

Efficacy of sheep as a digestibility model for cattle when fed concentrate-based or forage-based diets

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ABSTRACT: The objectives were to determine the efficacy of sheep as a digestibility model for cattle feeding two diets, forage or concentrate based, under current genetics. Twelve Suffolk wethers were blocked into two periods with six wethers in each period. Within each period, wethers were fed a forage-based diet ($n = 3$) or a concentrate-based diet ($n = 3$). Six angus steers were also fed a forage-based diet ($n = 3$) or a concentrate-based diets ($n = 3$) in switchback design with two periods. All animals were adapted to diets for a minimum of 3 wk, then feed intake, refusals, and feces were collected. Feed and fecal dry matter (DM), organic matter (OM), neutral detergent fiber (NDF), acid detergent fiber (ADF), and starch were analyzed. Refusals were analyzed for DM. Data were analyzed using Proc Mixed in SAS with diet and species as fixed and period as a random effect. Dry matter intake as percentage of body weight for each animal within each period was used as a covariable. There was an

interaction ($P < 0.01$) between species and diet for DM and OM digestibility. When fed the concentrate-based diet, DM and OM digestibility were similar between wethers and steers ($P > 0.18$); however, when fed the forage-based diet, DM and OM digestibility was less ($P < 0.01$) for wethers than steers. Like DM and OM, an interaction ($P < 0.05$) between species and diet was present for starch digestibility. When fed the forage-based diet, starch digestibility did not differ ($P = 0.66$) between wethers and steers; however, when fed concentrate-based diet, wethers had a greater starch digestibility ($P < 0.05$) than steers. There was no interaction ($P > 0.45$) between species and diet for NDF and ADF digestibility. Regardless of the diet fed, NDF and ADF digestibilities were greater ($P < 0.05$) in steers than wethers. Present day sheep were not a good model for cattle when fed forage-based diets, but sheep were an acceptable model for cattle when fed concentrate-based diets.

Key Words: cattle, concentrate, digestibility, forage, sheep

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INTRODUCTION

For over 100 yr, sheep have been used as a model for the ruminant system because they are less expensive to purchase and feed than cattle. However, it has also been traditionally accepted

that forages with 65% or more neutral detergent fiber (NDF) are more readily digested by cattle than sheep due to greater ruminal retention times for cattle than sheep (Playne, 1978; Prigge et al., 1984). In the last 25 yr, the only study comparing forage digestibility between the two species (Soto-Navarro et al., 2014) found no difference in dry matter (DM), NDF, or acid detergent fiber (ADF) digestibility between cattle and sheep fed grass hay with 75% NDF. Similarly, most

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recent studies comparing concentrate digestibility between cattle and sheep (O'Mara et al., 1999; Woods et al., 1999) have also contradicted the earlier literature that suggested that sheep are superior concentrate digesters to cattle by reporting similar digestibility between cattle and sheep for most concentrate feeds.

Despite the common assumption that sheep are good models for cattle and the abundance of data published under that assumption (National Research Council (NRC), 2001; Cole et al., 2003), there is a dearth of recent information comparing nutrient digestibility between sheep and cattle. In most previous studies, either individual forage (Playne, 1978; Prigge et al., 1984; Soto-Navarro et al., 2014) or concentrate (O'Mara et al., 1999; Woods et al., 1999) ingredients have been compared between two species. There is limited research available comparing forage- and concentrate-based diets between two species when fed a total mixed ration (Colucci et al., 1989). Thus, the objectives of our study were to determine the efficacy of using sheep as a digestibility model for cattle when fed diets differing in forage:concentrate. We hypothesized that in present-day genetics, sheep are a good model for cattle digestibility when feeding concentrate-based diet, but their efficacy as a digestibility model for cattle is impacted when feeding forage-based diets.

MATERIALS AND METHODS

All procedures for animal use were approved by the Pennsylvania State University Institutional Animal Care and Use Committee (No. 47773 for sheep and No. 47255 for cattle). This experiment was conducted at the Beef Nutrition Research Lab (State College, PA) of the Pennsylvania State University. Two diets, concentrate based and forage based, were formulated using grass hay, dry rolled corn, soybean meal, and urea (Table 1). Diets were formulated for each species to meet growth requirements according to the National Academies of Sciences, Engineering, and Medicine (2016) for steers and NRC (2007) for wethers. Within species, there was an attempt to formulate isonitrogenous diets according to book values. However, the crude protein of the concentrate-based diet for wethers was 2% less than their forage-based diet because the corn contained less protein than expected values (6.1% vs. 8.5%; Table 1). Different mineral supplements for wethers and steers were used to ensure species requirements were met.

Animal and Diet Management

Twelve Suffolk wethers [body weight (BW) = 49.9 ± 5.8 kg; 4.9 ± 0.3 mo of age] were blocked into two periods with six wethers in each period. Within each period, wethers were divided into two groups (A and B) with three wethers in

Table 1. Diet composition for wethers and steers

Ingredients, % DM	Concentrate		Forage	
	Steer	Wethers	Steer	Wethers
Grass hay ¹	20.00	20.00	80.00	80.00
Ground corn	71.00	69.80	9.25	8.10
Soybean meal	7.00	8.45	8.75	10.15
Mineral and vitamin supplement ^{2,3}	2.00	0.75	2.00	0.75
Urea	0.00	0.50	0.00	0.50
NH ₄ Cl	0.00	0.50	0.00	0.50
Analyzed nutrient composition, % DM				
DM	63.4	85.7	70.8	85.7
NDF	19.7	20.7	54.3	56.8
ADF	9.0	9.3	30.0	29.9
Starch	53.8	47.8	8.4	7.1
CP	12.1	11.9	11.7	14.1

¹Grass hay fed to steers had 66.1% NDF, 36.8% ADF, and 7.20% crude protein (CP), while grass hay fed to wethers had 69.0% NDF, 36.6% ADF, and 8.57% CP.

²Mineral and vitamin premix composition for steers (min values): 35.6% urea, monensin 1,550 g/ton, Ca 25%, NaCl 15%, P 4.00%, Salt 14.40%, Mg 1.00%, K 3.50%, Zn 1,000 mg/kg, Cu 180 mg/kg, Se 16 mg/kg, and Vit A 130,000 IU/lb.

³Mineral and vitamin premix composition for wethers (min values): Ca 16.54%, P 4.00%, NaCl 14.40%, Cl 10.07%, Na 5.06%, Mg 2.00%, K 0.500%, S 1.00%, C 20.00 mg/kg, Cu 0.00 mg/kg, I 80.00 mg/kg, Fe 1,797.41 mg/kg, Mn 1,500 mg/kg, Se 38 mg/kg, Zn 1,500 mg/kg, Niacin 1.81 mg/kg, Choline 35.50 mg/kg, Vit A 181,800 IU/lb, Vit D 58,750 IU/lb, and Vit E 227 IU/lb.

each group. Wethers in group A were fed a forage-based diet, while wethers in group B were fed a concentrate-based diet. Digestibility collection was done in two periods, six wethers (three from each treatment group) in period 1 and six wethers (three from each treatment group) in period 2. Thus, each period was balanced for treatment but set to allow for total fecal collection on all 12 wethers. Wethers were fed for ad libitum intake. Wethers were adapted for 3 wk to their respective diets before being shifted, by period, to metabolism crates for total collection. Wethers were acclimated to the metabolism crates for 2 d and then total collection of feces and orts was conducted in the metabolism crate for the next 96 h to determine DM, OM, NDF, ADF, and starch digestibility. Feces were collected with a plastic bucket placed under the metabolism crate. Wethers were fed equal portions of the daily ration twice a day, at 0830 and at 1630 h, while in metabolism crates ($1.37 \times 0.56 \times 0.91$ m).

Six Angus steers (BW = 499 ± 28 kg, 15 ± 1 mo of age) were also split into two groups (A and B) with three steers in each group. Steers were fed in a crossover design. In period 1, steers from group A were fed a forage-based diet, while group B steers were fed a concentrate-based diet. In period 2, steers from group A were fed a concentrate-based diet, while group B steers were fed a forage-based diet. Each period was of 35 d, with 4 wk of diet adaptation and 1 wk of total collection. Steers were fed equal portions of the ration twice a day, at 0630 and at 1530 h, in individual tie stalls (1.83×1.35 m) with rubber mat flooring. Intake was restricted to 2% of steer BW (DM basis) in both periods. In addition, 10% inclusion of water was added to each diet to improve palatability of feed. The addition of water and the restriction of feed intake placed on the steers differed from the management of the wethers. However, these management decisions were necessary to ensure cattle consumed the diet and transitioned without ruminal upset in the crossover design. Total fecal output was collected in coated canvas fecal bags attached to the steers with a leather harness during the collection phase.

Sampling and Analysis

During the collection period of 96 h for both steers and wethers, total feed offered and refused was weighed daily. Each day of collection, 100 g of each feed ingredient was saved and composited at the end of the collection phase into one sample for analysis. Feces were collected twice per day and

10% of collected feces were saved and stored. Fecal and feed refusal samples collected over 96 h were composited by animal to make one sample per animal for each collection period. Feed, refusal, and fecal samples were stored in the -20 °C freezer between collections. A subsample of the composited feed ingredient, fecal, and refusal samples were analyzed for DM (24 h at 105 °C). The remaining wet individual feed ingredient and composited fecal samples were dried for 48 h at 55 °C, then ground through a Wiley mill (1 mm screen, Arthur H. Thomas, Philadelphia, PA). Ground samples of feces and feed were then analyzed for ADF and NDF (using Ankom Technology methods 5 and 6, respectively; Ankom200 Fiber Analyzer, Ankom Technology, Macedon, NY), starch by the method of Hall (2009), and total ash (500 °C for 12 h, HotPack Muffle Oven Model: 770750, HotPack Corp., Philadelphia, PA) to calculate digestibility.

Statistical Analysis

Data were analyzed using Proc Mixed in SAS (vs 9.4 SAS Inst., Cary, NC) with diet, species, and the interaction as fixed effects. The fixed effect of period was tested but not significant; therefore, period was included as a random effect. Dry matter intake as percentage of body weight for each animal within each period was used as a covariate. One steer fed the concentrate-based diet was removed from a single collection period. One wether fed the concentrate-based diet was also removed from collection period.

RESULTS

There was an interaction between species and diet for DM ($P < 0.01$) and OM ($P < 0.01$; Table 2) digestibility. When fed a concentrate-based diet, steers had similar OM digestibility to wethers; however, when fed a forage-based diet, steers had a 45% greater OM digestibility than wethers. Similarly, for DM, when fed a concentrate-based diet, steers had similar digestibility to wethers and when fed a forage-based diet steers had a 52% greater digestibility than wethers.

There were no interactions ($P \geq 0.46$) between species and diet for NDF or ADF digestibility (Table 2). However, there were main effects of both species and diet ($P < 0.01$). When fed concentrate-based diet, steers had an NDF digestibility that was 2.5 times and ADF digestibility that was 3.6 times greater than wethers. Similarly, when fed forage-based diet, ADF digestibility was 1.9 times

Table 2. Effect of ruminant species, steers or wethers, and diet, forage or concentrate based, on intake, fecal output, and apparent total tract digestibility

Item, DM basis	Concentrate		Forage		SEM	<i>P</i> -values ¹		
	Steers	Wethers	Steers	Wethers		S	D	S × D
DM								
Intake, g	9,567	1,089	7,664	794	170	<0.01	<0.01	<0.01
Fecal output, g	2,453	304	2,121	416	132	<0.01	0.38	0.09
Digestibility, %	74.0	70.5	73.4	48.3	2.3	<0.01	<0.01	<0.01
OM								
Intake, g	9,095	1,052	7,229	747	160	<0.01	<0.01	<0.01
Fecal output, g	2,284	281	1,937	372	130	<0.01	0.30	0.08
Digestibility, %	74.6	72.2	74.0	50.9	2.4	<0.01	<0.01	<0.01
NDF								
Intake, g	1,885	226	4,164	451	83.6	<0.01	<0.01	<0.01
Fecal output, g	754	160	1,221	268	56.1	<0.01	<0.01	<0.01
Digestibility, %	58.1	23	74.2	43.1	5.4	<0.01	<0.01	0.52
ADF								
Intake, g	863	100	2,295	238	45.8	<0.01	<0.01	<0.01
Fecal output, g	356	75.4	727	155	29.5	<0.01	<0.01	<0.01
Digestibility, %	56.3	15.8	72.8	37.8	6.2	<0.01	<0.01	0.46
Starch								
Intake, g	5,144	521	642	56.7	42.8	<0.01	<0.01	<0.01
Fecal output, g	587	22.1	28.3	3.0	85.3	<0.01	<0.01	<0.01
Digestibility, %	88.8	97.1	95.7	94.7	2.8	0.08	0.47	0.02

¹S = effect of species; D = effect of diet; S × D = interaction of species and diet.

and NDF digestibility was 1.7 times greater for steers than wethers.

There was an interaction ($P = 0.01$) between species and diet for starch digestibility (Table 2). Contrary to OM and DM digestibility, when fed a forage-based diet, steers had similar starch digestibility to wethers; however, when fed a concentrate-based diet, steers had 9.3% less starch digestibility than wethers.

DISCUSSION

Although sheep have long been used as model for cattle digestion (Cipolloni et al., 1951), different opinions do exist about whether sheep digestibility results could be extrapolated to cattle or not (Lindgren, 1981; Colucci et al., 1989). In addition to these conflicting opinions, most of the research in the area is dated. Therefore, the objectives of this study were to determine the efficacy of sheep as a digestibility model for cattle using two diets, forage or concentrate based. In our study, the two diets tested between the species were fed as a total mixed ration (TMR) containing several ingredients (Table 1), but in most previous studies referenced throughout the discussion, either individual forage (Playne, 1978; Prigge et al., 1984; Soto-Navarro et al., 2014)

or concentrate (O'Mara et al., 1999; Woods et al., 1999) ingredients have been compared.

Historically, cattle were known to have superior digestibility of grass when compared with sheep (Rees and Little, 1980) because they can retain grasses for a longer time in rumen than sheep (Prigge et al., 1984). For example, the digestibility of switchgrass (73% NDF) was 17.4% greater in cattle compared with sheep (Prigge et al., 1984). Similarly, the digestibility of grass hay (70% NDF) was 43% greater when it was fed to cattle compared with when it was fed to sheep (Playne, 1978). In our study, a similar trend was present, steers had greater DM and OM digestibility than wethers when fed forage-based diet, but the magnitude of the difference between the species was greater than previous reports that fed grass hay of similar quality (Playne, 1978; Prigge et al., 1984). Part of this greater DM digestibility difference between species may be attributed to the fact that the steers in our experiment had greater fiber digestibility (NDF and ADF) than those in the Playne (1978) experiment. In the current study, steers fed the forage-based diet had 72% greater NDF and 93% greater ADF digestibility when compared with the wethers. Even though the dietary NDF was about 25% less in the current study than that of the diets fed by Playne (1978), this author observed that while steers had

greater NDF and ADF digestibility than wethers, the difference was only 46% and 37%, respectively. Thus, the magnitude of the difference was much less than the current experiment. In the last few decades, greater selection pressure has been applied in the beef industry which may be one of the reasons for the improvements noted in digestibility for the steers when compared with past research.

While these data may suggest that steers with present-day genetics have a superior ability to digest forage when compared with wethers, other factors have to be considered. Results from the current experiment are also not consistent with the most recently published study (Soto-Navarro et al., 2014) on comparative forage digestibility in sheep and cattle. Soto-Navarro et al. (2014) found no difference in OM, NDF, and ADF digestibility of a warm-season grass hay mix (75% NDF) between steers and wethers. The OM, NDF, and ADF digestibility reported by Soto-Navarro et al. (2014) was more than 80%, far greater than observed in our experiment or by Playne (1978) and Prigge et al. (1984). One key difference between the studies worth noting, however, is that the current study employed total fecal collection to calculate digestibility, whereas Soto-Navarro et al. (2014) used the fecal grab method and the use of chromic oxide as a digesta marker. The use of chromic oxide as an external digestibility marker for a forage-based diet may cause more variation in results than total fecal collection because chromic oxide passes from the rumen more quickly than coarse fiber particles (Van Soest, 1994). Thus, the method used for digestibility evaluation should be considered, as well as the species and diet comparisons, when comparing different studies.

Another area where the methodology differed was that in our study the steers were restricted, whereas wethers were fed for ad libitum intakes; thus, wethers did have refusals. The steers were limit-fed to reduce the risk for ruminal upsets and to aid the transition when feeding the forage- and concentrate-based diets in a switchback design. Colucci et al. (1989) fed diets of varying forage and concentrate proportions at several different intakes. These authors report that greater intakes depressed the digestion of NDF and ADF in both cattle and sheep. Therefore, some of the depression noted in NDF and ADF concentrations between the species in our study could have been related to intake. However, in the present study, Angus steers were targeted to consume 2% of their BW (on DM basis) and actually consumed 1.9% and 1.5% (on DM basis) of their BW on average when fed the concentrate- or the forage-based diet, respectively.

Meanwhile, wethers in the present study consumed 2.2% and 1.6% (on DM basis) of their BW on average when fed the concentrate- or the forage-based diets, respectively. Typically, sheep consume a larger percentage of their BW than cattle, so this reduced intake may have influenced these results. Even still, while the slightly reduced intake for steers might have improved their DM digestibility (Van Soest, 1994), DM intake as a percent of BW was not vastly different between the species when fed the concentrate- or forage-based diets.

In our experiment, starch digestibility was similar between species when a forage-based diet was fed. In agreement with our study, Colucci et al. (1989) reported similar starch digestibility for sheep and cattle fed a 70% forage diet (47% NDF) at restricted intake (1.3% to 1.4% BW). In our study, intake (as a percent of BW) for steers and wethers was consistent with the restricted intake of cattle and sheep reported by Colucci et al. (1989) when fed the concentrate-based diets.

It is important to note, while evaluating comparisons with previous data, that when animals were fed the concentrate-based diet in the present experiment, the diet contained 69.8% and 71% corn for wethers and steers, respectively. To the best of our knowledge, there is no study available comparing the digestibility of diet with $\geq 60\%$ corn in these two species. Perhaps the closest comparison comes from Colucci et al. (1989), and they evaluated the digestibility of a corn-based diet between sheep (58.55% corn inclusion DM basis) and lactating dairy cows (56.25% corn inclusion DM basis). Therefore, data are discussed relative to summaries from previous experiments, bearing in mind that the corn inclusion is greater in the present concentrate-based diets than in past experiments.

At ad libitum intakes, DM and starch digestibility was greater for sheep than cattle when fed corn-based diets (Colucci et al., 1989). In the present study, a similar trend was present for starch digestibility as wethers had greater starch digestibility than steers. However, the DM digestibility results conflict with Colucci et al. (1989) because wethers had similar DM digestibility to steers. One reason this may have occurred is that in the present study, steers consumed 42% less DM (1.9 vs. 3.3%) than the cattle used by Colucci et al. (1989). For wethers, DM intake was 20% less (2.2% vs. 2.76%) than the intake of sheep reported in Colucci et al. (1989). Digestibility is more negatively affected by greater intake in cattle than in sheep (Colucci et al., 1989). The lesser intake for steers might have improved their DM digestibility (Van Soest, 1994).

The similar DM and OM digestibilities between steers and wethers when fed concentrate-based diets in this experiment are in agreement with the most recent studies published by O'Mara et al. (1999) and Woods et al. (1999) comparing different individual concentrate sources between these two species. These authors reported sheep to be an acceptable digestibility model for young cattle when fed a wide range of concentrates, that is, barley, citrus pulp, beet pulp, maize gluten feed, or grain screenings, copra meal, sunflower meal, dry corn gluten feed, dry corn gluten feed, soyhulls, and palm kernel meal. However, it is important to note that they did not feed a TMR but fed the individual components only.

Corn is the most widely used concentrate feed in the U.S. livestock industry and, traditionally, sheep have been regarded as having superior concentrate digestibility when compared with cattle (Cipolloni et al., 1951). The results from the present experiment appear to agree that sheep have greater starch digestibility when compared with cattle when fed a concentrate-based diet. However, cattle have greater NDF and ADF digestibility when compared with wethers, regardless of the diet type, concentrate or forage based. In this study, present-day sheep and cattle were more comparable when fed concentrate-based diets than when fed forage-based diets when DM and OM only were considered, but their ability to utilize different nutrient fractions varied based on the diet type.

CONCLUSION

Data from the current experiment suggest that greater digestibility differences exist between sheep and cattle when fed forage-based diets. Apparent total tract digestibility coefficients were more similar between sheep and cattle when fed concentrate-based diets. Sheep were not an adequate model for cattle when fed forage-based diets but were an acceptable model for cattle when concentrate-based diets were fed. Therefore, when fed a total mixed ration, present-day sheep may be an adequate digestibility model for cattle when fed concentrate-based diets.

Conflict of interest statement. None declared.

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