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Phosphorus supplementation of range cows in the Northern Great Plains

JAMES F. KARN

Author is a research animal scientist, USDA-Agricultural Research Service, Northern Great Plains Research Laboratory, P.O. Box 459, Mandan, N.D. 58554.

Abstract

Low phosphorus (P) levels in Northern Great Plains rangeland forage combined with limited data on the P requirements of range cows (*Bos taurus*), precipitated 2 studies conducted to compare the performance of P supplemented and no P supplemented (control) beef cows. Phosphorus supplementation levels ranged from 4 to 8 g day^{-1} depending on estimated P needs at different times of the year. The 2 groups of cows previously had been involved in replacement heifer growing studies, with P treatments established 462 and 402 days, respectively, before initiation of these studies. Winter feed consisted of mixed hay, primarily smooth bromegrass (*Bromus inermis* Leyss.), with corn silage (*Zea mays* L.) fed only in 1982 and 1983 from calving to the time cows were turned on summer pasture. Summer pastures contained primarily western wheatgrass [*Pascopyrum smithii* (Rydb.) A. Löve], needleandthread (*Stipa comata* Trin. and Rupr.), green needlegrass (*S. viridula* Trin.), blue grama [*Bouteloua Gracilis* (H.B.K.) Griffiths] and upland sedges (*Carex* spp.). The P status of cows used in these studies appeared to be estimated more reliably by forage P than by serum or fecal P. According to P levels in hay and pasture, the diets of control cows were below recommended P levels for about 9 months of the year. However, weight change differences between P supplemented and control cows during the first lactation and gestation periods were gradually lost by the end of the studies. Conception rates of control cows were slightly lower ($P<0.08$) in the first but not the second study. There were no differences in average calving date or calf birth weights, but P supplementation did increase ($P<0.01$) calf weaning weights. Cow weight changes, calf weaning weight differences, forage and serum P data, and in the first study conception rate differences indicate that Northern Great Plains forages are marginal to deficient in P for optimal production of beef cows. The most consistent benefit from P supplementation was an increase in calf weaning weights. Data also indicate that energy supplementation for 30 days after calving may increase conception rates.

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Forages grown on Northern Great Plains rangelands are often low in phosphorus (P) (Sarvis 1941) compared to NRC (1984) recommendations. However, Karn (1992) reported that range cows offered ad libitum access to P in a mixture with salt showed no benefit from the practice over 3 grazing seasons, probably due to low and variable P intakes. In subsequent research with growing heifers, Karn (1995) obtained P intake levels of 4–6 g day^{-1} using ground oats and dried molasses to stimulate consumption. However, heifer weight gains were not consistently affected; in 1984 P supplementation of Hereford-Simmental heifers increased weight gains, but in 1981 weight gains of Hereford and Hereford-Angus crossbred heifers were not affected. In other research, Call et al. (1978) reported no response to P supplementation of grazing cattle in Utah and Judkins et al. (1985) reported that supplementation of grazing cows in New Mexico was beneficial only during a drought. Read and Engels (1986a) reported that P suplementation at one location in South Africa dramatically improved cow and calf weight gains and reproductive performance, while reducing mortality, but at another location only weaning weights were improved. Fishwick et al. (1977) reported that 12 g P daily was inadequate for beef cows, but in a subsequent study this group reported that 10–12 g P daily was adequate to maintain normal blood P concentration, voluntary intake and digestibility (Bass et al. 1981).

Blood P is often used to estimate P status, but Read and Engels (1986b) indicated that unless plasma P was below 20 mg liter^{-1} it was insensitive to changes in dietary P. Diet P itself, is difficult to determine for grazing animals because extrusa samples are affected by salivary P (Langlands 1966), and it is difficult to clip samples as selectively as animals graze (Langlands 1974). Thus, Holechek et al. (1985) used fecal P to predict dietary P levels in range cattle. In short-term feeding trials, Sanson et al. (1990) reported an r^2 of 0.78 between P intake and fecal P, but cautioned that the usefulness of this relationship may be limited by differences in the availability of dietary P.

Phosphorus supplementation is recommended for grazing cattle in the Northern Great Plains, but documented benefits are lacking. Thus, the objectives of this research were to determine the effect of P supplementation on the performance of range cows and to compare diet, serum, and fecal P as methods of determining the P status of grazing cattle.

Materials and Methods

Phosphorus supplementation studies with young beef cows, just before their first parturition, were initiated on 19 February 1982 and 1 March 1985 and continued until 4 November 1983 and 26 October 1987, respectively. Fifty-three Hereford and Hereford-Angus crossbred cows were used in the first study and 55 Hereford-Simmental cows were used in the second study. Twenty-six cows in the first study and 28 in the second were assigned to receive supplemental P and 27 cows in each group were maintained as controls and received no supplemental P. These cows had previously been used in replacement heifer growing studies (Karn 1995) and were continued on the same P treatments. Thus P supplemented cows in the current studies had already been receiving 4–6 g P day^{-1} for 462 and 402 days, respectively when these studies were initiated. Average initial cow weights were 407 kg in the first study and 470 kg in the second study.

Supplementation

Cows were supplemented by treatment group and fed in a bunk. Monosodium phosphate was used as the supplemental P source and ground oats and dried molasses were used as a carrier to aid mineral consumption. Supplements for P supplemented and control cows, and the periods they were used are shown in Table 1. Control cows received only the carrier used with the P supplement. In 1982, before calving, both treatment groups were maintained together, except when supplemented, but after calving they were maintained in separate groups until they were turned on summer pasture. During the summer of 1982, and for all subsequent time periods in both studies, cows were maintained together at all times except when they were corralled, separated by treatment group, and supplemented. Cows had previously been trained to go into 2 separate pens at feeding; training was facilitated by using either a mild electric shock as a negative reinforcement or supplement as a positive reinforcement (Karn and Lorenz 1984). This separation procedure facilitated relatively rapid supplementation, resulting in minimum disturbance to normal cow grazing patterns, even when calves were at side. Generally, cows were penned only 45–60 minutes for feeding. Supplements were fed on Monday, Wednesday, and Friday from 19 February to 31 May 1982; for the remainder of the 1982 study and for all of the 1985 study, cows were fed only on Monday and Friday when they received 4 and 3-day portions of supplement, respectively.

Table 1. Supplements and the periods they were fed to phosphorus (P) supplemented and no P supplemented (control) range cows during studies beginning in 1982 and 1985 and ending in 1983 and 1987[1].

Period		P		Control	
	P	Ground oats	Dried molasses	Ground oats	Dried molasses
	---- (g day^{-1}) ----			-- (g day^{-1}) --	
1982					
19 Feb. 1982–12 Mar. 1982	6	28.5	28.5	28.5	28.5
12 Mar. 1982–15 Nov. 1982	8	57.0	28.5	57.0	28.5
15 Nov. 1982–11 Mar. 1983	4	28.5	28.5	28.5	28.5
11 Mar. 1983– 4 Nov. 1983	8	57.0	28.5	57.0	28.5
1985					
1 Mar. 1985–15 Mar. 1985	6	28.5	28.5	28.5	28.5
15 Mar. 1985–12 Nov. 1985	8	57.0	28.5	57.0	28.5
12 Nov. 1985–17 Mar. 1986	4	28.5	28.5	28.5	28.5
17 Mar. 1986– 7 Nov. 1986	8	57.0	28.5	57.0	28.5
7 Nov. 1986–16 Mar. 1987	4	28.5	28.5	28.5	28.5
16 Mar. 1987–26 Oct. 1987	8	57.0	28.5	57.0	28.5

[1]Supplement amounts are daily averages for supplements fed at 2, 3 or 4 day intervals.

In 1986 and 1987 in addition to their normal treatment supplements, every other cow to calve on both the P supplemented and control treatments, respectively, received supplemental oats fed Monday through Friday at the rate of 1.8 kg day^{-1} from the day after calving until 27 May in 1986 and 29 May in 1987. Supplemental oats were fed for an average of 30 days in 1986 and 32 days in 1987. The oats contained 125 g kg^{-1} crude protein and 3.5 g kg^{-1} P. Cows were bunk fed supplemental oats in the same pens where they were normally supplemented. Cows not receiving supplemental oats received only their previously described supplements (Table 1).

Management and Sampling

During the winter, mixed hay which was primarily smooth bromegrass (*Bromus inermis* Leyss.) was fed free choice. Cows received corn silage (*Zea mays* L.) at about 8 kg day^{-1} for approximately 90 days after calving in 1982 and 1983 only. From the time cows began to calve in April until they were turned on summer pasture, for all years except 1983, they were maintained in small calving pastures with access to harvested feeds and some grass. In 1983 cows were confined to a drylot during this period and fed only harvested feeds. Vitamin A was provided during the winter, at the rate of 20,000 IU per day, via a vitamin A, D, and E premix fed with treatment supplements.

During the summer, cows were rotated between adjoining 92 and 99 ha native pastures containing primarily western wheatgrass [*Pascopyrum smithii* (Rydb.), A. Löve], needleandthread (*Stipa comata* Trin. and Rupr.), green needlegrass (*S. viridula* Trin.), blue grama [*Bouteloua gracilis* (H.B.K.) Griffiths], and upland sedges (*Carex* spp.). These pastures have been described in more detail by Karn (1992). Trace mineralized salt containing 96-98.5% salt, 0.35% zinc, 0.34% iron, 0.20% manganese, 0.033% copper, 0.007% iodine, and 0.005% cobalt (Akzo Salt, Inc., Clarks Summit, Penn.) was available at all times.

Hereford and Hereford-Angus crossbred cows used in the first study were mated to Tarentaise bulls in 1982 and 1983, while Hereford-Simmental crossbred cows used in the second study were mated to Angus bulls in 1985 and to Simmental bulls in 1986 and 1987. Two bulls were used each year over a 60-day breeding season. Pregnancy was determined by rectal palpation following weaning in 1983 and 1987.

Cows were weighed following an overnight stand without feed or water at the beginning and end of each study, at monthly intervals during each summer grazing season and just before each calving period. Summer grazing seasons were from 2 June to 10 November 1982, 23 May to 4 November 1983, 3 June to 6 November 1985, 2 June to 30 October 1986, and 1 June to 26 October 1987. Calves were weighed at birth, at monthly intervals during the summer and when they were weaned at the end of the summer grazing season. Calves were allowed to remain with their mothers until just before being weighed.

Milk production was estimated over 24 hours by the weigh-suckle-weigh technique described by Neville (1962) using a morning and evening nursing cycle on 22 August and 6 October 1983, 16 July 1985, and 31 July 1986. In 1987 one nursing cycle following a 13 hour separation period on 8 October was used to estimate 24 hour milk production (Williams et al. 1979). Milk samples were collected for mineral analysis by hand milking on 4 November 1983. This was facilitated by injecting 2 ml of oxytocin into the tail vein just before milking.

Blood samples were collected from the jugular vein of each cow on 10 June and 5 November 1982; 23 May and 28 October 1983; 31 May and 25 October 1985; 31 March, 11 June and 23 October 1986; and 6 March, 1 June and 26 October 1987. Serum was removed from samples by centrifugation, frozen and stored for approximately 6 months before analysis.

Extrusa samples were collected from pastures every 2 weeks during each grazing season with 3 mature esophageally fistulated steers. Steers were allowed to graze until collection bags were full, which usually occurred within 30 minutes. Fistulated steers were penned off feed over night before each sampling date; this procedure did not appear to affect grazing selectivity. Individual steer collections were mixed, subsampled, frozen, and freeze dried for nitrogen (N) and in vitro digestible organic matter (IVDOM) analyses. Extrusa subsamples for mineral analyses were squeezed to remove saliva (Hoehne et al. 1967) and dried in a forced air oven at 50°C.

Fecal samples were obtained in 1986 and 1987 from 2 randomly determined subgroups of cows within each of the P supplemented and control groups. At least 6 cows within each subgroup were sampled at each collection period and an attempt was made to sample the same cows each time. Collections were made on alternate weeks, the day after extrusa forage samples were taken. Samples were obtained immediately after defecation and composited over cows within each subgroup, providing 2 fecal samples for the P supplemented group and 2 samples for the control group. Samples were frozen and freeze dried. Winter feed, extrusa, and fecal samples were ground to pass a 1 mm screen before being analyzed.

Chemical and Statistical Analyses

Phosphorus and N in extrusa, hay, and corn silage and P in serum, milk, and feces were determined with a Technicon Autoanalyzer (Technicon Industrial Systems, Tarrytown, N. Y. 10591). Atomic absorption was used to determine Ca, Mg, and K in extrusa and fecal samples, Ca and Mg in serum and milk and Ca in hay and corn silage. In vitro digestible organic matter was determined by the procedure of Moore and Mott (1974).

Cow weights, calf birth dates, and milk production were analyzed according to a completely randomized design. Fecal data were analyzed as a randomized complete block and treatment was tested with the treatment × date interaction term. Conception rate data were analyzed for each study separately and over both studies using chi-square analysis. Calf weaning weights were analyzed by GLM covariance procedures (SAS 1985), by year and over all 5 years, using birth date to correct for differences in calf age and least squares means to adjust for unequal animal numbers. When calf weaning weight data for the 2 studies were combined the following model was used: treatment, study, treatment × study, calves (treatment × study), calf sex, treatment × calf sex, year (study), and treatment × year(study). The treatment × study term was not significant, therefore it was eliminated from the model. The treatment and study terms were tested using calves (treatment × study) as the error term. It was assumed there was no method of supplementation interaction, therefore animals were considered as experimental units. Serum data were analyzed by covariance, using element levels determined when treatments were first established with these animals in replacement heifer studies (Karn 1995), in order to correct for initial element differences among animals. Treatment differences were considered significant at the 5% probability level unless otherwise indicated.

Results and Discussion

Hay fed during calving and lactation periods in the winter of 1982 had the highest P level of any hay used during these studies (Table 2). Corn silage fed after calving in the first study also had a relatively high level of P, compared to the range of 2.2 to 2.7 g kg^{-1} recommended by the NRC (1984) for cows with average and superior milk production, respectively. Hays used in 1985, 1986 and 1987 had P levels that were well below the NRC (1984) recommendation (2.1 g kg^{-1}) for dry pregnant cows during the last third of gestation.

Table 2. Mean (± SD) phosphorus (P), calcium (Ca), crude protein (CP), and in vitro digestible organic matter (IVDOM) of hay and corn silage fed to P supplemented and control cows in studies beginning in 1982 and 1985.

Feed	Year	P	Ca	CP	IVDOM
		(g kg^{-1} dry matter)			($g kg^{-1}$)
			1982		
Hay	1982	1.89±0.56	5.10±1.56	—	—
Corn Silage	1982	2.28±0.15	2.31±0.29	—	—
Hay	1983	1.16±0.24	4.44±1.27	—	—
Corn Silage	1983	2.11±0.16	4.45±0.51	—	—
			1985		
Hay	1985	1.25±0.24	7.11±1.70	104±27	688±39
Hay	1986	1.19±0.36	7.43±3.04	104±38	582±24
Hay	1987	1.42±0.32	11.40±4.08	108±27	549±38

Extrusa P levels, averaged over years by month for the first study (1982-1983), were adequate (NRC 1984) for lactating cows, based on percent P in the extrusa, only in June. However during other summer months, especially in 1983, it is possible that even with low forage P levels (Table 3) cows could have consumed more P than expected through increased forage consumption. Extrusa P data for the second study (1985–1987) suggest that average monthly P levels may have been slightly higher than in the first study, but for much of the time based on percent P in the extrusa, levels were still marginal to deficient for lactating cows. Magnesium levels in the extrusa were below 2.0 g kg^{-1}, which is the level suggested by Underwood (1966) as necessary to prevent grass tetany, for all monthly averages except July 1982-1983. However, there were no instances of grass tetany. Mean extrusa crude protein levels were marginal to deficient for lactating beef cows (NRC 1984) during September and October, of both studies and extrusa K levels were marginal (NRC 1984) during September and October of the first study. Although extrusa samples were squeezed to remove saliva as suggested by Hoehne et al. (1967), samples may still have contained higher P levels than unmasticated forage (Langlands 1966). This suggests that dietary P levels for control cows may have been even lower than indicated by data in Table 3. Although there may be problems using extrusa samples for mineral analysis, they are more readily accepted than hand clipped samples as a means of sampling pastures for chemical analysis.

Table 3. Mean (± SD) monthly chemical composition data from extrusa samples of native pastures grazed by phosphorus (P) supplemented and control cows in 1982-83 and 1985-87[1,2]

Month	P	Ca	Mg	K	Crude Protein	IVDOM[3]
	(g kg^{-1} dry matter)					(g kg^{-1})
			1982-83			
Jun.	2.18 ± 0.35	6.78 ± 2.4	1.78 ± 0.51	12 ± 1.0	132 ± 17	696 ± 53
Jul.	1.96 ± 0.41	6.24 ± 1.7	2.07 ± 0.22	11 ± 2.0	107 ± 16	637 ± 64
Aug.	1.75 ± 0.12	5.40 ± 1.3	1.37 ± 0.24	7 ± 0.3	99 ± 15	610 ± 47
Sep.	1.54 ± 0.18	4.54 ± 1.2	1.35 ± 0.01	6 ± 0.2	67 ± 5	602 ± 39
Oct.	1.32 ± 0.33	3.06 ± 0.8	0.89 ± 0.08	4 ± 0.6	56 ± 1	580 ± 37
Season mean	1.77 ± 0.40	5.32 ± 1.9	1.49 ± 0.47	8 ± 3.0	94 ± 30	628 ± 60
			1985-87			
Jun.	2.20 ± 0.32	5.29 ± 2.3	1.65 ± 0.50	27 ± 13.6	100 ± 16	703 ± 54
Jul.	2.14 ± 0.25	6.03 ± 2.1	1.86 ± 0.37	24 ± 11.4	90 ± 16	668 ± 78
Aug.	2.15 ± 0.40	5.62 ± 1.4	1.57 ± 0.34	21 ± 12.7	91 ± 24	638 ± 59
Sep.	1.87 ± 0.12	4.57 ± 1.2	1.42 ± 0.26	18 ± 10.0	81 ± 19	624 ± 60
Oct.	1.71 ± 0.28	3.51 ± 0.4	1.00 ± 0.24	14 ± 8.6	74 ± 15	615 ± 56
Season mean	2.02 ± 0.33	5.05 ± 1.8	1.52 ± 0.45	21 ± 11.6	88 ± 19	652 ± 67

[1]Monthly means are averages of 3 or 4 collection dates for 1982-83 and 6-7 collection dates for 1985-87.
[2]Means over months are averages of 10 dates for Mg and K and 19 dates for other data in 1982-83 and 32 dates for all data in 1985-87.
[3]IVDOM=in vitro digestible organic matter.

Fecal P levels averaged over the grazing season were higher (P<0.05) for P supplemented cows in 1986 (Table 4), and differences between treatments were consistent at all sampling dates (Fig. 1). Season-long differences in fecal P levels between P supplemented and control cows also occurred in 1987, and they were consistent among sampling dates (Fig. 2) but differences were less than in 1986 (Table 4). Read and Engels (1986b) reported that fecal P differences between P supplemented and unsupplemented cows decreased when feed intake and consequently fecal output declined for unsupplemented cows. In the current study, P supplemented and control cows were gaining weight at approximately the same rate, therefore P supplemented cows may have been absorbing and utilizing more P in 1987 than in 1986, thus less P was eliminated in the feces. Early in the season in both 1986 and 1987 fecal P was much higher than forage (extrusa) P, but by October fecal P from control cows was only slightly higher than forage P (Fig. 1 and 2). There was an r^2 of 0.64 between fecal P from control cows and forage (extrusa) P in 1986 but in 1987 the r^2 was only 0.28. In 1986 fecal Ca levels were higher and fecal K levels were lower, and in 1987 fecal Mg levels were lower for P supplemented cows, but fecal N levels were not affected by supplemental P in either year (Table 4).

Serum P was higher for control than P supplemented cows in June of 1982, but P supplemented cows had higher serum P in November of 1982 (P<0.08) and May and October of 1983 (Table 5). Normal serum P levels according to Underwood (1981) range between 40-60 mg liter^{-1}. Read and Engels (1986b) reported that plasma P levels below 20 mg liter^{-1} were useful in identifying P deficiency, but at higher levels, plasma P seemed to be of little use in distinguishing between P adequate and P deficient animals. The lowest average serum P levels (38 and 33 mg

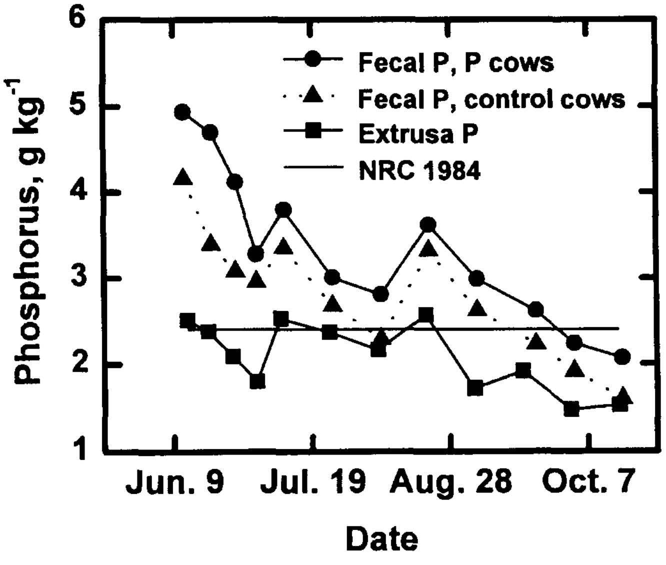

Fig. 1. Phosphorus (P) levels in pasture (extrusa) samples compared to fecal P from P supplemented and no P supplemented (control) range cows in 1986.

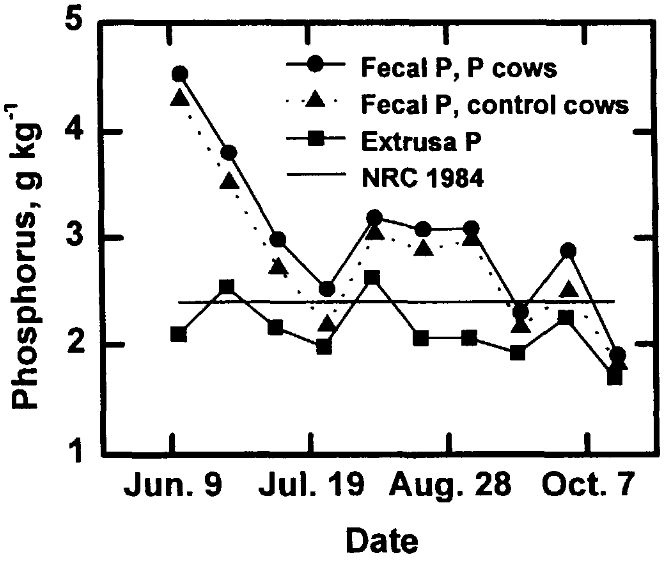

Fig. 2. Phosphorus (P) levels in pasture (extrusa) samples compared to fecal P from P supplemented and no P supplemented (control) range cows in 1987.

Table 4. Phosphorus (P), calcium (Ca), magnesium (Mg), potassium (K), and nitrogen (N) in fecal samples collected from P supplemented and no P supplemented (control) range cows during the summers of 1986 and 1987[1].

Treatment	1986 P	1986 Ca	1986 Mg	1986 K	1986 N	1987 P	1987 Ca	1987 Mg	1987 K	1987 N
	(g kg^{-1} dry matter)					(g kg^{-1} dry matter)				
P	3.20*	14.4*	5.13	5.66*	17.4	3.03*	12.0	3.96*	6.37	18.4
Control	2.68*	13.4*	4.77	6.20*	17.6	2.81*	13.2	4.12*	6.32	18.7
SE[2]	.002	.007	.004	.002	.004	.001	.012	.001	.004	.003

[1]Treatment means are averages of 2 replications and 11 dates in 1986 and 2 replicates and 10 dates in 1987.
[2]SE = Standard error of the mean = $\sqrt{EMS/N}$, where EMS = error mean square used to test treatments, and N = the number of observations/mean.
* Within a year and mineral, treatments differ (P<0.05).

liter^{-1}) for control cows in these studies were in October 1983 and March 1986, respectively. Low serum P in 1983 was likely due to low forage P for about 3 months and the demands of lactation; in 1986 low serum P was likely the result of 7 months on a low P diet. The lowest serum P level for P supplemented cows was 44 mg liter^{-1} in June of 1982.

Serum P in the second study was higher for P supplemented cows in October 1985, March 1986 and October of 1986 (P<0.08). Serum Ca was higher for control cows in November 1982, May 1983, and October of 1985 (Table 5). Similar increases in plasma Ca for unsupplemented compared to P supplemented cows was reported by Read and Engels (1986b), but the effect was more prevalent in late lactation. Underwood (1966) indicated that this inverse relationship between plasma P and Ca was the result of mobilization of these elements from bone to supply needed P, with the corresponding Ca remaining as excess in the plasma. Serum Mg levels above 20.0 mg liter^{-1} are considered normal for grazing cows by the Committee on Mineral nutrition (1973). All cows in both studies, except P supplemented cows (19.0 mg liter^{-1}) in May of 1983 had serum Mg levels above 20.0 mg liter^{-1} (Table 5).

Milk samples collected in October 1983 were similar in P, Ca, and Mg levels for control and P supplemented cows and averaged 1042, 1375, and 128 mg liter^{-1} on a whole milk basis, respectively. Milk levels of Ca, P, and Mg were within normal limits (Committee on Mineral Nutrition 1973, Kemp 1971). Read and Engels (1986a) reported that milk composition was only slightly affected in cows with a severe P deficiency.

Milk production for 24 hours (±SE), estimated on 22 August and 6 October 1983, 16 July 1985, 31 July 1986 and 8 October 1987 by the weigh-suckle-weigh technique was 5.3 ± 0.06 vs 4.7± 0.06, 3.4 ± 0.07 vs 2.6 ± 0.08, 7.4 ± 0.04 vs 7.0 ± 0.05, 9.5 ± 0.06 vs 8.4 ± 0.07 and 8.3 ± 0.08 vs 7.5 ± 0.08 kg for P supplemented and control cows, respectively. Although milk production for P supplemented cows was numerically greater at each sampling period, differences were only significant (P<0.05) for the 31 July 1986 date.

Cow weights at the beginning of these studies were 406 and 407 kg, and 473 and 466 kg for P supplemented and control cows used in the first and second studies, respectively. Weight gain or loss comparisons between P supplemented and control cows in Table 6 were always made with cows that had similar calving and lactation histories. Cows that lost calves or failed to breed were not included in weight comparisons during that breeding and lactation cycle, because their weight gains were always much higher than those of lactating cows. During the 1982 calving and nursing period P supplemented cows lost more weight (P<0.05) than control cows (Table 6), but during the following winter gestation period, P supplemented cows gained more weight (P<0.05) than control cows. Cow weight changes were not different during the

Table 5. Serum phosphorus (P) ± SE, calcium (Ca) ± SE, and magnesium (Mg) ± SE for P supplemented and no P supplemented (control) range cows for studies beginning in 1982 and 1985 and ending in 1983 and 1987[1,2,3].

Date	P: P	P: Ca	P: Mg	Control: P	Control: Ca	Control: Mg
	(mg liter^{-1})			(mg liter^{-1})		
1982						
Jun. '82	44 ± 1.6*	92 ± 1.5	—	53 ± 1.6*	93 ± 1.5	—
Nov. '82	45 ± 1.8[4]	95 ± 0.8*	—	41 ± 1.7[4]	101 ± 0.7*	—
May '83	76 ± 2.3*	90 ± 0.9*	19 ± 0.1*	57 ± 2.4*	96 ± 1.0*	21 ± 0.1*
Oct.. '83	51 ± 1.8*	102 ± 1.1	22 ± 0.2	38 ± 1.8*	105 ± 1.2	22 ± 0.1
1985						
May '85	54 ± 1.4	101 ± 0.7	20 ± 0.4	55 ± 1.5	102 ± 0.8	21 ± 0.4
Oct.. '85	61 ± 1.8*	103 ± 0.6*	20 ± 0.3	46 ± 1.9*	107 ± 0.6*	20 ± 0.3
Mar. '86	47 ± 0.9*	107 ± 0.9	22 ± 0.3	33 ± 0.9*	107 ± 0.9	21 ± 0.4
Jun. '86	53 ± 2.6	97 ± 1.0	25 ± 0.4	55 ± 2.8	98 ± 1.1	24 ± 0.4
Oct.. '86	48 ± 1.2[4]	99 ± 0.7	22 ± 0.3	45 ± 1.3[4]	99 ± 0.7	23 ± 0.3
Mar. '87	46 ± 1.4	93 ± 1.3	23 ± 0.4	48 ± 1.5	94 ± 1.4	23 ± 0.4
Jun. '87	53 ± 1.8	100 ± 1.4	24 ± 0.4	56 ± 1.9	96 ± 1.4	24 ± 0.4
Oct.. '87	48 ± 2.0	90 ± 2.4	22 ± 0.6	47 ± 2.0	92 ± 2.5	22 ± 0.7

[1]All means except serum Mg for May and October 1983 are least squares adjusted.
[2]Summer data are for lactating cows only.
[3]SE = Least squares mean standard error from SAS GLM.
[4]Treatments within a date and mineral are different (P<0.08).
*Treatments within a date and mineral are different (P<0.05).

Table 6. Weight changes (±SE) for phosphorus (P) supplemented and no P supplemented (control) cows during calving and nursing, and gestation periods for studies beginning in 1982 and 1985 and ending in 1983 and 1987[1,2]

Period	Beginning Date	Length	P: No. cows[3]	P: Gain	Control: No. cows[3]	Control: Gain
		(days)		(kg)		(kg)
				1982		
Calving & Nursing '82	2-19-82	259	23	-31.8 ± 0.9*	22	-8.8 ± 1.0*
Gestation '83	11-05-82	117	22	52.0 ± 0.7*	21	34.9 ± 0.8*
Calving & Nursing '83	3-03-83	246	23	25.5 ± 0.8	21	22.6 ± 0.8
Cumulative Gain	2-19-82	622	23	52.6 ± 1.6	21	65.1 ± 1.8
				1985		
Calving & Nursing '85	3-01-85	250	27	8.3 ± 0.6[4]	23	0.3 ± 0.7[4]
Gestation '86	11-06-85	124	27	43.9 ± 0.5*	25	21.4 ± 0.5*
Calving & Nursing '86	3-11-86	226	25	36.7 ± 0.8[4]	23	47.8 ± 0.9[4]
Gestation '87	10-23-86	151	23	15.4 ± 0.7	22	8.2 ± 0.7
Calving & Nursing '87	3-24-87	216	23	31.8 ± 0.9	21	39.1 ± 1.0
Cumulative Gain	3-01-85	967	23	137.7 ± 1.1	21	137.5 ± 1.2

[1]SE = Standard error of the mean = $\sqrt{EMS/N}$, where EMS = error mean square used to test treatments, and N = the number of observations/mean.

[2]Initial cow weights were 406 and 407 kg in 1982 and 473 and 466 kg in 1985 for P supplemented and control cows, respectively.

[3]One cow on each treatment died in the first study and 2 control and 1 P supplemented cows died in the second study. Two P supplemented and 5 control cows in the first study and 3 cows on each treatment in the second study were eliminated because they were open or lost calves. Retained dry cows were not included in calving and nursing or in the following gestation period data, but they were included in the next cycle if they were lactating.

[4]Treatments differed (P<0.08).

* Treatments differed (P<0.05).

calving and nursing period of 1983, and cumulative weight gains for the study were not significantly different. In the second study, P supplemented cows gained slightly more weight than control cows (P<0.08) during their first calving and lactation period and during the subsequent winter gestation period (P<0.05). However, during the 1986 calving and lactation period control cows gained more (P<0.08) weight than P supplemented cows, which agrees with results for the 1982 calving and lactation period when control cows lost less weight than P supplemented cows (Table 6). Weight gains for the remainder of the second study and cumulative weight gains for the full study were not significantly different between treatments.

Conception rates of P supplemented cows, analyzed over the 2 years of the first study, were higher (P<0.08) than rates of control cows (100 vs 93.6%) (Table 7). However, there were no conception rate differences between P supplemented and control cows in the second study, or when both studies were analyzed together. Feeding 1.8 kg oats, 5 days per week, post calving in 1986 and 1987 did have a positive effect on conception rate, resulting in a conception rate of 100% across P supplemented and control treatment cows for the 2 years combined, compared to an 88% conception rate for cows not receiving supplemental oats post calving. Oats were fed after calving to determine if milk production and calf weight gains were limited more by energy than P during this period. The apparent positive effect on conception rate was unexpected. Feeding oats after calving did not affect cow weights or calf weaning weights and there were no interactions between oats and P for any performance trait measured. Fishwick et al. (1977) reported that a long period of P inadequacy did not affect the subsequent reproductive performance of cows grazing on green grass at the time of breeding, and Call et al. (1978) reported that reproduction in Hereford cows was not adversely affected by

Table 7. Conception rates for phosphorus (P) supplemented and no P supplemented (control) range cows for studies beginning in 1982 and 1985 and ending in 1983 and 1987.

Calving year	Post calving treatment	P: No. exposed	P: No. bred	P: Conception	Control: No. exposed	Control: No. bred	Control: Conception
				--- (%) ---			--- (%) ---
				1982			
1982	—	24	24	100.0	26	25	96.2
1983[1]	—	23	23	100.0	21	19	90.5
1982-83		47	47	100.0[2]	47	44	93.6[2]
				1985			
1985	—	28	27	96.4	26	25	96.2
1986	Oats	13	13	100.0	11	11	100.0
1986	—	13	11	84.6	13	11	84.6
1987[1]	Oats	12	12	100.0	10	10	100.0
1987[1]	—	12	11	91.7	12	11	91.7
1985-87		78	74	94.9	72	68	94.4
1982-87		125	121	96.8	119	112	94.1

[1]Data were based on palpation results in the fall.

[2]Treatment means for 1982-83 were different (P<0.08).

Table 8. Mean birth date (±SE), birth weight (±SE) and least squares adjusted weaning weights (±SE) of calves from phosphorus (P) supplemented and no P supplemented (control) cows for studies beginning in 1982 and 1985 and ending in 1983 and 1987[1,4].

Year	No. calves	P Birth date	P Birth wt	P Adj. Wean wt.[3]	No. calves	Control Birth date	Control Birth wt.	Control Adj. Wean wt.[3]	Wean wt. difference
		(DOY[2])	(kg)	(kg)		(DOY[2])	(kg)	(kg)	(kg)
				1982					
1982	26	97.0 ± 0.5	28.5 ± 0.1	171.9 ± 3.5[5]	24	97.5 ± 0.5	28.6 ± 0.2	162.2 ± 3.5[5]	9.7
1983	24	97.9 ± 0.5	34.5 ± 0.1	216.0 ± 3.8	25	97.1 ± 0.4	35.0 ± 0.1	210.9 ± 4.1	5.1
				1985					
1985	28	101.8 ± 0.4	32.9 ± 0.1	236.8 ± 3.3	26	100.7 ± 0.4	33.1 ± 0.2	234.4 ± 3.6	2.4
1986	27	105.7 ± 0.3	37.6 ± 0.2	258.0 ± 3.1[5]	25	103.5 ± 0.4	36.8 ± 0.2	248.3 ± 3.2[5]	9.7
1987	23	105.0 ± 0.6	37.8 ± 0.2	271.4 ± 3.5[5]	22	108.6 ± 0.6	36.8 ± 0.2	259.5 ± 4.1[5]	11.9
1982-87	128	101.5 ± 0.1	34.2 ± 0.1	223.8 ± 2.0**	122	101.3 ± 0.1	34.1 ± 0.1	215.9 ± 2.3**	7.9

[1]Calf numbers are for birth date data, calf numbers for birth weight and adjusted weaning weights may vary due to death loss.
[2]DOY=Day of Year
[3]Weaning weights were analyzed using birth date as a covariant to adjust for differences in calf age and least squares to adjust for unequal numbers.
[4]SE=Standard error
[5]Adjusted weaning weights were different ($P<0.06$).
**Adjusted weaning weights over all 5 years were different ($P<0.01$).

a diet containing only 1.4 g kg^{-1} P. Read and Engels (1986a) however, reported markedly different reproductive results from 2 locations in South Africa; P supplementation of cows at 1 location had no effect on reproduction, but at a second location P supplementation resulted in a 50% improvement in conception rate. Improved reproduction in P supplemented cows at the second location was likely due to a substantial increase in feed intake.

Mean birth dates (day of year) of calves were not different between P supplemented and control cows in either study (Table 8). It had been anticipated that P supplemented cows might return to estrus and rebreed earlier than control cows. Calf birth weights were also unaffected by P supplementation (Table 8) which agrees with Fishwick et al. (1977). However, birth weights were increased by P supplementation at one location in South Africa where feed intakes had been severely depressed, but not at another location where feed intakes were normal (Read and Engels 1986a). Calf weaning weights adjusted by birth date in a covariance analysis and adjusted for unequal calf numbers using least squares procedures were higher ($P<0.06$) for P supplemented cows in 1982, 1986, and 1987 (Table 8). Treatment differences between unadjusted weaning weights were as great or greater than differences between adjusted weaning weights each year. Over the 5 calf crops of these 2 studies, adjusted weaning weights of calves from P supplemented cows were 7.9 kg heavier ($P<0.1$) than calves from control cows. These results are supported by the tendency of P supplemented cows to produce more milk and are in agreement with Fishwick et al. (1977) and Read and Engels (1986a).

In the studies reported here extrusa forage P was probably the best indicator of the cows' dietary P status. Serum P has been reported in other studies to be an unreliable indicator of an animal's P status, but at times in these studies, usually in the fall, lower serum P levels in control cows seemed to reflect forage P levels. The relationship between dietary and fecal P needs more study before fecal P can be considered a useful indicator of P intake.

Forage P levels encountered in these studies were below NRC (1984) recommendations much of the year, however differences in cow weight changes early in the studies were gradually lost by the end of the studies. The effect of consuming forages with low P levels during fall and winter months may have been offset by consumption of forages with relatively high P levels during early summer. Nevertheless P supplementation resulted in an apparent increase in conception rates in the first study and significantly heavier calf weaning weights 3 out of 5 years. Thus, P supplementation of range cows in the Northern Great Plains appears to be beneficial, and based on forage P levels the most useful time to supplement appears to be during the late summer and fall period. The most consistent benefit of P supplementation was heavier calf weaning weights. The data also suggest that conception rates may be improved by providing an energy supplement for 30 days after calving.

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