Table 2. Trial results

Item	Concentration of Captan, ppm 0	160	320	640
Dry matter digestibility (%)				
Ruminal	65.1	72.8	69.4	74.3
Total	82.1	81.9	82.4	82.0
Starch digestion (%)				
Ruminal	87.7	93.6	89.3	92.2
N digestibility	74.8	72.1	77.3	74.8
Non-ammonia nitrogen				
Ruminal outflow, g/day	142.1[b]	132.8[ab]	126.7[ab]	110.6[a]
Ruminal ammonia, mg/dl	3.4	3.6	4.3	2.5
Nitrogen retention, g/day	45.2	47.8	50.4	49.2
Urine volume, liter	25.2	27.7	26.8	27.4
Abomasal passage				
Liquids, liter/day	66.4	80.8	80.8	75.2
Organic matter, g/day	1316	968	1136	947
Starch, g/day	306	138	256	183

[ab]Means in a row with different superscripts differ significantly ($P<.05$).

Ruminal Availability of Phosphorus and Its Effect on Digestion

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Story in Brief

The phosphorus concentration in ruminal fluid was determined for steers limit-fed rations with phosphorus concentrations ranging from .06 to .17 percent. Ruminal phosphorus concentration was increased with phosphorus intake at dietary concentrations below .12 percent for steers. This relationship was employed to estimate the ruminal availability of phosphorus from four phosphorus sources. Compared with sodium phosphate, assumed to have a ruminal phosphorus availability of 100 percent, a 21-percent phosphorus mono-dical, an 18.5-percent phosphorus mono-dical, and a defluorinated rock phosphate were found to be 59, 42 and 28 percent as available in the rumen. Phosphorus solubility in solutions buffered at pH 5, 6 and 7 paralleled the apparent availability in the rumen. Low ruminal dietary phosphorus did not reduce total tract or ruminal digestibility greatly, however, suggesting that ruminal concentrations above 210 mg per liter are adequate for microbial digestion in the rumen.

Introduction

Phosphorus in the form of some inorganic phosphorus supplement is added to most livestock rations to help meet the requirement of animals. With non-ruminant animals, the phosphorus requirement is often assessed by feeding trials and growth measurements. Ruminants require phosphorus both for growth of tissue and bone, as well as multiplication of microorganisms within the rumen. Phosphorus availability, thereby, becomes important at two sites for the ruminant. Rate of growth of bacteria and rate of digestion of feed components within the rumen may be limited by phosphorus supply. Through reduced microbial activity, a deficiency of phosphorus may precipitate deficiencies of energy or protein. This concept is supported by the observation that loss of appetite is one of the first clinical signs of a phosphorus deficiency in ruminants. Two added factors in phosphorus metabolism are peculiar to ruminant animals. First, ruminal phytase liberates bound phytin phosphate. Phytin phosphate is of low availability for non-ruminant animals. Secondly, pancreatic ribonuclease is secreted into the small intestine of ruminant animals in large amounts. Ribonuclease will liberate phosphorus from nucleic acids for recycling to the rumen via saliva.

Ruminal microbes obtain needed phosphorus from ruminal fluid and from feedstuffs being digested. Phosphorus in ruminal fluid is derived from solubilized or degraded feed ingredients as well as from recycling to the rumen.

Little information has been published on ruminal phosphorus concentrations and ruminal availability of various phosphorus sources. Therefore, these trials were designed 1) to determine if ruminal phosphorus concentration was linearly related to phosphorus intake so that it might be used to evaluate ruminal availability of phosphorus from various phosphorus sources, 2) to estimate ruminal availability of various phosphorus sources for mature cattle, 3) to measure solubility of phosphorus sources in a buffer solution as influenced by pH and time and 4) to determine if low dietary phosphorus levels decrease digestion in the rumen or the total digestive tract.

Materials and Methods

Standard curve

Six mature ruminally cannulated Hereford steers (1122 lb) were individually fed 7.1 lb of a basal ration (Table 1) twice daily. Sodium phosphate was added as the standard phosphorus source to provide ration phosphorus concentrations of .068, .123 and .173 percent. After a five-day adaptation period, a ruminal fluid sample was collected via ruminal cannula for analysis of inorganic phosphorus concentration. The line relating ruminal phosphorus concentration to ration phosphorus concentration was used to determine the relative ruminal availability of various phosphorus sources fed in the availability trial.

Ruminal availability of phosphorus sources

Steers used in the standard curve trial were individually fed 13.9 lb per day of a basal ration (Table 1) supplemented with phosphorus from sodium phosphate (a

Table 1. Basal ration composition

Item	Trial		
	Steer std curve	Steer avail.	Steer digestibility
	% of ration		
Cottonseed hulls	97.0	97.0	77.9
Supplement	3.0	3.0	22.1
Dehy cane molasses	0	0	20.1
Urea	1.6	1.6	1.1
TM salt	.5	.5	.5
$CaCO_3$	.07	.07	0
P source + $NaHCO_3$	.85	.85	.44
Vitamins A & D	+	+	+

standard source), a mono-dicalcium phosphate with 21 percent phosphorus[1], a mono-dicalcium phosphate with 18.5 percent phosphorus[2], or a defluorinated rock phosphate with 18 percent phosphorus[3] (Table 2). Steers were fed twice daily for a five-day adaptation period. On day six, a ruminal fluid sample was collected via ruminal cannula and analyzed for inorganic phosphorus concentration. Relative ruminal availability of the various sources of phosphorus was calculated by relating ruminal phosphorus concentrations to the standard curve for sodium phosphate generated in the previous trial.

In vitro solubility of phosphorus sources

Each of the four phosphorus sources was incubated in Ohio buffer at a pH of 5, 6 or 7. Samples were taken at 30 minutes, 1, 2 and 3 hours. Samples were analyzed for inorganic phosphorus, and solubilities relative to the standard (sodium phosphate) were calculated.

Phosphorus and ruminal digestion

Four Hereford-Brown Swiss and two Hereford-Angus steers (1527 lb) housed in metabolism stalls were individually fed at maintenance based on body weight, a basal ration (Table 1) containing .118 percent phosphorus or supplemented with sodium phosphate to achieve a phosphorus level of .227 percent in the ration. After a seven-day ration adaptation period, total feces were collected for five days. On the fifth day of the collection period, ruminal fluid samples were obtained, and nylon bags containing ground corn, cottonseed hulls or cotton duck strips were incubated in the rumen for a 24 hour period. Ruminal fluid and fecal samples were analyzed for inorganic phosphorus. Nylon bags and cotton duck strips were thoroughly washed, dried, and weighed to determine disappearance rate of dry matter.

Results and Discussion

Standard curve

Cattle fed diets with sodium phosphate added to obtain.068, .123 and .173 percent phosphorus had ruminal phosphorus concentrations of 264, 406 and 434 mg phosphorus per liter of ruminal fluid (Figure1). The higher level of phosphorus addition increased ruminal phosphorus only slightly, suggesting that concentration may have begun to plateau.

Table 2. Supplement composition

	Trial								
Phos. source	Steer	std	curve[a]	Steer avail.[a]				Steer dig.[b]	
	% of ration								
$Na_2HPO_4 \cdot 7H_2O$	0	.43	.85	.85	—	—	—	—	—
Na_2HPO_4	—	—	—	—	—	—	—	0	.44
21% P dical	—	—	—	—	.47	—	—	—	—
18.5% P dical	—	—	—	—	—	.54	—	—	—
Defluor. P	—	—	—	—	—	—	.55	—	—
$NaHCO_3$	.85	.42	0	0	.38	.31	.30	0	0

[a]Added to urea, limestone, trace mineralized salt and vitamin mix to form the total supplement.
[b]Added to dehydrated cane molasses, urea, trace mineralized salt and vitamin mix to form the total supplement.

[1]Occidental Chemical Co., Houston, Texas.
[2]International Minerals and Chemical Corp., Mundelein, Illinois.
[3]Borden Chemical/Borden Inc., Norfolk, Virginia.

Ruminal availability of phosphorus sources

Sodium phosphate, 21 percent phosphorus mono-dical, 18.5 percent phosphorus mono-dical or defluorinated rock phosphate were added to a basal ration (.067 percent phosphorus) to increase the phosphorus level to approximately .17 percent. Ruminal fluid phosphorus concentrations of the three commercial sources were compared with the sodium phosphate standard curve for steers (Figure 1). Estimates for ruminal availability relative to sodium phosphate at 100 percent were 59.3 percent for 21 percent phosphorus mono-dical, 42.2 percent for 18.5 percent phosphorus mono-dical, and 28.4 percent for defluorinated rock phosphate. Ration and ruminal fluid phosphorus concentrations for the three phosphorus sources are presented in Table 3.

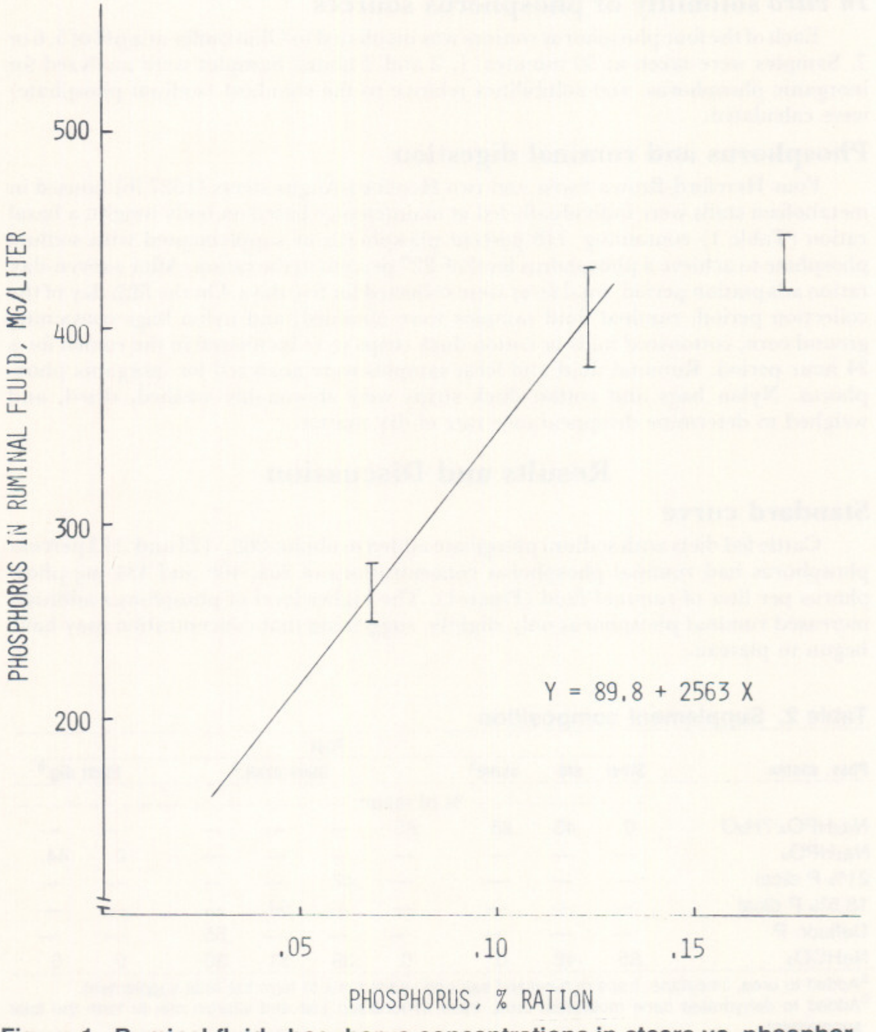

Figure 1. Ruminal fluid phosphorus concentrations in steers vs. phosphorous intake

In vitro solubility of phosphorus sources

Phosphorus sources differed ($P<.01$) in solubility. Sodium phosphate was virtually all soluble in the buffer solution, while the 21 percent phosphorus mono-dical was more soluble (46.4 percent) than 18.5 percent phosphorus mono-dical (28.8 percent). Deflourinated rock phosphate was virtually insoluble (2.5 percent, Figure 2). This order of solubility for the four phosphorus sources is identical to the order of ruminal availability (Figure 3).

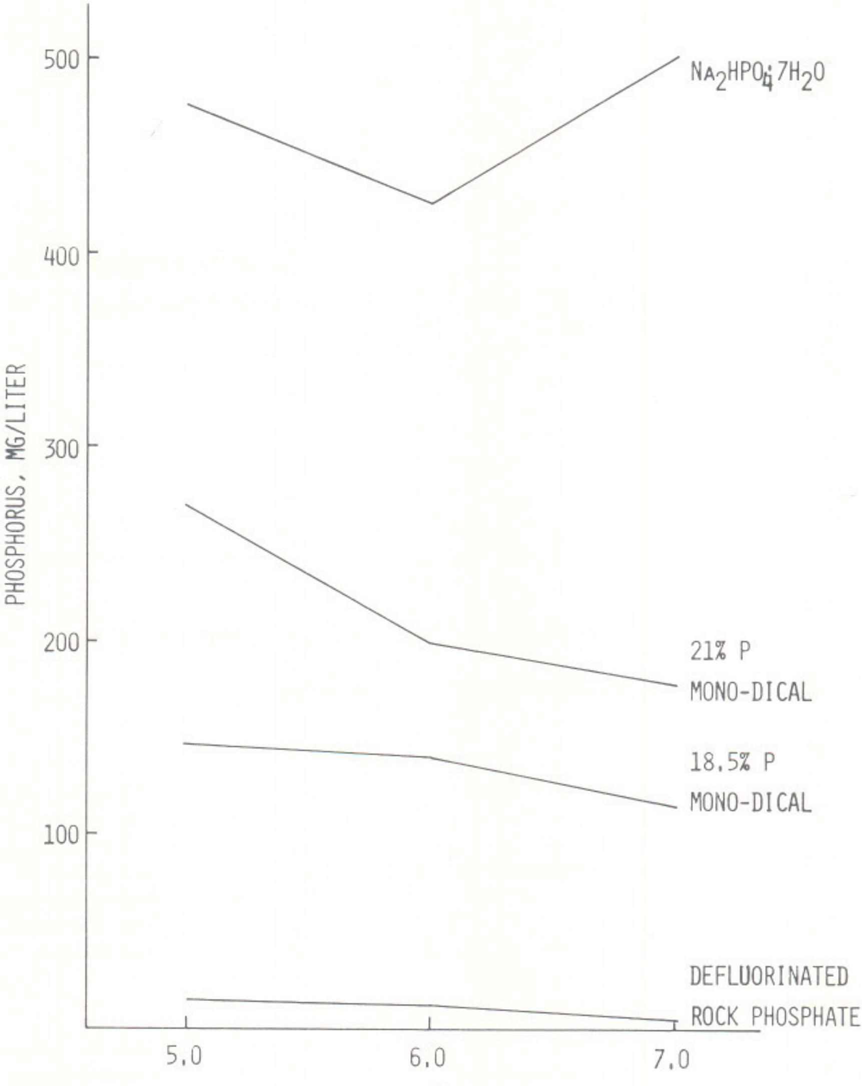

Figure 2. Effect of pH phosphorous solubility

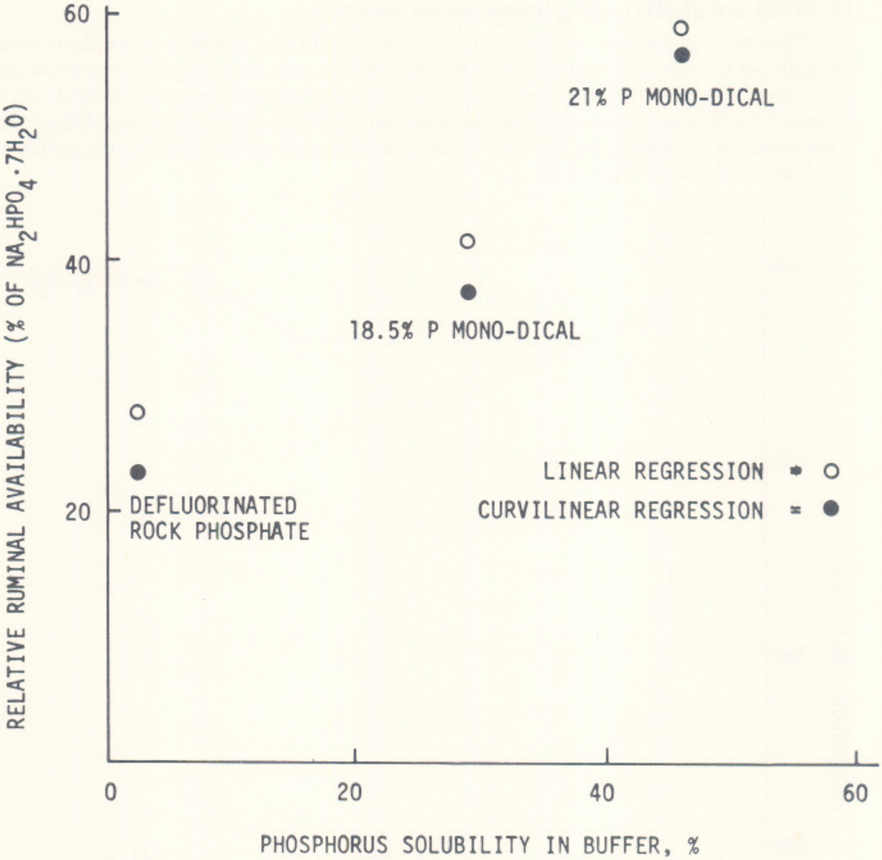

Figure 3. Ruminal availability vs. buffer solubility

The standard sodium phosphate was more soluble at pH 5 and 7 than at pH 6. Both mono-dicalcium phosphates exhibited increased solubility at lower pH values. Defluorinated rock phosphate was virtually insoluble at all pH levels. Over 90 percent of the phosphorus ultimately found in solution was in solution within two minutes.

Results indicate that phosphorus from commercial inorganic phosphorus sources may be more available in the rumen at lower ruminal pH values. The limited solubility of rock phosphate may need to be considered when using it as a supplemental source of phosphorus, if low ruminal phosphorus levels reduce digestion.

Phosphorus and ruminal digestion

Some workers have indicated that cellulose digestion and cell growth by ruminal microbes decrease when ruminal phosphorus is low. However, the ruminal requirement for phosphorus has not been quantitated. The dietary phosphorus requirement for maintaining beef cattle is listed as .18 percent of the dry ration (NRC Beef Cattle, 1976). In this study, rations containing phosphorus at levels of .119 percent and .227

Table 3. Calculation of ruminal availability of phosphorus sources

Phosphorous source	Phosphorus Basal ration	Phosphorus Added	Ruminal phosphorus	Ruminal availability[a]	Ruminal availability[b]
	%	%	mg/1	%	%
$Na_2HPO_4 \cdot 7H_2O$	.067	.0560	406 ± 26	100	100
$Na_2HPO_4 \cdot 7H_2O$	.067	.1060	434 ± 14	100	100
21% P dical	.067	.0885	397 ± 16	59.3	57.1
18.5% P dical	.067	.1038	375 ± 25	42.2	37.6
Defluor. P	.067	.1000	336 ± 14	28.4	23.0
None	.067	.0000	264 ± 15	—	—

[a]Calculated from linear standard curve as follows:

$$\text{Availability} = 100 \times \frac{\text{Availability P}}{\text{Added P \%}} = 100 \times \frac{(\text{Ruminal P} - 264)/142 \times .056}{\text{Added P\%}}$$

[b]Calculated from curvilinear standard curve.

Table 4. Effect of phosphorus level on ruminal and total-tract digestibility

Item	Phosphorus in ration .119%	Phosphorus in ration .227%
Dry matter intake, g/day	8025	8075
Phosphorus intake, g/day	9.5[a]	18.3[b]
Fecal output, g/day	2857.0	2693.7
Fecal phosphorus, %	.307	.369
Phosphorus retention, g/day	1.0[a]	8.3[b]
Dry matter digestibility, %	64.8	67.0
Organic matter digestibility, %	64.8	66.9
Ruminal phosphorus mg/liter	208.1[a]	398.1[b]
Ruminal disappearance per day		
Cottonseed hulls, %	8.3	8.2
Cotton duck, %	22.5	23.2
Ground corn grain, %	42.2	41.0

[ab]Means in a row with different superscripts differ significantly ($P<.01$).

percent were fed to determine whether a phosphorus-deficient ration and low ruminal phosphorus would alter ruminal and total-tract digestibility. The low-phosphorus ration reduced daily phosphorus retention and phosphorus concentration in ruminal fluid (Table 4). However, differences in dry matter digestibility or organic matter digestibility for the two rations were very small. Ruminal digestion also appeared similar for the cattle fed the two rations.

Since no relationship was detected, this implies that a ruminal phosphorus concentration of 210 mg per liter is adequate for digestion, though inadequate for maximum phosphorus retention. This suggests that availability of phosphorus in the rumen is less important than availability of phosphorus in the total digestive tract. Consequently, phosphorus solubility at the acidic conditions of the abomasum may be more indicative of the value of phosphorus to ruminants than would be phosphorus solubility at the ruminal pH or ruminal phosphorus concentration.