A COMPARISON OF SUPPLEMENTAL FORMS OF PHOSPHORUS

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Four yearling Holsteins were utilized in a 4 × 4 latin square designed experiment to assess the availability of phosphorus in four chemical forms: dicalcium phosphate; monocalcium phosphate; monoammonium phosphate and monosodium phosphate. The chemical form of supplement had no apparent effect on plasma levels of phosphorus, calcium or magnesium or on the fecal excretion of phosphorus. Dry matter intake and digestibility of dry matter were not influenced by chemical form of supplement but digestibility of the acid detergent fiber fraction was higher, 59.2 vs. 56.5, for monosodium phosphate compared with monoammonium phosphate. The molar proportion of propionate in the rumen fluid was significantly greater ($P<0.05$) when monosodium phosphate was fed compared with the feeding of either monocalcium phosphate or monoammonium phosphate. Under the conditions of this experiment it was concluded that there were no differences in availability of phosphorus among the four chemical forms studied.

Quatre Holstein d'un an ont servi à une expérience en carré latin 4 × 4 visant à évaluer l'assimilabilité du phosphore sous quatre formes chimiques: phosphate bicalcique, phosphate monocalcique, phosphate d'ammonium et phosphate de sodium. La forme chimique des suppléments ne semble pas avoir eu d'effet visible sur les teneurs plasmatiques en phosphore, en calcium, en magnésium ou sur l'éxcrétion fécale de phosphore. Elle n'a pas non plus influé sur l'ingestion ni sur la digestibilité de la matière sèche bien que la digestibilité de la fibre (fraction au détergent acide) ait été supérieur (59.2) avec le phosphate de sodium qu'avec le phosphate d'ammonium (56.5). La proportion molaire de propionate dans le liquide du rumen était significativement plus importante ($P<0.05$) avec l'emploi du phosphate de sodium qu'avec celui du phosphate d'ammonium ou du phosphate monocalcique. Dans le cadre de l'expérience, il ne semble donc pas y avoir de différences d'assimilabilité entre les quatres formes de phosphore étudiées.

In the rations of dairy cattle, the supplemental requirement for the macrominerals calcium and phosphorus usually has been provided by dicalcium phosphate. However, when the forage portion of the ration is made up primarily of legumes, more supplemental phosphorus than calcium is required and hence another form of phosphorus is needed. In certain instances, animal responses have been observed when only phosphorus has been added to ruminant diets. This was demonstrated by Playne (1969) who observed an increase in the voluntary intake of forage in response to supplemental phosphorus and by Morrow (1969) who found that dairy heifers supplemented with phosphorus required fewer services per conception. Observations such as these have indicated that sources of phosphorus other than dicalcium phosphate need to be used in ruminant rations. Ozanne et al. (1976) indicated that supplemental phosphorus fed to sheep was not as effective in increasing growth rate as the same amount of phosphorus provided naturally in the forage, an observation which implied that the chemical form of phosphorus influenced its effectiveness.

There are several chemical forms of phosphorus normally available to the feed industry for use in ruminant rations. The study under discussion was designed to compare the availability and effectiveness of phosphorus from four of these sources as estimated by the intake and digestibility of a forage ration, by the relative molar proportions of rumen volatile fatty acids, and the response of plasma phosphorus levels of yearling Holsteins.

MATERIALS AND METHODS

Four yearling Holsteins (two heifers and two steers) were employed in this trial which was designed as a 4 × 4 latin square to assess the availability of phosphorus in four supplements: dicalcium phosphate (phosphorus 18%, calcium 31–34%); monocalcium phosphate (phosphorus 21%, calcium 15–18%); monoammonium phosphate (phosphorus 24%, nitrogen 11.0%) and monosodium phosphate (phosphorus 21.5%) (the four sources of phosphorus were provided by East Chilliwack Co-op, Chilliwack, B.C.).

The four animals were restrained in metabolism stalls for a 14-day preliminary period and then for four 21-day experimental periods consisting of 14 days for establishing maximum intake of hay and a further 7 days of total collection for estimation of dry matter digestibility and mineral balance. Each supplement was mixed with molasses and fed with 0.45 kg of grain daily at 0800 h to provide 5.0 g of supplemental phosphorus per day. An orchard grass hay of medium quality was fed free choice. During the preliminary period and each collection period, blood samples were taken from each animal on the 2nd and 5th days at 0800, 1130, 1530 and 2200 h. These samples were analyzed for phosphorus, magnesium and calcium by atomic absorption procedures. A sample of rumen fluid was obtained from each animal at 1130 h on the 2nd day of the collection periods and analyzed for volatile fatty acids by gas chromatography (Erwin et al. 1961). Fecal samples were taken daily during the digestion trial and were analyzed for calcium, phosphorus and magnesium by atomic absorption procedures.

RESULTS

Body weight of the animals averaged 289, 300, 263 and 241 kg during the trial, with a calculated phosphorus requirement ranging from 17 to 19 g phosphorus/day according to theoretical requirements (National Academy of Sciences–National Research Council 1971) or 18–20 g/day (Agricultural Research Council 1965).

The addition of dicalcium and monocalcium phosphate to the molasses resulted in a granular mixture which tended to settle out. The monoammonium phosphate, upon mixing with molasses, formed a less granular mixture that did not settle out whereas the monosodium phosphate formed a thick but uniform mixture.

The average intake of hay, which contained 0.23% phosphorus, coupled with the small amount of grain fed as a carrier for the supplement, provided a total average daily consumption of phosphorus of 21.4, 21.3, 21.1 and 21.6 g/day for treatments of A, B,

Table 1. Effects of source of supplemental phosphorus on intake and digestibility of forage dry matter

	Dicalcium phosphate	Monocalcium phosphate	Monoammonium phosphate	Monosodium phosphate	SE of mean
Dry matter intake (kg/day)	6.44	6.39	6.30	6.51	±0.102
DM intake (% of body wt)	2.34	2.35	2.30	2.36	±0.069
DM digestibility (%)	60.6	59.8	59.3	60.4	±0.69
Intake dig. DM (kg/day)	3.90	3.82	3.74	3.93	±0.940
Dig. of acid detergent fiber (%)	58.1 *ab*	58.0 *ab*	56.5 *a*	59.2 *b*	±0.54
Dig. of protein (%)	59.6	57.7	57.7	55.3	±2.13

a,b Means with a common letter were not significantly different ($P>0.05$).

Table 2. Effects of source of supplemental phosphorus on percent hematocrit and levels of calcium, magnesium and phosphorus in blood plasma

	Dicalcium phosphate	Monocalcium phosphate	Monoammonium phosphate	Monosodium phosphate	SE of mean
Hematocrit %	30.6	30.3	30.2	30.7	±0.061
Calcium (mg/100 ml)	9.01	9.03	9.06	8.93	±0.049
Magnesium (mg/100 ml)	1.97	1.88	1.87	1.92	±0.173
Phosphorus (mg/100 ml)	7.82	8.02	7.90	7.89	±0.065

C and D, respectively. Supplemental phosphorus represented approximately 23% of the total phosphorus intake.

Forms of phosphorus supplementation did not influence hay dry matter (DM) intake (Table 1) expressed either as kg/day, or as percent of body weight. Intake of digestible DM was 3.74 kg/day for animals fed monoammonium phosphate compared with 3.82, 3.90 and 3.93 kg/day when animals were fed monocalcium phosphate, dicalcium phosphate or monosodium phosphate, respectively. Digestibility of DM was not influenced by form of phosphorus supplementation, but the digestibility of the acid detergent fiber fraction was significantly lower ($P<0.05$) when animals were fed monoammonium phosphate than when monosodium phosphate was fed. The digestibility of forage protein was greater at 59.6% ($P<0.10$) when dicalcium phosphate was fed compared with 55.3% when monosodium phosphate was fed. Percent hematocrit did not appear to be influenced by source of phosphorus (Table 2), nor were the levels of calcium, phosphorus and magnesium in the plasma influenced by treatment, but the decrease in plasma Mg levels when dicalcium phosphate was fed compared with the feeding of monocalcium phosphate was significant ($P<0.10$).

The content of mineral in the plasma did not appear to be influenced by time of sampling with the exception of plasma phosphorus which was highest at the 0800-h sampling and lowest at 1130-h sampling; however, using data from only the 0800- or 1130-h sampling times in the statistical analysis did not provide a more sensitive measure of differences in plasma mineral levels between treatments (Table 3).

The molar proportions of volatile fatty acids in the rumen fluid (Table 4) were influenced by source of phosphorus, with propionate being significantly higher ($P<0.05$) when the animals were fed monosodium phosphate than when either monocalcium phosphate or monoammonium phosphate was the source of phosphorus. Likewise, ratio of acetate to propionate was less ($P<0.05$) in rumen fluid samples taken from animals fed monosodium phosphate than from those fed monoammonium or monocalcium phosphate (Table 4).

The percent magnesium excreted in feces (Table 5) was significantly greater ($P<0.05$) when monocalcium phosphate was fed compared with the feeding of either dicalcium phosphate or monosodium phosphate. Source of phosphorus did not influence the percent phosphorus excreted in the

Table 3. Influence of time of sampling on blood hematocrit and mineral content of the plasma

	No. of observations	Hematocrit (%)	Ca	P	Mg
			mg/100 ml		
0800 h	32	29.9	9.05	8.30	1.97
1130 h	32	30.2	8.94	7.57	1.82
1530 h	32	30.0	9.02	7.74	1.82
2200 h	32	31.0	9.01	8.07	1.93

Table 4. Rumen fluid *p*H and molar proportions of volatile fatty acids as influenced by chemical form of phosphorus in the diet

	Dicalcium phosphate	Monocalcium phosphate	Monoammonium phosphate	Monosodium phosphate	SE of mean
Rumen *p*H	6.99	6.89	7.09	7.02	±0.077
Volatile fatty acids					
Acetate (molar %)	70.5	72.2	73.8	70.4	±2.13
propionate (molar %)	15.9*ab*	14.6*b*	14.9*b*	17.8*a*	±0.67
Butyrate (molar %)	9.2	11.3	10.3	10.5	±0.59
Valerate (molar %)	1.22	1.09	0.78	1.31	±0.30
Acetate/propionate	4.88*ab*	4.98*a*	4.95*a*	4.08*b*	±0.234

a,b Means with common letters were not significantly different ($P>0.05$).

feces but the excretion of calcium was greater ($P<0.05$) for those supplements containing appreciable amounts of calcium.

DISCUSSION

In this experiment, the response of plasma and fecal phosphorus levels to the inclusion of various phosphorus supplements was used to compare the effectiveness of these supplements. These techniques have been used previously by McDonald and Belonje (1975) who found that plasma phosphorus levels were effective in estimating phosphorus intake when the total daily excretion of phosphorus was constant. Guéguen et al. (1976) have estimated the availability of phosphorus from both monoammonium phosphate and monosodium phosphate using male lambs and measuring both fecal excretion of phosphorus and levels of phosphorus in the plasma. Ritchie and Fishwick (1977) observed increased plasma phosphorus levels in grazing cows supplemented with magnesium phosphate.

In addition, forage DM intake and digestibility, and molar proportions of rumen volatile fatty acids were employed in this study to compare the various sources of phosphorus. Ozanne et al. (1976) observed an increase in the intake of low quality forage when dicalcium phosphate was fed, although Playne (1969) and Cohen (1972) did not observe an increase in animal performance as a result of an increased DM intake caused by an addition of phosphorus. Since the DM intake of the forage in this study was similar for dicalcium phosphate and the other three forms tested, it was concluded that these latter sources of phosphorus were equivalent to dicalcium phosphate in their influence on DM intake.

With the exception of Durand et al. (1976) who observed that supplementation of ruminant rations with monoammonium phosphate resulted in a lower rate of production of volatile fatty acids, there have been few observations made on the influence of phosphorus on the pattern of rumen fermentation. The larger molar proportion of propionate and narrower ratio of acetate to propionate observed in this study when monosodium phosphate was fed corre-

Table 5. Effects of chemical form of supplemental phosphorus on percent of calcium, phosphorus and magnesium in fecal dry matter

	Dicalcium phosphate	Monocalcium phosphate	Monoammonium phosphate	Monosodium phosphate	SE of mean
Magnesium %	0.38*b*	0.44*a*	0.42*ab*	0.39*b*	±0.015
Phosphorus %	0.43	0.51	0.56	0.48	±0.038
Calcium %	1.88*a*	1.84*ab*	1.71*bc*	1.61*c*	±0.041

a-c Means with common letters were not significantly different ($P>0.05$).

sponded to a somewhat higher intake of forage DM. This effect of monosodium phosphate on rumen propionate would be of practical importance if it improved the efficiency of conversion of forage DM matter as suggested by Van Soest (1963). Durand et al. (1976) had previously observed that feeding monoammonium phosphate at high levels (4% of DM) resulted in lower concentrations of total volatile fatty acids and reduced the palatability of the ration. Neither of these effects of monoammonium phosphate was apparent with the relatively low amounts fed in this trial.

The results of this trial, where the supplemental sources of phosphorus provided approximately one quarter of the total dietary phosphorus to yearling calves, indicated that monocalcium phosphate, monosodium phosphate and monoammonium phosphate were as effective as dicalcium phosphate in providing supplemental phosphorus. However, positive observations for monosodium phosphate and negative observations for monoammonium phosphate in terms of rumen metabolism when compared with responses to other forms of phosphorus supplementation suggested that further studies could be carried out in this area.

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