented intakes of both lactating and dry cattle, whereas in the + P group all animals were lactating. Freer (1981) suggested that the capacity of the rumen is greater during lactation than even in the dry animal but there is still some uncertainty as to the rate of expansion after parturition and to changes in the rate of disappearance of digesta from the rumen, which would in turn affect feed intake.

Table 2 Digestible organic matter intake (g/day) of the cattle at both experimental sites

Year	Physiological status[a]	Glen: Treatment – P	Glen: Treatment + P	Glen: Treatment PR	Glen: Level of significance[b]	Armoedsvlakte: Treatment – P	Armoedsvlakte: Treatment + P	Armoedsvlakte: Level of significance[b]
1978	P	–	–	–	–	4 489	5 804	**
1979	L	7 674	6 789	6 490	NS	3 798	6 198	**
	P	–	–	–	–	2 752	4 925	**
1980	L	6 201	7 507	7 896	NS	3 587	3 859	NS
	P	4 727	4 836	4 905	NS	–	–	–
1981	L	7 081	7 481	7 562	NS	2 532	4 260	**
	P	4 335	4 699	4 489	NS	2 460	6 514	**
1982	L	7 736	8 142	7 463	NS	2 308	3 059	*
	P	4 696	3 373	4 060	NS	1 394	3 351	**

[a]P = late pregnancy/early lactation; L = late lactation/early pregnancy
[b]NS = non significant; *$P < 0,05$; **$P < 0,01$

The anorexia of the – P cattle may be related to decreased microbial digestion caused by poor availability of P for the rumen micro-organisms (Witt & Owens, 1983) although these authors were unable to demonstrate this and concluded that tissue stores of P may be mobilized before the digestibility of nutrients is reduced, and that this permits survival through short periods of deficiency. The prolonged deficiency of the – P cattle at Armoedsvlakte may have affected microbial digestion. Besides these intraruminal effects, the stiff-legged gait, which is one of the characteristic symptoms of aphosphorosis, severely impaired locomotion and therefore grazing behaviour and probably feed intake.

Contrary to the situation at Armoedsvlakte, P supplementation at Glen had no significant effect on digestible organic matter intake (DOMI, Table 2) within a specific physiological condition. Considering that Little (1968) observed a significant linear response in the intake of P-deficient cattle when given graded supplements of P to an otherwise adequate diet, the DOMI of the PR group might have been expected to be higher than that of the + P group and both these supplemented groups higher than the – P. As this was not the case, it might be inferred that the natural pasture at Glen provided sufficient P to prevent a depression in feed intake. Although in the case of a 'latent' P deficiency neither intake nor the digestibility of crude nutrients may be affected (Fix, 1977).

As was the case with DOMI, there were no differences between the crude protein intakes (CPI) of the three groups of cattle at Glen (Table 3), whereas at Armoedsvlakte there was a tendency for smaller differences between groups in CPI than occurred with DOMI (Tables 2 and 3). This may be explained by a tendency of the – P cattle to select a diet higher in CP (Read, 1984), a phenomenon also observed by Little (1975) who concluded that supplementation tended to make cattle graze less selectively.

By assuming that 1 g DOM is equivalent to 16,0 kJ ME (Engels & Malan, 1975) the observed intakes may be compared with tabulated values (NRC, 1976). Except during 1982

Table 3 Crude protein intake (g/day) of the cattle at both experimental sites

		Experimental site						
		Glen				Armoedsvlakte		
	Physiological	Treatment			Level of significance[b]	Treatment		Level of significance[b]
Year	status[a]	−P	+P	PR		−P	+P	
1978	P	–	–	–	–	618	725	NS
1979	L	769	601	574	NS	479	759	*
	P	–	–	–	–	478	685	*
1980	L	1 266	1 439	1 513	NS	537	632	NS
	P	622	654	641	NS	–	–	–
1981	L	975	1 030	1 041	NS	353	546	NS
	P	419	454	434	NS	435	919	**
1982	L	734	773	709	NS	409	689	*
	P	633	455	548	NS	377	797	**

[a]P = late pregnancy/early lactation; L = late lactation/early pregnancy
[b]NS = non significant; *$P < 0{,}05$; **$P < 0{,}01$

when the grazing at Armoedsvlakte was not very plentiful, and during early lactation of 1979, the +P cattle at both experimental sites consumed more and at Glen even twice their requirements for DOM. The +P cattle also appear to have satisfied their protein requirements according to NRC (1976) standards.

Bodymass and viability

The insertion of rumen cannulae (during the last half of March 1978) may have placed the PR group at a disadvantage during 1978, although they seem to have recovered towards the beginning of 1979. The three groups (at Glen) differed slightly during 1982 but for the remainder of the trial the mean bodymass of all three groups were essentially similar (Figure 1).

There were very considerable differences in bodymass of the +P and −P groups at Armoedsvlakte (Figure 2). From 1979 onwards, the −P group was, on average, 121 kg lighter, although both groups followed the same pattern in monthly bodymass changes, due to their being exposed to the same set of environmental conditions.

In complete contrast to Glen, not only were there consider-

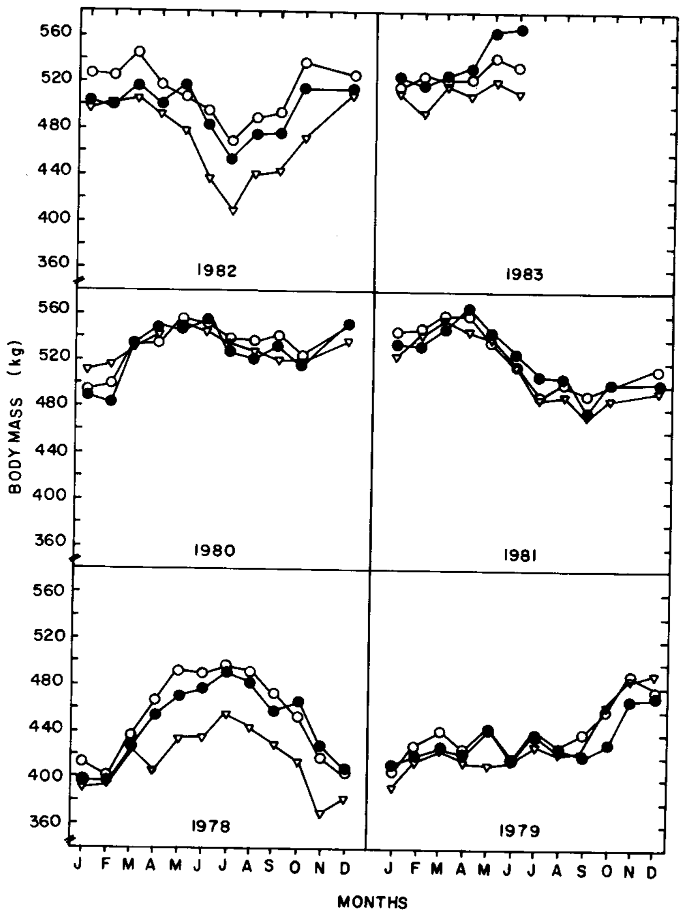

Figure 1 Effect of phosphorus supplementation on bodymass of cattle at Glen from 1978 to 1983 (○, +P group; ●, −P group; ▽, PR group receiving P supplement via rumen cannula)

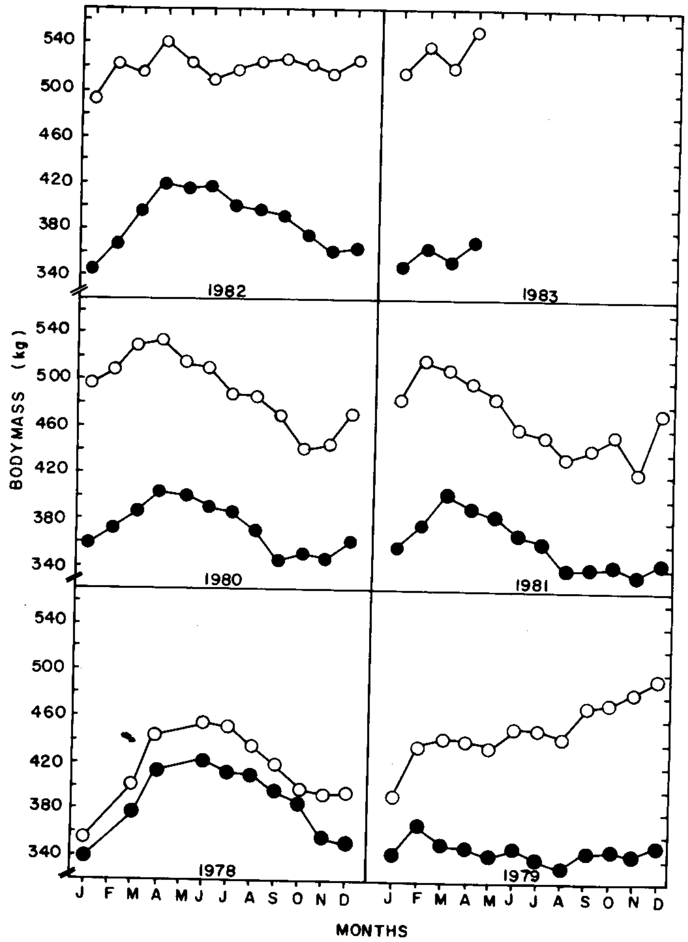

Figure 2 Effect of phosphorus supplementation on bodymass of cattle at Armoedsvlakte from 1978 to 1983 (○, +P group; ●, −P group)

Table 4 Mortality rate (%) of the cattle at Armoedsvlakte

	per year[a]		cumulative[b]	
Year	+P	−P	+P	−P
1978	0,0	0,0	0,0	0,0
1979	4,5	8,3	4,5	8,3
1980	9,5	13,6	13,6	20,8
1981	5,3	15,8	18,2	33,3
1982	11,1	18,8	27,3	45,8
1983[c]	0,0	23,1	27,3	58,3

[a]Calculated as number in group during January/number in group during December × 100
[b]Calculated as number in group during December/number in group at start of trial × 100
[c]1983: includes data only up to April

able differences in bodymass of the +P and −P groups, but also in their viability, as shown by the high cumulative mortality rate of the −P group, which was twice that of the +P cattle (58,3 vs 27,3%, Table 4). The mortality rate per year increased at an increasing rate in the −P group, indicating a more rapid deterioration in the condition of the cattle with increasing age and by a prolonged deprivation of P. Death occurred more sporadically in the +P group. Similar observations have also been reported by Du Toit & Bisschop (1929) and Holmes (1981), whereas Theiler, Green & Du Toit (1927) concluded that '. . . cattle would *die out* on this pasture [Armoedsvlakte] unless rationed with phosphorus compounds . . .'

Reproduction

A depression in reproductive ability is one of the most striking results of a P deficiency (Hemingway, 1967). However, at Glen, there were no consistent responses to P supplementation (Tables 5 and 6). The observed differences were probably due rather to a 'bull effect', as, except for 1981, two different breeds of bulls (two Simmentaler and one Africaner) were rotated between the three groups of cattle. No explanation could be found for the low rates observed at Glen during 1979/80. In contrast the two groups at Armoedsvlakte differed vastly in reproductive ability from the second calving season (1979/80) onwards. The response during 1979/80 and 1981/82

Table 5 Reproductive performance of the cattle at both experimental sites

		Calving season				
Measurement	Treatment	1978/79	1979/80	1980/81	1981/82	1982/83
Glen						
Conception rate (%)	−P	87,5	53,3	86,7	93,3	66,7
	+P	93,8	73,3	93,3	86,7	92,9
	PR	93,8	50,0	92,9	100,0	85,7
Calving percentage[a]	−P	87,5	53,3	86,7	93,3	66,7
	+P	93,8	73,3	93,3	86,7	92,9
	PR	93,8	50,0	92,9	107,1	85,7
Weaning percentage[b]	−P	87,5	53,3	80,0	86,7	66,7
	+P	93,8	66,7	93,3	73,3	92,9
	PR	87,5	50,0	92,9	100,0	78,6
Armoedsvlakte						
Conception rate (%)	−P	83,3	29,2	54,5	26,3	62,5
	+P	83,3	70,8	90,5	78,9	72,2
Calving percentage[a]	−P	83,3	29,2	54,5	26,3	62,5
	+P	83,3	70,8	90,5	78,9	72,2
Weaning percentage[b]	−P	79,2	25,0	50,0	21,1	62,5
	+P	70,8	70,8	85,7	63,2	72,2

[a]Calculated as number of calves born/number of cows mated × 100
[b]Calculated as number of calves weaned/number of cows mated × 100

Table 6 Performance of calves at both experimental sites

		Calving season				
Measurement	Treatment	1978/79	1979/80	1980/81	1981/82	1982/83
Glen						
Birth mass (kg)	−P	32,2	36,2	38,9	41,4	36,0
	+P	33,4	36,0	40,5	37,9	35,9
	PR	33,7	37,0	40,6	38,9	33,6
Weaning mass[a]	−P	198	238	233	234	207
(kg)	+P	218	284	246	233	222
	PR	205	250	252	239	205
ADG[b] (g)	−P	789	967	924	923	864
	+P	880	1 178	977	929	887
	PR	817	1 011	1 004	947	816
Armoedsvlakte						
Birth mass (kg)	−P	31,7	32,7	33,4	36,2	36,0
	+P	33,8	38,4	38,0	39,3	38,9
Difference (%)		6,2	14,8	12,1	7,9	7,5
Weaning mass[a]	−P	168	205	186	168	182
(kg)	+P	192	242	245	243	237
Difference (%)		12,5	15,3	24,1	30,9	23,2
ADG[b] (g)	−P	651	830	722	643	694
	+P	755	969	982	971	943
Difference (%)		13,8	14,3	26,5	33,8	26,4

[a]Corrected for 210 days of age; [b]ADG = average daily gain from birth to weaning

seasons being even greater than the doubling of young stock cited in Theiler & Green (1932). That '. . . one or more barren years are required to build up skeletal reserves before pregnancy again ensues' (Du Toit & Bisschop, 1929) is also demonstrated by the biennially low conception rate of the –P cows (Table 5).

Despite this relatively strong evidence for impaired reproduction in P-deficient cattle Theiler, Du Toit & Malan (1937) found no abnormalities of the reproductive tract or ovulation in heifers deficient in P. Cohen (1975) suggested that a P deficiency *per se* may not affect reproduction whereas McDonald (1968) thought it wiser to '. . . consider the failure of reproduction as one aspect only of a general cellular deprivation of P'.

Even the birth mass (Table 6) of calves from –P cattle was lower by, on average, 9,8% (34,0 vs 37,7 kg). This agrees with the results of Bisschop (1964) although the contrary has also been reported (Du Toit & Bisschop, 1929). The inconsistency is most likely explained by the condition of the dam as she would sacrifice herself for the calf *in utero*. The +P group weaned on average 27,5% heavier calves (231,8 vs 181,8 kg) which is in good agreement with the 23,6% increase reported by Bisschop (1964) and 23,3% of Lebdosoekojo, Ammerman, Raun, Gomez & Little (1980). This probably resulted from the higher milk yields of the supplemented dams whilst the –P cattle were unable to provide even adequate quantities of milk for their calves. However, the P content of milk samples of the –P group differed only very slightly from those of the +P group (Table 7) as was previously observed (Theiler, *et al.*, 1927; Bisschop, 1964). Not unexpectedly, the P content of milk samples from the three groups at Glen, did not seem to differ. These results therefore confirm the conclusion of Theiler, *et al.* (1927) that even in acute cases, a P deficiency may not necessarily be reflected in the composition of the milk although it may limit milk yield.

Table 7 The P and Ca content of the milk of the unsupplemented (–P) and supplemented (+P, PR) cattle at the two experimental sites

		Experimental site			
		Glen		Armoedsvlakte	
Date	Treatment	P (%)	Ca (%)	P (%)	Ca (%)
Feb 1981	–P	0,093	0,119	–	–
	+P	0,109	0,138	–	–
	PR	0,113	0,139		
Apr/May 1981	–P	0,093	0,123	0,081	0,129
	+P	0,097	0,123	0,100	0,140
	PR	0,099	0,122		
Feb 1982	–P	0,086	0,111	–	–
	+P	0,085	0,112	–	–
	PR	0,085	0,109		
Jan/Feb 1983	–P	0,096	0,119	0,096	0,116
	+P	0,096	0,126	0,103	0,134
	PR	0,094	0,117		
Apr 1983	–P	0,097	0,121	0,092	0,128
	+P	0,100	0,128	0,109	0,129
	PR	0,095	0,124		

Table 8 summarizes the effects of supplementary P on animal performance at Armoedsvlakte and illustrates the financial advantage of supplementation.

Conclusions

The consequences of a severe P deficiency were once again typified in this study by the performance of the –P cattle

Table 8 Summary of supplementary P intake of the cattle at Armoedsvlakte, its effects on reproduction and the economics of supplementation

		Calving season				
Measurement	Treatment	1978/79	1979/80	1980/81	1981/82	1982/83
Number of calves weaned	–P	19 (24)	6 (24)	11 (22)	4 (19)	10 (16)
(and cows in group)	+P	17 (24)	17 (24)	18 (21)	12 (21)	13 (18)
Average weaning	–P	168	205	186	168	182
mass (kg)	+P	192	242	245	243	237
Mass of weaners (kg)	–P	3 192	1 230	2 046	672	1 820
	+P	3 264	4 114	4 410	2 916	3 081
Value of weaners[a] (R)	–P	3 830	1 476	2 455	806	2 184
	+P	3 917	4 937	5 292	3 499	3 697
Marginal income due	–P	0	0	0	0	0
to supplementation (R)	+P	87	3 461	2 837	2 693	1 513
Supplementary diCaP	–P	0	0	0	0	0
lick consumed (kg)	+P	411	648	464	477	343
Marginal cost of supple-	–P	0	0	0	0	0
ment[b] (diCaP) (R)	+P	154	243	175	179	129
Marginal income above	–P	0	0	0	0	0
marginal cost[c] (R)	+P	–67	3 218	2 662	2 514	1 384
Return on investment	–P	0	0	0	0	0
in supplementation[d] (%)	+P	–43	1 324	1 521	1 073	1 073

[a]Determined by assuming a value of R1,20/kg livemass
[b]Determined by assuming a price of R0,37/kg diCaP (dicalcium phosphate)
[c]Determined as: marginal income due to supplement minus marginal cost of supplement
[d]Determined as: marginal income above marginal cost/marginal cost of supplement × 100

at Armoedsvlakte. Possibly the most serious of these was the depressed feed intake, resulting in stunted growth, high mortality rates and very poor reproductive performance. At Glen, however, no advantage was realized in any aspect of animal performance of supplemented vs unsupplemented cattle, but before ruling out the possibility of a sub-clinical deficiency at this site, it may be advisable to monitor more sensitive indicators, e.g. bone, blood and faeces of the P status than animal performance as described in part 3 of this series (Read, Engels & Smith, 1984b). The degree of deficiency experienced by the cattle therefore differed markedly between the two experimental sites.

In contrast to various reports, the supplemented cattle at both sites appeared to satisfy their requirements for both crude protein and ME. This implies the occurrence of an uncomplicated P deficiency at Armoedsvlakte and supports Cohen's (1972) postulate that a possible mechanism for a response to P supplementation may be mediated through its stimulating effect on feed intake provided that the diet contains adequate protein.

Acknowledgements

The authors are indebted to Messrs A. Malan and J.A. Vermeulen for care and management of the experimental animals, D. Els and Miss M. Baard for statistical analysis of the data and to Miss H. de Bruyn for skilled laboratory assistance.

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