The Effect of Intake Level of a Soy Hull Diet on Digestibility in Ram Lambs and Mature Non-Lactating Ewes

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by
Danielle C. Hein
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Dr. Michael Thonney

Abstract

There is a positive effect of soy hull feed supplementation on production and intake in ruminants. This is due to the high fraction of fermentable neutral detergent fiber (FNDF) found in soy hulls, which is highly digestible by rumen microbes and may optimize VFA production for rumen health. However, high levels of intake of a soy hull diet can decrease digestibility due to an increased rate of passage. In this project, the effect of feeding soy hull-based diets at intake levels of 2, 3, or 4% of body weight was quantified in weanling ram lambs and mature, non-lactating ewes. The apparent dry matter digestibility (DMD) and digestibility of NDF were quantified using a chromium marker which was measured in the feed and feces. In ram lambs, apparent DMD decreased by 8.3 percentage units and digestibility of NDF decreased by 12.1 percentage units for each 1 percentage unit increase in DMI as a percentage of BW ($P<0.001$). In mature ewes, the depression in digestibility was less pronounced, with DMD decreasing by 2.9 percentage units and digestibility of NDF decreasing by 4.5 percentage units for each 1 percentage unit increase in DMI as a percentage of BW ($P = 0.034$). These experiments demonstrated a linear decrease in digestibility with increased intake, and the decrease was less severe in sheep being fed at or near their maintenance requirement.

Acknowledgements

I would like to express my gratitude to everyone who guided and supported me through this project. Namely I would like to thank Debbie Ross, who taught me numerous laboratory techniques and oversaw my use of the lab for the two-year duration of this project; Natasha Pettifor, a graduate student under Dr. Thonney who assisted me with chores at the Teaching and Research Center sheep barn; Brian Weitzner, who came out to the barn with me and helped collect sheep poop for an afternoon; and the barn manager Brian Magee. I would also like to thank Dr. Susan Quirk for her leadership and guidance as the chair of the honors committee in animal sciences, and for always being very helpful and supportive. Finally, I would especially like to thank my research advisor Dr. Michael Thonney, without whom this project obviously would not have been possible, but who also made it a very pleasant, virtually stress-free, fun, and educational experience. Dr. Thonney personally helped me with everything from scooping sheep poop at the barn to helping edit the following document.

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Introduction

A diet that includes soy hulls has been shown to increase intake and production in dairy cows and sheep (Ipharraguerre & Clark, 2003; Araujo R. C., *et al*., 2008a; Araujo R. C., *et al*., 2008b). The reason for this effect is not fully understood, although researchers at Cornell University have long postulated that including a minimum level of highly-fermentable fiber in diets can increase intake (Thonney & Hogue, 1999). The improvement in production due to soy hull supplementation is often attributed to the improvement in digestibility of this ingredient compared to hay, especially when soy hulls increase intake simultaneously. However, improvement in production may also be due to optimization of volatile fatty acid (VFA) production in the rumen by rumen microbes. Ruminal fermentation of the non-structural carbohydrates found in grains causes a high proportion of lactic acid production, which can lead to ruminal problems such as acidosis. However, the highly-fermentable fiber found in soy hulls results in optimal ruminal VFA production and does not have the adverse effect of high lactic acid production (Elliot, Drackley, Fahey, & Shanks, 1995).

As soy hulls become a more expensive feed supplement, the effect of high intakes of this ingredient on digestibility is an important consideration. Higher intake increases rate of passage of feed through the digestive tract, decreasing the time for digestion. A recent experiment on the effect of a soy hull-based diet on production, intake, and digestibility in lactating ewes demonstrated fiber digestibility as low as 32% in a diet that that contained 35% FNDF (Schotthofer, 2007). From this information, it can be concluded that quantification of the depression in digestibility with increasing intake of a high-fiber diet is important to maximize production efficiency in ruminants. The purpose of the experiments in the present study was to quantify the effect of feeding increasing amounts of a high-fiber soy hull-based diet on digestibility in weanling ram lambs and in non-lactating mature ewes.

Review of the Literature

Increasing Intake Decreases Digestibility

In 1967, researchers D.G Wagner and J. K. Loosli at Cornell University established a negative relationship between intake level and digestibility of a diet, specifically observing that this negative relationship was less pronounced in diets of increasing hay:concentrate ratios (Wagner & Loosli, 1967). They concluded from this experiment that the digestibility of any diet decreases with increasing intake, but that this phenomenon occurs to a greater extent with a greater percentage of concentrate in the diet. As indicated later in the present thesis, this finding has important implications in animal agriculture, whereby farmers cannot always feed high-producing dairy cattle enough to supply their needs, even on a high concentrate diet that is rich in energy and other nutrients. The information presented by Wagner & Loosli (1967), which tied depression in digestibility with increased intake to concentrate level, was among the first to suggest that the hay:concentrate ratio can be manipulated in order to increase productivity and digestibility of feed at high intake levels.

Effects of Dietary NDF on Intake

Since 1967, methods for evaluating the quality of a feed source have been developed that can predict digestibility and intake based on forage content (Van Soest, 1967). The main assay in these methods determines the neutral detergent fiber (NDF) content in the diet. NDF analysis measures the proportion of cell wall and structural components lignin, hemicellulose, and cellulose in a feed ingredient. This measurement, therefore, is a direct reflection of the fraction of structural plant fiber, which is often associated with a lower digestibility and energy content. It is widely accepted that feed intake is limited for animals fed high-forage diets by physical constraints, or "gut fill," as can be predicted by the level of dietary NDF. Thus, even if the digestibility of forages decreases less with increased intake levels than does the digestibility of concentrates, animals may not be able to consume enough forage to meet their nutritional needs.

In 1987, Dr. Hogue presented evidence that the level of indigestible NDF (INDF), which constitutes a portion of NDF, has an effect on voluntary feed intake by lambs (Hogue, 1987). He showed that high (15%) INDF levels did not restrict intake, but instead that lambs fed a diet high in INDF would adjust their intake level to meet their nutritional needs and would gain the same as lambs fed a diet lower in INDF.

In another experiment, Hogue (1987) investigated the effects of higher INDF concentrations on intake, using soy hulls and oat hulls as dietary fiber sources. At equal levels of INDF, the rate and extent of fermentation determined *in vitro* was found to be greater in the soy hull than in the oat hull diets, indicating that soy hulls have a higher percentage of fermentable NDF than oat hulls. In this experiment, lambs that were fed oat hulls at levels above 15% INDF decreased intake, but lambs fed soy hulls increased intake linearly with increased INDF levels up to 20%, the highest level fed. From this information, it was concluded that the rate and extent of fermentation of a fiber source, governed by fermentable NDF (FNDF), is the important indicator of feed intake, rather than levels of NDF or INDF.

Thonney and Hogue (1999) further investigated the relationship between fiber source, concentration of fiber, and intake, using a corn-based diet that was supplemented with either soy hulls or oat hulls to contain 14%, 19%, or 24% INDF, where diets supplemented with soy hulls contained more dietary NDF (and therefore more FNDF) at each INDF level. In this experiment, daily gains were unaffected by diet, and dry matter intake (DMI) was significantly higher for lambs fed soy hull diets than for lambs fed oat hull diets. There was also an increase in DMI as a percentage of body weight for increasing INDF in the soy hull diets, but DMI decreased with increasing INDF in the oat hull diet. The researchers concluded that rapid production of fermentation products in the rumen in animals fed the soy hull diets lead to increased intake, and that NDF alone is not a good predictor of intake.

Effects of Soy hulls on Intake and Digestibility

Due to the evidence that soy hulls are an excellent source of digestible dietary fiber and can increase intake in a high forage diet limited by gut fill, additional experiments focused on the benefits and possible drawbacks of soy hulls in ruminant diets. A review of the research regarding soy hulls as a feed in lactating dairy cows published in 2003 provides a good basis of current knowledge (Ipharraguerre & Clark, 2003). The authors of this paper concluded that soy hulls are highly digestible by rumen microbes and are quickly digested, as supported by the previous work of Hogue and Thonney (1999). As a replacement for hay, therefore, soy hulls can be fed in greater quantities because they pass through the rumen more quickly and are still able to be digested. However, the *in vitro* digestibility (about 90%) of soy hulls as fed to ruminants is always observed to be significantly higher than the *in vivo* digestibility (about 50%) by rumen microbes, especially when fed *ad libitum* and as the main dietary component (Anderson, Merill, McDonnell, & Klopfenstein, 1988). This may be a result of the high rate of passage of soy hulls through the digestive tract due to their small particle size and high specific gravity (Titgemeyer, 2000). However, limiting intake or adding a minimal amount of long fibrous hay to the diet in order to limit rate of passage through the tract can minimize this effect. Limiting intake would lessen the negative effect that increased DMI has on digestibility through increased rate of passage, as already described. Adding long fibrous hay would contribute to the ruminal mat, retaining the contents of the rumen within the rumen for a longer time (Weidner & Grant, 1994). Thus, the data presented in the paper of Ipharraguerre & Clark (2003) suggest that replacement of either forage or concentrate with soy hulls has either no effect or a positive effect on production. This is possibly due to the fact that inclusion of soy hulls either creates the same or greater concentrations of total VFA in the rumen. It has been proposed that this could be a result of the high percentage of FNDF, which could provide for more complete ruminal fermentation (Elliot, Drackley, Fahey, & Shanks, 1995). This provides for equal or improved production (e.g. increased milk fat levels in dairy cows).

Two more recent experiments by Araujo *et al* (2008a,b) further quantified and elucidated the effect of soy hull addition to diets in sheep. The first experiment, which focused on soy hull digestibility and effects on intake in ram lambs, involved the addition of soy hulls to replace hay in a traditional high-forage diet (Araujo R. C., *et al*., 2008b). This study demonstrated a linear increase in intake when soy hulls replaced up to 90% of the hay. In agreement with the review article by Ipharraguerre and Clark (2003), this effect was attributed to the fact that soy hulls move more quickly through the rumen than hay, preventing feed accumulation and limiting intake depression due to gut fill. A linear relationship between soy hull concentration and dry matter digestibility was also observed, likely due to the higher digestibility of soy hulls when compared to the hay component of the feed. However, it was concluded that digestibility was maximized when soy hulls were at only 77% of the dietary dry matter. The decrease in digestibility with very high fractions of soy hulls in the diet was concluded to possibly be due to the decreased ruminal mat formation by lack of long hay particles, which constituted very little of the diets with high soy hull concentrations. It was speculated in this study that retention of feed in the rumen by the ruminal mat is required for maximal fermentation of soy hull NDF. At high soy hull levels, digestibility might also be decreased by the resultant depressed pH that has been found in diets fed that are 80% or 90% soy hulls on a dry matter basis. This pH depression could possibly be attributed to decreased rumination in animals fed soy hulls leading to less saliva buffer production. However, compared with the high lactic acid end product from the fermentation of non-structural carbohydrates, fermentation of soy hull fiber likely results in normal VFA production with fewer rumen metabolic problems even at very high levels of intake.

In another sheep experiment published in 2008, this same research team (Araujo *et al*., 2008a) found similar effects on intake level as those previously reported for soy hull inclusion (Hogue, 1987; Hogue, 1991; Araujo *et al*., 2008b). Araujo *et al*. (2008a) focused on areas of animal production, like milk production in ewes, and the effect of substitution of soy hulls for hay in the diet. Araujo *et al*. (2008a) determined that substitution of up to 67% of the hay with soy hulls increased milk production. There was no advantage in milk production when 100% of the hay was replaced with soy hulls. The increase in milk production with 67% soy hull substitution was attributed to both the increased intake and digestibility of soy hulls when compared to the original hay diet. The quality and proportions of all milk components remained unaffected by soy hull intake level, even at 100% substitution for hay. This is at odds with previously reported data for dairy cows, which implied that a minimal amount of hay was necessary for normal and healthy rumination, below which a depression in milk fat was observed. This difference could be attributed to a difference between sheep and cattle in rate of passage of feed, because of differences in the base diets used in these experiments, or because similar experiments have not been done with dairy cattle.

Low In Vivo *Digestibility of Soy hulls*

Recently, Schotthofer (2007) described an experiment in which soy hulls replaced corn in a diet fed to highly productive lactating ewes to formulate diets with 15, 25, or 35% potentially fermentable NDF. In agreement with previous research, the observed *in vivo* digestibility of soy hulls was lower than expected; however, the 32 to 39% digestibility of NDF was much lower than previously reported. This could be explained by the extremely high level of intake that the ewes exhibited on the 35% FNDF diet, which was 5.3% DMI as a percentage of ewe body weight. Despite the low NDF digestibility, the ewes increased feed intake and milk production with increasing potentially fermentable NDF levels in the diet, which resulted in faster lamb growth and positive ewe weight gain during the first 6 weeks of lactation. This effect was attributed to the effect of FNDF on rumen microbes, allowing them to flourish and optimize VFA production. This conclusion is in agreement with speculations on the effect of soy hull supplementation on dairy cow production, presented previously (Ipharraguerre & Clark, 2003).

The purpose of the experiments in the present study was to quantify the effect of feeding increasing amounts of a high-fiber soy hull-based diet on digestibility in weanling ram lambs and in non-lactating mature ewes.

Materials and Methods

Experiment 1: Ram Lambs

All procedures involving sheep were approved by the Institutional Animal Care and Use Committee (IACUC) at Cornell University. Forty-eight weaned (3 months old) 18 kg ram lambs born in August and September of 2007 at the Cornell University Sheep Farm were housed in 24 expanded metal floor pens in pairs. Each pen was randomly assigned to feed intake corresponding to 2, 3, or 4% of the average starting body weight (2BW, 3BW, and 4BW), with 8 pens of 2 lambs each fed at each intake level. The diet was formulated to contain 70% soybean hulls, 15% corn, 7.9% soybean meal, 4.5% molasses, 1% vitamin-mineral premix[1], 0.75% ammonium chloride, 0.5% chromic oxide, 0.25% vitamin E premix, and 0.025% Deccox (Appendix I).

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[1] Premix contained 50% Salt, 5% Deccox, 6% concentrate, 0.5% mineral oil, 2,500 ppm manganese, 30 ppm selenium, 2,000 ppm zinc, 80 ppm iodine, 20 ppm cobalt, 264,552 IU/kg vitamin A, 33,069 IU/kg vitamin D, 2,205 IU/kg vitamin E.

Chromic oxide was included as an indigestible marker that can be detected in the feces to determine digestibility.

The diets were fed to each pen of lambs once daily for a ten-day adaptation period, after which feces were collected under each pen on sheets of plastic for two days. The fecal samples and two feed samples were then dried and ground for determination of NDF, dry matter, and chromic oxide concentrations.

Experiment 2: Non-Lactating Ewes

Twenty-four non-lactating, mature ewes were kept individually in expanded metal floor pens and fed at 2, 3, or 4% of body weight (2BW, 3BW, and 4BW) with 8 ewes fed each diet. Diets were randomly assigned to ewes in pens set up similarly to trial 1. The diet was balanced and formulated to contain 72% soybean hulls, 20% corn, 2% soybean meal, and 4.5% molasses,1% mineral-vitamin premix (see footnote 1), and 0.5% chromic oxide as an indigestible marker for digestibility determination (Appendix II). After a ten-day adaptation period, feces were collected for two days in porous netting for easy separation of urine from feces. Uneaten feed was measured and recorded to determine actual feed intake. The feces samples and two feed samples were dried and ground for determination of NDF, dry matter, and chromic oxide concentrations.

Chromic Oxide Determination

Feces were dried in a 60°C oven over a period of 10 days until the dry weights were constant. After drying, samples were ground through a 1mm screen in a Wiley Mill. Then 0.2 g of each sample was weighed into an Erlenmeyer flask. The 24 fecal samples were analyzed in duplicate while the feed samples were analyzed in quadruplicate due to the importance of feed sample values for determination of digestibility. To oxidize the chromic oxide for detection, 4 mL of concentrated nitric acid (HNO_3) were added to the flasks, after which the flasks were heated at 110°C for one hour. The samples were then allowed to cool and 10 mL of 70% perchloric acid was added. Then the samples were heated at 220°C for thirty minutes, or until all chromium became oxidized, signified by a color change of the solution to orange.

The solution in the flasks was allowed to cool and was then transferred to 100 mL volumetric flasks. Distilled water was used to fill the flasks to 100 mL of solution. Samples from the volumetric flasks were poured into 14 mL test tubes in duplicate and sent for analysis to the Nutrient Analysis Laboratory, where the liquid was analyzed for milligrams of chromic oxide per milliliter of solution. The apparent dry matter digestibility (DMD) was found using these data in the equation: DMD = 1 – (Cr as a % of DM in the feed / Cr as a % of DM in the feces) for each fecal sample.

NDF Determination

Neutral detergent fiber concentration was determined by starting with 0.5 g of each sample measured into a 600 mL beaker in duplicate for fecal samples and in triplicate for feed samples. To each beaker was added 0.5 g sodium sulfite, 100 mL NDF buffer solution, and 0.2 mL of heat-stable amylase. The sodium sulfite served to break disulfide bonds in the sample protein matrix, while the buffer solution and amylase digested and solubilized other non-NDF components of the samples. The sample solutions were then refluxed for one hour. The hot solution was filtered through Whatman 934-AH 1μm filter in a Gooch crucible, using boiling water to rinse the sample twice and acetone as the final rinse. The crucibles were then dried in an oven at 106°C overnight and hot-weighed. Finally, the sample residues were ashed in a muffle furnace at 505°C over night, cooled to 106°C, and hot-weighed. Ash determination was used to calculate ash-free NDF. Digestibility of NDF was calculated for each fecal sample using the equation FNDF = 1 – (Cr as a % of NDF in the feed / Cr as a % of NDF in the feces)

Dry Matter (DM) Determination

The dry matter concentration of each sample was determined by weighing duplicate 1 g samples into 25 mL beakers. The samples were then dried in an oven at 106°C overnight and hot-weighed. Finally, the samples were ashed in a muffle furnace at 505°C overnight and hot-weighed to determine ash concentrations.

Data Analysis

The effect of level of intake was analyzed by one-way analysis of variance. A quadratic regression equation was then fitted to the data to quantify the effect of level of intake on apparent dry matter and NDF digestibility. In each case, the quadratic effect was nonsignificant so the simple linear regression equations are reported.

Results and Discussion

Experiment 1: Ram Lambs

The initial weights of lambs fed at each intake level were similar (Table I). However, the final weights of the lambs were affected by intake level (P=0.004), especially between 2BW and the two higher levels (Table I), where significance was defined by a P-value of 0.05 or less. The lambs fed at 2BW lost weight, indicating that this level of intake was insufficient to meet their nutritional requirements. While the lambs fed at 3BW also lost weight, this loss was less than that of the lambs fed at 2BW and very close to the average final weight of the lambs fed at the 4BW intake level.

As expected, the daily DM intake by weight and on a percentage of BW basis increased as level of intake increased (P<0.001). The lambs offered feed at 4BW consumed up to an average of 3.7% of their BW (Table I). This high intake level is in agreement with previous observations that lambs fed a high-fiber diet will increase their intake level to meet nutritional needs (Hogue, 1987). This also implies that lambs fed at 2.7 percentage of BW or less were consuming suboptimal amounts of this feed, resulting is suboptimal growth.

Table I. Effect of level of dry matter intake on DM and NDF digestibility by lambs.[1]

	DM intake, % BW				
Item	2	3	4	SE	P-value
Number of pens (2 lambs each)	8	8	8		
Initial weight, kg	17.9	19.0	17.7	0.69	0.348
Final weight, kg	15.6	17.9	18.1	0.51	0.004
Average weight, kg	16.8	18.5	17.9	0.59	0.140
Daily dry matter intake, g	330	495	656	2.4	<0.001
DM intake, % BW	2.0	2.7	3.7	0.09	<0.001
Apparent DM digestibility, %	78.3	75.0	64.4	1.55	<0.001
Daily digestible DM intake, g	258	371	423	8.8	<0.001
Digestible NDF, % NDF	82.0	76.1	60.5	1.96	<0.001

[1]The apparent DM digestibility was determined using the proportion of detected chromic oxide in the feces as compared to the feed. Digestible NDF as a % of NDF was determined by the proportion of NDF in the feces and in the feed.

The apparent DM digestibility (DMD) decreased (P<0.001) with increasing intake, in accordance with previous research that showed that increasing intake has a negative effect on digestibility (Wagner & Loosli, 1967) and where feeding large quantities of a soy hull-based diet specifically decreased observed digestibility (Anderson, Merill, McDonnell, & Klopfenstein, 1988; Schotthofer, 2007; Araujo R. C., *et al.*, 2008b). The rate of passage through the digestive tract of soy hulls is high when compared to high-forage diets, possibly due to the high specific gravity and small particle size of this feed component (Titgemeyer, 2000). This high rate of passage is only increased further by increased intake, which forces feed to move more quickly through the tract to make room for high amounts of incoming feed. While the *in vivo* digestibility of soy hulls can be very high (around 90%; Anderson, Merill, McDonnell, & Klopfenstein, 1988), feeding a large quantity of this small-particulate feed can dramatically reduce digestibility. This may be a result of failure to produce a ruminal mat, which is an aggregation of long fibrous material in the rumen that slows down the rate of passage of all feed components, thus allowing them to ferment more completely (Weidner & Grant, 1994). Therefore, it might be suggested that a minimum amount of long fibrous material be included in a soy hull diet to ensure ruminal mat formation for maximal fermentation of the highly digestible fiber in this ingredient.

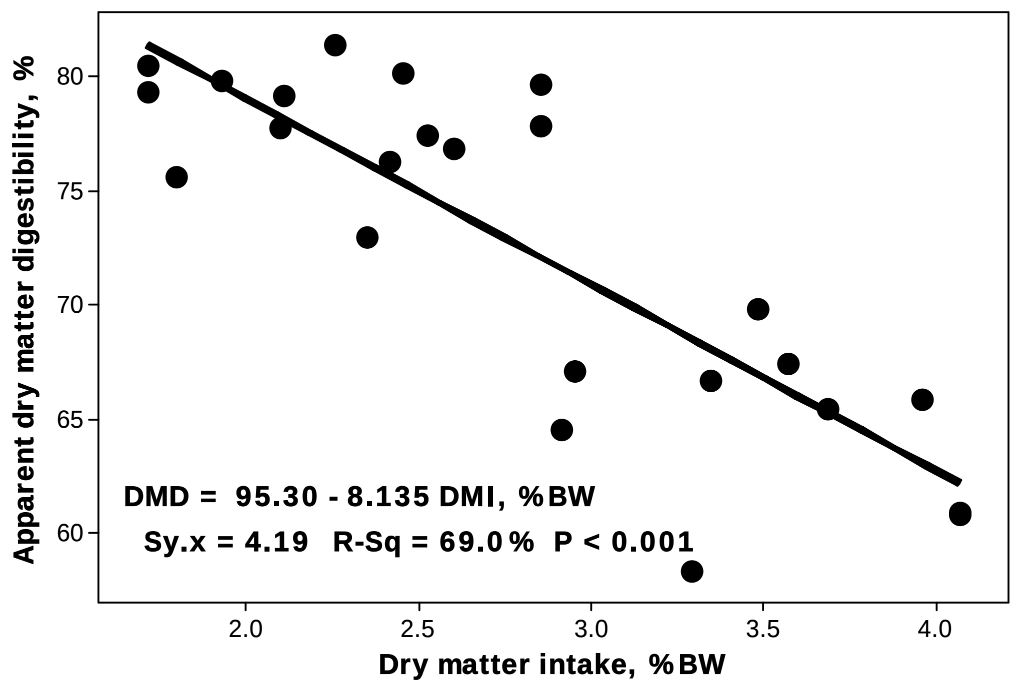

Figure 1. Apparent dry matter digestibility (DMD) by lambs as a function of dry matter intake. The relationship between DMD and DMI as a percentage of BW was determined by a one-way analysis of variance and quantified by regression, where a simple linear regression equation was significant ($P<0.001$). A Sy.x value of 4.19 corresponds to a standard deviation of 4.19 percentage points at the mean DMI.

The relationship between apparent DMD and actual DM intake as a percentage of BW was best represented by the simple negative linear equation in Figure 1. The slope of the equation shows that a one-percentage unit increase in DMI as a percentage of BW decreases DMD by 8.1 percentage units. This equation could be useful in predicting the value of a soy hulls in diets at high intake levels, where digestibility may decline to as low as 64% at an intake level of 4BW (Figure 1).

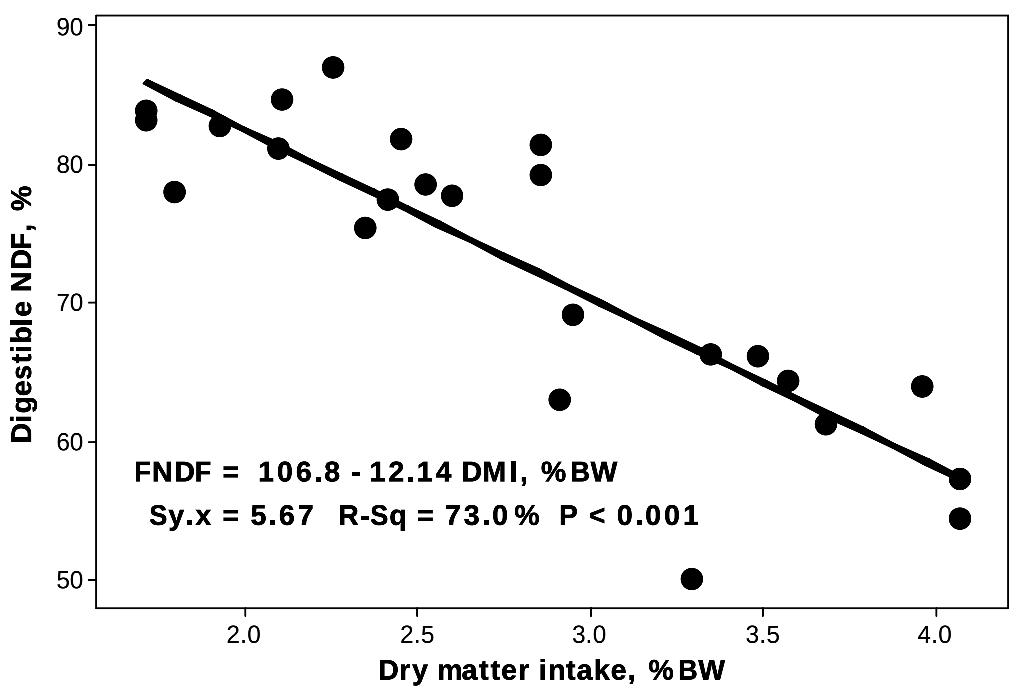

Figure 2. NDF digestibility by lambs as a function of dry matter intake. The relationship between digestibility of NDF and DMI as a percentage of BW was determined by a one-way analysis of variance and quantified by regression, where a simple linear regression equation was significant (P<0.001). A Sy.x value of 5.67 corresponds to a standard deviation of 5.67 percentage points at the mean DMI.

The digestibility of NDF decreased as intake level increased in the lambs (P<0.001) (Table I). This indicates that the decrease in DMD is mostly due to a decrease in fermentability of the NDF portion of the soy hull diet. These data provide evidence that, as the dietary intake level increased, the soy hulls passed more quickly through the digestive tract so that rumen microbes had less time to ferment them.

Like the regression between DMD and individual intake levels, there was a simple negative linear relationship between digestibility of NDF and intake as a percentage of BW (Figure 2). The slope of the equation, 12.1 ($P<0.001$), indicated that the digestibility of NDF declined faster with increasing intake than did apparent dry matter digestibility. This was probably due to the faster digestibility of the soybean meal that made up much of the rest of the diet.

Experiment 2: Non-Lactating Mature Ewes

The initial weights of ewes assigned to the three levels of intake were similar (Table II). There was no significant relationship between intake level and final weight ($P = 0.361$), and the ewes did not lose a significant amount of weight during the experiment. This indicates that the diet at intake levels of 2BW, 3BW, and 4BW were sufficient to meet the maintenance requirements of the ewes. However, a single-degree of freedom contrast showed that ewes fed at 4BW gained more weight ($P = 0.05$) than ewes fed at 2BW or 3BW (Table II).

As expected, there was a significant relationship between assigned DMI and actual DMI ($P<0.001$). This indicates that the sheep consumed significantly more feed at each increased intake level, though these values differed from 2BW, 3BW, and 4BW, with actual levels of 2.0, 2.6, and 3.1% of BW, respectively. The actual DMI as a percentage of BW for each diet indicates that the feed consumed by the ewes was sufficient to meet maintenance requirements, allowing them to maintain a constant weight (2BW and 3BW) or slightly increase (4BW) their weights throughout the experiment. The ewes often did not consume the feed offered to them because they adjusted their intake to meet their nutritional needs, which was between 2BW and 3BW, where intake leveled off. However, the fact that body weight was maintained at 2BW, 3BW, and only slightly increased at 4BW, suggests that the value of the feed diminished as intake increased.

Table II. Effect of level of dry matter intake on DM and NDF digestibility by mature ewes.[1]

	DM intake, % BW				
Item	2	3	4	SE	P-value
Number of ewes	8	8	8		
Initial weight, kg	67.1	68.3	61.6	2.28	0.113
Final weight, kg	67.1	68.2	63.2	2.54	0.361
Average Weight Change, kg	-0.06[a]	-0.11[a]	1.53[b]	0.634	0.139
Average weight, kg	67.1	68.2	62.4	2.39	0.213
Daily dry matter intake, g	1321	1786	1945	93.3	<0.001
DM intake, % BW	2.0	2.6	3.1	0.14	<0.001
Apparent DM digestibility, %	68.3	67.0	62.1	1.50	0.002
Daily digestible DM intake, g	901	1198	1204	60.8	0.002
Digestible NDF, % NDF	67.8	64.8	58.8	1.88	0.009

[1]The apparent DM digestibility was determined using the proportion of detected chromic oxide in the feces as compared to the feed. Digestible NDF as a % of NDF was determined by the proportion NDF in the feces and in the feed.

[a] These values were considered statistically similar (P = 0.950).

[b]This value was considered statistically dissimilar from values for 2DM and 3DM intake levels[a] (P = 0.050).

Like the digestibility by the lambs, the apparent DM digestibility by ewes decreased significantly with increased intake (P = 0.002). This was also likely due to the increased rate of passage of the soy hulls through the digestive tract, caused by their small particle size and high specific gravity (Titgemeyer, 2000) and the lack of ruminal mat formation due to a lack of forage (Weidner & Grant, 1994). Similar to the results for the lamb experiment, these data enable the depression in digestibility with increased intake of a soy hull diet to be quantified.

The relationship between apparent DMD and actual DMI as a percentage of BW was best represented by a simple linear equation as shown in Figure 3. The slope of this equation indicates that a 1 percentage unit increase in DMI as a percentage of BW causes DMD to decrease by 2.9 percentage units. These results are similar to the results from the lamb experiment, although the precise relationship between these two variables in ewes fed at 2BW, 3BW, and 4BW is less dramatic than that in lambs, where percent DMD decreased by 8.1 for each 1 percentage unit increase in intake as a percentage of body weight. The smaller slope of the regression line between DMI and DMD in ewes might be caused by the smaller maintenance requirement of ewes as a percentage of BW. The lambs, unlike the ewes, were growing and therefore needed more nutrients. Also, the lambs in experiment 1 consumed up to about 3.7% of DM as a percentage of BW (Table I), while the ewes in experiment 2 only consumed up to about 3.1% of feed as a percentage of BW (Table II). Therefore, most of the data in experiment 2 covered only a span for intake of about 1 percent of BW at levels of intake at or near maintenance, whereas the data from the lamb experiment covered a greater span of actual DMI at levels much higher than maintenance. This may have contributed to the difference in relationships between DMD and DMI between lambs and ewes.

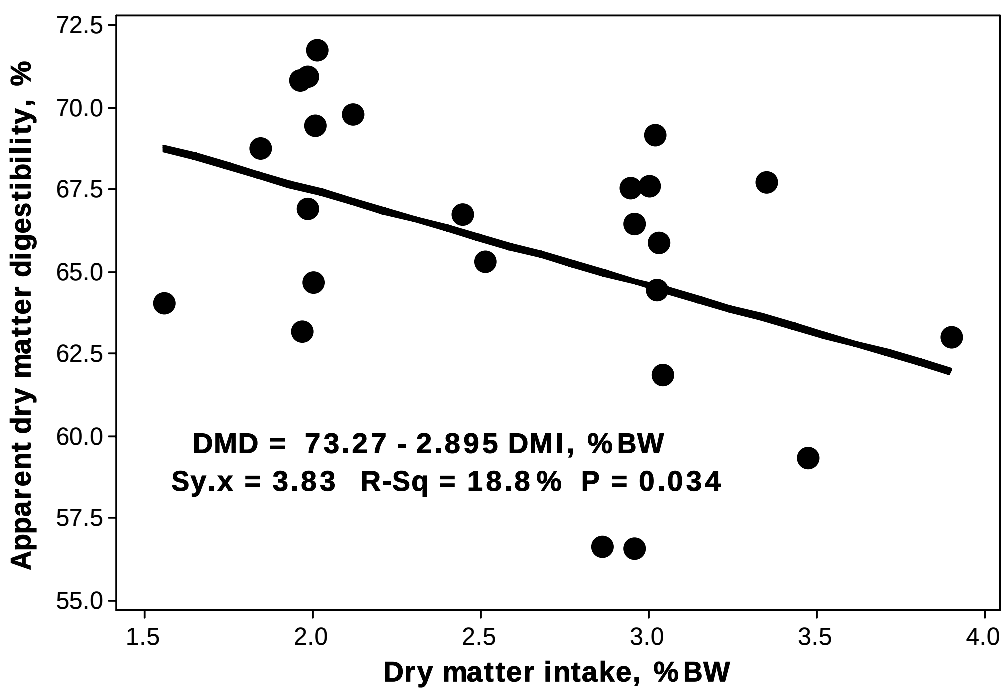

Figure 3. Apparent dry matter digestibility (DMD) by ewes as a function of dry matter intake. The relationship between DMD and DMI as a percentage of BW was determined by a one-way analysis of variance and quantified by regression, where a simple linear regression equation was significant ($P<0.001$). A Sy.x value of 3.83 corresponds to a standard deviation of 3.83 percentage points at the mean DMI.

The relationship between the digestibility of NDF and DMI as a percentage of BW was also found to be significant ($P=0.009$) (Table II), with digestibility of NDF decreasing with increasing intake. Like the results in the lamb experiment, this observation can be explained by the increased rate of passage of the feed through the rumen, which decreased the amount of time the feed spent undergoing fermentation in the digestive tract.

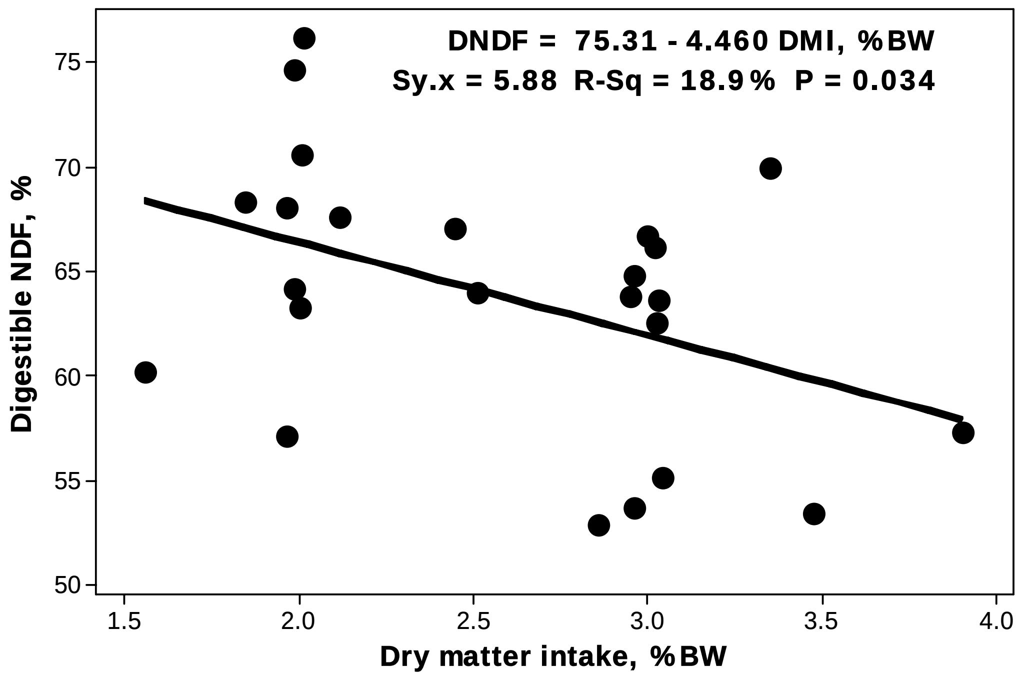

Figure 4. NDF digestibility by ewes as a function of dry matter intake. The relationship between digestibility of NDF and DMI as a percentage of BW was determined by a one-way analysis of variance and quantified by regression, where a simple linear regression equation was significant (P<0.001). A Sy.x value of 5.67 corresponds to a standard deviation of 5.67 percentage points at the mean DMI.

The relationship between digestibility of NDF and DMI as a percentage of BW was found to be a simple linear equation shown in Figure 4 (P = 0.034). The slope of this line suggests that FNDF decreased by a 4.4 percentage units for a 1-percentage unit increase in DMI as a percentage of BW. The slope of this line was much smaller than that observed in the lambs, which was 12.1. This observed difference might be for reasons similar to those for the difference between lambs and ewes for the relationship between DMD and intake; feed intake levels of 2BW, 3BW, and 4BW resulted in intakes at or slightly above maintenance in ewes where these same levels were likely below levels required for maximum growth of ram lambs, causing less dramatic change in NDF digestibility by ewes than by the lambs.

Conclusions

In agreement with a wealth of literature, most recently that of Arujo *et al* (2008a,b) and Schotthofer (2007), a simple negative linear effect on digestibility was found with increased intake. Because soy hulls are such a valuable feed, often maximizing production and growth by increasing intake without sacrificing rumen health, it is important to determine the relationship between digestibility and intake in order to optimize the efficiency of sheep farming. The equations determined in this experiment for the relationship between intake and digestibility may be useful in predicting the depletion in value of soy hulls fed at high intake levels, as well as for diet formulation. Further research is needed to produce more reliable equations to represent the relationships between these two variables at different intake level ranges and in different dietary formulations containing soy hulls.

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Appendix I: Lamb feed.

Feed

Experimental lamb feed	10/30/2007	M. Thonney

Ingredient	%	Per ton: Ingredient	Per ton: Feed	% DM	Per ton DM: Ingredient	Per ton DM: Feed
Bypr - Soy hulls - 14 Sep	71.73	$140.00	$100.43	72.331	$154.19	$111.52
Prot - Soybean meal, 49%	21.47	$230.00	$49.37	21.453	$255.56	$54.82
Bypr - Molasses; sugarcane (add la	4.50	$160.00	$7.20	3.7479	$213.33	$8.00
Prmx - Hewitt/Old Mill Premix 2007	1.00	$1,305.00	$13.05	1.055	$1,373.68	$14.49
Min - Calcium carbonate	0.50	$104.00	$0.52	0.5552	$104.00	$0.58
Min - Chromic oxide	0.50	$1,000.00	$5.00	0.5552	$1,000.00	$5.55
Vit - CSF E Supra Premix	0.25	$619.63	$1.55	0.2476	$694.84	$1.72
Med - Deccox, 6% concentrate	0.05	17,440.00	$8.72	0.0555	$17,440.00	$9.68
Totals:	100.00		$185.83	100.00		$206.36
Cost per pound, ¢:			9.3			10.3

Estimated component composition

003a Young lambs | 20.0 lb | 27.0 kg | Estimated DM intake: 0.8 lb or 1.1 kg

Ca:P 5.00

	DM, %	DDM, %	CP, %	NDF, %	Indigestible NDF, %	Fermentable NDF, %	NSCHO, % (max)	EE, %	Ash, %	Ca, %	P, %
Feed:	90.18	79.56	11.70	62.92	8.23	54.80	16.81	1.89	5.57	0.64	0.13
Suggested level:		80.00	20.00		10.00	20.00	40.00	5.00	5.00	0.42	0.21
Feed minus level:		-0.44	-8.30		-1.77	34.80	-23.19	-3.11	0.57	0.22	-0.08

	K, %	Mg, %	S, %	I, ppm	Fe, ppm	Cu, ppm	Mo, ppm	Co, ppm	Mn, ppm	Zn, ppm	Se, ppm
Feed:	1.23	0.31	0.13	0.97	388.41	10.97	0.85	0.22	44.19	68.54	0.53
Suggested level:	0.80	0.18	0.26	0.80	50.00	10.00	0.50	0.20	40.00	33.00	0.30
Feed minus level:	0.43	0.13	-0.13	0.17	338.41	0.97	0.35	0.02	4.19	35.54	0.23

	VitA, kIU/lb	VitD, kIU/lb	VitE, IU/lb	Decoquinate, g/lb	Monensin, mg/lb	Lasalocid, mg/lb
Feed:	1.33	0.17	95.16	0.0302	0.0	0.0
Suggested level:	0.53	0.15	112.00	0.0136		15.0
Feed minus level:	0.80	0.02	-16.84	0.0166		-15.0

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Appendix II: Ewe feed.

Feed

2008 Hein ewe experiment **9/30/2008** **Thonney**

Ingredient	%	Per ton: Ingredient	Per ton: Feed	% DM	Per ton DM: Ingredient	Per ton DM: Feed
Bypr - Soy hulls - DEH	72.00	$180.00	$129.60	72.46	$200.00	$144.93
Grn - Corn grain - DEH	20.00	$260.00	$52.00	20.13	$288.89	$58.15
Bypr - Molasses; sugarcane (add la	4.50	$440.00	$19.80	3.77	$586.67	$22.14
Prot - Soybean meal, 49%	2.00	$431.00	$8.62	2.01	$478.89	$9.64
Prmx - Hewitt/Old Mill Premix 2007	1.00	$1,600.00	$16.00	1.06	$1,684.21	$17.89
Min - Chromic oxide	0.50	$1,000.00	$5.00	0.56	$1,000.00	$5.59
Totals:	100.00		$231.02	100.00		$258.34
Cost per pound, ¢:			11.6			12.9

Estimated component composition

016 Ewes: Late gestation (2 lambs) 180.0 lb 81.0 kg Estimated DM intake: 7.2 lb or 3.2 kg

Ca:P 2.53

	DM, %	DDM, %	CP, %	NDF, %	Indigestible NDF, %	pINDF, %	NSCHO, % (max)	EE, %	Ash, %	Ca, %	P, %
Feed:	89.43	81.03	12.05	52.82	7.17	45.76	27.87	2.30	4.96	0.51	0.20
Suggested level:		63.00	11.50		23.00	22.00	34.00	5.00	5.00	0.40	0.24
Feed minus level:		18.03	0.55		-15.83	23.76	-6.13	-2.70	-0.04	0.11	-0.04

	K, %	Mg, %	S, %	I, ppm	Fe, ppm	Cu, ppm	Mo, ppm	Co, ppm	Mn, ppm	Zn, ppm	Se, ppm
Feed:	1.38	0.23	0.13	0.97	462.62	10.66	1.58	0.22	52.04	55.12	0.50
Suggested level:	0.80	0.18	0.26	0.80	50.00	10.00	0.50	0.20	40.00	33.00	0.30
Feed minus level:	0.58	0.05	-0.13	0.17	412.62	0.66	1.08	0.02	12.04	22.12	0.20

	VitA, kIU/lb	VitD, kIU/lb	VitE, IU/lb	Decoquinate, g/lb	Monensin, mg/lb	Lasalocid, mg/lb
Feed:	1.34	0.17	47.65	0.0152	0.0	0.0
Suggested level:	1.42	0.15	59.00	0.0136		
Feed minus level:	-0.08	0.02	-11.35	0.0016		

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Appendix III: Lamb data.

Pen	Assigned intake, % BW	Initial weight, kg	Final weight, kg	Average weight, kg	Daily DM intake, g	DMI, % of BW	Apparent dry matter digestibility, %	Digestible NDF, % of NDF
1	4	20	20	20	660	3.3	66.7	66.3
2	4	19	20	19	627	3.3	58.4	50.2
3	4	15	17	16	660	4.1	60.9	54.5
4	3	18	16	17	495	2.9	64.5	63.1
5	4	19	19	19	660	3.5	69.8	66.2
6	4	18	19	18	660	3.6	67.5	64.5
7	3	20	19	20	495	2.5	77.5	78.6
8	2	20	18	19	330	1.7	80.5	83.2
9	3	21	19	20	495	2.5	80.2	81.9
10	2	15	14	14	330	2.3	73.0	75.5
11	3	17	17	17	495	2.9	79.7	81.4
12	2	20	17	18	330	1.8	75.7	78.0
13	2	21	18	19	330	1.7	79.3	83.9
14	2	18	16	17	330	1.9	79.8	82.8
15	4	16	17	16	660	4.1	61.0	57.4
16	2	15	14	15	330	2.3	81.4	87.1
17	3	21	20	21	495	2.4	76.3	77.5
18	4	17	17	17	660	4.0	65.9	64.0
19	2	16	15	16	330	2.1	79.2	84.8
20	4	18	18	18	660	3.7	65.5	61.3
21	3	20	18	19	495	2.6	76.9	77.8
22	2	17	15	16	330	2.1	77.8	81.2
23	3	17	17	17	495	2.9	67.1	69.2
24	3	18	17	17	495	2.9	77.9	79.3

Appendix IV: Ewe data.

Ewe	Assigned intake, % BW	Initial weight, kg	Final weight, kg	Average weight, kg	Daily DM intake, g	DMI, % of BW	Apparent dry matter digestibility, %	Digestible NDF, % of NDF
1	2	63	63	63	1242	2.0	71.0	74.6
2	2	57	55	56	1125	2.0	69.4	70.6
3	3	68	66	67	2025	3.0	64.5	62.6
4	3	65	63	64	1930	3.0	69.2	66.1
5	4	76	80	78	2237	2.9	56.7	52.9
6	4	51	53	52	2016	3.9	63.0	57.3
7	4	65	66	66	2286	3.5	59.3	53.4
8	4	61	64	63	1851	3.0	56.6	53.7
9	3	69	70	69	2052	3.0	66.5	64.8
10	3	70	71	71	2078	2.9	67.6	63.8
11	4	66	65	66	1651	2.5	65.4	64.0
12	4	64	66	65	2179	3.3	67.7	69.9
13	3	65	65	65	1587	2.4	66.8	67.1
14	4	52	53	52	1585	3.0	61.9	55.1
15	2	64	65	64	1260	2.0	70.9	68.0
16	4	58	58	58	1753	3.0	65.9	63.6
17	2	64	62	63	1269	2.0	71.8	76.2
18	2	74	73	73	1467	2.0	64.7	63.3
19	2	78	78	78	1557	2.0	67.0	64.2
20	2	69	70	70	1282	1.8	68.8	68.3
21	3	66	64	65	1945	3.0	67.6	66.7
22	2	69	70	70	1368	2.0	63.2	57.2
23	3	72	70	71	1105	1.6	64.1	60.2
24	3	72	76	74	1570	2.1	69.8	67.6