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The Effects of Supplementing Napier Grass (*Pennisetum purpureum*) with Rock Phosphate and Steamed Bone Meal Compared with a Commercial Mineral Mix on Phosphorus Absorption in Cattle

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ABSTRACT

Twelve Boran steers with a mean live weight of 215.8 ± 13.9 kg were used in an incomplete Latin Square experiment to compare the apparent phosphorus (P) absorption in cattle when Napier grass (*Pennisetum purpureum*) was supplemented with Busumbu rock phosphate (BRP), Minjingu rock phosphate (MRP), steamed bone meal (SBM) or a commercial mineral mix (CMM). The steers were housed individually and supplemented with P at 0, 4.5 or 17.5 g P/day. Dry matter intake (DMI) and dry matter digestibility (DMD) were not affected ($p > 0.05$) by the source of P. Live weight gains (LWG) were different ($p < 0.05$) across the sources of P. The coefficient for apparent P absorption from the supplement (CAPA), DMD and LWG decreased linearly ($p < 0.05$) with period. Dry matter intakes were not significantly different ($p > 0.05$) across periods. The level of P supplementation had no significant effect ($p > 0.05$) on DMI or LWG. However, increasing the level of P supplementation significantly increased ($p < 0.05$) the DMD of the basal diet. There was also a significant ($p < 0.05$) source × level interaction for CAPA. The CMM had the highest CAPA, which decreased from 106% to 74.7% with increasing level of P supplementation. For SBM, BRP and MRP, increasing P supplementation also increased CAPA. The CAPA for SBM and BRP and BRP and MRP were not significantly ($p > 0.05$) different from each other. These results suggest that BRP has potential as a source of P for ruminants.

Keywords: absorption, cattle, digestibility, live weight, nutrition, phosphorus, rock phosphate

Abbreviations: ADF, acid detergent fibre; BRP, Busumbu rock phosphate; CAPA, coefficient for apparent phosphate absorption from the supplement; CMM, commercial mineral mix; CP, crude protein; DCP, dicalcium phosphate; DM, dry matter; DMD, dry matter digestibility; DMI, dry matter intake; LW, live weight; LWG, live weight gain; MRP, Minjingu rock phosphate; NDF, neutral detergent fibre; P, phosphorus; PEF, phosphorus excreted in the faeces; SBM, steamed bone meal

INTRODUCTION

It has long been established that many soils over large areas of East and Central Africa are deficient in phosphorus (P) (Smaling *et al.*, 1993). The forages grown on these P-deficient soils are also P-deficient (Jumba *et al.*, 1995). The occurrence and degree of inadequacy of P in ruminant diets originates from this low concentration of P encountered in herbage (Abate and Abate, 1991). Among the major minerals that are required by the body, P is most important as it is required in large quantities (Underwood, 1981). Phosphorus is required for healthy formation of bones and teeth, reproductive physiology and metabolism of fats, protein, and carbohydrates; it takes part in the body's energy storage system and helps maintain healthy blood sugar levels (Underwood, 1981). Phosphorus deficiency can therefore affect many aspects of animal performance.

In most parts of the world, dicalcium phosphate (DCP) is the P supplement of choice. In Kenya, the use of DCP as a source of supplementary P is limited because it is not locally available and so has to be imported, making its use expensive (1 kg of a commercial mineral mix containing 12% P costs about Ksh 200 (US$1 = Ksh 78, January 2001.) An alternative is to exploit indigenous resources, such as the rock phosphates (RP) (Jubb and Crough, 1988) that are widespread in East and Southern Africa (Van Kauwenbergh, 1991). Two such deposits, which are easily accessible and have abundant reserves, are the Busumbu deposits in Uganda, at Busumbu Hill, 10 kg west of the Kenyan border at 0° 54′ 12″ N and 34° 15′ 55″ E, and the Minjingu deposits in Northern Tanzania, about 110 km southwest of Arusha, along the main Arusha–Dodoma highway. About 5 million tonnes of Busumbu rock phosphate of 8–35% P_2O_5 content have been estimated to be present at Busumbu Hill (Davies, 1947, 1956). At Minjingu, reserves amounting to 3.3 million tonnes of soft ore (30–32% P_2O_5) and 4.8 million tonnes of hard ore (28–30% P_2O_5) have been estimated to be present (P van Straaten, personal communication, 2001). The objective of this experiment was to compare the coefficients for apparent phosphorus absorption from these rock phosphates with that of bone meal and of a commercial mineral mix, as supplements to Napier grass (*Pennisetum purpureum*).

MATERIALS AND METHODS

Animals and experimental design

Twelve Boran steers, with a mean live weight of 216 ± 13.9 kg, were used. The steers were housed individually in concrete-floored pens without bedding. The experiment was set up as an incomplete Latin Square with nine treatments and three periods, so that each of the P sources was represented eight times, four times at each level. The control was represented four times. Each of the three 7-day collection periods was preceded by a 21-day depletion period when only the basal diet of Napier grass was fed and 14 days for the steers to adjust to the treatments.

Dietary treatments

The steers were fed a basal diet of Napier grass equivalent to 2.5% of their body weight on a dry basis, except during the 7-day collection periods, when the amount offered was further restricted to 2.4% body weight to ensure all the feed offered was consumed. (The total dry matter intake would be less than 2.4% body weight if an animal did not finish its feed allocation for the day.) The treatments consisted of the basal diet of Napier grass supplemented with Busumbu rock phosphate (BRP), Minjingu rock phosphate (MRP), steamed bone meal (SBM) or a commercial mineral mix (CMM) to supply either 4.5 or 17.5 g P/day. (CMM: Unga high-P mineral mix, Unga Feed (K) Ltd, Nairobi, Kenya. Ca = 12%; P = 12%; NaCl = 25%; Mg = 2.5%; Mn = 0.4%; Zn = 0.5%; I = 0.5%; Cu = 0.2%; Fe = 0.3%; Co = 0.005%; Se = 0.0012%.) The harvested Napier grass was chopped into lengths of approximately 10–15 mm using a chaff-cutter to minimize selection by the steers against stem materials. The P supplements were fed by mixing the supplement with 0.5 L of molasses (P = 379.01 mg/kg) diluted with 1 L of water, which was then thoroughly mixed to a paste with a small amount of Napier grass at a time until the entire supplement was incorporated. The supplement/Napier grass paste was first fed to the animals on its own before allowing the steers further access to the grass. The control diet was also mixed with molasses, as above, but without adding the P supplements. The steers had free access to water at all times.

Dry matter digestibility and the coefficient for apparent P absorption from the supplement

During the collection period, the total amounts of Napier grass offered and refused, if any, and all the faeces voided were collected daily and weighed to determine the dry matter intake (DMI) and the dry matter digestibility (DMD) of the basal diet. The collected faeces were thoroughly mixed and a 200 g composite sample was taken daily, stored in a refrigerator at 4°C and bulked weekly for P analysis. Urine was not collected because urinary excretion of P is usually considered to be negligible (Agricultural Research Council, 1980; Care, 1994). The following formula was used to estimate the coefficient for the apparent P absorption from the supplement (CAPA), using the mean of the four assessments for the basal diet:

$$\text{CAPA} = \frac{(\text{Total P intake} - \text{P in basal diet}) - (\text{Total faecal P} - \text{P excreted from basal diet})}{(\text{Total P intake} - \text{P in basal diet})} \times 100$$

It was assumed that the contribution of the basal diet to the faecal P excretion was constant across the treatments.

Chemical analysis

The mineral analysis on the supplements was done using an X-ray diffraction method by Geoscience Laboratories, Ontario, Canada. Samples of the Napier grass were taken every fortnight for chemical analysis. The dry matter was determined by oven drying at 60°C to constant weight; crude protein was determined by the method of Parkinson and Allen (1975), and detergent fibre as described by van Soest (1963). Bray 2 extractable P in the Napier grass and the faeces was determined using the molybdate–ascorbic acid procedure of Murphy and Riley (1962) as described by Okalebo and colleagues (1993).

Statistical analysis

The dependent variables were analysed using the PROC GLM procedure (SAS, 1988). Significant effects were recognized at $p < 0.05$. Tukey's multiple comparison and linear/quadratic contrast procedures were used to conduct *post hoc* tests.

RESULTS

The concentrations of P in the supplements, Napier grass and faeces are shown in Table I. The average concentration of P in the Napier grass was 0.09% ± 0.03% (±SD), while that in the faeces was 0.51% ± 0.26% across all treatments.

The DMI, DMD, live weight gain (LWG), P excreted in the faeces (PEF), and coefficient for the apparent P absorption from the supplement (CAPA) for the steers are shown in Table II. The actual amounts of P intake from the basal diet, P intake from the supplement, faecal P concentration, faecal P output, P retained by the animals and the coefficient for the apparent P absorption from the supplement are also shown in Table III. The DMI and DMD were not significantly affected ($p > 0.05$) by the source of P. The LWG and PEF were significantly different ($p < 0.05$) across the sources of P (Table II). Correlation analysis of the CAPA with LWG, PEF and DMD revealed coefficients of 0.47, –0.55 and 0.41, respectively. The CMM had the lowest PEF, which was not significantly different from that for SBM. The PEF for SBM and BRP and BRP and MRP were not significantly different from each other. There was a significant ($p < 0.05$) source × level interaction for CAPA. CMM had the highest CAPA, but the mean fell from 106% to 74.7% as the level of supplementation increased from 4.5 to 17.5 g P/day. For SBM, BRP and MRP, increasing the level of P supplementation resulted in an increase in the mean CAPA. The level of supplementation had no significant effect on the DMI. However, the DMD increased ($p < 0.05$) with increasing level of supplementation.

The DMD and CAPA declined linearly ($p < 0.05$) with time, while the PEF increased linearly ($p < 0.05$) with time (Table II). DMI did not change significantly with time.

TABLE I
The phosphorus content of the sources used as supplements and the composition of Napier grass with time

Sample	%				
	DM	CP	ADF	NDF	P
P supplement[a]					
Commercial mineral mix	–	–	–	–	12.1
Steamed bone meal	–	–	–	–	10.5
Busumbu rock phosphate	–	–	–	–	13.3
Minjingu rock phosphate	–	–	–	–	13.5
Basal diet[b]					
Napier grass week 1	92.6	9.7	45.3	68.6	0.12
Napier grass week 3	92.5	8.1	49.3	69.5	0.13
Napier grass week 5	92.7	7.1	47.0	67.3	0.09
Napier grass week 7	92.7	5.3	49.6	72.5	0.07
Napier grass week 9	92.6	4.8	47.9	70.9	0.12
Napier grass week 11	92.6	4.3	48.3	71.4	0.06
Napier grass week 13	93.8	3.2	46.4	68.2	0.05

DM, dry matter; CP, crude protein; ADF, acid detergent fibre; NDF, neutral detergent fibre

[a]X-ray diffraction method, Geoscience Laboratories, Ontario, Canada

[b]Animal Production Analytical Laboratories, Kenya Agricultural Research Institute Muguga

DISCUSSION

As expected, the CMM had the highest CAPA. This is in agreement with the findings by Tillman and Brethour (1958) and Wise and colleagues (1958) that DCP contains P in a form which is readily available to cattle. Although the CMM had the highest CAPA, this decreased from 106% to 74.7% as the level of supplementation increased from 4.5 to 17.5 g P/day, whereas increasing the level of P supplementation for SBM, BRP and MRP resulted in an increased CAPA. This latter is in agreement with the findings of Braithwaite (1983, 1984) that the absorption of dietary P is closely related to P intake. However, Challa and colleagues (1989) found that, whereas the rate of P absorption was related to the amount of P supplied, the efficiency of P absorption differed according to the source of the supply. These authors showed that the absorption efficiency was low on P-deficient diets, increasing with supplementation until the supply met requirements and then decreasing at higher rates of supply. Challa and colleagues (1989) also found that supplies of P greater than 75 mg/day per kg LW did not result in a further increase in P absorption. The 17.5 g P/day given in the

TABLE II
Dry matter intake, DMD, LWG, PEF and CAPA for steers fed a basal diet of Napier grass and those supplemented with MRP, BRP, CMM and SBM

	Dry matter intake (g)	Dry matter digestibility (%)	Live weight gain (g/day)	Phosphorus excreted in the faeces (g/day)	Coefficient for P absorption from the supplement (%)
Source of P					
CMM	4221.7[a]	59.7[a]	95.8[a]	5.8[c]	90.4
SBM	4364.7[a]	63.0[a]	–120.8[ab]	8.3[bc]	52.0
BRP	4396.2[a]	61.4[a]	–154.2[b]	10.0[ab]	32.7
MRP	4146.0[a]	59.7[a]	–125.0[ab]	12.0[a]	20.5
Control	4427.0[a]	67.7[a]	–66.7[ab]	3.8[d]	–
Period					
1	4301.8	65.5	25.0	6.3	62.8
2	4278.3	61.5	–125.0	8.4	42.1
3	4314.7	57.0	–125.0	10.6	37.4
Linear	NS	*	*	*	*
Quadratic	NS	NS	NS	NS	NS
Level					
0	4427.0[a]	64.7[a]	66.7[a]	3.8[a]	–
1	4325.9[a]	59.1[b]	–29.2[a]	6.2[a]	44.7
4	4238.5[a]	62.7[ab]	–122.9[a]	11.9[b]	53.1
SED	262.85	3.26	138.66	1.74	12.00

DMD, dry matter digestibility; LWG, live weight gain; PEF, phosphorus excreted in the faeces; CAPA, coefficient for P absorption from the supplement; SBM, steamed bone meal; CMM, commercial mineral mix; MRP, Minjingu rock phosphate; BRP, Busumbu rock phosphate

[a,b]Means within the same column with the same superscript letter do not differ significantly

*Significant ($p < 0.05$)

NS, not significant

current trial was equivalent to 81.02 mg/day per kg LW, exceeding the 75 mg/day per kg LW cut-off defined by Challa and colleagues (1989), which might explain the decreased CAPA, and the increased PEF for CMM at the higher level of intake. Symonds and Forbes (1993) also reported increased faecal P excretion with an increasing level of P intake. The low P absorption at low P intakes could also be due to low P availability in forages, precipitation of dietary P by calcium or poor absorption across the intestinal walls, when there is only a small gradient in

TABLE III
Source of phosphorus, P intake from the basal diet, P intake from the supplement, faecal P concentration, faecal P output, P retained and the coefficient for the apparent P absorption from the supplement

Source of P	P intake from Napier grass (g/day)	P intake from the supplement (g/day)	Faecal P concentration (g/kg)	Faecal P output (g)	P retained (g)	Coefficient for the apparent P absorption from the supplement (%)
Control	5.8 (0.54)[a]	0.0	0.24 (0.019)	3.8 (0.63)	2.1 (0.55)	–
Steamed bone meal	5.7 (0.50	4.5	0.39 (0.043)	6.4 (0.93)	3.8 (0.68)	41.4 (16.56)
Busumbu rock phosphate	5.8 (0.38)	4.5	0.39 (0.071)	7.5 (1.04)	2.8 (1.24)	15.1 (25.65)
Minjingu rock phosphate	5.6 (0.47)	4.5	0.43 (0.016)	7.3 (1.25)	2.7 (1.03)	16.4 (23.74)
Commercial mineral mix	5.7 (0.64)	4.5	0.20 (0.055)	3.5 (0.74)	6.6 (0.83)	106.2 (18.22)
Steamed bone meal	5.8 (0.30)	17.5	0.64 (0.111)	10.3 (3.00)	13.0 (2.93)	62.2 (16.92)
Busumbu rock phosphate	5.7 (0.30)	17.5	0.86 (0.162)	12.4 (3.32)	10.8 (3.55)	50.3 (19.69)
Minjingu rock phosphate	5.3 (0.14)	17.5	0.98 (0.193)	16.1 (5.69)	6.2 (5.6)	24.7 (33.02)
Commercial mineral mix	5.4 (0.10)	17.5	0.49 (0.124)	8.1 (3.09)	14.8 (3.08)	74.7 (18.03)

[a]Means followed by standard deviations in brackets

concentration between the lumen of the small intestine and the blood plasma (Hendricksen and colleagues, 1994). The results of this work did not agree with previous results, which have shown that the availability of P in bone meal is equal to that in DCP (Long *et al.*, 1957), probably because of differences in treatment, animals or the quality of the bone meal.

The DMI of the steers did not change significantly ($p > 0.05$) over time. This is in agreement with the findings of Anindo and Potter (1994), who reported no effect on DMI with time. There was, however, a linear ($p < 0.05$) decline in DMD with time, probably due to the coincidental decline in the quality of the Napier grass (Table I). In Muguga (Kenya), it has been shown that the chemical composition of Napier grass can vary considerably with seasons. Anindo and Potter (1994) reported that its *in vitro* DMD was 56% and 72% in the dry and wet seasons, respectively. Elsewhere, P supplementation has been shown to have little effect on DMD (Fishwick *et al.*, 1977; Ternouth and Budhi, 1996; Campbell *et al.*, 1996; Gartner *et al.*, 1982). There was a linear ($p < 0.05$) reduction in P absorption with time and a significant ($p < 0.05$) linear increase in PEF with time. The results of Challa and colleagues (1989), showing that the efficiency of P absorption is low when the dietary intake of P is deficient, and increases with intake of P until the requirements of the animal are met before tapering off, might also explain the increased excretion of P with time (Table II).

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Les effets d'un apport en *Pennisetum purpureum*, en ajout phosphaté et en nourriture à base d'os bouilli comparés avec une alimentation commerciale basée sur un apport mixte en minéraux, sur l'absorption du phosphore chez les bovins

Résumé – Douze bouvillons de la race Boran avec un poids moyen de $215{,}8 \pm 13{,}9$ kg furent utilisés pour comparer l'absorption du bétail alimenté avec *Pennisetum purpureum*, de l'os bouilli (SBM), du phosphate en morceaux (MRP) ou un mélange commercial de minéraux (CMM). Les animaux furent gardés individuellement et reçurent du phosphore de l'ordre de 0 ou 4,5 ou 17,5 g/jour. La prise de matière sèche

(DMI) et la digestibilité pour les matières sèches (DMD) ne furent pas changées en fonction de la source de phosphore ($p > 0{,}05$). Le gain en poids (LWG), par contre, varia en fonction des sources de phosphore ($p < 0{,}05$). Le coefficient d'absorption du phosphore (CAPA), les teneurs en DMD et LWG diminuèrent linéairement pendant cette période ($p < 0{,}05$) mais la prise de matières sèches ne varia pas de façon significative ($p > 0{,}05$) et n'eut pas d'effet sur les taux en DMI et LWG ($p > 0{,}05$). Cependant l'augmentation du phosphore augmenta le taux de DMD ($p < 0{,}05$). Il y eut aussi une intéraction significative ($p < 0{,}05$) entre niveau et source de phosphore sur le taux CAPA. L'apport par CMM eut la plus haute valeur en CAPA qui cependant diminua de 106 à 74,7% lors de l'augmentation de l'apport en phosphore. Pour les régimes alimentaires avec SBM, BRP et MRP l'augmentation du phosphore augmenta aussi le taux CAPA. Ce même taux ne fut pas significativement différent entre SBM et BRP ou entre BRP et MRP ($p > 0{,}05$). Ces résultats montrent que l'apport par BRP est une source potentielle de phosphore pour les ruminants.

Efecto de la suplementación de la hierba Napier (*Pennisetum purpureum*) con fosfato mineral o hueso cocido al vapor, comparados con una mezcla mineral comercial, sobre la absorción de fósforo en ganado vacuno

Resumen – Doce bueyes Boran con un peso vivo medio de $215{,}8 \pm 13{,}9$ kg fueron usados en un experimento con diseño de cuadrado latino incompleto para comparar la absorción aparente de fósforo (P) en ganado vacuno cuando se suplementó la hierba Napier (*Pennisetum purpureum*) con fosfato mineral de Busumbu (BRP), fosfato mineral de Minjingu (MRP), hueso cocido al vapor (SBM), o una mezcla mineral comercial (CMM). Los bueyes se estabularon individualmente y fueron suplementados con P a niveles de 0; 4,5; o 17,5 g de P día-1. La ingestión de materia seca (DMI) y la digestibilidad de la materia seca (DMD), no se vieron afectadas ($p > 0{,}05$) por la fuente de P. La ganancia de peso vivo (LGW) fue diferente ($p > 0{,}05$) según las fuentes de P. El coeficiente de absorción aparente de P del suplemento (CAPA), la DMD y la LWG descendieron linealmente ($p < 0{,}05$) con el periodo. La ingestión de materia seca no difirió significativamente ($p > 0{,}05$) durante los periodos. El nivel de la suplementación de P no tuvo efecto ($p > 0{,}05$) en la DMI o en la LWG. Sin embargo, el incremento del nivel de suplementación de P incrementó significativamente ($p < 0{,}05$) la DMD de la dieta basal. También hubo una interacción significativa ($p < 0{,}05$) entre fuente y nivel para el CAPA. La CMM tuvo el CAPA más elevado, que descendió de 106 a 74,7% con el incremento del nivel de suplementación de P. Para el SBM, el BRP, y el MRP, incrementar el suplemento de P también incrementó el CAPA. Los CAPA para el SBM y BRP, y el BRP y MRP no mostraron diferencias significativas ($p > 0{,}05$). Estos resultados sugieren que el BRP tiene potencial como fuente de P para rumiantes.