JOURNAL OF ANIMAL SCIENCE
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J Anim Sci 2001. 79:19-25.

Effects of grain sorghum planting density and processing method on nutrient digestibility and retention by ruminants[1]

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ABSTRACT: Grain sorghum grown in 38-cm rows (high density [HD]) or 76-cm rows (normal density [ND]) was treated as follows: steam-flaked (SF), high-moisture-harvested followed by rolling and ensiling (HM), or dry-rolled (DR). Resulting grains were evaluated using lambs in two 5 × 5 Latin square digestion trials. Treatment diets contained either SF-HD, SF-ND, HM-HD, HM-ND, or DR-ND grain sorghum in two trials; a 90 or a 60% concentrate diet was fed in each trial. High-density planting increased ($P < 0.10$) the apparent absorption of P relative to ND planting for both 60 and 90% concentrate diets. Steam flaking decreased ($P < 0.10$) the apparent absorption of P in the 90% concentrate diet and decreased ($P < 0.10$) the apparent absorption of N in both the 90 and 60% concentrate diets. Despite differences in N digestibility, steam flaking and HM ensiling resulted in similar ($P > 0.10$) N retention as a percentage of N intake in both trials. However, changes in the distribution of N between feces and urine among processing methods could affect N content of manure and alter nutrient management strategies. These results indicate that both planting density and grain processing can alter the apparent absorption of grain sorghum P by ruminants. Furthermore, it seems that grain processing can alter the route of N excretion in ruminants without changing total N retention.

Key Words: High Density Planting, Ruminants, Sorghum

 J. Anim. Sci. 2001. 79:19–25

Introduction

Management of nutrient inputs and outputs from feedlots requires knowledge of nutrient content of feed ingredients and nutrient excretion data. Feed grains are a major source of nutrients in cattle and sheep finishing operations; hence, understanding how grain processing and(or) agronomic practices affect nutrient content and excretion from grains is vital to nutrient management. Agronomic practices affect the yield, chemical composition, and kernel size of feed grains; however, little is known of the effects that these practices have on the utilization of feed grains by ruminants. Jones and Johnson (1997) indicated that short-season grain sorghum varieties grown in 38-cm rows (high density; 158,147 seeds/ha) matured faster and produced yields similar to or greater than sorghum grown in 76-cm rows (normal density; 79,074 seeds/ha). The extent to which the effects of planting density might interact with subsequent processing method on the in vivo nutrient utilization of grain sorghum by ruminants is unknown. Because dietary roughage concentration also could alter nutrient input-output relationships, we fed a 60% and a 90% concentrate diet in two separate digestion trials with lambs to determine how grain processing and planting density affect the route and extent of N excretion and apparent digestibility of starch, DM, P, Ca, Mg, Cu, Zn, and Mn. Because the minerals evaluated are typically supplemented in cattle and sheep feeding operations, data on the apparent absorption of these minerals might become an important component of nutrient management in feedlots.

Materials and Methods

Ten Saint Croix wethers were used in two separate 5 × 5 Latin square digestion trials at the USDA-ARS Conservation and Production Research Laboratory at Bushland, TX. High-density (**HD**) and normal-density (**ND**) grain sorghum (Pioneer-8699) used in both trials was harvested and processed (steam-flaked [**SF**], dry-rolled [**DR**], or high-moisture-harvested followed by

[1]Funding was provided by the West Texas A&M Univ. Environ. Agric. Initiative, Canyon. The authors thank C. R. Richardson of CFIRE/Texas Tech Univ. for providing the facilities and help with steam-flaking the grains.

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Received April 17, 2000.

Accepted August 29, 2000.

Table 1. Composition of the 90 and 60% concentrate diets fed in each trial

Ingredient	90% Concentrate trial, amounts[a]/100 kg	60% Concentrate trial, amounts[a]/100 kg
Sorghum, kg	72.6	44.8
Alfalfa, dehydrated, kg	5.0	20.0
Cottonseed hulls, kg	5.0	20.0
Cottonseed meal, kg	8.0	6.0
Fat, kg	3.0	3.0
Molasses, kg	5.0	5.0
Ammonium sulfate, kg	0.50	0.50
Salt, kg	0.30	0.30
Potassium chloride, kg	0.20	0
Limestone, kg	0.20	0.20
Magnesium oxide, kg	0.10	0.10
Cobalt chloride, g	0.03	0.001
Copper sulfate, g	0.50	0.20
Manganese sulfate, g	12.0	5.0
Iron sulfate, g	11.3	11.3
Sodium selenite, g	0.04	0.02
Zinc sulfate, g	15.0	15.0
Vitamin E, g[b]	30.0	30.0
Vitamin A, g[c]	5.0	5.0
Tylan premix, g[d]	13.0	0
Rumensin premix, g[e]	25.0	0

[a]Dry matter basis.
[b]88,000 IU of vitamin E/kg.
[c]88×10^6 IU of vitamin A/kg.
[d]Active ingredient = 88 g of tylosin/kg of Tylan premix (Elanco Animal Health, Greenfield, IN).
[e]Active ingredient = 132 g of monensin/kg of Rumensin premix (Elanco Animal Health).

rolling and ensiling [**HM**]) as described by Defoor et al. (2000). The SF grains were spread out on a concrete floor indoors and allowed to air-dry overnight at room temperature after processing to prevent molding during storage. All grains were then stored in metal barrels (approximately 75 L) lined with double plastic bags and mixed into either 60 or 90% concentrate diets approximately every 21 d during the experiment (initial mixing occurred 84 d after harvest for SF and DR grain and 105 d after harvest for HM grain).

The five lambs in the 90% concentrate trial (average BW = 35 kg, approximate age = 8 mo) were fed a diet containing 10% roughage (Tables 1 and 2), whereas the five lambs in the 60% concentrate trial (average BW = 45 kg, approximate age = 8 mo) were fed a diet containing 40% roughage (Tables 1 and 3). Five diets of each concentrate level were formulated to meet all nutrient requirements (NRC, 1985) and contained either the SF-HD, SF-ND, HM-HD, HM-ND, or DR-ND grain sorghum. A dry-rolled, high-density treatment was not included because only 10 lambs were available for use in the two 5 × 5 Latin squares. Lambs were fed once daily at 1030 and were allowed free access to fresh water. Feed allowances were adjusted so that DMI was similar among treatments at approximately 2% of BW. To determine nutrient intake, the weight of feed offered was recorded each day, and a random sample (approximately 50 g) of each diet was obtained beginning 1 d before collection and composited over a 5-d collection period for subsequent analyses. Likewise, feed refusals from individual lambs were weighed and composited over the collection period.

Each period of the Latin squares was 21 d in length. During the first 10 d of each period, lambs were adjusted to diets in individual pens with rubber-coated, expanded metal floors elevated approximately 45 cm above a concrete floor in an air-conditioned building. Lambs were then moved to digestion stalls in the same building for an additional 6-d adaptation period, followed by a 5-d total urine and feces collection period. Each day during the 5-d collection period, collected feces were weighed and stored in a refrigerator. At the end of the 5-d collection period, the feces from each day were mixed in a large bucket, and approximately 300 g was taken for laboratory analyses. The sample was dried at 60°C for 48 h to determine DM content and allowed to air-equilibrate for approximately 3 d before it was ground to pass a 1-mm screen in a Wiley mill. After grinding, feces were stored in plastic bags at room temperature.

Urine was collected from each lamb every 24 h over the 5-d collection period by placing plastic buckets under the digestion stalls to catch urine as it was excreted. Approximately 125 mL of 20% (vol/vol) HCl were added to the urine buckets daily to prevent loss of ammonia. After collection, subsamples of 20% of the total weight of urine from each lamb were composited into individual

Table 2. Chemical composition of the 90% concentrate diets (DM basis)

Component	Diet[a]				
	SF-HD	SF-ND	HM-HD	HM-ND	DR-ND
DM, %	90.1	90.6	69.3	67.9	90.2
OM, %	95.6	95.1	94.8	95.0	95.1
Ash, %	4.4	4.9	5.2	5.0	4.9
NDF, %	17.1	17.9	17.5	15.6	20.6
CP, %	13.7	15.0	14.6	15.6	15.4
Insoluble CP, %	10.9	12.1	10.3	10.6	12.0
Phosphorus, %	0.35	0.37	0.39	0.42	0.41

[a]SF-HD = steam-flaked, high density; SF-ND = steam-flaked, normal density; HM-HD = high-moisture, high density; HM-ND = high-moisture, normal density; DR-ND = dry-rolled, normal density.

Table 3. Chemical composition of the 60% concentrate diets (DM basis)

	Diet[a]				
Component	SF-HD	SF-ND	HM-HD	HM-ND	DR-ND
DM, %	91.5	91.3	77.0	75.7	91.3
OM, %	93.0	93.3	93.6	93.3	93.1
Ash, %	7.0	6.7	6.4	6.7	6.9
NDF, %	37.3	36.6	34.3	34.3	38.7
CP, %	13.9	14.2	14.9	15.1	14.2
Insoluble CP, %	10.7	10.8	10.6	11.0	10.9
Phosphorus, %	0.32	0.31	0.34	0.34	0.41

[a]SF-HD = steam-flaked, high density; SF-ND = steam-flaked, normal density; HM-HD = high-moisture, high density; HM-ND = high-moisture, normal density; DR-ND = dry-rolled, normal density.

containers and stored in a refrigerator. At the end of the 5-d period, approximately 200 mL of urine from the 5-d composite for each lamb was subsampled for analysis and stored frozen.

During the fifth period of the 90% concentrate Latin square, one of the lambs (treatment diet was DR-ND) was diagnosed with urinary calculi and was, therefore, removed from the study. Thus, a missing data point was recorded in the fifth period of the data file for this lamb. In addition, one lamb in the first period and one lamb in the fifth period in both the 90 and 60% concentrate trials had low (< 1% of BW) feed intakes (treatment diets being fed were SF-HD and HM-ND in the 90% concentrate trial and SF-HD and SF-ND in the 60% concentrate trial). The data collected from each lamb during the period in which it had low feed intake were removed from the data file, resulting in a missing data point in periods one and five in both trials.

The percentage of insoluble CP in the diet samples and the DM and starch in the diet samples, orts, and fecal samples were determined as described by Defoor et al. (2000). Nitrogen and P in the diet samples, feed refusals, feces, and urine were determined by digesting samples in a block digester and analyzing the digested sample for ammonia (ammonia-salicylate complex) and P (phospho-molybdenum complex) using automated procedures (Technicon, 1977). Calcium, Mg, Cu, Zn, and Mn were determined by atomic absorption spectroscopy (Model #3110, Perkin Elmer, Norwalk, CT). The NDF content of the diets was determined using the Ankom modification (Vogel et al., 1999) of the procedures of Goering and Van Soest (1970).

Digestibility and retention data were analyzed separately for each trial using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC). Sources of variation included in the model were treatment, period, and animal. Orthogonal contrasts with the residual mean square as the error term were used to detect differences among least squares means. Orthogonal contrasts (Steel and Torrie, 1980) included DR-ND vs the average of HM and SF (for ND only), HM vs SF, HD vs ND (for SF and HM only), and the interaction between processing (SF and HM only) and planting density. Because there was no DR-HD treatment, the DR processing method was not included in the orthogonal contrast for an interaction between processing and planting density.

Results

No differences in total tract DM digestibility ($P > 0.10$) were detected among the treatments in either the 90 or 60% concentrate trials. Starch digestibility values for all treatments in the 90 and 60% concentrate trials were high, averaging approximately 98% to 99%. In both trials, however, starch digestibility was less ($P < 0.10$) for the DR sorghum than for the average of the SF and HM sorghum (Tables 4 and 5).

Total tract N digestibility was greater ($P < 0.10$) for the HM sorghum than for the SF sorghum in both trials (Tables 4 and 5). Nitrogen retention as a percentage of N intake did not differ ($P > 0.10$) among processing methods in either trial but was greater ($P < 0.10$) for HD than for ND sorghum in the 60% concentrate trial (Table 5). No difference ($P > 0.10$) in N retention as a percentage of N intake was detected between the two planting densities in the 90% concentrate trial (Table 4). Nitrogen retention as a percentage of absorbed N was greater ($P < 0.10$) for the SF than for the HM sorghum in the 90% concentrate trial (Table 4) but did not differ ($P > 0.10$) among processing methods in the 60% concentrate trial (Table 5). The N retained as a percentage of N absorbed did not differ between the two planting densities in the 90% concentrate trial, but in the 60% concentrate trial the N retained as a percentage of N absorbed was greater ($P < 0.10$) for HD than for ND sorghum (Table 5).

Apparent absorption of P was greater ($P < 0.10$) for HD than for ND sorghum in both trials (Tables 6 and 7). Apparent absorption of P did not differ ($P > 0.10$) among processing methods in the 60% concentrate trial (Table 7) but was greater ($P < 0.10$) for the HM sorghum than for the SF sorghum in the 90% concentrate trial (Table 6). Planting density did not affect ($P > 0.10$) apparent absorption of Ca with the 90% concentrate diet (Table 6). No differences ($P > 0.10$) were detected in apparent absorption of Ca between the SF and HM sorghum in the 90% concentrate trial; however, the apparent absorption of Ca was greater ($P < 0.10$) for

Table 4. Effects of processing method and planting density on nutrient digestibility and N retention in the 90% concentrate trial

	Processing method and planting density[a]					
	SF		HM		DR	
Item	HD	ND	HD	ND	ND	SEM[b]
DM						
Intake, g/d	648	626	610	651	651	—
Total digestion, %	84.2	83.1	83.2	83.0	84.2	0.95
Starch						
Intake, g/d	375	329	334	356	331	—
Total digestion, %[c]	99.5	99.1	99.3	99.2	98.9	0.12
Nitrogen						
Intake, g/d	13.7	16.2	14.2	16.1	16.3	—
Total digestion, %[d]	68.3	69.9	72.7	74.9	74.5	1.70
Retention, % of intake	24.6	23.4	17.3	21.5	19.0	4.24
Retention, % of absorbed[d]	37.3	33.5	24.0	28.3	25.6	5.24
Urinary excretion[de]	42.8	46.5	55.1	53.7	55.4	3.36

[a]SF = steam-flaked; HM = high-moisture; DR = dry-rolled; HD = high density; ND = normal density.
[b]Values for SEM represent the pooled standard error of the means, n = 5.
[c]DR vs SF and HM ($P < 0.10$).
[d]HM vs SF ($P < 0.10$).
[e]Urinary excretion as a percentage of intake.

the DR sorghum than for the mean of the SF and HM sorghum (39.9 vs 26.2%, respectively). An interaction ($P < 0.10$) between planting density and processing method was detected for apparent absorption of Ca in the 60% concentrate trial. Nonetheless, the only difference detected among the treatment combinations was that apparent absorption of Ca for the SF-HD and HM-ND was greater ($P < 0.10$) than the digestibility of Ca for the SF-ND and HM-HD (Table 7). Apparent absorption of Mg did not differ ($P > 0.10$) among treatments in either trial (Tables 6 and 7).

No differences ($P > 0.10$) in the apparent absorption of Cu, Zn, or Mn were detected among treatments in the 90% concentrate trial (Table 6), nor were any differences detected in the apparent absorption of Cu in the 60% concentrate trial (Table 7). Relative to the HM sorghum, the SF sorghum had a greater ($P < 0.10$) apparent absorption of Zn in the 60% concentrate trial. In addition, the apparent absorption of Zn in the 60% concentrate trial was greater ($P < 0.10$) for HD than for ND sorghum (Table 7). Planting density did not affect ($P > 0.10$) the apparent absorption of Mn in the

Table 5. Effects of processing method and planting density on nutrient digestibility and N retention in the 60% concentrate trial

	Processing method and planting density[a]					
	SF		HM		DR	
Item	HD	ND	HD	ND	ND	SEM[b]
DM						
Intake, g/d	868	891	916	881	922	—
Total digestion, %	74.1	74.1	74.2	73.3	74.1	0.62
Starch						
Intake, g/d	328	310	306	311	285	—
Total digestion, %[c]	98.2	98.4	98.0	98.4	97.9	0.21
Nitrogen						
Intake, g/d	19.3	20.2	21.9	21.3	20.9	—
Total digestion, %[d]	63.4	64.5	67.3	66.8	66.7	1.03
Retention, % of intake[e]	21.4	17.5	24.1	17.8	19.6	2.01
Retention, % of absorbed[e]	33.3	27.2	35.7	26.1	29.2	2.93
Urinary excretion[f]	42.3	47.0	43.3	49.4	47.2	4.57

[a]SF = steam-flaked; HM = high-moisture; DR = dry-rolled; HD = high density; ND = normal density.
[b]Values for SEM represent the pooled standard error of the means, n = 5.
[c]DR vs SF and HM ($P < 0.10$).
[d]HM vs SF ($P < 0.10$).
[e]HD vs ND ($P < 0.10$).
[f]Urinary excretion as a percentage of intake.

Table 6. Effects of processing method and planting density on apparent absorption of trace and macrominerals in the 90% concentrate trial

	Processing method and planting density[a]					
	SF		HM		DR	
Item	HD	ND	HD	ND	ND	SEM[b]
Phosphorus						
Intake, mg/d	2,062	2,117	2,357	2,732	2,637	—
Apparent absorption, %[cde]	49.5	41.9	60.7	53.6	59.5	3.73
Calcium						
Intake, mg/d	2,304	2,412	2,493	2,518	2,536	—
Apparent absorption, %[c]	18.2	31.3	28.5	26.7	39.9	6.48
Magnesium						
Intake, mg/d	1,602	1,680	1,854	1,968	1,995	—
Apparent absorption, %	55.1	57.0	59.2	62.3	62.7	2.35
Copper						
Intake, mg/d	5.6	5.6	5.4	5.7	6.0	—
Apparent absorption, %	24.1	19.2	15.8	14.6	21.7	5.88
Zinc						
Intake, mg/d	45.1	43.6	46.3	47.0	47.0	—
Apparent absorption, %	15.2	12.3	10.6	11.1	9.5	5.59
Manganese						
Intake, mg/d	45.8	44.7	48.4	49.1	54.1	—
Apparent absorption, %	8.6	6.9	11.5	7.7	11.0	7.92

[a]SF = steam-flaked; HM = high-moisture; DR = dry-rolled; HD = high density; ND = normal density.
[b]Values for SEM represent the pooled standard error of the means, n = 5.
[c]DR vs SF and HM ($P < 0.10$).
[d]HM vs SF ($P < 0.10$).
[e]HD vs ND ($P < 0.10$).

Table 7. Effects of processing method and planting density on apparent absorption of trace and macrominerals in the 60% concentrate trial

	Processing method and planting density[a]					
	SF		HM		DR	
Item	HD	ND	HD	ND	ND	SEM[b]
Phosphorus						
Intake, mg/d	2,531	2,852	3,135	2,992	3,053	—
Apparent absorption, %[c]	22.1	17.5	22.3	15.1	15.7	3.82
Calcium						
Intake, mg/d	6,157	6,018	6,095	6,096	6,638	—
Apparent absorption, %[d]	31.4	20.7	22.7	29.8	28.3	3.88
Magnesium						
Intake, mg/d	2,742	2,906	2,887	2,730	3,015	—
Apparent absorption, %	47.1	44.0	42.9	41.9	44.5	2.26
Copper						
Intake, mg/d	8.5	8.7	7.5	7.4	10.1	—
Apparent absorption, %	32.9	27.7	26.6	21.1	23.1	4.11
Zinc						
Intake, mg/d	67.5	69.6	62.0	63.6	75.2	—
Apparent absorption, %[ce]	24.7	16.2	16.9	12.5	19.3	2.25
Manganese						
Intake, mg/d	55.4	55.2	49.0	49.6	63.9	—
Apparent absorption, %[ef]	23.9	18.2	15.3	15.2	25.5	1.50

[a]SF = steam-flaked; HM = high-moisture; DR = dry-rolled; HD = high density; ND = normal density.
[b]Values for SEM represent the pooled standard error of the means, n = 5.
[c]HD vs ND ($P < 0.10$).
[d]Processing × density ($P < 0.10$).
[e]HM vs SF ($P < 0.10$).
[f]DR vs SF and HM ($P < 0.10$).

60% concentrate trial; however, the apparent absorption of Mn was greater ($P < 0.10$) for DR sorghum than for the average of SF and HM sorghum and was greater ($P < 0.10$) for SF sorghum than for HM sorghum with the 60% concentrate diet (Table 7).

Discussion

Starch digestibilities of the HM and DR grain were higher and more similar to the SF sorghum than would be expected when these grains are fed to cattle (Theurer, 1986). This result might be attributable to the lower intakes by our sheep as a percentage of BW, or to the ability of the sheep to masticate grain to a greater extent than cattle, thereby negating much of the difference in starch availability between extensively and nonextensively processed sorghum (Ørskov, 1986).

The greater total tract digestibility of N in the HM relative to the SF sorghum is consistent with greater solubility of N in the HM than in the SF sorghum (Defoor et al., 2000). Although less N in the SF sorghum was absorbed compared with the HM sorghum, a greater proportion of the absorbed N from the SF sorghum in the 90% concentrate trial was retained, resulting in no difference ($P > 0.10$) in the N retention as a percentage of N intake between the two processing methods. Moreover, urinary excretion of N as a percentage of N intake was less ($P < 0.10$) for SF than for HM sorghum when fed in the 90% concentrate diets (Table 4). Similar results were reported by Sip and Pritchard (1991), who fed corn-based diets with four levels of CP to steers in one trial and two levels of CP to lambs in a second trial. Nitrogen retention as a percentage of N intake increased as the level of CP decreased in the first trial, and the diet with the lower CP digestibility had the higher N retention as a percentage of N absorbed in the second trial (Sip and Pritchard, 1991).

Changes in the distribution of N between feces and urine among processing methods could affect N content of manure and alter nutrient management strategies. The N digestibility and retention data from the 90% concentrate trial suggest that when grain sorghum is fed in high-concentrate diets, the method of processing has a greater effect than planting density on the digestibility and retention of N. In high-concentrate diets, the overall retention of N seems to be approximately equal for SF and HM sorghum, despite differences in N digestibility. Eskeland et al. (1973) reported that i.v. infusion of glucose and propionate increased N retention by decreasing urinary N excretion, whereas acetate and butyrate were much less effective. Thus, it is possible that the greater retention of absorbed N by lambs fed the high-concentrate SF sorghum diets compared with the HM and DR sorghum diets could have resulted from greater propionate production associated with the SF sorghum diets. Because propionate is a major source of glucose via gluconeogenesis in ruminants, it is likely that greater production of propionate results in increased glucose available to fuel protein deposition and spare amino acid oxidation by the animal, thereby decreasing N excreted in the urine (Matras and Preston, 1989).

As in the 90% concentrate trial, the N digestibility and retention data from the 60% concentrate trial suggest that processing had the greatest effect on total tract digestibility of N. However, in contrast to the data from the 90% concentrate trial, HD planting increased the N retention as a percentage of N intake and the N retention as a percentage of N absorbed. Because no differences in N digestibility were detected ($P > 0.10$) between the two planting densities, the higher N retention as a percentage of N intake and the higher N retention as a percentage of N absorbed resulted from lower urinary excretion of N by the lambs fed the HD sorghum. Reasons for this difference in N retention are not clear.

Assuming that ruminal pH was less when lambs were fed the SF sorghum (Defoor et al., 2000), this might have decreased the activity of phytase enzyme (Kemme et al., 1997) in the rumen and caused the lower P digestibility in the SF sorghum relative to the HM sorghum. It also seems possible that the heat involved in the steam flaking process might somehow have altered the digestibility of P in the SF grain. The total tract digestibility of P did not differ ($P > 0.10$) among processing methods in the 60% concentrate trial, perhaps because ruminal pH of the animals fed the high-roughage diets might not have differed markedly among processing methods. Reasons for the greater apparent absorption of P with the HD diets in both trials are not clear. Effects of planting density and grain processing on P excretion should provide data for establishing nutrient management plans when sorghum grain is fed to confined ruminants.

The Ca digestibility data from the 90 and 60% concentrate trials suggest that Ca digestion was not affected by sorghum planting density. However, the data from the 90% concentrate trial suggest that relative to dry rolling, steam flaking and high-moisture ensiling might decrease the apparent absorption of Ca. The reason for this effect is unclear.

With the exception of small changes in apparent absorption of Zn and Mn with the 60% concentrate diet, no major effects of planting density and processing method were noted for nutrient balance patterns of the trace minerals that we evaluated. These results suggest that manipulation of trace mineral excretion would be most effective by changing inputs rather than by attempting to alter trace mineral absorption or retention.

Implications

These data should be useful in defining nutrient input-output relationships for cattle feeding operations in which processed sorghum is the primary dietary grain. Although high-density planting had limited effects on dry matter, N, and starch digestibility, it increased the apparent absorption of P in both 60 and 90% concentrate diets. In contrast, steam flaking decreased the apparent absorption of P relative to high-moisture ensiling and dry rolling. Hence, planting density and steam flaking might alter excretion of P and potential nutrient management planning. Based on our results, however, neither planting density nor processing method would greatly alter total N excretion, but processing might alter the route of N excretion by ruminants.

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