EFFECT OF GRAIN SUPPLEMENTATION ON VOLUNTARY INTAKE AND UTILIZATION OF WHEAT STRAW BY LAMBS

by

Roberto Zambrano Gaytan

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SIGNED: Roberto Zamborra J

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

R. S. Swingle
R. S. SWINGLE
Associate Professor of Animal Science

August 29, 1978
Date

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ABSTRACT

Sixteen ewe lambs (36 kg initially) were assigned to four equal treatment groups. Lambs were individually fed and had chopped wheat straw (with molasses-urea added) available at all times. Treatments consisted of a control (no added grain) and three levels of supplemental dry rolled sorghum grain. Each diet contained approximately 10% crude protein on a dry matter basis, but daily crude protein intakes increased as grain level increased.

During a 42-day feeding period, grain intakes averaged 275, 550 and 798 g/day for the three added-grain treatments. Daily straw intakes averaged 540, 609, 601 and 443 g/day for the control and added-grain treatments, respectively. Daily gains increased linearly ($P<.05$) from -80 g for the control lambs to 209 g for those fed the highest level of grain.

Digestibilities of dietary dry matter, organic matter and gross energy increased ($P<.05$) linearly as level of grain increased. Digestibilities of neutral detergent fiber and all cell wall components decreased ($P<.05$) linearly as supplemental grain increased. Analysis of the data by linear regression gave estimates for neutral detergent fiber digestibility in wheat straw and sorghum grain of 50.6 and 19.1%, respectively. Digestibility data were also analyzed using simultaneous equations and there was no indication that straw fiber digestibility decreased as grain level increased. This suggests that the decreases in digestibility of diet fiber due to added grain resulted from the low

digestibility of grain fiber, not from a decrease in digestibility of straw fiber.

INTRODUCTION

Low quality roughages, especially crop residues like straws, represent a large potential source of energy for ruminants. Wheat straw as a by-product is readily available in Arizona and the adjacent Mexican State of Sonora.

Low quality roughages such as wheat straw are presently utilized in relatively small amounts by the cattle feeding industry because rations containing large amounts of these roughages will not support satisfactory levels of animal performance. This is due to the bulky nature and low energy density and protein content of those feeds which tend to depress feed intake and lower the amount of energy available for production. Nevertheless, increasing the extent of their use and improving the utilization of these feedstuffs, which cannot be utilized directly by humans or other monogastric animals, is a very important challenge, especially in those countries where production of food crops has priority over that of feedstuffs for animals and also because these crop residues are a disposal problem.

With present knowledge and technology, rations containing a high proportion of low quality roughages can be used only if one is willing to accept low rates of animal performance. One method of improving performance on these roughages is to improve their feeding value by adding nitrogen, minerals and feeds having a high content of readily available carbohydrates. There is considerable evidence that added dietary nitrogen either as a natural protein or non-protein nitrogen (NPN) improves intake and fiber utilization of low quality roughages (Raleigh and Wallace, 1963; Ammerman et al., 1972; Bhattacharya and Khan, 1973; Bhattacharya and Pervez, 1973; Swingle, Araiza and Urias, 1977). However, supplementation of nitrogen, independently of energy, to low quality roughages will not result in maximum animal performance (Andrews et al., 1972; Mulholland, Coombe and McManus, 1976).

Maximal benefit from nitrogen supplementation is dependent upon a readily available source of carbohydrates. The optimum level of energy supplementation to these roughages is not clear. Low levels of supplementation tend to improve roughage intake and may improve fiber utilization, but rates of gain are usually still unacceptably low. High levels of supplementation, while improving animal performance, tend to depress fiber digestibility and utilization of the roughage (Montgomery and Baumgardt, 1965a, b; Swan and Lamming, 1970; Andrews et al., 1972; Mulholland, Coombe and McManus, 1976; Coleman and Barth, 1977). The objective of this experiment was to investigate the effect of various levels of grain supplementation on voluntary intake and nutrient digestibilities of wheat straw by lambs.

LITERATURE REVIEW

Results of several early studies indicate that addition of readily available carbohydrates to ruminant diets decreases digestibility of roughage components.

Mitchell, Hamilton and Haines (1940) formulated diets to contain approximately 6, 10, 15 and 20% crude protein using combinations of corn, cottonseed meal and timothy hay. Each diet was fed to steers with and without the addition of 1093 g/day of glucose. Glucose additions depressed dietary crude fiber digestibility by more than 25% (from approximately 39 to 29%), regardless of the level of protein fed.

Hamilton (1942) fed sheep a basal diet consisting of timothy hay, ground yellow corn and cottonseed meal in the approximate ratios of 2:2:1. Digestibility of nutrients were determined in this basal diet and the basal diet plus 20 to 30% glucose. The basal and basal + glucose diets contained 14.6 and 13.1% protein and 15.5 and 11.8% crude fiber, respectively. Addition of glucose resulted in increased digestibility of dry matter (68 vs 65%) and total carbohydrates (72 vs 69%) but decreased digestibility of nitrogen (54 vs 62%) and crude fiber (32 vs 44%).

Swift et al. (1947) reported that the effect of carbohydrates on fiber digestibility was dependent upon the level of supplementation. When 75 g (7.8% of diet) of corn sugar were supplemented to lambs receiving a basal ration of 420 g alfalfa-timothy hay, 420 g corn meal and 48 g linseed meal/day, digestibility of dry matter and energy in the diet increased (from 74.9 to 77.2% and from 72.6 to 75.0%, respectively) with no significant change in digestibility of protein (approximately 70%) or crude fiber (approximately 50%). However, when the amount of corn sugar was doubled, digestibility of crude fiber decreased to 43% and digestibility of crude protein was also decreased. Addition of 72 g of starch or 68 g of corn oil/day also decreased fiber digestibility by 8 and 17%, respectively. Protein content of the diets ranged from 12.4 to 13.5%

Burroughs and co-workers reported a series of studies on the effects of starch on digestibility of roughages. The first study (Burroughs et al., 1949a) was conducted to determine the effect of substituting dried skimmilk for mineralized starch on the digestion of corncobs by steers. Rations fed consisted of 5 lb/day of corncobs and 5 lb/day of supplement. Supplements were: (1) 4 lb of starch + 1 lb of dried skimmilk; (2) 3.25 lb of starch + 1.75 lb of skimmilk; (3) 2.5 lb of starch + 2.5 lb of skimmilk; (4) 1.5 lb of starch + 3.5 lb of skimmilk; and (5) 5 lb of skimmilk. Protein content of the rations increased from 5 to 18.5% as skimmilk replaced starch. Apparent digestibility of corncobs increased from 48 to 64% with increases in dried skimmilk up to the 13.5% protein level (ration 4). No further increase in corncob digestion was noted as protein increased to 18.5% (ration 5). In another experiment, digestibility of corncobs (5 lb/day) by steers was not improved by addition of .5, 2.5 or 5.0 lb of dried skimmilk/day when starch was not included in the diet. Protein content of the diets ranged from 4 to 18% and cob digestibilities were 58.9 to 62.6%. To further examine this relationship between protein and starch and their effect on roughage digestion, a third experiment was conducted.

A basal ration consisting of 5 lb of corncobs, 4 lb of starch and 1 lb of skimmilk was fed alone and with addition of 1 and 2 lb of dried skimmilk. Protein content of the rations ranged from 5.5 to 10.5%. Digestibility of corncobs in the basal ration was low (38.9%) and was increased to 46% by addition of 1 lb of skimmilk to the daily ration. Increasing skimmilk to 3 lb/day did not further increase corncob digestibility.

In a second study (Burroughs et al., 1949b), steers receiving a basal ration of 4 lb of ground corncobs and 1.6 lb dried skimmilk/day were supplemented with 0, 1.6, 3.2 or 4.0 lb/day of mineralized corn starch. Addition of starch decreased protein content of diets from 11.4 to 7.5% of dry matter. Digestibility of corncob dry matter was 57% when no starch was added and decreased to 55, 36 and 35% with each increment of added starch. In contrast, digestibility of alfalfa hay was not decreased by addition of 2 to 6 lb of starch per day even though crude protein contents of these diets were in the same range (7.4 to 11.4%) as those used in the corncob trial.

In another study, Burroughs et al. (1950) investigated the effect of starch and casein upon roughage digestibility by steers. Treatments included a basal ration of 4 lb corncobs + 1 lb alfalfa hay, basal + 4 lb of starch, basal + 4 lb of starch + 1 or 2 lb of casein. Addition of starch alone resulted in a decrease in roughage digestion which was paralleled by a decrease in rumen bacteria numbers. Addition of either 1 or 2 lb of casein to the basal + starch ration increased digestibility of the roughage and resulted in increased numbers of rumen bacteria.

In the above series of experiments (Burroughs et al., 1949a, b, 1950), protein (casein or skimmilk) supplementation increased corncob digestibility whenever starch was included in the ration. Little or no improvement in corncob digestion was noted due to protein addition when no starch was fed. The authors concluded that the protein requirement for efficient roughage digestion in cattle is low when roughages are fed in the absence of starch or grains. When starch forms a part of the ration, the need for protein supplementation is increased if efficient roughage digestion is to be maintained. They also felt the effect of starch upon roughage digestion could best be explained on the basis of adequate or inadequate nutrients for growth of microorganisms in the digestive tract.

El-Shazly, Dehority and Johnson (1961) conducted *in vitro* and *in vivo* studies to determine the nature of the inhibition by starch of cellulose digestion by rumen microorganisms. *In vitro* studies indicated that the inhibition was due primarily to a competition between the cellulolytic and amylolytic groups of bacteria for nutrients. The major nutrient was nitrogen, although the results suggested other nutrients (unspecified) could also be involved. *In vivo* trials with filter paper in nylon bags in the rumen of sheep showed similar inhibition of cellulose digestion when sheep were fed increasing proportions of corn in hay and corn rations. With hay corn ratios of 2:1 or 1:1, partial or complete alleviation of the inhibition of cellulose digestion could be obtained by supplementing the rations with urea; however, when the hay: corn ratio was 1:2, additional nitrogen as urea was ineffective.

Since the earlier investigations by Burroughs et al. (1949a, b, 1950) numerous other studies have observed the depressing effect of soluble carbohydrates on digestibility of dietary fiber components, and most have also investigated the effect of level and type of nitrogen supplementation on this effect. In three digestion trials, steers were used to determine the effect of adding different amounts of cerelose to wintering rations containing 8, 10 or 12% protein (Fontenot, Gallup and Nelson, 1955). Each protein level was evaluated in a separate trial. Desired protein levels were achieved by additions of cottonseed meal (270 to 600 g/day) to a basal ration of prairie hay (2600 to 2800 g/day). All rations were supplemented with salt, calcium and phosphorous. Cerelose was added at the rate of 350, 700 and 1050 g/day to the 8% protein ration, and 700 and 1050 g/day to the 10 and 12% protein rations. The cerelose additions caused a decrease in the protein percentages in the rations. Each addition of cerelose depressed cellulose digestibility at all three protein levels (from 72 to 49% at 8% protein; from 65 to 47% at 10% protein; and from 64 to 48% at 12% protein). In most cases, digestibility of the nitrogen free extract fraction increased with cerelose addition so that total organic matter digestibilities of the diets were minimally affected.

Ellis and Pfander (1958) fed lambs semi-purified diets containing one of three levels of cellulose (21, 31 or 42%) and one of three protein levels (10, 12.8 or 15%). Cellulose and nitrogen levels were varied by substituting purified sources of cellulose (wood pulp) and protein (soybean protein) for cornstarch. As the percentage of cellulose decreased (and starch, thus, increased), digestibility of cellulose decreased linearly and digestibilities for organic matter and nitrogen free extract increased. Response curves for digestibilities of cellulose, organic matter, nitrogen free extract and crude protein as influenced by dietary level of protein followed a quadratic pattern. Digestibilities of cellulose, organic matter and nitrogen free extract were significantly higher in the 12.8% crude protein ration than in those containing either 10 or 15% protein. Crude protein digestibility was higher for the 12.8% diet than for the 10% diet, but no further increase was obtained by increasing to the 15% crude protein level.

Montgomery and Baumgardt (1965a) conducted a study comparing four completely pelleted diets consisting of the following alfalfa meal to ground shelled corn ratios: 100:0; 80:20; 60:40; and 40:60. The diets were fed to eight Holstein heifers in two digestion trials designed as 4 x 4 latin squares. Crude protein and cellulose content decreased (from 19.6 to 10.7% and from 26.2 to 12%, respectively) as the amount of corn in the ration increased. Dry matter consumption decreased and dry matter digestibility increased linearly with added grain (from 2.3 to 1.6% of body weight and from 55.9 to 68.9%, respectively). There was no significant difference in crude protein digestibility, even with the difference in crude protein content of the rations. Cellulose digestibility decreased ($P<.05$) when corn was added (from 45.3 to 31.5%).

Montgomery and Baumgardt (1965b) conducted an experiment in which eight rations varying in physical form and concentrate level were fed to 12 Holstein heifers in an incomplete block design. Rations were as follows: (1) long alfalfa hay; (2) long oat straw; (3) long alfalfa hay plus pelleted ground shelled corn to supply 50% of the daily dry matter intake; (4) long oat straw plus 50% pelleted ground shelled corn; (5) pelleted alfalfa hay; (6) ground oat straw; (7) pelleted ration of 50% alfalfa hay and 50% ground shelled corn. Rations varied in cellulose and crude protein content from 15.0 to 42.7% and from 4 to 17.9%, respectively. Apparent digestibility of dry matter ranged from 45.3% for long oat straw to 69.2% for long alfalfa hay plus corn, cellulose digestibility was higher for all rations containing straw than for the similar rations with alfalfa hay. Additions of corn decreased digestibility of cellulose in both straw and alfalfa hay diets. Depressions in cellulose digestion were less for the long roughages (5 to 10 percentage units) than for pelleted or ground roughages (14 percentage units). The depression was less for long hay than for long straw (5 vs 10 units), but no differences in magnitude of depression were observed when the roughages were ground or pelleted.

Sheep were used to determine digestibility of pelleted diets containing 30, 50 or 70% ground barley straw supplemented with maize and soybean (Swan and Lamming, 1970). Crude protein content of diets were 14.3, 14.8 and 12.0% and crude fiber content 14.3, 23.4 and 30.4% for 30, 50 and 70% straw diets, respectively. Apparent digestibility of dry matter determined at the maintenance level of feeding decreased (72, 64 and 54%, respectively) as the percentage of crude fiber in the dry matter increased. Intake of apparently digested energy declined with each increment of straw from 3.4 to 2.5 mcal/kg. Daily live weight gain by steers fed those diets was 1.29, 1.19 and 1.02 kg/day for the 30, 50 and 70% straw, respectively.

Chicco et al. (1972) conducted an experiment with steers to evaluate the effects of three levels of forage intake (50, 75 and 100% of ad libitum intake) with and without molasses-urea supplementation (3.0 kg of molasses + 150 g of urea/animal/day). The forage used was mature guinea grass containing 6% crude protein. Organic matter digestibility was lowest for the unsupplemented 50% forage intake treatment and was improved ($P<.05$) by molasses-urea supplementation at the 50 and 75% consumption level. Cellulose digestion was improved ($P<.05$) by supplementation at the 50 and 75% levels of forage intake from 52.3 to 65.7% and from 60 to 66.5%, respectively. Restricting forage intake decreased weight gains ($P<.01$) while supplementation improved ($P<.01$) gains at all forage intake levels.

Effects of energy and protein supplementation on voluntary intake and digestibility of straw by 200 to 300 kg cattle were studied in two experiments conducted by Andrews et al. (1972). In the first experiment, long barley straw was supplemented with four levels of crude rpotein (185, 375, 570 and 765 g/head/day) and five levels of energy (3.7, 4.4, 5.2, 5.9 and 6.6 mcal/ME/head/day) in a factorial arrangement of treatments. Protein supplementation was from ground nut meal and energy from either barley or a 9:1 mixture of strach and molasses. At the lowest crude protein level (5.6% of diet), there was a significant decline (from 57.7 to 55.5 g/$W_{kg}^{.75}$) in daily straw intake as the energy level increased. When protein content of the diet was 8.8% or more, straw intake was only slightly depressed at the high energy levels. With the lowest protein level, daily gains were low (.34 kg) and did not respond to energy supplementation. With the other nitrogen levels, daily gain increased from approximately .43 to .79 kg as energy intake increased. In the second experiment, cellulose and organic matter digestibilities were determined for diets containing oat or barley straw fed alone or supplemented with either 260 or 520 g/day of crude protein and either 6.3 or 10.3 mcal ME/day. Organic matter digestibility for all supplemented diets was higher than for straw alone, with little difference being observed due to level of protein or energy supplementation. Cellulose digestion was higher in straw than in the supplemented diets and decreased with increasing energy at each level of protein.

Ammerman et al. (1972) conducted three experiments with 63 yearling wethers to investigate the influence of supplemental nitrogen in the form of natural protein (soybean meal or cottonseed meal) or as urea and biuret combined with an energy source on voluntary intake, digestibility of nutrients and nitrogen balance when sheep were fed low quality (2.57 and 4.6% crude protein) pangolagrass hay. In general, the supplements which contained oilseed meals, dried citrus pulp and molasses as energy sources were consumed at levels of 130 to 150 g per sheep daily which provided 8 to 9.5% total dietary crude protein. In each of the 3 experiments, addition of supplemental nitrogen with an energy source increased ($P<.01$) hay intake (from 653 g to 728 g) and improved ($P<.01$) the apparent digestibility of nitrogen. In general, dietary organic matter was significantly more digestible when a supplement was fed than when hay was fed alone (48.2 to 57.8%). This resulted primarily from addition of a more digestible feed to a hay of lower digestibility. Cellulose digestibilities were higher in all supplemented diets than when hay was fed alone and no differences were observed in cellulose digestibility due to source of supplemental nitrogen.

Two experiments were conducted with 68 yearling wethers to determine the influence of supplemental nitrogen (biuret) and supplemental energy (a mixture of 50% corn meal, 25% corn starch and 25%

sucrose) on voluntary intake, nutrient digestibility and nitrogen balance when sheep were fed low quality (3.28 and 4.51% crude protein) pangolagrass hay (Fick et al., 1973). In experiment 1, the 2 x 4 factorial arrangement of treatments involved 0 or 10 g added nitrogen and 0, 50, 100 or 200 g energy supplement per sheep daily. Experiment 2 was a 3 x 3 factorial with 0, 8 or 16 g added nitrogen and 0, 60 or 120 g energy supplement per sheep daily. Total dietary crude protein levels were 3.88 and 9.71% when 0 and 10 g nitrogen per sheep daily were provided in experiment 1 and 3.08, 7.4 and 12.3% when 0, 8 and 16 g nitrogen per sheep daily were supplied in experiment 2. In both experiments, supplemental nitrogen increased hay intake and apparent digestibility of nitrogen, organic matter and cellulose. Increasing supplemental nitrogen from 8 to 16 g per head daily did not influence the parameters tested. Energy supplementation did not influence nitrogen digestibility among treatments containing biuret, however, nitrogen balances became positive suggesting better nitrogen utilization. Energy supplementation has no significant effect on the digestibility of organic matter; however, the average digestion coefficients increased from 45.2 to 55.5% as the energy supplement increased from 0 to 200 g daily, this probably reflected the addition of a supplement containing more digestible organic matter. Cellulose digestibility decreased with each increase in energy supplementation at both levels of supplemental nitrogen. In both experiments, the highest level of energy supplementation decreased hay consumption and the decrease was greater without supplemental nitrogen.

White, Hembry and Reynolds (1974) conducted a digestion trial with steers fed rations containing 0, 20, 40, 60, 80 or 100% dehydrated coastal bermudagrass or pelleted rice straw to study the influence of roughage level on ration digestibility. In each case a high grain mixture comprised the remainder of the diet. As the level of roughage increased, digestibilities of energy, dry matter, organic matter and nitrogen free extract decreased. As the roughage level increased, crude fiber digestibility of bermudagrass diets increased linearly from 26 to 60%. As rice straw level increased from 0 to 80%, fiber digestibility increased from 34 to 53%, but all rice straw diet had a fiber digestibility of only 41%.

Mulholland et al. (1976) reported the results of an experiment in which a basal ration of ground, pelleted oat straw, urea and minerals supplemented with 0, 5, 10, 15, 20, 30 or 40% starch were fed to a Leicester x Merino wethers. The diets were isonitrogenous (1.6% N). Dry matter intake reached a maximum of 2000 g/day with 30% starch; above this starch level digestive disturbances were observed. Organic matter digestibility was increased by the additions of starch, but cellulose digestibility was depressed by as much as 18 units with the addition of 30% starch. Up to 10% starch had little effect on cellulose digestibility. Live weight change was significantly correlated with digestible organic matter intake. Mean daily weight gains varied from 22 g with no starch to 104 g with 30% starch.

Coleman and Barth (1977) conducted two digestibility studies to evaluate the effect of readily available supplemental energy sources on utilization of non-protein nitrogen (NPN) by steers fed low protein hay. In experiment 1, twelve yearling steers averaging 221 kg in body weight were placed in individual metabolism crates and fed a diet of low quality tall fescue-broomsedge hay (6.7% crude protein) and one of four supplements, urea, biuret and biuret with 9.3% molasses or 8.1% corn meal. In a second experiment, rations containing biuret or no supplemental N were factored with three supplemental energy sources; control (no supplemental energy); corn and citrus pulp (7% each in diet); and molasses (approximately 15%). In experiment 1, source of NPN did not affect digestibilities of diet components. Digestibilities of dry matter, gross energy and acid detergent fiber were increased by additions of corn or molasses. However, in the second digestion study no difference in acid detergent fiber digestibility due to supplemental energy was observed. Results of experiment 1 suggest that small amounts of supplemental energy may stimulate fiber digestion; whereas, larger amounts compete with and reduce digestion of fibrous materials.

In summary, the early studies clearly indicate that addition of purified sources of starch or sugar to ruminant diets substantially reduce digestibility of dry matter and fiber from low quality roughage. *In vivo* and *in vitro* studies conducted to determine the nature of the inhibition suggested it was due to a competition between amylolytic and cellulolytic microorganisms for nutrients, primarily nitrogen. Nitrogen supplementation was usually effective in alleviating the depression in fiber utilization caused by supplementation of readily available carbohydrates. Similar observations have been made when non-purified feedstuffs such as oilseed meals and cereal grains were used for supplementing energy and protein to high roughage diets.

From the literature reviewed, it is difficult to accurately predict at what level of energy supplementation fiber digestion will be significantly affected and what the extent of depression will be. This is because these parameters are affected by type of roughage fed, type and level of energy supplementation and protein content of the diet. Also, in most of those studies, the parameters tested were measured in the total diet and not over the roughage itself. The influence of any type of energy supplement on fiber or cellulose digestion should represent a more direct measure of its effects on roughage utilization, because of the associative effects (interaction) of one food or ration ingredient on others. In general, however, there is an agreement that small amounts of supplemental energy may stimulate cellulose digestibility; whereas, larger amounts would reduce digestion of fiber components.

EXPERIMENTAL PROCEDURE

Sixteen ewe lambs with an average initial weight of 36 kg were assigned to four equal treatment groups. The treatments consisted of a control (no added grain) and three levels of supplemental dry rolled sorghum grain calculated (Garrett, Meyer and Lofgreen, 1959) to provide either 0, 25, 50 or 75% of the digestible energy required to produce 200 g of gain/day. These added grain treatments were designated as low, medium and high. Grain supplements were fed twice daily and each lamb had chopped wheat straw (with the crude protein content increased to approximately 10% by addition of a molasses-urea mixture) available at all times. The amount of grain offered to each of the supplemented groups was adjusted bi-weekly in response to body weight changes. Lambs were individually fed and had access to block salt and drinking water at all times.

Daily straw intake, average daily gains and feed efficiency were determined over a 42-day feeding period. Following this feeding trial, the ewes were used in a digestion and metabolism trial, which actually consisted of two collection periods. Eight ewes, two from each treatment, were used for each period. Each period consisted of a 6-day adjustment period to the metabolism cages and a 7-day total collection period.

For each collection period total feces and urine from each ewe lamb were collected daily. A 10% aliquot of daily fecal excretion was dried to constant weight at 45 C in a forced air oven. At the conclusion of each period, the daily samples from each ewe were pooled and ground through a 1 mm screen in a Wiley mill and a portion of the ground composite was retained for analysis. Urine was collected in glass containers to which 25 ml of hydrochloric acid diluted 1:2 with water had been added. Daily urine collections were diluted to 1400 ml with water and filtered through glass wool and a 25 ml aliquot was retained. Daily aliquots were composited and stored under refrigeration until analyzed. Samples of straw and sorghum grain were taken every day during each collection period and prepared for analysis in the same manner as were fecal samples.

Nitrogen, final dry matter, ether extract and ash were determined according to Association of Official Agricultural Chemists (A. O. A. C., 1970) procedures. Gross energy in the feed and feces was determined in an adiabatic bomb calorimeter. Acid detergent fiber (ADF), cellulose and lignin were determined as described by Goering and Van Soest (1970). Neutral detergent fiber (NDF) was determined according to Robertson and Van Soest (1977) method for dietary fiber estimation in concentrate feedstuffs. Hemicellulose was estimated as the difference between NDF and ADF (Goering and Van Soest, 1970).

Following each collection period, rumen fluid samples were obtained from each ewe immediately prior to and at 3 hr after the morning feeding. Samples were strained through two layers of cheese cloth and preserved by addition of 1 ml saturated mercuric chloride to 50 ml of strained rumen fluid. The preserved rumen fluid was used for pH determination using a Corning pH meter.

Analysis of variance was used for statistical treatment of the data, and means were compared using Duncan's multiple range test (Steel and Torrie, 1960).

RESULTS

Chemical composition and gross energy of sorghum grain and the wheat straw supplemented with molasses and urea used in this study are shown in Table 1. The high crude protein content in the straw was due to addition of urea. Earlier analyses (Swingle and Waymack, 1977; Swingle et al., 1977) indicated unsupplemented wheat straw contained only 2.8 to 5.3% crude protein.

Mean composition of the diets, as actually consumed in this study are in Table 2. Percentages of straw in the low, medium and high grain treatments were 69, 52 and 34%, respectively. Crude protein content was approximately equal (9.8 to 10.6%) for all diets. The percentages of acid detergent fiber (ADF) and ash in diets decreased (from 42 to 17% and from 10 to 5%, respectively) and nitrogen free extract (NFE) and gross energy (GE) increased (from 36 to 65% and from 4.0 to 4.3 mcal/kg, respectively) as the level of supplemental grain increased.

Performance data for the first 42 days are shown in Table 3. Voluntary consumption of straw averaged 540 g DM/day when no supplemental grain was offered. The two lower levels of grain supplementation did not ($P>.05$) depress straw intake, in fact, straw intake was increased approximately 11.5% at the lowest level of added grain, although the difference was not significant. However, at the highest level of added grain, voluntary straw intake decreased ($P<.05$) to only 443 g/day. Total daily dry matter intake increased with each increment of added grain, however, differences between the two highest levels of grain

Table 1. Chemical composition and gross energy of sorghum grain and wheat straw.

	Sorghum grain	Wheat straw[a]
Dry matter	85.9	83.4
Composition, dry matter basis		
Crude protein, %	11.1	9.8
Neutral detergent fiber, %	9.6	67.1
Acid detergent fiber, %	4.5	41.9
Lignin, %	1.2	6.6
Cellulose, %	3.1	31.1
Hemicellulose, %	5.2	25.2
Nitrogen free extract, %[b]	79.8	35.9
Lipid, %	2.8	2.0
Ash, %	1.8	10.4
Gross energy, kcal/kg	4470	4039

[a]Wheat straw Cajeme 71 wheat. No IRN listed. Wheat straw 90.64%, molasses 5.86%, urea 2.68%, mono-dicalcium phosphate .82%. Molasses and the same amount of water, plus urea were thoroughly blended before being added to the roughage.

[b]Nitrogen free extract calculated using acid detergent fiber in place of the conventional crude fiber.

Table 2. Mean ingredients composition, chemical composition and gross energy of diets.

	Added grain treatments			
	0	Low	Medium	High
Ingredient composition, % dry matter				
Straw	100	69	52	34
Grain	---	31	48	66
Chemical composition, dry matter basis				
Crude protein, %	9.8	10.2	10.3	10.6
Acid detergent fiber, %	41.9	30.4	23.9	17.2
Nitrogen free extract, %	35.9	49.4	57.1	64.9
Lipid, %	2.0	2.3	2.4	2.6
Ash, %	10.4	7.7	6.3	4.7
Gross energy, kcal/kg	4039	4173	4246	4323

Table 3. Mean feed intake and performance of ewe lambs fed wheat straw supplemented with different levels of sorghum grain for 42 days.

	Added grain treatments			
	0	Low	Medium	High
Daily intakes, g				
Grain	---	275	550	798
Straw	540^{b}	609^{b}	601^{b}	443^{c}
Total	540^{b}	884^{c}	1151^{d}	1241^{d}
Daily gain, g	-80^{b}	41^{c}	154^{d}	209^{e}
Feed/kg gain, kg	---	21.5	7.4	5.9

[a]Four lambs per treatment. All intake values are on dry matter basis.

[b,c,d,e]Means on the same line with different superscripts are significantly different ($P<.05$).

(1151 vs 1241 g) were not different (P>.05), due to the higher intake of straw at the medium grain level.

As expected, average daily gains increased (P<.05) as the amount of grain consumed increased. The straw diet without added grain did not support positive weight gain (-80 g/day), while gains for the three levels of added grain averaged 41, 154 and 209 g/day, respectively. Feed requirements per unit of gain were the lowest for the highest level of grain. Feed efficiency improved with each increment of added grain (21.5, 7.4 and 5.9 kg feed/kg gain).

Mean dry matter and energy intake and digestion coefficients determined during the metabolism trial are given in Table 4. Straw and total dry matter intake showed the same trend in the metabolism trial as was observed in the feeding trial. Straw intake was depressed (P<.05) only at the highest level of supplemental grain and total dry matter intake increased with each increment of added grain.

Digestibility coefficients for dry matter, organic matter and gross energy increased with increasing levels of supplemental grain, while coefficients for protein, NDF, ADF, hemicellulose and cellulose decreased. With the exception of crude protein, the differences between the control and all added grain treatments were significant (P<.05). Within the added grain treatments, the differences were significant only between the lowest and highest levels, except for cellulose digestibility which was different (P<.05) for all treatments. Digestion coefficients for crude protein were different (P<.05) only between the control and highest grain level.

Table 4. Mean dry matter and energy intake and apparent digestibility by ewe lambs fed wheat straw supplemented with different levels of sorghum grain.[a]

	Added grain treatments			
	0	Low	Medium	High
Dry matter intake/day				
Sorghum grain, g	---	283	575	877
Straw, g	604^{b}	651^{b}	604^{b}	419^{c}
Total, g	604^{b}	934^{c}	1179^{d}	1286^{d}
Total, $g/W_{kg}^{.75}$	45.5^{b}	61.5^{c}	71.6^{d}	74.6^{d}
Energy intake, kcal/day				
Gross energy	2435	3896	5012	5610
Digestible energy	1130	2088	2812	3411
Apparent digestibility, %				
Dry matter	46.2^{b}	53.4^{c}	55.7^{cd}	60.6^{d}
Organic matter	48.3^{b}	55.4^{c}	57.7^{cd}	62.2^{d}
Gross energy	46.4^{b}	53.6^{c}	56.1^{c}	60.8^{d}
Protein	64.7^{b}	61.2^{bc}	54.6^{c}	53.5^{c}
Neutral detergent fiber	49.9^{b}	42.0^{bc}	35.9^{cd}	29.0^{d}
Acid detergent fiber	43.0^{b}	36.0^{bc}	29.7^{cd}	25.0^{d}
Hemicellulose	61.1^{b}	51.0^{bc}	45.3^{cd}	34.8^{d}
Cellulose	53.3^{b}	46.1^{c}	38.5^{d}	28.5^{e}
Lignin	9.5	10.6	14.6	12.4

[a]Each value is the mean of four observations.

[b,c,d,e]Means on the same line with different superscripts are significantly different ($P<.05$).

Nitrogen balance data are shown in Table 5. The daily nitrogen intake increased ($P<.05$) as the level of dietary grain increased, reflecting the differences in total daily intake among groups. Fecal nitrogen excretion also increased ($P<.05$) with increasing grain levels as was indicated by lower apparent digestion coefficients for protein (Table 4). Urinary nitrogen excretion was not different among diets, however, nitrogen retention was higher for lambs on those diets with added grain, because of their higher N intake. Expressed as a percentage of N consumed, nitrogen retention ranged from a negative value for control lambs to a positive 20% for lambs receiving the highest level of supplemental grain. Among the added grain treatments, N retention was lower ($P<.05$) for the lowest level of added grain than for the other two treatments (9.9 vs 19.3 and 20.3). Nitrogen retention expressed as percentage of N absorbed followed the same pattern.

Effects of grain supplementation on rumen pH before and after feeding are summarized in Table 6. Prior to feeding, there were no differences in rumen pH among any of the treatments. At 4 hr post-feeding, pH decreased from 7.0 for control lambs to 6.5 for lambs receiving the highest level of added grain ($P<.05$). Rumen pH of lambs fed the two lower levels of added grain were the same (6.8) and different ($P<.05$) from both the control and highest level of grain.

Table 5. Mean nitrogen balance by ewe lambs fed wheat straw supplemented with different levels of sorghum grain.[a]

	Added grain treatments			
	0	Low	Medium	High
Nitrogen intake, g/day				
Straw	9.5	10.2	9.5	6.6
Grain	0	5.0	10.2	15.6
Total	9.5[b]	15.2[c]	19.7[d]	22.2[e]
Nitrogen excretion, g/day				
Fecal	3.3[b]	5.9[c]	9.0[d]	10.4[d]
Urinary	6.5	7.8	6.9	7.3
Nitrogen retention				
Grams per day	- .3[b]	1.5[c]	3.8[d]	4.5[d]
Intake, %	---[b]	9.9[c]	19.3[d]	20.3[d]
Absorbed, %	---[b]	16.2[c]	35.5[d]	38.1[d]

[a]Each value is the mean of four observations.

[b,c,d,e]Means on the same line with different superscripts are significantly different ($P<.05$).

Table 6. Mean of pH of rumen content of ewe lambs fed wheat straw supplemented with different levels of sorghum grain.[a]

	Added grain treatments			
	0	Low	Medium	High
Time post-feeding, hr				
0	7.1	6.9	7.0	6.9
4	7.0[b]	6.8[c]	6.8[c]	6.5[d]

[a]Each value is the mean of four observations.

[b,c,d]Means on the same line with different superscripts are significantly different ($P<.05$).

DISCUSSION

The data clearly indicate that supplementation of grain to the lambs was beneficial as measured by live weight gains, efficiency of feed conversion (Table 3) and nitrogen balance (Table 5). These responses can be attributed to the increases in total dry matter and digestible energy intakes (Table 4) achieved on the supplemented diets, although differences in daily protein intake could have also been a factor. Dry matter intakes ranged from .6 kg/day for unsupplemented lambs to 1.3 kg/day for those fed the highest level of added grain. Digestible energy and crude protein intakes increased from 1.1 to 3.4 mcal/day and 60 to 140 g/day, respectively, as the level of dietary grain increased. These values compare with recommended daily allowances [National Research Council (N. R. C.), 1975] of 1.3 kg dry matter, 3.6 mcal digestible energy and 130 g crude protein for 30 kg replacement lambs gaining 180 g/day.

While the effect of grain supplementation on animal performance is probably of the greater economic importance, the effects on intake and digestibility of straw are also important considerations if maximal utilization of the roughage is desired. In this study, voluntary consumption of straw was not depressed by grain supplementation, except at the highest level of grain intake (Tables 3 and 4). Mulholland et al. (1976) found voluntary consumption of oat straw by sheep was not significantly decreased by addition of 50 to 300 g of starch/day, but was severely depressed by supplementation of 400 g/day. Andrews et al.

(1972) reported voluntary intake of straw by cattle fed low protein (less than 8%) diets was linearly decreased as energy supplementation increased from 1.2 to 2.0 kg/day, but that at protein levels of 8.8% or more, there was no effect of energy supplementation on intake of straw. Fick et al. (1973) found that supplementation of 200 g/day (but not 100 g/day) of soluble carbohydrate supplement tended to decrease voluntary intake of low protein (3 to 4%) pangolagrass hay. In that study, no effect of energy supplementation on hay intake was observed when dietary protein levels were increased to 9 to 10%.

In the other studies reviewed, it was not possible to determine the effect of energy supplementation on roughage intake because either complete mixed diets were fed or a specific amount of roughage was fed daily. It is apparent, however, that intake of straw by sheep is not adversely affected by moderate supplementation of grain (up to 50% of the diet dry matter), when protein content of the diet is adequate.

In general, dry matter, organic matter and gross energy digestibilities of the diets were improved with each increment of added grain (Table 4). Montgomery and Baumgardt (1965a, b), Coleman and Barth (1977) and Ammerman et al. (1972) also reported that digestibility of these parameters was increased by the addition of readily fermentable energy sources. This probably results simply from the addition of more digestible feed to a roughage of lower digestibility.

On the other hand, NDF, ADF, hemicellulose and cellulose digestibilities of the diets decreased with increasing levels of grain supplementation (Table 4). Montgomery and Baumgardt (1965a) reported similar results when steers were fed different proportions of ground shelled corn and alfalfa meal. Digestibility of cellulose decreased linearly with increasing increments of corn in the diets. White et al. (1974) found a gradual decrease in crude fiber digestibility of dehydrated coastal bermudagrass or rice straw as the level of high grain supplement increased from approximately 40 to 100% of the ration. Coleman and Barth (1977) suggested that small amounts of molasses or corn grain (up to 9% of diet approximately) plus NPN nitrogen sources may stimulate fiber digestion of a low protein hay, whereas, larger amounts compete with and reduce digestion of fibrous materials. These observations of depressed utilization of fiber components when natural feedstuffs containing high amounts of soluble carbohydrates are included in ruminant diets are in good agreement with studies in which supplementation of pure carbohydrate sources significantly decreased digestibility of roughages (Mitchell et al., 1940; Hamilton, 1942; Burroughs et al., 1949b, 1950; Mulholland et al., 1976).

In those studies, inclusion of the carbohydrate usually decreased the protein content of the diet and it was found that supplementation with protein or NPN would partially or completely alleviate the depression in roughage utilization (Burroughs et al., 1949a, 1950; el-Shazly et al., 1961).

In this study, the crude protein content of all diets was approximately 10% (Table 2); however, because of differences in dry matter intake (Table 4), daily crude protein intake increased from 60 to 138 g/day as grain intake increased. Furthermore, as the percentage of grain in the diet increased, the percentage of dietary non-protein nitrogen decreased. These factors should have acted to minimize the effect of grain supplementation on fiber utilization. However, despite the increases in daily protein intake, digestibility of all fiber components decreased substantially as the percentage of grain in the diet increased.

Simple linear regression analysis (Steel and Torrie, 1960) was used in an attempt to isolate the effect of grain and straw on dietary fiber digestibility. Level of grain supplementation (% of diet dry matter) was used as the independent variable and digestibility of neutral detergent fiber in the diet as the dependent variable (Figure 1). The correlation between the two parameters was .99 and the regression equation was $Y = 50.1 - .315\ X$, where Y is NDF digestibility and X is percent of grain in diet. This equation predicts that digestibility of fiber in straw fed alone would be 50%. Other studies at this station have shown dry matter or organic matter digestibility of Cajeme wheat straw to be 50 to 55% (Swingle and Waymack, 1977; Swingle et al., 1977). The equation also predicts that digestibility of fiber in sorghum grain fed as 100% of the diet would be approximately 19%. This relationship suggests that the decrease in diet NDF digestibility observed when supplemental grain was fed could have been due to the low digestibility of grain fiber and not to a decrease in digestibility of straw fiber.

To further examine this possibility, simultaneous equations were used to calculate digestibilities for straw and grain at the different dietary levels. Kromann (1967) has suggested this method as a means of determining whether or not associative effects exist between dietary components fed at different levels. In this method, pairs of equations are written to describe the digestibilities of diets containing two adjacent levels of each ingredient. For example, in this study the medium and high

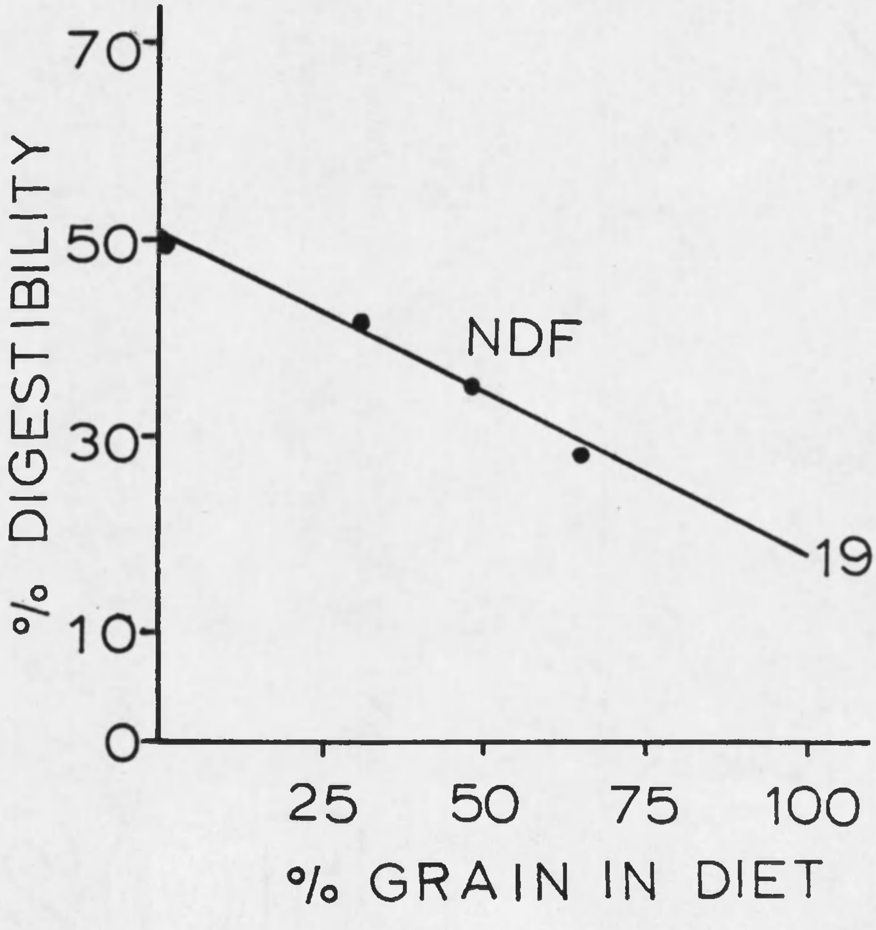

Figure 1. Relationship between percentages of sorghum grain in diets and digestibility of neutral detergent fiber ($Y = 50.1 - .315X$).

added grain diets actually contained 48% and 66% grain on a dry matter basis (Table 2) and had NDF digestibilities of 35.9 and 29.0% respectively (Table 4). For this pair of diets, the simultaneous equation becomes:

$$.48\ X + .52\ Y = 35.9$$

$$.66\ X + .34\ Y = 29.0$$

X and Y are apparent digestibility coefficients for grain and straw, respectively. This pair of equations can then be solved for the unique set of digestion coefficients which will satisfy both equations.

Digestion coefficients for NDF in grain and straw determined by this method are shown in Table 7. There is no evidence that NDF digestibility of straw is decreased at any level of added grain and the digestibility coefficients are in good agreement with those obtained by regression analysis. While not shown, these analyses were also conducted for digestibilities of all other fiber fractions in the diet. In each case, the decreasing digestibility of the fiber component as grain intake increased could be explained on the basis of low digestibility of grain fiber.

Data from the study by Montgomery and Baumgardt (1965a) in which cattle were fed pelleted diets, containing various ratios of corn to alfalfa meal were also analyzed by these methods. The regression analysis indicated that digestibility of cellulose in corn grain fed as 100% of the diet would be 23.4% which agrees closely with the value of 19% for digestibility of NDF in sorghum grain calculated in this study. Further, the simultaneous equations indicated that digestibility of cellulose in corn decreased from 37.5% for diets containing 0 to 20% corn to 16.1% for diets containing 40 to 60% corn. Digestibilities

Table 7. Estimation of neutral detergent fiber digestibilities using simultaneous equations.

Straw:grain ratios	% Digestibility in	
	Straw	Grain
100:0 69:31	50	24
69:31 52:48	53	17
52:48 34:66	54	16

calculated for cellulose in alfalfa hay increased from 45 to 54% as the percentage of corn increased. These data are also in agreement with results from this study.

These indications of low digestibility of fiber components in grain are not in agreement with values of 40 to 60% for digestibility of fiber in cereal grains given in current tables of feed composition [Morrison, 1959; National Academy of Science (N. A. S.), 1971]. Also, estimates of fiber digestibilitity determined in high or all-grain diets are usually higher than those calculated in this study. For example, Saba (1964) reported crude fiber digestibilities for all concentrate diets containing 97.7% milo or 98.7% barley of 39.1 and 40.6%, respectively. Carrillo-Mendez (1975) reported a digestibility coefficient of 52.8% for acid detergent fiber in an all concentrate diet containing 93.3% wheat and 6% molasses. White et al. (1974) reported digestibilities of 26.5 and 34.4% for crude fiber in all concentrate mixtures containing 97% sorghum grain.

The accuracy of the above reported values could be questioned on the basis that (1) most of the table values were probably determined by difference and (2) it is difficult to accurately measure digestion coefficients of diet components present in small amounts (Schneider and Lucas, 1950), as would be the case for fiber in grains. Also, the use of crude fiber could bias the estimates upwards since this fraction would not include any lignin, which is essentially indigestible (Van Soest, 1966).

If, in fact, the digestibility of grain fiber is as low as the estimates calculated in this study would indicate, it could be due to an inherent low digestibility of the fiber because of the cell wall structure in grains or because the comparatively rapid rate of passage of grain through the digestive tract does not allow sufficient time for maximal digestion of fiber components. In this regard, it is interesting that the data from this study and that from Montgomery and Baumgardt (1965a) both suggest that digestibility of grain fiber is higher in high roughage diets (when rate of passage would be slowed) than in low roughage diets which usually have a more rapid rate of passage.

The suggestion that straw fiber digestibility is not depressed by addition of grain to the diet-roughage is in direct contrast to the data which clearly shows that addition of starch or sugar to the diet significantly depresses roughage utilization. This discrepancy may be related to differences in diet composition, particularly with regard to fiber source and protein level. Most of the early studies used a single source of fiber and usually the percentage of protein in the diet decreased as the level of supplemental carbohydrate increased. However, even though the protein percentage decreased, the total amount of protein consumed did not always change since a constant amount of protein supplement was usually fed.

In this study, dietary fiber was from two sources, straw and grain and percentage of crude protein in the diet did not change as grain level increased. However, the percentage of NPN in the total protein decreased and total crude protein intake increased with increased grain. It is extremely difficult to avoid these complications with source and level of protein and additional research is indicated.

Another explanation for the apparent contrasting results of this and other studies may be that the effect of purified carbohydrates is different from the effect of natural sources of carbohydrates which exist in complex with other nutrients. This could relate to difference in rate or extent of hydrolysis of carbohydrate.

The use of purified carbohydrates has the advantage that diets evaluated differ in only one constituent but the results may not apply to the practical feeding of livestock. On the other hand, use of natural feedstuffs in this type of study, more closely follows practical feeding condition, but sources and levels of all nutrients cannot be as closely controlled, and thus interpretation of the data may be more difficult.

CONCLUSIONS

On the basis of the results of the feeding and digestibility trials reported in this thesis and the information available in the literature, the following conclusions were drawn.

1. Inclusion of up to 50% grain in the diet did not decrease but tended to enhance voluntary intake of wheat straw. In this study, higher grain intakes depressed straw consumption, but the exact level at which this occurs could not be determined.
2. Daily digestible energy intakes, live weight gains and efficiency of feed conversion by lambs were improved by supplementation of wheat straw with grain.
3. Digestibility of fiber components in the total diet decreased as the level of supplementary grain increased.
4. Digestibility of fiber components in sorghum grain is low (approximately 20%). The low digestibilities for fiber components in the diets with added grain were apparently due to this low digestibility of grain fiber, not to decreased digestibility of fiber in the straw.
5. Additional research is needed with respect to digestibility of grain fiber.
6. Additional research is also needed to separate the effects of protein and starch on utilization of roughages.

7. Moderate levels of grain can be supplemented to straw-based diets to improve animal performance without decreasing the utilization of wheat straw.

APPENDIX

STATISTICAL ANALYSES AND RAW DATA

Table 8. Analysis of variance of data in table 3.

Sources of variation	df	Mean squares: Straw intake	Total intake	Daily gain
Block	3	.013	.0159	.000321
Treatment	3	.027*	.5162*	.0618*
Error	9	.0043	.00615	.0010

*Significance ($P<.05$).

Table 9. Analysis of variance of data in table 4.

Sources of variation	df	Mean squares											
		Intake			Digestibility								
		Straw	Total	Total $g/W_{kg}^{.75}$	DM	OM	GE	CP	NDF	ADF	Hemi-cellulose	Cellulose	Lignin
Block	3	.0124	.0124	12.618	48.0*	44.1*	38.6*	21.5	28.9	71.9	5.4	38.5	173.8
Treatment	3	.04199*	.375*	683.78*	144.2*	134.2*	144.4*	114.1	317.0*	245.5*	474.6*	449.7*	19.8
Error	9	.00919	.0092	35.463	9.3	8.6	8.4	30.4	12.7	29.0	49.3	18.7	66.7

*Significance ($P<.05$).

Table 10. Analysis of variance of data in table 5.

Sources of variation	df	Mean squares: Nitrogen utilization — Intake	Fecal	Urinary	Retained	% Intake	% Absorbed
Block	3	140.9	135.6	8.0	33.0	14.0	18.3
Treatment	3	6067.7*	1947.8*	63.5	930.2*	362.8*	1280.2*
Error	9	101.9	111.3	85.8	11.7	7.0	20.6

*Significance (P<.05).

Table 11. Analysis of variance of data in table 6.

		Mean squares	
		pH of rumen content	
Sources of variation	df	Before feeding	After 4 hr feeding
Block	3	.0101	.0148
Treatment	3	.0173	.1636*
Error	9	.0226	.0116

*Significance (P<.05).

Table 12. Chemical analysis and gross energy of wheat straw and sorghum grain in metabolism trials.[a]

	DM %	Nitrogen %	Ash %	OM %	GE cal/g	EE %
Trial 1						
Wheat straw	84.20	1.59	10.58	89.42	3993	1.91
Sorghum grain	86.09	1.73	1.79	98.21	4452	2.90
Trial 2						
Wheat straw	82.76	1.56	10.25	89.75	4086	2.11
Sorghum grain	85.84	1.82	1.82	98.18	4489	2.84
$\bar{X}$						
Wheat straw	83.48	1.57	10.41	89.58	4039.5	2.01
Sorghum grain	85.96	1.77	1.80	98.19	4470.5	2.87

[a]All values on dry matter basis.

Table 13. Chemical analysis of wheat straw and sorghum grain in metabolism trial.[a]

	DM %	NDF %	ADF %	Hemi-cellulose %	Cellulose %	Lignin %
Trial 1						
Wheat straw	84.20	66.6	42.80	23.8	31.57	7.02
Sorghum grain	86.09	9.8	4.50	5.3	3.20	1.11
Trial 2						
Wheat straw	82.76	67.6	40.92	26.68	30.71	6.10
Sorghum grain	85.84	9.5	4.47	5.03	2.99	1.25
$\bar{X}$						
Wheat straw	83.48	67.1	41.86	25.24	31.14	6.56
Sorghum grain	85.96	9.65	4.48	5.16	3.09	1.18

[a]All values on dry matter basis.

Table 14. Feed consumption and feces excretion of ewes during collection periods.[a]

Treatment	Trial	Pen	Crate	Intake, g Straw	Grain	Total	Feces, g
0	1	15	2	4840.7	------	4840.7	2475.7
	1	11	5	4359.9	------	4359.9	2481.9
	2	7	4	3723.8	------	3723.8	2022.2
	2	3	5	3974.9	------	3974.9	2107.3
Low	1	14	1	4314.4	1988.7	6303.1	2838.9
	1	9	6	4748.9	1988.7	6737.6	3036.2
	2	6	1	4450.0	1982.9	6432.9	3175.3
	2	1	6	4706.6	1982.9	6689.5	3152.5
Medium	1	10	3	5043.6	4037.6	9081.2	4133.2
	1	13	4	3721.6	4037.6	7759.2	3469.1
	2	2	2	4690.8	4025.9	8716.7	4224.1
	3	5	3	3449.4	4025.9	7475.3	2881.5
High	1	16	7	3516.2	6146.8	9663.0	4074.9
	1	12	8	3378.9	6146.8	9525.7	3624.3
	2	4	3	3479.2	6128.9	9608.1	4507.6
	2	8	8	1365.5	6128.9	7494.4	2283.5

[a]All values on dry matter basis, 7 days collection.

Table 15. Chemical analysis of feces from ewes.

Treatment	Trial	Pen	Crate	DM %	Nitrogen %	Ash %	Organic matter %	Gross energy Cal/g	EE %
0	1	15	2	27.93	1.03	13.83	86.17	3991	1.87
	1	11	5	28.43	1.00	14.03	85.97	3989	1.76
	2	7	4	27.66	0.99	13.73	86.27	4063	1.65
	2	3	5	26.24	1.12	14.90	85.10	4035	1.92
Low	1	14	1	34.68	1.49	11.78	88.22	4190	2.36
	1	9	6	33.72	1.33	12.26	87.74	4121	2.13
	2	6	1	29.56	1.36	11.99	88.01	4126	2.43
	2	1	6	30.78	1.27	11.94	88.06	4152	2.27
Medium	1	10	3	29.51	1.65	12.04	87.96	4132	2.17
	1	13	4	30.15	1.76	9.89	90.11	4206	2.01
	2	2	2	28.70	1.58	10.29	89.71	4169	1.70
	3	5	3	32.53	1.91	10.27	89.73	4356	2.25
High	1	16	7	34.58	1.93	8.78	91.22	4277	2.11
	1	12	8	31.11	1.68	8.45	91.55	4333	2.19
	2	4	3	28.13	2.20	9.18	90.82	4253	1.72
	2	8	8	31.47	2.31	7.81	92.19	4407	2.40

Table 16. Chemical analysis of feces from ewes.

Treatment	Trial	Pen	Crate	DM %	NDF %	ADF %	Hemi-cellulose %	Cellu-lose %	Lignin %
0	1	15	2	27.93	63.5	45.02	18.48	26.53	11.27
	1	11	5	28.43	63.1	42.74	20.36	27.63	10.10
	2	7	4	27.66	62.0	47.08	14.92	27.34	11.00
	2	3	5	26.24	60.8	42.40	18.40	26.50	11.58
Low	1	14	1	34.68	60.1	42.09	18.01	25.59	9.49
	1	9	6	33.72	62.3	41.69	20.61	25.79	9.36
	2	6	1	29.56	63.1	41.22	21.88	27.28	9.27
	2	1	6	30.78	61.3	41.47	19.83	25.58	9.43
Medium	1	10	3	29.51	56.9	36.92	19.98	23.76	7.88
	1	13	4	30.15	56.3	37.81	18.49	24.66	7.76
	2	2	2	28.70	56.2	37.52	18.68	24.27	7.36
	3	5	3	32.53	55.3	36.72	18.58	23.51	7.19
High	1	16	7	34.58	50.7	33.89	16.81	22.19	7.34
	1	12	8	31.11	49.9	29.60	20.30	22.32	6.96
	2	4	3	28.13	49.7	32.67	17.03	21.89	6.46
	2	8	8	31.47	48.7	26.77	21.93	19.44	5.07

Table 17. ML and nitrogen content of urine from ewes.

Treatment	Trial	Pen	Crate	Total urine ml	Nitrogen %	Nitrogen g
0	1	15	2	14000	0.39	54.6
	1	11	5	14000	0.36	50.4
	2	7	4	14000	0.28	39.2
	2	3	5	14000	0.26	36.4
Low	1	14	1	14000	0.36	50.4
	1	9	6	14000	0.41	57.4
	2	6	1	14000	0.37	51.8
	2	1	6	14000	0.42	58.8
Medium	1	10	3	14000	0.37	51.8
	1	13	4	14000	0.32	44.8
	2	2	2	14000	0.40	56.0
	3	5	3	14000	0.30	42.0
High	1	16	7	14000	0.43	60.2
	1	12	8	14000	0.43	60.2
	2	4	3	14000	0.26	36.4
	2	8	8	14000	0.34	47.6

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