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WHEAT STRAW: DIGESTIBILITY AND UTILIZATION BY STEERS AS AFFECTED BY PROCESSING AND THE ADDITION OF MONENSIN, STARCH AND PROTEIN.

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WHEAT STRAW: DIGESTIBILITY AND UTILIZATION BY STEERS AS AFFECTED BY PROCESSING AND THE ADDITION OF MONENSIN, STARCH AND PROTEIN

by

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I hereby recommend that this dissertation prepared under my direction

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be accepted as fulfilling the dissertation requirement for the Degree

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SIGNED: Luis E Carrillo

Con profundo cariño y agradecimiento
dedico este trabajo.

A mi esposa Martha Elena y mis hijos, Luis Enrique, Marcos Alejandro y Martha Elena

A mi mamá, Lucinda y mis hermanas, Bertha Esthela, Alejandrina, Edna y Yolanda

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ABSTRACT

Four digestion trials were conducted with yearling Okie steers fed diets containing wheat straw, to measure its digestibility and utilization as affected by: (1) type of straw (Durum or short stemmed) and particle size (fine and coarse); (2) addition of 33 ppm of monensin; (3) fine grinding and grinding and pelleting; and (4) supplementation of protein (low and high levels) and starch (zero, low, and high levels). All steers were individually fed.

In each trial, total feces were collected during a 7-day collection period. Samples of feed and feces were composited during the 7-day period for chemical analysis. Digestion coefficients were computed for gross energy and all fractions of the diets. Nitrogen balance was conducted in trial 2 and rumen volatile fatty acid concentrations were measured in trials 2, 3, and 4.

In trial 1, 12 steers were allotted to four treatments of three steers each and fed for 59 days. The diets contained 83% straw with urea as the nitrogen supplement. Feed intake was increased by 13% for the diets prepared finely ground as compared to the coarse ground diets which resulted in an increased ($p < .05$) average daily gain (.170 vs. .070 kg). Type of wheat straw had no significant effect on either feed intake or average daily gain. The

digestibility of dry matter and neutral detergent fiber (NDF) was significantly higher ($p < .05$) for the coarse ground diets as compared to the fine ground diets. Crude protein digestibility was not affected by treatment.

In trial 2, 11 steers were allotted to two treatments with 5 monensin and 6 control steers fed for 62 days. The straw (INIA) was coarse ground with urea as the nitrogen supplement. Monensin did not affect the digestibility of gross energy or of any of the fractions of the diets. Feed intake was depressed 15% by the addition of monensin. Daily gain was negative and similar for both treatments. Monensin altered rumen VFA ratio by depressing acetate concentration by 9% and increasing propionate by 21%. Monensin did not improve nitrogen retention.

In trial 3, 10 steers were allotted to two treatments of 5 steers each and fed for 59 days. The roughage portion of the diets contained 88.5% straw and was supplemented with .500 kg of cottonseed meal per steer daily. The diets were fed as fine ground or fine ground and pelleted.

Pelleting increased voluntary intake by 21% and average daily gain by .074 kg ($p < .05$) (.162 vs. .088 kg). The digestibility of gross energy and all fractions of the diet, with the exception of crude protein, were significantly higher ($p < .05$) for the ground diet. Concentration of rumen VFA was similar for both treatments.

In trial 4, 10 steers were allotted to four treatments and fed for 63 days. The fine ground straw was supplemented as follows: (1) 800 g of cottonseed meal (CSM); (2) 800 g CSM plus 650 g of starch (S); (3) 800 g CSM plus 1300 g S; and (4) 1600 g CSM plus 1300 g S.

Straw intake was depressed by 17% when starch was added at either the low or high level. Average daily gain increased linearly from .44 to 1.0 kg as supplement feeding level increased.

Dry matter digestibility was not significantly different ($p > .05$) among treatments, however the highest value corresponded to treatment 4 which contained the highest level of protein and starch supplementation. Crude protein digestibility was related to protein content of the diet.

Fiber digestibility was depressed by 15% when either the low or high level of starch was added to straw with the low level of protein. When protein level was increased, fiber digestibility was raised to within 5% of the control treatment. Protein addition only partially corrected the depression in cellulose digestibility due to starch addition, while in the case of hemicellulose the depression in digestibility was completely corrected.

INTRODUCTION

Low quality roughages, particularly the crop residues from cereals, represent a large potential source of feed for ruminants. This is particularly true in developing countries where grain is used primarily for human consumption and only limited amounts are diverted to cattle feeding. Currently, small grain straws are utilized very little due to their low content of protein and digestible energy but ". . . considering the increasing demand for feed in today's world it seems that a reexamination of these poor quality roughages for maximum exploitation of their energy for practical livestock production is inevitable . . ." (Bhattacharya and Pervez, 1973, p. 976).

Utilization and digestibility of diets containing low quality roughages can be improved by physical or chemical treatments. Treating the roughages with alkali solutions to break the lignin-cellulose bond are well documented and discussed by several workers (Beckman, 1921; Chandra and Jackson, 1971; Klopfenstein, 1975; Dyer, 1973; Guggolz, Kohler, and Klopfenstein, 1971; etc.). There are many problems associated with alkali treatment of low quality roughages, such as cost, equipment, reagents, and pollution effects. Only in areas of critical feed shortages has any potential application been made with alkali treated roughages.

When low quality roughage forms 50% or more of a diet for cattle, voluntary intake is the most important factor determining total energy consumption. It has generally been accepted that voluntary intake of roughages is related to the amount of digesta in the reticulo-rumen prior to feeding which likewise is related to the rate of digestion (Campling, Freer, and Balch, 1961).

The physical form in which roughages are fed has a direct effect on the voluntary intake and the rate of passage of a feed. Ground material is consumed in larger quantities than unground material and will also pass faster through the gastro-intestinal tract resulting in a lower rate of digestibility particularly of the crude fiber fraction (Montgomery and Baumgardt, 1965b).

Fine grinding and pelleting of low quality roughage will markedly improve feed intake and daily gain (Blaxter, Graham, and Wainman, 1956). However, there is only limited use of these techniques due primarily to the energy cost for grinding and pelleting as related to the available energy from the final product. In addition there are problems associated with collection and transport of the roughages to a location for processing.

Recently, a product known as monensin has been approved for use with beef cattle. This compound exerts its effect by altering rumen fermentation to provide increased production of propionic acid (Brown et al., 1974; Richardson et al., 1976). Recovery of energy from the fermentation of the hexose molecule in the rumen is more efficient by way of propionate than from acetate or butyrate. In addition, propionate is utilized more efficiently by the tissues than are the other two volatile fatty acids. Since acetate production is very high in the rumen when high roughage levels are fed, monensin could be useful for increasing the energy available from straw.

As wheat straw is low in both protein and digestible energy, proper supplementation must be provided to achieve reasonable animal performance. It is generally accepted that addition of readily available carbohydrates to roughage diets will result in a decrease in the digestibility of the crude fiber fraction and if efficient roughage digestion is desired, additional protein must be provided (Burroughs et al., 1949a, 1949b; Burroughs, Gall et al., 1950; Burroughs, Long et al., 1950). This appears to be due to a competition for nutrients, particularly nitrogen, between amylolytic and cellulolytic bacteria.

Economic considerations usually prevent the addition of sufficient protein to have a significant effect on utilization of low quality roughages because even then, the available energy from the roughage is low when compared to a high quality roughage such as alfalfa. However, additional studies are necessary to determine the relationship of soluble carbohydrate and protein addition to wheat straw diets.

Recently, high grain yielding varieties of wheat have been developed. A marked characteristic of these wheats is the short length of the stem. Very little is known about the feeding value of the straw from the short stemmed wheats. The possibility exists that the feeding value of these wheat straws may be entirely different from the long stemmed varieties.

To obtain additional information which might permit more efficient utilization of wheat straw by cattle, research was conducted to determine the effect of the following on digestibility and intake of wheat straw:

1. The effect of type of wheat straw (Durum and short stemmed) and particle size (coarse and fine).
2. The effect of the addition of monensin.
3. The effect of pelleting.
4. The effect of protein and energy supplementation on fiber digestibility.

LITERATURE REVIEW

Types of Straws

Wheat varieties are most commonly grown to produce grain for flour or for manufacturing of products for the pastry industry. In 1972, plant breeders began to release short, stiff-stemmed wheat varieties which could be used for heavy fertilization programs without suffering lodging which was the case with the conventional tall wheat varieties. Most of these varieties were developed in Mexico. The main characteristic is that they are very high yielding but some of the varieties will not meet the standards required by the milling industry in the United States. For this reason they have been used for feeding in the southwestern United States and have become known as feeding wheats.

Swingle (1979) conducted an experiment to determine chemical composition and *in vitro* dry matter disappearance of straws from two varieties of wheat and barley. *In vitro* dry matter disappearance (DMD) was determined on 0.5 g samples incubated for 48 hours with buffered rumen inoculum and followed by 48 hours pepsin digestion. The rumen inoculum was obtained from a fistulated steer maintained on alfalfa hay. Results are shown in Table 1. Chemical composition did not reveal any major differences between wheat varieties although dry matter disappearance of Cajeme

Table 1. Chemical composition and *in vitro* dry matter disappearance of wheat and barley straws.

Item	Wheat		Barley	
	Cajeme 71	Siete Cerros	Arimar	Arizona 70-1
Air dry basis composition %				
Crude protein	1.5	1.5	2.2	2.3
Neutral detergent fiber	70.7	70.8	71.1	70.8
Acid detergent fiber	46.6	48.9	48.1	46.8
Hemicellulose	24.1	21.9	23.0	24.0
Lignin	9.2	9.6	10.0	9.8
Acid in soluble ash	4.5	4.8	3.3	4.3
In vitro DMD %	48.2	44.1	39.9	41.8

was slightly higher than Siete Cerros and definitely DMD is higher for the wheat straws as compared to the barley straws.

Taylor et al. (1976) found that straw from short stemmed feeding type wheat, Cajeme 71, had equal feeding value to cottonseed hulls in dry cow diets and that the feeding value of straw was improved by the addition of 58% water at time of slicing which was approximately 21 hours prior to feeding. Taylor, Selke, and Hale (1977) conducted a trial to evaluate one of the Durum type wheat straws (Cocorit) and to repeat the water treatment. Sixty-two pregnant dry cows were assigned to three treatments: (1) sliced wheat straw 7 kg + .681 kg of cottonseed meal/head; (2) 3.5 kg of sliced wheat straw + 3.5 kg of cottonseed hulls + .681 kg of cottonseed meal; and (3) same as treatment (2) but the straw was wetted at slicing time. Protein intake was estimated to be .531 kg for treatment (1) and .608 kg for treatments (2) and (3) per head per day. Results obtained indicate that Durum straw was significantly less satisfactory than the diet containing half straw and half cottonseed hulls. Cows in treatment (1) lost 15 kg in 55 days as compared with 4 kg for cows in treatment (2) and cows in treatment (3) gained 4.5 kg. On the all-straw treatment two cows died of abomasal displacement. Similar cows in 1976 gained weight when fed a like amount of Cajeme 71 and no health problem developed. Durum type wheat straw (Cocorit) was satisfactory when fed as one-half of the roughage allowance with cottonseed hulls. The limited information available suggests that different types of wheat straws may differ in utilization by cattle.

Effects of Physical Preparation of Roughages on Its Utilization by Ruminants

Physical preparation of low quality roughages includes grinding, pelleting, and cubing. The different preparations of the roughages have an effect on prehension, mastication, rate of passage, and digestibility which result in different degree of utilization by the animal. In regard to physical preparation, of particular importance is the relationship to voluntary intake. In this section, results obtained in experiments involving different physical forms of roughages will be discussed.

Campling et al. (1961) studied the relationship between amount of digesta in the reticulo-rumen, its rate of disappearance from the digestive tract, and the voluntary intake (VI) of fistulated cows fed either hay or straw _ad libitum_, or controlled levels (10 and 15 lbs) of each. Cows were fed once daily. The mean VI of hay was more than twice that of straw. The authors associated this to a lower overall digestibility and in the reticulo-rumen, due to a lower digestibility of crude fiber and a longer time of retention of food residues. Immediately after ad lib feeding, the dry weight of rumen-reticulo digesta in the hay-fed cows was 35% more than in the cows on straw. However, as a result of the slow rate of disappearance of straw, the difference was only 6% just before the next meal. It is suggested that the VI of these two roughages was regulated by their respective rate of disappearance from the gastro-intestinal tract in such a way as to maintain a constant amount of residues in the reticulo-rumen immediately before feeding.

Blaxter and Wilson (1962) used eight steers to measure the VI of roughases. Four roughases were fed, one at a time, to eight steers for periods of 35 days. The roughages were: one dried grass, two hays, and an oat straw. Results indicated that the mean VI was related to the mean apparent digestibility of the energy of the roughages. Apparent digestible energy was 69% for the dried grass and intake was 90.3 g/kg wt$^{.75}$ as compared with straw where digestible energy was 46% and intake was 44 g/kg wt$^{.75}$. Mean weight gains were proportional to amount of energy apparently digested. Significant differences occurred among animals in VI and those animals which consumed the most roughage had lowest digestibility values.

Dinius and Baumgardt (1970) conducted an experiment to determine VI by sheep of diets varying in digestibility and caloric density and to describe diets in which intake is limited by fill. A basic concentrate diet was diluted from 5 to 50% with four diluents, then pelleted. The authors observed that dry matter intake increased as the digestible energy per gram increased to 2.5 kcal. Above this value, dry matter intake decreased and digestible energy remained static. Apparently, fill limited intake of sheep when energy was less than 2.5 kcal per gram whereas above this level, energy intake was regulated. The point between bulk limitation of food intake and energy regulation is not well defined.

Balch (1950) conducted five trials with Shorthorn cows to measure the rate of passage of food. Diets were stained so undigested particles could be identified in the feces. Ground hay given in small additions to unground hay was invariable excreted more rapidly than the unground hay. Ground hay in diets in which all the hay was ground was usually excreted over a longer period of time than unground hay in a similar diet.

Blaxter et al. (1956) reported the results obtained in eighteen experiments with six sheep designed to study the effect of the method of preparing dried grass and the level of feeding on digestibility and passage through the digestive tract. Grass was given in the long form or in cubes made from either medium or finely ground grass. The cubes passed through the digestive tract more quickly and had a lower digestibility than the long material. Increasing the feeding level resulted in an increase in the passage of the food and a fall in digestibility. The latter effect was most marked with the cubes made from the finely ground material. It is concluded that the method of preparation modified the rate of passage through the gut and that this rate was the determinant of its digestibility.

McCroskey et al. (1961) measured the effect of pelleting steer fattening rations with different concentrate to roughage ratios. Forty-eight Hereford steers in two trials were fed diets containing either 1:4 or 4:1 concentrate to roughage ratios. Both rate of gain and feed intake were significantly increased by pelleting the 1:4 ration. Pelleting the 4:1 ration resulted in no significant change in rate of gain but caused a decrease in feed intake. Apparent digestibility of rations components was not significantly altered by pelleting either ration although it tended to reduce the digestibility of crude fiber.

Keith et al. (1961) measured the effect of physical form on the nutritive value of hay fed to lactating cows. Four Holstein cows were fed a mixture of alfalfa hay-orchardgrass as the sole source of nutrients, either ground, pelleted, chopped, or in the long form. Feed intake, nutrient digestibility, and rate of passage were measured using Cr_2O_3. Intake was 48 lbs for the ground and pelleted diets versus 38 and 34 lbs for the chopped and long form, respectively. Crude fiber digestibility was 59, 44, 62, and 63% for the ground, pelleted, chopped, and long hay, respectively. The number of hours after feeding that chromium recovery from feces was highest was: 22, 20, 32, and 28 for the ground, pelleted, chopped, or long material, respectively, indicating a faster rate of passage for the ground and pelleted hays.

Moore (1964) in the symposium on forage utilization states that pelleting increases dry matter intake, reduces time of prehension and mastication, probably reduces saliva secretion, decreases rumination, increases rate of digestion in the rumen, increases rate of passage of feed particles from the rumen, decreases dry matter and crude fiber digestibility, and increases the feeding value of poor quality forages but not that of high quality forages.

Montgomery and Baumgardt (1965b) fed eight rations varying in physical form and energy concentration to 12 Holstein heifers. Rations fed were: (1) long alfalfa hay, (2) long oat straw, (3) long alfalfa hay + pelleted ground shelled corn to supply 50% of the daily dry matter intake, (4) long oat straw + shelled corn as in (3), (5) pelleted alfalfa hay, (6) ground oat straw, (7) pelleted alfalfa + shelled corn 50% each, and (8) same as (7) with oat straw replacing alfalfa. Cellulose levels varied from 15 to 43% and crude protein from 4 to 18%. Total dry matter intake was increased when corn was added to either of the roughages as compared to the roughage alone. Grinding and pelleting of hay increased intake while grinding of the straw decreased the intake. Pelleted rations composed of 50%

roughage and 50% corn resulted in greater digestible energy intake than the corresponding ground or pelleted roughages. Addition of corn to the roughage diets increased dry matter digestibility, decreased the digestibility of cellulose, and increased rumen retention time for the roughage portion of the diet. Pelleting of hay reduced cellulose digestion from 57.4 to 46.9%. Grinding of straw reduced cellulose digestion from 63.7 to 58.9% as compared with the roughages in the long form.

Cullison (1961) compared intake and feed to gain ratio of Bermuda hay fed either in the long form, ground, and ground and pelleted to weanling beef calves with 12 steers per treatment. Roughage was fed ad libitum and two pounds of cottonseed meal was fed daily to each steer. Results indicated that pelleting increased intake from 10.3 to 14.4 lbs as compared with the long hay. As for the ground preparation, intake was 13.4 lbs. Feed to gain ratios were 17, 14, and 11.3 lbs for the long hay, ground, and ground and pelleted, respectively.

Minson (1963) in in extensive review of the effect of pelleting and wafering on the feeding value of diets containing 50% or more roughage concluded that pelleting apparently depressed dry matter digestibility of the ration but there was no evidence of an alteration in the net energy value. This conclusion was confirmed by the similar live weight gain of sheep and cattle when fed equal quantities of presented in different physical forms. The extent of the improvement achieved by pelleting depends upon the quality of the unpelleted ration and recognizes that improvement in feeding values have often been obtained by pelleting hay rations.

Burt (1966) compared the nutritive value of ground and pelleted versus long barley straw for growing Ayrshire heifers; the diets were: (1) long barley straw plus concentrates, (2) same as in treatment (1) but most of the straw ground and pelleted with a roughage to concentrate ratio of 70:30, and (3) a pelleted 70:30 roughage concentrate mixture to provide a theoretical starch equivalent intake to treatment (1). Average daily gain over a period of 10 weeks was 0.55, 0.99, and 1.23 lb/day for treatments 1, 2, and 3, respectively. Differences indicate a marked response in energy value due to processing the straw. Substitution of ground and pelleted for long straw reduced the time taken to consume the feeds from 4 to 1 hour a day and rumination time was reduced from 13% to 7% of the day. Grinding and pelleting changed the proportion of rumen volatile fatty acids toward a lower production of acetic acid with a reduction in methane production.

Lamming, Swan, and Clarke (1966) studied the substitution of maize by milled barley straw on performance of beef fattening steers with all pelleted diets. Sixty-four 270-kg steers were allotted to diets containing 0, 10, 20, 30, 40, or 50% milled barley straw + maize and soybean meal. Protein was adjusted to 12% air dry basis in all diets. Growth rates in the range of 8.3 to 9.5 kg/week/head were obtained with growth rates decreasing significantly ($p < .05$) by 0.36 ± .15 kg per week for each 10% increase in straw. The efficiency of food conversion varied from 6.5:1 for the 0% straw to 7.7:1 for the 50% straw. Feed intake increased as the per cent of straw in diet rose above 20%. Neither carcass nor meat quality differed significantly in animals given 20% and 50% ground straw. The results of digestibility with male hoggets (young sheep) showed a linear depression in the digestibility of diets as the percentage of straw increased.

Swan and Lamming (1968) tested the possibility of replacing supplemental vegetable protein with urea in milled barley straw and maize diets. Thirty-two yearling steers were used in a 2 x 2 factorial experiment with the following treatments: (1) sources of supplemental nitrogen, soybean meal or urea and (2) physical form of diet, pelleted or meal. The diets contained 30% ground barley straw. There was no significant difference between treatments in daily live-weight gain, feed intake, or commercial carcass acceptability. Digestibility trials with wethers showed the apparent digestibility of nitrogen and dry matter of the diet containing urea to be significantly lower ($p < .01$) than that of the diet containing soybean meal. Values obtained were: for nitrogen, 72.8 and 76.3% and for dry matter, 70.2 and 75.3%, respectively.

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

Kay (1972) reported the results of an experiment with 120 kg Friesian steers fed concentrates and chopped straw (10 cm length) or a pelleted diet with the same concentrates and ground straw. Percentages of straw were 10, 20, 30, 40, and 50% of total diet. Results showed that dry matter intake increased as the proportion of straw increased in the pelleted diet. Intake decreased as proportion of chopped straw increased in non-pelleted diets. Dry matter digestibility decreased as the proportion of straw increased and decline was somewhat greater for the pelleted diets.

The efficiency decline as the proportion of both chopped or ground straw in the diet was increased by the decline was less with the pelleted diet.

In summary, studies clearly indicate that physical preparation influences voluntary intake and rate of passage. Rate of passage will apparently affect the digestibility of some of the components of the diet, particularly crude fiber, although as reported by Minson (1963) there is no evidence of an alteration in the net energy value of the roughages due to physical preparation. Roughage, presented in long particles, passes through the alimentary tract at a slower rate than ground material. This is important as voluntary intake appears to be regulated to gut distention or filling when the caloric density of the diet is low; Dinius and Baumgardt (1970) indicated that if the caloric density is above 2.5 kcal/gm of digestible energy, caloric intake will determine voluntary intake.

Effect of Nitrogen and Energy Supplementation on the Digestibility and Utilization of Low Quality Roughages

Results obtained in several experiments indicate that when ruminants are fed high roughage diets, the digestibility of the fiber fraction of the diet is decreased if readily digestible carbohydrates such as starches or sugars are added to the diet. Moreover, they relate this decrease in digestibility to an increased competition for nitrogen due to the carbohydrate digesting bacteria.

Mitchell, Hamilton, and Haines (1940) reported the effect of adding glucose to diets containing different protein levels. Four diets were formulated with corn, cottonseed meal, and timothy hay to approximately 6, 10, 15, and 20% crude protein. Each diet was fed to steers with and without the addition of 1093 g/day of glucose. Glucose addition depressed dietary crude fiber digestibility from 39 to 29% regardless of the level of protein fed.

Swift et al. (1947) reported that with lambs 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 added to a basal ration of 426 g alfalfa-timothy hay plus 420 g corn meal and 43 g linseed meal/day, digestibility of dry matter of the diet increased from 74.9 to 77.2%. Digestible energy increased from 72.6 to 75.0% with no significant change in digestibility of protein or crude fiber. However, when the amount of corn sugar was doubled, digestibility of crude fiber decreased from 50 to 43% with a slight depression of crude protein digestibility. Addition of 72 grams of corn starch to the basal ration decreased crude fiber digestibility from 50 to 46%. Protein content of the diets was about 14.0%.

Burroughs et al. (1949a, 1949b), Burroughs, Gall et al. (1950), and Burroughs, Long et al. (1950) determined the effects of starch and protein levels on the digestibility of roughages by steers. The first experiment of a series measured the effect of substituting dried skimmilk for mineralized starch on the digestibility of corncobs by steers. Diets consisted of 5 lb/day of corncobs plus 5 lb/day of supplement as follows: (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 diets 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 13.5% protein level in diet 4. No further increase in corncob digestion was noted as protein increased from 13.5 to 18.5%. Digestibility of corncobs (5 lb/day) was not improved by addition of 0.5, 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, a third study with a basal diet of 5 lb of corncob, 4 lb of starch, and 1 lb of skimmilk was fed either alone or with addition of 1 and 2 lb of dried skimmilk. Protein contents of the diets ranged from 5.5 to 10.5%. Digestibility of corncobs in the basal diet was increased from 38.9% to 46% by the addition of 1 lb of skimmilk. Increasing skimmilk to 3 lb/day did not further increase digestibility of the corncobs.

In a second report (Burroughs et al., 1949b), steers received a basal diet of 4 lb of ground corncobs and 1.6 lb of dried skimmilk/day. The basal diet was 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 increasing 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 content of these diets were in the same range as those used in the corncob trial.

Burroughs, Gall et al. (1950) investigated the effect of starch and casein upon roughage digestibility by steers. Treatments included a basal diet of 4 lb corncobs + 1 lb alfalfa hay, basal diet + 4 lb of starch, basal diet + 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 diet increased the digestibility of the roughage and resulted in increased number of rumen bacteria.

From the above series of experiments conducted by Burroughs and coworkers it was concluded that protein supplementation either from casein or skimmilk increased corncob digestibility whenever starch was included in the diet. Little or no improvement was noted due to protein addition when no starch was fed. The authors concluded that the protein requirements for efficient roughage digestion in cattle is low when roughages are fed in the absence of starch or grains. When starch forms part of the diet, 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.

Burroughs, Long et al. (1950) presented in vitro evidence that certain grains and protein-rich feeds contribute to the nutrition of cellulose digesting rumen microorganisms. Feeds used were: dried distiller's solubles, linseed meal, soybean meal, dried skimmilk, molasses, ground yellow corn, wheat bran, cottonseed meal, meat scraps, fish meal, and ground oats. Three control flasks (artificial rumen) were used containing filter paper with one, two, or three of the following supplements: ammonium sulfate, complex minerals, and autoclaved water extract from manure. Cellulose digestion in the control flask was compared with that in three others which were similar except for the addition of the feed being studied. Results indicated that many feeds influence rumen microorganisms favorable in respect to cellulose digestion. Dried distiller's solubles, soybean meal, and linseed meal appeared most useful, with molasses, corn, wheat bran, and cottonseed meal being less effective. Meat scraps, fish meal, liver meal, and oats showed little or no favorable influence upon cellulose digestion.

Ellis and Pfander (1958) fed lambs semi-purified diets containing one of three levels of cellulose (21, 31, or 42%) and one of three levels of protein (10.0, 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 digestibilties 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 diet than in those containing either 10 or 15% protein. Crude protein digestibility was higher for the 12.8% 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 where four completely pelleted diets varying in energy concentration were fed to eight Holstein heifers in two digestion trials. The diet consisted of the following: alfalfa meal:shelled corn at ratios of 100:0, 80:20, 60:40, and 40:60. Results indicated that apparent digestibility of dry matter and gross energy increased as the per cent corn increased in the diet. Daily dry matter consumption decreased as the corn increased and daily energy consumption was similar for all diets. There was no significant effect on crude protein digestibility. Cellulose digestibility decreased as corn increased in the diet.

Van Soest (1965) reported the results obtained in a regional project designed to determine basic factors which govern the intake of forage as related to chemical composition and digestibility. One hundred and twenty-one forages were compared, fed as green cut material, and digestion trials conducted at maximum intake with groups of six sheep. His conclusion was that chemical composition was much more closely related to digestibility than voluntary intake (VI). In some forage species such as orchardgrass, bromegrass, and sudangrass, the relation between VI and chemical components was very high. With alfalfa, bluegrass, and timothy this relation was not clear. In terms of chemical composition the only consistent effect observed for all forages was that as the cell wall constituent (fibrous fraction) increased, VI decreased. In forages with low cell wall content, digestibility and intake were apparently not related, while with high cell wall content, intake was highly correlated with both chemical composition and digestible dry matter. The total fibrous portion of legumes does not appear to be large enough to inhibit intake. The point at which fiber mass appears to become limiting occurs when cell wall content lies between 50 and 60% of the forage dry matter.

Templeton and Dyer (1965) measured the effect of diet on bovine rumen amylase activity with four, two-year old rumen fistulated steers fed the following diets: (1) 100% alfalfa, (2) 50% + 50% alfalfa concentrates, and (3) 20% alfalfa + 80% concentrates. Amylase activity was measured as micro moles of glucose formed per minute. The values obtained were: 7.6, 34, and 69.6, respectively, as the concentrate level increased. As concentrate level of a diet increased the amylase activity also increased.

Yoder, Trenkle, and Burroughs (1966) studied the *in vitro* influence of rumen protozoa and bacteria upon cellulose digestion and found that addition of washed rumen protozoa to a washed suspension of rumen bacteria substantially increased cellulose digestion and acid production. Molar per cent of acetic acid was decreased and butyric acid was increased when both types of microorganisms were present. Addition of protozoa increased cellulose digestion by rumen bacteria cultured *in vitro* in the presence of added volatile fatty acids, combination of vitamin B_{12} and biotin, or hydrolized casein.

Karr, Little, and Mitchell (1966) used eight yearling Angus steers fistulated in the abomasum, rumen, and posterior illeal to measure starch disappearance from different segments of the digestive tract. The steers were fed diets containing from 19 to 63% starch (from ground yellow corn). Grams of starch consumed in four groups were: 946, 1655, 2520, and 3155, respectively. The quantity of starch passing the rumen undigested increased as the starch intake increased. Abomasal recovery for the four groups were 149, 472, 914, and 1190 grams, respectively, which indicates that post ruminal starch digestion is important. Previously, Huber et al. (1961) demonstrated that glucose is readily absorbed from the small intestine but hydrolysis of starch to glucose in this segment is slow.

Andrews et al. (1972) conducted two experiments with steers weighing 200 to 300 kg, to determine the effect of energy and protein supplementation on the voluntary intake and digestibility of barley straw. In the first study, long barley straw was supplemented with four levels of crude protein (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 supplement was ground nut meal and energy supplement was either barley grain or a 9:1 mixture of starch and molasses. At the lowest protein level, 5.6% of diet, there was a significant decline from 57.7 to 55.5 g/kg $W^{.75}$, 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 supplementations. With the other protein levels daily gain increased from .43 kg to .79 kg as energy intake increased. In the second experiment, cellulose and organic matter digestibility 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 of metabolizable energy per day. Organic matter digestibility for all supplemented diets was higher than for straw alone and little difference was observed due to level of protein or energy supplementation. Cellulose digestion was higher in straw alone than in the supplemented diets and decreased with increased energy at each level of protein.

Bhattacharya and Pervez (1973) conducted four experiments and nitrogen balance trials with lambs fed diets containing 50% wheat straw or barley hay, each supplemented with 0, 1, or 2% urea. The 0 diet had soybean meal as only source of protein supplement. Diets were isocaloric and isonitrogenous. No significant difference was observed in the digestibility between the urea supplemented diets although crude fiber, energy, and ether extract digestibility tended to increase with urea supplementation. Replacing 70% of the soybean meal nitrogen with urea reduced feed intake (not significantly) and consequently average daily gain.

Fick et al. (1973) studied the influence of supplemental energy and biuret nitrogen on the utilization of low quality roughages by sheep in two experiments with 68 lambs. In experiment one, 0 or 10 g of nitrogen was added to a basal Pangola hay diet of about 4% crude protein. Also four levels of supplemental energy were added: 0, 50, 100, and 200 grams of a 50% corn meal, 25% sucrose, and 25% starch mixture. In experiment two, 0, 8, or 16 g of nitrogen were added and 0, 60, or 120 g of the energy supplement. In both experiments supplemental nigrogen increased hay intake ($p < .05$) and apparent digestibility of nitrogen and cellulose also increased. All sheep on supplemental nitrogen were in positive nitrogen balance. Those fed hay alone or with energy supplement only were in negative balance. Increasing supplemental nitrogen from 8 to 16 grams per head daily did not influence parameters tested. Supplemental energy did not increase voluntary intake of hay and depressed cellulose digestibility ($p < .01$).

Coleman and Barth (1977) reports the results obtained in two digestion trials in which the effect of readily available supplemental energy sources on utilization of non-protein nitrogen (NPN) by steers fed low protein hay was evaluated. In trial 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) plus one of four supplements: urea, biuret, and biuret with either 9.3% molasses or 8.1% corn meal. In trial 2, diets containing biuret or no supplemental nitrogen were factored with three supplemental energy sources as follows: control (no supplemental energy); corn and citrus pulp, 7% of each in diet; and molasses, approximately 15% of diet. In experiment 1, source of NPN did not affect digestibility of diets components. Digestibility of dry matter, gross energy, and acid detergent fiber were increased by addition of corn or molasses. However, in the second study, no difference was observed in acid detergent fiber digestibility due to supplemental energy. Results in experiment 1 suggest that small amounts of supplemental energy may stimulate fiber digestion, whereas larger amounts compete with and reduce digestion of fibrous material.

Zambrano Gaytan (1978) reported the effect of grain supplementation on voluntary intake and utilization of wheat straw by lambs. He used 16 lambs and fed the following diets: (1) wheat straw + molasses and urea; in diets 2, 3, and 4, dry rolled sorghum grain was added at levels of 275, 550, or 798 g/head/day, respectively. On a dry matter basis protein was approximately 10% of diet, although daily protein intake increased as grain level increased in diet. Straw intake averaged 540, 609, 601, and 443 g/day for the four treatments. Average daily gain increased linearly ($p < .05$) from -80 g in the control to 209 g for the higher grain level. Digestibility of dry matter, organic matter, and gross energy increased ($p < .05$) as level of grain increased. Digestibility of neutral detergent fiber (NDF) and cell wall components decreased ($p < .05$) as supplemental grain increased. Analysis by linear regression gave estimates for NDF 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 decrease in digestibility of diet fiber due to added grain resulted from the low digestibility of grain fiber and not from a decrease in digestibility of straw fiber.

In summary it may be concluded that the addition of readily available carbohydrates will reduce the digestibility of dry matter and crude fiber from low quality roughages particularly if the total diet is low in protein. Supplementation of nitrogen will alleviate this situation, supporting the theory that the decrease in digestibility is a consequence of the proliferation of amylolytic bacteria which will compete for nutrients, particularly nitrogen, with the cellulose and hemicellulose digestors. It is important to determine at which level of energy supplementation fiber digestion will be affected. However, recent observations suggest that with adequate protein diets, the apparent depression of crude fiber digestibility of the roughages due to the addition of grain may actually be due to the low digestibility of the grain fiber.

Effect of Addition of Monensin to High Roughage Diets for Steers

The use of additives in the United States to improve cattle performance and feed efficiency has been a common practice for a number of years. In 1974, monensin, a new type of additive, was released. The mode of action of this product is at the rumen level by shifting the volatile fatty acids ratio produced. More propionate and less acetate is produced in the rumen fluid of cattle fed monensin which results in an improved feed efficiency. Ever since, numerous experiments have been conducted in feedlots and pasture and with different types of diets to measure the effect of adding monensin to cattle feeds. Pooled summaries of 19 feedlot trials indicates that maximum feed efficiency was obtained when monensin was fed at a concentration of 30 g/ton of feed. The feeding of 30 g of monensin per ton resulted in savings of one pound of feed per pound of gain when compared to a similar diet without monensin (Anonymous, 1975).

Embry and Swan (1974) measured the effects of monensin on feedlot performance of growing and finishing steers. During the growing phase, 128 Hereford steers weighing about 272 kg were fed a high roughage diet during a 111-day period. The diets contained 75% alfalfa-bromegrass forage and 25% corn and supplement. Treatments were: 0, 10, 20, or 30 g of monensin per ton of air dry diet. Results indicated no difference in weight gains of the cattle. Feed consumption decreased with increased levels of monensin in the diets. The decrease in food consumption coupled with a similar rate of gain resulted in an improvement in feed efficiency. The improvement was 4.1, 3.1, and 10.4%, respectively, for the 10, 20, and 30 g/ton levels.

Hale and co-workers (1975) conducted a similar experiment and 93 steers weighing 204 kg were allotted to eight pens and given the following treatments: (1) control, (2) monensin 20 g/ton of diet, (3) monensin 30 g/ton of diet, and (4) monensin 40 g/ton of diet. During the growing phase (115 days) steers were full fed ground alfalfa plus 1.8 kg of dry rolled milo per steer per day. During this period addition of monensin at either level did not affect daily gain. Feed intake appeared to be reduced on the 30 and 40 g/ton levels. Feed requirements were reduced about 7% for the 30 and 40 g levels as compared to the control and 20 g level.

Linn, Meiski, and Goodrich (1975) studied the effect of monensin on diets of silage for growing steers. Thirty steer calves were placed on a high silage growing diet and the same number on a similar diet but with 200 mg of monensin per head per day. Monensin addition had little or no effect on daily gain but significantly reduced diet dry matter intake, from 5.9 to 5 kg/head/day. Feed efficiency improved by 16.2% due to monensin. Digestibility of dry matter and crude protein in the diet were not significantly influenced by the feeding of monensin.

Thornton et al. (1976) reported the effect of monensin on methane production and state that the alteration in volatile fatty acids production pattern in the rumen of animals fed diets with monensin suggests that methane production would also be reduced. In five trials conducted over a 5- to 6-hour period following a meal, monensin decreased methane production an average of 20%. In one trial conducted over 24 hours, the effect of monensin decreased with time. In all trials steers were fed a 60% roughage diet once daily and gas collection began immediately following the meal.

Dinius, Simpson, and Marsh (1976) report the effects of monensin fed with forages on the digestion and ruminal ecosystem of steers. For this trial, monensin was blended with a 90% chopped orchardgrass diet at levels of 0, 11, 22, and 33 ppm and fed to steers to determine its effects on:

cotton fiber cellulose, dietary carbohydrates and nitrogen digestibility, ruminal VFAs concentration and ratios, and number of ruminal microbes. In an in vitro study cellulose digestibility of cotton fiber was not different ($p < .10$) when incubated in ruminal fluid from steers fed the above levels of monensin; neither were differences when samples were placed within the rumen of steers for 72 hours. In vivo digestion of dry matter, crude protein, and cellulose was not significantly different for either treatment. Total ruminal VFAs concentration was not affected with monensin but molar proportion of acetate decreased and propionate increased (66.7 to 61.3 and 20.1 to 26.1) and no other VFAs were affected. Neither the number of protozoa, total bacteria, or cellulolytic bacteria in ruminal fluid were affected by feeding up to 33 ppm monensin.

Simpson, Marsh, and Dinius (1976) tested monensin and other antibiotics on in vitro digestion of cellulosic substrates in ruminal fluid from steers not previously exposed to antibiotics. They used the fermentation procedure of Goering and Van Soest (1970) and found that monensin is a potent inhibitor of cellulolytic activity by non-adapted ruminal microorganisms.

Utley (1976) presented a reivew of the use of monensin in growing and finishing beef cattle and in the case of high roughage diets the author states that average daily gains have been variable, however in most studies, feed intake was reduced and therefore the feed required per unit of gain was lower. Cattle fed high roughage diets in the growing phase and supplemented with 33 ppm of monensin per ton of diet or 150 to 200 mg/head/day required 6 to 17% less feed per unit of gain and produced average daily gains similar to control animals. As more energy can be derived from feeds by the addition of monensin and with low quality roughages energy is a limiting factor, information is needed to determine the value of monensin added to low protein wheat straw.

TRIAL 1: DIGESTIBILITY BY STEERS OF WHEAT STRAW AS AFFECTED BY TYPE AND PARTICLE SIZE

The utilization of crop residues, such as straws from cereals, represents a large potential source of energy for ruminants, particularly for developing countries where production of food crops has priority over that of feedstuffs for animals. Currently, only small amounts of straws are utilized by ruminants due to their low protein and digestible energy which results in an insufficient voluntary intake to meet the requirements of acceptable animal performance. Very little information is available regarding the effect of type of straw on its digestibility and utilization by cattle and this particularly applies to the short stemmed varieties which have only recently been developed. Consequently, an important goal in ruminant experimentation has been to improve both voluntary intake and efficiency of utilization of energy. The purpose of this trial was to determine the effect of two types of wheat straw, short stemmed and Durum, and two particle sizes, coarse and fine, on digestibility, intake, and performance on growing steers.

Methods

Twelve yearling Okie steers weighing 253 kg were used in a digestion trial with a 2 x 2 factorial arrangement of treatments. The steers were allotted based on type and weight to each of the following four treatments: (1) straw from Cajeme wheat processed in a coarse form, (2) same as (1) but straw finely ground, (3) straw from Durum wheat processed in a coarse form, and (4) same as (3) but straw finely ground. The finely ground material was obtained by passing the straw through a hay mill with a 2.34 cm screen. The particle size obtained ranged from a meal to 1.5 cm in length. The coarse material was obtained by passing the straw through a Crose hay slicer with 96 blades on the rotor. The particle size obtained ranged from 2 to 10 cm in length.

The experimental diets are shown in Table 2. To prepare the diets, urea and molasses were dissolved in water and the mixture added to the straw in a mixer wagon. The dicalcium phosphate was top dressed over the straw and all ingredients mixed for about 25 minutes.

The steers were confined to individual concrete floor pens as described by Mehen (1966). Diets were full fed twice daily. Daily records of feed intake and feed weigh back were maintained. The steers had access to block salt and drinking water at all times.

An adjustment period of 34 days served to determine exact feed intake for each steer during the digestion trial. Four days prior to a 7-day collection period the steers were placed on a feed intake of 95% of the intake of the full fed period in order to assure constant intake during the

Table 2. Experimental diets, trial 1.

Ingredient	As Fed Basis %
Wheat straw	83.3
Cane Molasses	6.7
Urea 45% N	2.4
Water	7.0
Dicalcium phosphate	0.7

Analysis Dry Matter Basis:

Crude Protein %[a]	10.1
Calcium %[b]	.34
Phosphorus[b]	.20

[a]Determined.

[b]Calculated.

collection period. Weights of the steers were taken at the beginning of the trial, just prior to the collection period and at the termination of the collection period. During the collection period, total feces from each steer were obtained and weighed daily as described by Mehen (1966). Daily samples of feed and feces were dried in a forced air oven at 55°C for 72 hours and were composited over the 7-day collection period. The composited samples were ground in a Wiley mill through a 1 mm screen. An aliquot was stored in glass containers for chemical analysis.

Table 3. Chemical analysis of diets, trial 1, dry matter basis.[a]

Diet	Crude Protein %	NDF[b] %	Hemicellulose %	Cellulose %	Lignin %	Cell Wall Ash %	Ether Extract %	Total Ash %	NFE %	cal/g
Durum fine	10.0	67.6	22.0	32.2	7.5	5.9	1.7	11.4	15.2	3920
Cajeme fine	10.3	68.9	23.2	32.3	7.8	5.1	1.8	10.7	13.5	3926
Durum coarse	10.0	70.8	23.8	33.5	7.9	5.2	1.7	11.4	11.3	3936
Cajeme coarse	10.3	66.6	20.9	33.4	7.5	4.8	1.8	10.7	15.4	3963

[a]Values were averaged from duplicate determination.

[b]NDF refers to cell wall constituents (hemicellulose, cellulose, lignin, and cell wall ash).

Dry matter, ash, and protein were determined on the composite samples according to the A.O.A.C. (1970). Gross energy was determined with a Parr adiabatic bomb calorimeter; acid detergent fiber (ADF), neutral detergent fiber (NDF), cellulose, and lignin were determined as described by Goering and Van Soest (1970). Hemicellulose was estimated as the difference between NDF and ADF. Nitrogen-free extract (NFE) was estimated by subtracting per cent protein, ether extract, NDF, and ash from one hundred. Apparent digestion coefficients were calculated for each fraction of the diet and gross energy (Table 5, p. 42). Analysis of variance and comparisons of means were made as outlined by Steel and Torrie (1960).

Results and Discussion

Chemical analysis of feeds are shown in Table 3. Feed intake and fecal output by individual steers and fecal chemical analyses are shown in Tables 20 and 21 (Appendix A).

Average daily gain (Table 4) was significantly higher ($p < .05$) for the steers consuming the fine prepared diet as compared with the steers on the coarse diet (.170 vs. .070 kg). Daily feed intake was significantly lower ($p < .05$) for the Durum coarse diet (3.9 kg/head). Daily feed intake of diets with Cajeme wheat straw was slightly higher for the finely ground diet (4.5 kg/head) as compared

Table 4. Daily gain and feed intake of steers fed two types of straw prepared either coarse or fine ground, trial 1.

Item	Cajeme fine	Cajeme coarse	Durum fine	Durum coarse
No. of steers	3	3	3	3
Days on experiment	59	59	59	59
Avg. initial Wt. kg	265	252	247	249
Avg. daily gain kg	$.15^{a}$	$.09^{b}$	$.19^{a}$	$.05^{b}$
Daily feed intake kg 59 days	4.5^{ab}	4.3^{ab}	4.8^{a}	3.9^{b}
Daily feed intake kg collection period only	4.3^{ab}	4.1^{ab}	4.8^{a}	3.6^{b}
Intake g/kg $Wt^{.75}$ 59 days	70^{ab}	70^{ab}	82^{a}	62^{b}
Digestible energy kcal/day	9336	9757	9824	8366

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

with the coarse diet (4.3 kg/head). The average daily gain data appear to be closely related to feed intake.

The performance data discussed above are useful as a guide only, due to the small number of animals and the length of the trial. If the fine and coarse preparations are combined independently of straw type, the digestibility of dry matter, cellulose, hemicellulose, ether extract, and gross energy was significantly greater ($p < .05$) for the diets prepared in the coarse form when compared to the fine form (Table 5). This was probably due to the lower feed intake on the coarse straw as compared to the fine ground straw. However, within straws the differences were not always significant; for example, the digestibility of cellulose for Cajeme straw was significantly greater ($p < .05$) for the coarse preparation as compared to the fine preparation but this was not the case with the Durum straw. The digestibility of cellulose from Durum straw prepared in the coarse form was significantly greater ($p < .05$) than the cellulose digestibility when Cajeme was prepared in the fine form. The above also applies to hemicellulose and NDF digestibilities.

Gross energy digestibility was significantly higher ($p < .05$) when Cajeme was prepared coarse as compared to the fine straw but this difference was not significant ($p < .05$) with the Durum straws.

Table 5. Apparent digestion coefficients of the various fraction of the diets, trial 1.

Item	Cajeme fine %	Cajeme coarse %	Durum fine %	Durum coarse %
Dry Matter	50.1^{b}	57.0^{a}	52.1^{b}	54.3^{ab}
Crude Protein	62.4^{b}	65.8^{ab}	69.7^{a}	65.6^{ab}
Neutral Detergent Fiber	48.7^{c}	57.6^{a}	52.3^{bc}	55.5^{ab}
Cellulose	58.0^{c}	66.4^{a}	61.0^{bc}	63.4^{ab}
Hemicellulose	58.9^{c}	66.4^{a}	59.8^{bc}	62.5^{b}
Lignin	11.6	12.4	14.2	12.7
Ether Extract	66.0^{ab}	69.5^{a}	63.1^{b}	67.0^{a}
Nitrogen Free Extract	61.4	57.9	58.3	59.7
Gross Energy	50.6^{b}	56.1^{a}	50.4^{b}	52.6^{ab}

^{a,b,c}Means in the same line with different superscripts are significantly different ($P < .05$).

Ether extract digestibility was similar for both Cajeme straw and Durum prepared in the coarse form, however the digestibility was significantly lower ($p < .05$) for the diet with Durum straw prepared finely ground when compared to the two coarse diets.

The digestibility values indicated that higher coefficients were obtained with the straws prepared in the coarse form as compared with the fine ones, for dry matter and crude fiber constituents. This is in agreement with results obtained in previous studies which attribute the difference in digestibility to a more rapid rate of passage for smaller particles than for coarse particles. A more prolonged retention in the gastrointestinal tract for the coarse particles allows them to undergo greater bacterial and enzymatic action (Blaxter et al., 1956; Keith et al., 1961; Balch, 1950).

There appeared to be no general effect of straw type and processing method on apparent protein digestibility. However, the protein digestibility of the fine ground Durum straw was significantly higher ($p < .05$) than the fine ground Cajeme but not different from the two coarse processed straws.

There was no significant difference ($p > .05$) for the digestibility of the nitrogen free extract fraction between any of the treatments. This was probably due to the high availability of this fraction. Daily intake of 62 g kg $Wt^{.75}$ of Durum coarse straw was similar to that obtained by Taylor et al. (1977) with dry beef cows (66 g/kg $Wt^{.75}$). Across straw types steers on the fine diet consumed 13% more than steers consuming the coarse diet. This increase in intake is in agreement with previous results in which high roughage diets were prepared in different forms (Kay, 1972; Moore, 1964; Cullison, 1961).

From the data obtained in this trial and from the literature reviewed, grinding a high roughage diet (50% or more) is advantageous over feeding a similar diet prepared either sliced or in the long form. Voluntary intake is increased and so is live-weight gain. Although the digestibility of dry matter, particularly crude fiber components appears to be decreased when diets are fine ground as compared to coarse ground diets, there is no evidence of an alteration in the net energy value of the diet as confirmed by similar live-weight gained by sheep fed equal amounts of hay prepared in different physical forms (Minson, 1963). Early studies also indicate that with ground material, a reduction in energy expenditures involving mastication and rumination is obtained (Burt, 1966). Less energy in the form of methane is lost in the rumen when the diets are ground as compared with long material (Blaxter and Wilson, 1962).

Summary

Digestibilities of dry matter, cellulose, hemicellulose, ether extract, and gross energy were significantly lower ($p < .05$) for the fine ground diets as compared to the coarse diets. In general, crude protein and nitrogen free extract digestibilities were not affected by either type or particle size of the straw.

Average daily gain (.17 kg) for the steers consuming the fine particle diets was significantly higher ($p < .05$) than gain for steers consuming the coarse particle diet (.07 kg). Across straw types feed intake was 13% higher for the steers on the fine particle diets ($p < .05$). However, with straw types, the difference was significant only for the Durum type ($p < .05$).

TRIAL 2: DIGESTIBILITY AND UTILIZATION OF WHEAT STRAW BY STEERS AS AFFECTED BY THE ADDITION OF MONENSIN

In the United States, the use of chemical additives in the cattle industry has been a common practice for improvement of cattle performance and feed utilization. Monensin, a new type of additive, has been recently approved. Monensin is orally fed and has an effect on rumen fermentation by altering the volatile fatty acid ratio in the rumen to favor propionic acid production. Propionic acid is used more efficiently by the animal than acetic acid and is also produced more efficiently in rumen fermentation. Little research has been conducted with the use of monensin to improve feed efficiency in high roughage diets, particularly low quality roughages where energy is a limiting factor.

In a review of response of growing cattle fed high roughage diets with monensin, Utley (1976) states that improvements in average daily gain have been variable, feed intake usually was reduced, and feed required per unit of gain was 6 to 17% less as compared to control animals.

The purpose of this trial was to determine the effect of adding monensin at a level of 33 ppm to a diet containing 83% wheat straw on rumen volatile fatty acids concentration, the digestibility of the diet, and nitrogen utilization by steers.

Methods

The steers used in this study were previously described in Trial 1. They were randomly allotted to the two treatments and full fed the diet shown in Table 2 with or without monensin at a level of 33 ppm. The straw was from the wheat variety INIA which is similar to Cajeme and was prepared in the coarse form. Formulation and preparation of the diets were as described in Trial 1. The steers were confined to individual pens and fed *ad libitum* for a 5-week period prior to being placed into metabolism crates. One steer on the monensin diet refused to eat and was removed from the trial. The steer was slaughtered and found to have abomasal displacement.

Eight steers were selected from the eleven on trial for the digestion and nitrogen balance study. They were placed into the crates in two groups of four at a time with two receiving monensin and two receiving the control diet. After an adjustment period of three days in the crates at a feed intake of about 95% of their previous *ad libitum* intake, a 7-day total fecal and urine collection was made. Twenty-five ml of 6 N hydrochloric acid were added to the urine containers to lower the pH. Aliquots of urine were saved daily, refrigerated, and composited for the 7-day period for nitrogen determination. Samples of feed and feces were also saved daily to produce a composite sample for chemical analysis. Procedures for sampling and preparation of samples as well as analytical procedures were as described in Trial 1. Rumen fluid for determination of volatile fatty acids was obtained from each steer one time by rumen pumping 3 hours post-feeding during the *ad libitum* feeding period. The rumen fluid was separated from whole digesta by filtering through four layers of cheesecloth and the microbial population in the filtrate killed with a saturated solution of mercuric chloride (1 ml of mercuric chloride per 100 ml of rumen fluid). One milliliter of a 25% W/v meta-phosphoric acid solution was added to two aliquots of 5 ml of rumen fluid from each steer and the mixture frozen. Ruminal VFAs were determined by gas chromatography as described by Erwin, Marco, and Emery (1961).

Results and Discussion

Chemical composition and gross energy for the two diets are shown in Table 6. Very similar values were obtained from both diets. Feed intake and fecal output by individual steers and fecal chemical analyses are shown in Tables 22 and 23, respectively (Appendix A). Steers on both diets lost weight during this trial (Table 7) even though average feed intake was 4.2 kg, which was similar to that with coarse straw in Trial 1. A possible explanation is that steers in Trial 1 were confined to individual pens during the entire trial, while steers in Trial 2 were in

Table 6. Chemical analysis of diets, trial 2, dry matter basis.[a]

Diet	Crude Protein %	NDF[b] %	Hemicellulose %	Cellulose %	Lignin %	Cell Wall Ash %	Ether Extract %	Total Ash %	NFE %	cal/g
Monensin	9.3	70.6	23.1	32.9	7.8	6.8	1.4	11.5	13.9	4004
Control	9.5	70.8	22.7	33.6	7.9	6.6	1.4	11.5	13.4	4039

[a]Values were averaged from duplicate determinations.

[b]NDF refers to cell wall constituents (hemicellulose, cellulose, lignin, and cell wall ash).

Table 7. Weights and feed intake for steers fed the wheat straw diet with or without monensin, trial 2.

Item	Control	Monensin
No. of Steers	6	5
Days on Experiment	62	62
Avg. Initial Wt. kg	258	263
Avg. Daily Gain kg	-.23	-.33
Daily Feed Intake kg[a]	4.3	3.6
Daily feed Intake g/kg $Wt^{.75}$[a]	67*	56
Daily Feed Intake kg[a] (Collection period only)[b]	3.9	3.2

*$P < .05$.

[a]Dry matter basis.

[b]Averaged from 4 steers on each treatment.

metabolism crates for a two-week period. Another possible explanation may be straw type, as Cajeme was fed in Trial 1 and INIA in this trial. On a metabolic weight basis, dry matter intake was significantly less on the monensin treatment than on the control treatment ($p < .05$). Chemical analysis of protein content of the diet in Trial 1 was 10.1 while that in Trial 2 was 9.4%.

Addition of monensin did not alter the digestibility of gross energy or of any of the fractions of the diet (Table 8). However, there appeared to be a slight reduction in the digestibility of nitrogen free extract and gross energy due to monensin addition. This is in agreement with previous results with high roughage diets in which the addition of monensin had no effect on the digestibility (Linn et al., 1975; Dinius et al., 1976).

The digestion coefficients obtained for dry matter in this trial were 20% lower (55.6 vs. 44.3) than in Trial 1 when the comparisons are made with straw prepared in the coarse form. The digestibility of cell wall constituents was 22% lower (56.6 vs. 44.2). This decrease in digestibility of the straw may be responsible for the loss in weight of the steers. Crude protein digestibility between the two trials was similar. The values reported in this trial for the digestibility of dry matter, crude protein, and cell wall constituents (NDF) are comparable to those obtained by Zambrano (1978) with a similar diet fed to lambs.

Table 8. Apparent digestion coefficients, trial 2.

Item	Control	Monensin
No. of Steers	4	4
Dry Matter %	44.7	43.9
Crude Protein %	65.8	66.1
Neutral Detergent Fiber %	44.1	44.3
Cellulose %	57.8	58.7
Hemicellulose %	51.3	54.3
Lignin %	13.7	10.6
Ether Extract %	77.6	76.1
Nitrogen Free Extract %	48.1	46.7
Gross Energy %	47.3	45.9

Nitrogen balance was negative with both treatments (Table 9). The nitrogen balance of the control steers was somewhat less negative than the monensin fed steers and this was probably due to the greater nitrogen intake of the control when compared to the monensin steers. The nitrogen balance data by individual steer are shown in Table 24. Zambrano (1978) also reported negative nitrogen balance with lambs fed a similar diet.

Rumen molar concentrations of volatile fatty acids as affected by monensin addition are given in Table 10. Molar per cent propionate increased from 20.2 to 26.5%

Table 9. Nitrogen balance of steers as affected by monensin, trial 2.

Item	Control	Monensin
No. of Steers	4	4
Nitrogen Intake, g/day[a]	55.4	45.6
Nitrogen Excretion, g/day[a]		
Fecal	19.0	15.4
Urinary	49.7	47.4
Total	68.7	62.8
Balance	-13.3	-17.2

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

Table 10. Molar concentration of volatile fatty acids as affected by monensin addition, trial 2.

Volatile Fatty Acid	Control	Monensin
Acetic Acid %	73.3*	66.8
Propionic Acid	20.2*	25.6
Butyric Acid	6.5	7.6
Total VFAs Concentration Micro Moles/mililiter	61.9	64.8

*P < .05.

($p < .05$) and acetate decreased from 73.3 to 66.8 ($p < .05$). These results are in agreement with previous studies in which monensin was added to high roughage diets (Raun, 1975; Richardson et al., 1976; Dinius et al., 1976).

Summary

Addition of monensin to a diet containing 83% wheat straw, prepared in the coarse form, reduced feed intake by 15% as compared with a similar diet without monensin. Monensin did not affect the digestibility of gross energy or of any of the fractions of the diet. Monensin did not improve nitrogen retention. Rumen propionate was increased and acetate decreased by the addition of monensin.

TRIAL 3: DIGESTIBILITY AND UTILIZATION OF WHEAT STRAW BY STEERS AS AFFECTED BY PELLETING

The effects of grinding and pelleting roughages for ruminants have been extensively studied (Blaxter et al., 1956; Cullison, 1961; McCroskey et al., 1961; etc.) to determine the influence on feed utilization. Pelleting of roughages by commercial feedlots would be advantageous because of mechanized feeding arrangements whereas coarse roughage presents mechanical handling problems (Burt, 1966). In addition, pelleting a high roughage diet results in an increased feed intake as compared to a similar diet presented in either ground or coarse form (Moore, 1964).

Minson (1963) reviewed the effects of pelleting and wafering upon the nutritive value of roughages and concluded that although grinding and pelleting appeared to reduce the digestibility of roughages, there was no evidence of any corresponding reduction in net energy value. The major effect was an increase in feed intake which led to increased gross energy efficiency of feed conversion due to a greater live weight gain. He also showed that the poorer the diet in terms of intake and live weight gain with *ad libitum* feeding, the greater the response in intake and live weight gain to grinding and pelleting.

The purpose of this trial was to compare the digestibility and utilization by growing steers of a diet containing 88% wheat straw and fed either pelleted or finely ground.

Methods

Ten yearling Okie steers, previously used in Trials 1 and 2, weighing 244 kg, were used in a digestion trial. The steers were confined to individual concrete floor pens as described in Trial 1 and full fed the diets shown in Table 11 either in a finely ground form or a pelleted form. To prepare the ground diet, the straw was passed through a 2.34 cm screen with a Miller mill. Tallow at a 2% level was poured on the straw prior to grinding. The straw was ground into a mixer wagon, mixed with molasses (50% molasses 50% water) and milo grain. The ground grain was used to carry the cobalt (cobalt carbonate). All ingredients were mixed for about twenty-five minutes. The pelleted diet was purchased from a commercial source. The straw for the two diets was from different sources but all indications were that both straws were Durum.

The steers were fed twice daily and supplemented with 0.5 kg of cottonseed meal per head per day divided into two equal portions, one with each feeding. The steers had access to block salt and water at all times.

Table 11. Experimental diet (basal),[a] trial 3.

Ingredient	% As Fed Basis
Wheat Straw (Durum)	88.5
Cane Molasses	7.0
Tallow	2.0
Milo Grain[b]	2.5
Cobalt Carbonate (.48% Cobalt)	1.25 grams

[a]All steers were supplemented with 0.5 kg cottonseed meal head/day; fed either in fine ground or pelleted form.

[b]Milo carried the cobalt.

The trial consisted of a five-week adjustment at _ad libitum_ feeding, followed by a 7-day collection period. Procedures followed in this trial with respect to fecal collection, sampling and preparation of samples of feed and feces, chemical analysis, gross energy determination, and statistical analysis were the same as in Trial 1.

Rumen fluid for determination of volatile fatty acids and pH was obtained twice from each steer at one week apart and three hours post-feeding. Procedures for rumen fluid collection, preparation of samples, and VFAs determination were as in Trial 2.

Results and Discussion

Chemical composition of basal diets and cottonseed meal is given in Table 12. Crude protein level for the pelleted roughage was 4.3% while the corresponding ground roughage had only 2.8% despite formulation to give a similar protein level. Based on these analyses, the steers on pellets consumed an average of .503 kg of crude protein per day as compared to .361 kg for the steers consuming the ground diet. National Research Council's (1970) Nutrient Requirements for Beef Cattle indicate a requirement of .495 kg of crude protein for a 250 kg steer with average daily gain of .250 kg. Feed intake and fecal output by individual steers and fecal chemical analyses are shown in Tables 25 and 26, respectively (Appendix A).

Steer performance data for the 59-day period, and daily feed intake during the collection period, are given in Table 13. Average daily gain for the steers consuming the pelleted diet was nearly twice ($p < .05$) that of the control steers (.163 vs. .088 kg). This was no doubt due to a 26% greater feed intake ($p < .05$) for the steers on the pelleted diet as compared to those on the ground diet.

Intake was 94 g/kg $Wt^{.75}$ for the ground diet as compared to 115 g/kg $Wt^{.75}$ for the pelleted diet, however the difference was not significant ($p > .05$) probably due to the differences in average weight of the steers between the two treatments.

Table 12. Chemical analysis of the feeds in trial 3, dry matter basis.[a]

Feed	Crude Protein %	NDF[b] %	Hemicellulose %	Cellulose %	Lignin %	Cell Wall Ash %	Ether Extract %	Total Ash %	NFE %	cal/g
Ground Straw mixture	2.8	70.0	21.9	31.9	8.2	8.0	3.6	13.1	18.6	4158
Pelleted Straw mixture	4.3	65.1	19.3	32.2	6.3	7.3	1.6	15.6	20.7	3907
Cottonseed Meal	43.1	36.9	16.3	14.1	5.8	.75	4.6	7.6	8.6	4867

[a]Values were averaged from duplicate determinations.

[b]NDF refers to cell wall constituents (hemicellulose, cellulose, lignin, and cell wall ash).

Table 13. Performance of steers fed either the ground or ground and pelleted straw diets, trial 3.

Item	Ground	Pelleted
No. of Steers	5	5
Days on Experiment	59	59
Avg. Initial Wt. kg	239	249
Avg. Daily Gain kg	.088	.162*
Daily Feed Intake kg[a]	5.7	7.2*
Daily Protein Intake kg[a]	.361	.503
Daily Feed Intake g/kg $Wt^{.75}$	94	115
Daily Feed Intake kg (Collection period only)	5.0	7.1*

*P < .05.

[a]Includes cottonseed meal.

The digestibility for all fractions (except crude protein) of the diet and for gross energy was significantly higher ($p < .05$) for the ground diet as compared to the pelleted diet (Table 14); crude protein digestibility was not affected by treatment. Digestion coefficients obtained for dry matter and neutral detergent fiber (55.9 and 54.5%, respectively) were comparable to the values obtained in Trial 1 (52.1 and 52.3%) in which a similar diet was fed.

Table 14. Apparent digestion coefficients, trial 3.

Item	Ground %	Pelleted %
Dry Matter	55.9*	50.4
Crude Protein	46.7	46.6
Neutral Detergent Fiber	54.4*	44.0
Cellulose	58.2*	51.1
Hemicellulose	66.0*	53.3
Lignin	17.6*	10.9
Ether Extract	83.3*	79.1
Nitrogen Free Extract	68.9*	58.5
Gross Energy	56.2*	50.0

*P < .05.

Cellulose digestibilities were depressed by 12% due to pelleting but hemicellulose digestibility was depressed by 19%. This is of considerable importance due to the high level of hemicellulose in wheat straw.

Rumen volatile fatty acids concentration and pH values are given in Table 15. Slightly lower acetate and higher propionate values were found with the pelleted diet as compared to the ground diet but the values were not significantly different ($p > .05$). Values obtained for pH were similar for both treatments.

Table 15. Rumen volatile fatty acids molar concentration and pH from samples in trial 3.

	Ground	Pelleted
Acetic Acid	71.2	69.1
Propionic Acid	20.7	21.7
Butyric Acid	8.1	9.2
pH	6.7	6.8

Summary

Ten yearling Okie steers were used in a digestion trial to compare a feed containing 88.5% Durum wheat straw (roughage portion only) prepared either ground or ground and pelleted. Cottonseed meal was added to the roughage portion at 500 g per steer daily.

Average daily gain for the steers during a 59-day feeding period was 1.62 kg on the pelleted diet as compared to .088 kg for the control steers ($p < .05$). Daily feed intake was 7.2 kg for the pelleted diet vs. 5.7 kg for the control diet ($p < .05$).

Apparent digestion coefficients for gross energy and all fractions of the diet (except crude protein) were significantly higher ($p < .05$) for the ground diet as compared to the pelleted diet.

Values obtained for rumen volatile fatty acids concentrations and pH showed no significant difference ($p > .05$) between treatments.

TRIAL 4: DIGESTIBILITY AND UTILIZATION OF WHEAT STRAW AS AFFECTED BY ENERGY AND PROTEIN SUPPLEMENTATION

Studies have indicated that supplemental nitrogen improves intake and fiber utilization of low quality roughages (Raleigh and Wallace, 1963; Fick et al., 1973; Bhattacharya and Pervez, 1975). Nitrogen supplementation to low quality roughages, independent of energy, will not result in maximal animal performance (Andrews et al., 1972).

In a series of experiments, Burroughs et al. (1949a, 1949b), Burroughs, Gall et al. (1950), and Burroughs, Long et al. (1950) concluded that the protein requirement for efficient roughage digestion in cattle is low when roughages are fed in the absence of starch or grains. If starch or grains are included, the need for supplemental nitrogen increases if efficient roughage digestion is to be maintained.

El-Shazly, Dehority, and Johnson (1961) conducted *in vitro* studies to determine the nature of the inhibition by starch of cellulose digestion by rumen microorganisms. Results indicated that the inhibition was due primarily to a competition between the cellulolytic and amylolytic groups of bacteria for nutrients, particularly nitrogen.

The optimum level of energy supplementation to low quality roughages is not clear. High levels will improve animal performance, but fiber digestibility tends to be lowered; low levels will improve roughage intake and may improve fiber utilization but will not substantially improve animal performance.

In this trial, three levels of starch and two levels of protein were studied as supplements to a wheat straw diet to determine their effect in the digestibility, particularly of the fiber fraction, of the straw and on performance of steers in terms of feed intake and live weight gain.

Methods

Ten yearling Okie steers, weighing initially 251 kg, and previously used in Trials 1, 2, and 3, were used to conduct a digestion trial. The steers were allotted on the basis of weight and type to the following treatments: (1) straw *ad libitum* plus 800 grams per head per day of cottonseed meal (three steers), (2) same as treatment (1) plus 650 grams of starch per head per day (three steers), (3) same as treatment (1) plus 1300 grams of starch per head per day (two steers), and (4) straw *ad libitum* plus 1600 grams of cottonseed meal plus 1300 grams of starch per head per day (two steers). The straw was Durum type and finely ground as described in Trial 1. The steers were fed twice daily and supplements divided in two equal portions and top dressed on the straw at each feeding. Other management procedures were as described for Trial 1.

The trial consisted of a feeding period of 51 days followed by a 7-day collection period. Prior to the collection period, straw intake was reduced to 95% of the previous *ad libitum* intake. Collection procedures were as described for Trial 1. Comparisons of means were made as outlined by Steel and Torrie (1960) for unequal number of observations.

Rumen fluid for determination of volatile fatty acids and pH was obtained twice from each steer during the *ad libitum* feeding period, each time one week apart and three hours post feeding. Procedures for rumen fluid collection, preparation of samples, and VFAs determinations were as described in Trial 2.

Results and Discussion

Chemical composition of the feeds used in Trial 4 is given in Table 16. The starch contained less than .5% protein and low levels were found for neutral detergent fiber (NDF) and ash. Solubility of the starch was found to be 96% at room temperature after 1 hour when added to autoclaved rumen fluid at either a 1 or 2% solution.

Feed intake and fecal output by individual steers and fecal chemical analyses are shown in Tables 27 and 28, respectively (Appendix A).

Average daily gain for the steers on treatment 4 was significantly higher ($p < .05$) than for the other three

Table 16. Chemical analysis of the feeds in trial 4, dry matter basis.[a]

Feed	Crude Protein %	NDF[b] %	Hemicellulose %	Cellulose %	Lignin %	Cell Wall Ash %	Ether Extract %	Total Ash %	NFE %	cal/g
Wheat Straw	2.34	75.1	22.0	38.7	8.2	6.2	3.9	9.9	15.0	3968
Corn Starch	0.47	7.7	2.8	3.7	0.3	0.9	1.3	1.1	90.4	4072
Cottonseed Meal	43.1	33.0	16.3	13.3	3.0	0.4	4.6	8.6	11.1	4814

[a]Values were averaged from duplicate determinations.

[b]NDF refers to cell wall constituents (hemicellulose, cellulose, lignin, and cell wall ash).

treatments. Average daily gain increased from .44 to 1.0 kg per head per day as supplemental feeding level increased (Table 17). This no doubt was due to increased energy intake. Straw intake was the highest with treatment 1 which received the cottonseed meal supplement only. For the three treatments receiving starch, daily intake was reduced by 1 kg and affected little by starch or protein level. However, feed intake was the highest with the highest levels of starch and protein supplementation. These findings are in agreement with Andrews et al. (1972) who found that with low protein levels (5.6% of diet), there was a significant decline in straw intake as the energy increases in the diet. With levels of crude protein of 8.8% or more, straw intake was depressed only slightly

Dry matter digestibility was very similar for treatments 1, 2, and 3, where straw accounted for 87, 73, and 67% of the total dry matter intake (Table 18). The highest dry matter digestibility was in treatment 4 where straw accounted for only 58% of the total dry matter intake; however, there were no significant differences ($p > .05$) among any of the treatments.

Digestibility of crude protein was related to the protein content of the diet (probably due to the relationship between fecal metabolic nitrogen and nitrogen intake [Table 18]). The lowest digestibility (54%) was obtained from the diet with the lowest crude protein (6.7%) and the

Table 17. Daily feed intake and gain as affected by starch and protein supplementation, trial 4.

	Treatment No.			
	1	2	3	4
	Straw + 800 g CSM	Straw + 800 G CSM + 650 g Stch.	Straw + 800 g CSM + 1300 g Stch.	Straw + 1600 g CSM + 1300 g Stch.
No. of Steers	3	3	2	2
Protein Level %	7.5	7.9	6.7	10.5
Days on Experiment	63	63	63	63
Avg. Initial Wt. kg	256	248	250	251
Avg. Daily Gain kg	.44[b]	.48[b]	.62[b]	1.0[a]
Daily feed Intake kg	6.1	5.4	6.5	7.3
Daily Straw Intake kg	5.3	4.0	4.4	4.4
Daily Feed Intake kg (collection period only)	6.1	5.2	6.3	6.9
Daily Straw Intake kg (collection period only)	5.3	3.8	4.2	4.0

[a,b]Different superscript on the same line means $P < .05$.

Table 18. Apparent digestion coefficients, trial 4.

	Treatment No.			
	1	2	3	4
	Straw + 800 g CSM	Straw + 800 g CSM + 650 g Stch.	Straw + 800 g CSM + 1300 g Stch.	Straw + 1600 g CSM + 1300 g Stch.
	%	%	%	%
Diet Protein Level	7.5	7.9	6.7	10.5
Diet Dry Matter from Straw	87	73	67	58
Digestion Coefficients				
Dry Matter	60.1	58.7	61.9	64.7
Crude Protein	57.9^{b}	57.0^{bc}	54.0^{c}	62.6^{a}
Neutral Detergent Fiber	59.4	50.2	50.5	56.1
Cellulose	64.9	54.7	55.3	58.4
Hemicellulose	66.3	56.8	55.5	65.8
Lignin	24.8^{a}	13.7^{b}	13.5^{b}	7.9^{b}
Ether Extract	81.6	79.7	81.7	83.6
Nitrogen Free Extract	62.7^{c}	81.0^{b}	86.3^{a}	82.9^{ab}
Gross Energy	60.4	58.8	62.3	64.9

^{a,b,c}Means in the same line with different superscripts are significantly different ($P < .05$).

highest digestibility (63%) was obtained when crude protein in diet was the highest (10.5%). These two values were significantly different ($p < .05$) and the highest protein digestibility (treatment 4) was significantly different ($p < .05$) from all other treatments.

The digestibility of neutral detergent fiber (NDF) was not significantly different between treatments, however the addition of 650 to 1300 grams of starch in the absence of the high protein level depressed the digestibility of NDF by 15% when compared to the no starch treatment. When additional protein was provided in treatment 4, NDF digestibility increased and was only 5% less than in treatment 1. Cellulose digestibilities were also depressed by the starch addition but was not greatly improved by the high level of protein addition. The depression in hemicellulose digestibility due to starch addition in treatments 2 and 3 was completely corrected by the high protein addition in treatment 4. These data are in agreement with results from previous studies (Burroughs et al., 1949a, 1949b; Burroughs, Gall et al., 1950; Burroughs, Long et al., 1950; Swan and Lamming, 1968) in which it was concluded that crude fiber digestibility in high roughage diets was inhibited by the addition of starch and if efficient fiber digestion was desired, additional protein must be provided.

No significant differences ($p > .05$) were observed among treatment for ether extract digestibility. Nitrogen free extract (NFE) digestibility was significantly lower ($p < .05$) for treatment 1 in which no starch was added, as compared to treatments 2, 3, and 4. Also, NFE digestibility for treatment 2 which contained the low level of starch was significantly lower ($p < .05$) than treatment 3 which contained the high level of starch but low level of protein.

Gross energy digestibilities were not statistically different between treatments, however the highest values obtained were with the highest levels of starch supplementation. Gross energy digestibility among treatments was very similar to dry matter digestibility.

The highest level of lignin digestibility was with treatment 1 ($p < .05$) however an interpretation of the lignin digestibility cannot be made other than than they were depressed due to starch addition.

Molar concentration of rumen volatile fatty acids and pH are given in Table 19. No significant differences ($p > .05$) were observed; however, the highest propionate levels were found with the highest levels of starch; corresponding to the increased propionate was a reduction in acetate levels. While rumen pH values were not significantly different ($p > .05$) the lowest values were observed on the highest starch feeding levels.

Table 19. Volatile fatty acids, % molar concentration, and pH from rumen fluid samples in trial 4.

	Treatment No.			
	1	2	3	4
Acetic Acid	77.6	79.2	75.1	74.2
Propionic Acid	16.0	14.3	17.4	18.1
Butyric Acid	6.5	6.5	7.6	7.7
pH	6.9	7.0	6.6	6.7

Summary

For the 63-day feeding period, average daily gain increased linearly from .44 to 1.0 kg per head as supplement feeding level was increased. The highest straw intake was with treatment 1 which received only the protein supplement and straw intake was depressed by 21% when starch supplement was added to the diets.

Dry matter digestibility was the highest with the high starch and protein supplementation but not significantly so ($p > .05$). Crude protein digestibilities varied with the protein level in the diets and was significantly higher ($p < .05$) with the diet with higher protein content.

Neutral detergent fiber (NDF) digestibilities were not significantly different ($p > .05$) however when starch was added to a diet with low level of protein the digestibility was depressed by 15%. The depression in NDF digestibility was essentially corrected to the control value with the high protein supplementation. Depression in hemicellulose digestibilities due to starch addition was completely corrected by the high protein addition.

Rumen volatile fatty acids molar concentrations were not significantly different ($p > .05$); however, the highest propionate levels and the lowest acetate levels were obtained with the highest feeding starch levels. Likewise, the lowest pH values were observed on the highest starch feeding levels.

GENERAL DISCUSSION

Ten of the original 12 steers remained on the straw diets for 245 days. One steer was lost at approximately 75 days due to a displaced abomasum. At 127 days another steer refused to eat the straw diet. The steer was then fed alfalfa hay at which time he returned to normal. He was not returned to the straw experiments. As none of the dietary components contained carotene all steers were injected with 1 million units of Vitamin A at 90 day intervals. Over the four trials the steers gained 37.4 kg per steer or an average of .15 kg per day (Table 29, Appendix A). The ten steers grew in frame size and remained healthy and were normal in all appearance except they were in thin condition at the completion of the trials.

The steers appeared to relish the straw and were always hungry at feeding time. This suggests there was some type of adaptation to the straw and that if ample protein, minerals, and vitamins are added to straw, steers may be maintained for long periods on diets high in straw. At the end of the four trials, the steers were placed on a conventional finishing ration (75% concentrate) and after a 2-week adjustment period, they gained rapidly and were later sold as fat steers.

It has been generally accepted that physical preparation such as grinding and pelleting will increase voluntary intake of low quality roughages by cattle and also, that as feed intake increases, the digestibility of dry matter, particularly the crude fiber fraction, will be depressed. In trial 1, with steers fed a diet containing 83% wheat straw, feed intake was increased by 13% ($p < .05$) when the diet was prepared fine ground as compared to a similar diet prepared coarsely ground. The digestibility of dry matter, cellulose, and hemicellulose was significantly lower ($p < .05$) in the fine diet; however, the steers consuming this diet had a significantly higher ($p < .05$) average daily gain (.17 kg) as compared to the steers on the coarse diet (.07 kg) and this was no doubt due to the higher feed intake (4.7 vs. 4.1 kg). In addition, feed requirement for the steers on the fine diet was 27.7 kg as compared to 62.9 kg per kg of gain for steers fed the coarse ground straw. The data indicate that the steers on the fine diet not only consumed a larger amount of energy but also that the energy consumed was more efficiently utilized. It appeared that protein digestibility was little affected by treatment ($p > .05$).

In the same trial, when the effect of type of straw (Durum or short stemmed Cajeme) was evaluated, differences were not significant ($p > .05$) for either feed intake or average daily gain of steers; however, previous results

(Taylor et al., 1977) suggested that the Durum type is less well utilized by cattle than the short stemmed straws. More information is needed before definite statements can be made regarding the feeding value of different type of wheat straws. While there were some differences in respect to digestibility between the two straw types as affected by processing method, the number of observations is too small to permit recommendation.

In trial 2, a coarse ground diet similar to the one used in the previous trial was fed to steers with or without the addition of monensin. During this trial, the steers lost weight and although not significantly different ($p > .05$) the steers on the monensin diet lost more weight than the control steers. The addition of monensin reduced feed intake by 15% as compared to the control which is in agreement with most previous studies with roughness (Utley, 1976). Monensin had no effect on the apparent digestibility of any of the fractions of the diet. Nitrogen retention was similar for steers on both treatments.

The addition of monensin increased propionate production by 21% and decreased acetate production by 9% when compared to the control steers. Although this shift in volatile fatty acids production represents an increase in energy utilization, more information is required to determine if the amount of energy produced by this shifting will compensate for the reduction in energy intake caused by the reduction in feed intake when monensin is added to a high roughage diet. There was no indication from this trial that monensin could exert a desirable effect with high wheat straw diets.

In trial 3, a comparison was made by feeding steers a diet containing 88.5% Durum wheat straw and prepared either fine ground or fine ground and pelleted. For the straw portion of the ground diet, intake was 85 g/kg $Wt^{.75}$ which was comparable to the intake of 82 g/kg $Wt^{.75}$ obtained in trial 1 in which a Durum straw diet was fed in the ground form. Feed intake was increased by 21% with the pelleted diet and the apparent digestion coefficients of gross energy and all the fractions of the diet (except crude protein) were significantly depressed ($p < .05$) by pelleting; however, average daily gain for the steers consuming the pelleted diet was nearly twice that of the ground diet (.162 vs. .088 kg) due, no doubt, to the greater feed intake. This trial reaffirmed previous findings and is in agreement with Minson (1963) who states that pelleting depresses the apparent digestibility of high roughage diets. On the basis of the above, the decision on pelleting a low quality roughage diet will be in terms of energy expenditures and costs involved in the processing method.

In trial 4, Durum straw prepared finely ground was supplemented with two levels of protein (low and high) and three levels of starch (zero, low, and high). Average daily gain increased from .44 to 1.0 kg as supplement increased in diet. Straw intake was higher for treatment 1 in which only the low level of protein was added to the straw. Straw intake was depressed by 17% when a low level of starch was added to treatment 1 but no further depression was observed on treatments 3 and 4 with high levels of starch and with low and high levels of protein, respectively.

While not significantly different ($p > .05$), dry matter digestibility was the highest with treatment 4 which contained the highest levels of protein and starch (48% of total intake). Digestibilities of treatments 1, 2, and 3 were similar.

The digestibility of the crude protein fraction correlated well with the protein content in the diet. The highest value was obtained with the diet with the highest protein content.

Fiber digestibility was depressed by 15% when either a low or high level of starch in treatments 2 and 3 was added to straw in the presence of a low level of protein. When the protein level was the highest in treatment 4, fiber digestibility was corrected to within 5% of the control treatment. While protein addition only partially corrected the depression in cellulose digestibility due to the starch addition, the depression in hemicellulose digestibility was completely corrected by the higher protein addition. This latter aspect is very important as the fiber portion of straws contains a higher level of hemicellulose than does good quality roughage.

As expected for gross energy digestibility, the higher values corresponded to treatments 3 and 4 in which the higher levels of starch were added to the straw.

Data from trial 4 indicate that protein and energy supplementation was beneficial to the animal as measured by live weight gain and feed requirements, however the effects of supplementation, particularly energy, on the utilization of the low quality roughage must be considered if an extensive use of these materials is desired. Economics must also be considered as the energy utilization from the straws remains low even after proper supplementation.

Conclusions

The results of four trials reported in this dissertation together with other available information are the basis for the following conclusions relating to utilization of wheat straw by ruminants:

1. Grinding wheat straw to a fine particle size in a diet containing 83% straw significantly increased ($p < .05$) voluntary intake when compared to a similar diet prepared coarsely ground.
2. When a diet containing 88% wheat straw was finely ground and pelleted and fed to growing steers, feed intake and live weight gain increased by 46 and 21%

respectively as compared to a similar diet prepared fine ground only.

3. Dry matter and fiber digestibilities were depressed when the diet was prepared finely ground as compared to a coarse ground diet. The same occurred when the diet was finely ground and pelleted as compared to a finely ground diet. This depression is attributed to faster passage through the digestive tract for the pelleted and finely ground material as compared to the coarse material. Crude protein digestibility appeared to be less affected by physical preparation.
4. Although a depression in digestibility was observed with the finely processed materials as compared to the coarse process, the total available energy for the animal was greater due to a higher feed intake which resulted in increased weight gains.
5. Type of wheat straw did not have a significant effect either on feed intake or digestibility of the straw. However, results have suggested that Durum type would be less acceptable than the short stemmed variety, Cajeme. More information is required to determine the effect of type of straw on utilization by cattle.
6. Addition of monensin at a level of 33 ppm to a diet containing 83% wheat straw resulted in a 15%

depression in feed intake when compared to the control diet. Weight gains were negative for all steers.

7. Monensin did not alter the apparent digestibility of gross energy or of any of the fractions of the diet. Nitrogen retention was not increased by monensin.
8. The addition of monensin altered the ratio of rumen volatile fatty acids (VFA) by increasing propionate by 21% and decreasing acetate by 9% when compared to the control. Total VFA production was not altered.
9. When a straw diet was supplemented with three levels of starch and two levels of protein, total dry matter intake and dry matter digestibility were increased as supplement level increased.
10. Straw intake was depressed by 19% with either a low level (650 g) or a high level (1300 g) of starch addition to the diet.
11. The addition of either the low or high level of starch to a straw diet containing 800 g of cotton-seed meal (CSM) resulted in a 15% decline in neutral detergent fiber (NDF) digestibility. When CSM increased to 1600 grams, the decline in NDF digestibility amounted to only 5%. Depression of hemi-cellulose digestibility due to starch addition could

be completely corrected by addition of the high level of CSM.

APPENDIX A

INDIVIDUAL STEER DATA

Table 20. Feed intake and fecal output of steers during collection period, trial 1.

Pen No.	Steer No.	Treatment	Intake kg[a]	Feces kg[a]
1	7	Cajeme long	32.5	14.0
2	13	Durum fine	35.7	18.2
3	1	Cajeme fine	31.4	15.6
4	28	Durum long	20.4	8.6
5	8	Durum long	30.1	13.7
6	24	Cajeme fine	31.3	16.1
7	4	Durum fine	33.9	15.4
8	139	Cajeme long	24.5	10.2
9	22	Durum fine	32.7	15.5
10	2	Durum long	25.2	12.6
11	27	Cajeme long	28.9	12.7
12	144	Cajeme fine	27.5	13.5

[a]All values on 95% dry matter basis.

Table 21. Chemical analysis of feces, trial 1, dry matter basis.[a]

Diet	Steer No.	Crude Protein %	NDF[b] %	Hemicellulose %	Cellulose %	Lignin %	Cell Wall Ash %	Ether Extract %	Total Ash %	NFE %	cal/g
Durum fine	13	7.9	71.8	20.0	29.9	12.5	8.4	1.3	15.0	12.4	4057
	4	7.4	72.1	20.0	28.7	14.5	8.9	1.3	15.8	12.3	4022
	22	7.5	72.1	20.6	27.2	13.5	8.0	1.2	15.8	11.1	4103
Cajeme fine	1	7.8	74.8	21.6	30.5	13.0	8.2	1.2	14.2	10.2	4118
	24	7.9	74.4	21.4	28.8	14.0	9.2	1.2	16.3	9.5	4019
	144	7.6	72.7	19.4	29.9	14.5	8.9	1.3	15.6	11.7	4013
Durum coarse	28	7.4	74.9	21.6	28.5	15.5	7.3	1.2	15.0	8.8	4071
	8	7.4	73.7	19.8	28.8	15.3	9.9	1.2	16.5	11.1	4071
	2	7.8	74.0	20.6	30.2	14.7	8.5	1.3	15.6	9.9	4093
Cajeme coarse	7	8.2	73.6	19.8	29.3	15.0	9.5	1.3	16.9	9.5	4037
	139	8.1	74.0	19.5	28.2	15.6	9.8	1.3	15.9	10.5	4051
	27	8.2	70.0	16.9	27.8	15.4	10.0	1.2	17.0	13.5	4046

[a]Values were averaged from duplicated determinations.

[b]NDF refers to cell wall constituents (hemicellulose, cellulose, lignin, and cell wall ash).

Table 22. Feed intake and fecal output of steers during collection period, trial 2.

Crate No.	Steer No.	Treatment	Intake kg[a]	Feces kg[a]
1	4	Monensin	17.2	9.5
2	22	Control	23.6	12.8
3	27	Monensin	26.0	14.3
4	144	Control	31.4	17.9
1	139	Monensin	22.9	13.3
2	24	Control	29.3	15.6
3	8	Monensin	24.8	13.7
4	7	Control	25.3	14.0

[a]All values on 95% dry matter basis.

Table 23. Chemical analysis of feces, trial 2, dry matter basis.[a]

Diet	Steer No.	Crude Protein %	NDF[b] %	Hemicellulose %	Cellulose %	Lignin %	Cell Wall Ash %	Ether Extract %	Total Ash %	NFE %	cal/g
Monensin	4	5.4	74.1	17.7	32.0	11.9	13.3	.47	19.3	13.0	3875
	27	5.8	74.0	17.8	28.9	13.0	14.3	.46	20.7	13.3	3833
	139	5.6	74.9	19.9	30.1	12.2	12.7	.68	19.1	13.4	3871
	8	5.8	74.2	19.8	29.2	12.8	13.6	.80	19.5	13.3	3895
Control	22	5.8	74.5	19.0	30.9	12.5	12.1	.47	18.7	12.6	3899
	144	5.8	74.9	19.6	30.8	12.0	12.6	.48	19.2	12.2	3915
	24	5.9	74.0	18.6	29.1	12.8	13.6	.55	19.8	13.3	3836
	7	6.0	73.6	18.9	30.2	12.1	12.2	.80	19.5	12.3	3907

[a]Values were averaged from duplicated determinations.

[b]NDF refers to cell wall constituents (hemicellulose, cellulose, lignin, and cell wall ash).

Table 24. Nitrogen balance by steer calves fed a diet containing 83% wheat straw and with or without monensin.

Treatment	Steer No.	Nitrogen Intake g/day	Nitrogen Excretion g/day Fecal	Urinary	Bal.
Monensin	4	34	11	50	-27
Monensin	27	52	18	47	-13
Monensin	139	46	16	46	-16
Monensin	8	50	17	46	-13
Mean		46	16	47	-17
Control	22	48	16	44	-12
Control	144	64	22	54	-12
Control	24	59	20	50	-11
Control	7	51	18	50	-17
Mean		56	19	50	-13

Table 25. Feed intake and fecal output of steers during collection period, trial 3.

Pen No.	Steer No.	Treatment	Intake kg[a]	Feces kg[a]
1	7	Pelleted	38.1	19.2
2	13	Pelleted	56.0	31.2
3	1	Pelleted	53.2	27.7
4	28	Pelleted	50.4	26.6
5	8	Ground	33.1	16.1
6	24	Ground	35.3	17.4
8	139	Pelleted	47.6	27.2
9	22	Ground	27.7	13.4
11	27	Ground	36.3	17.2
12	144	Ground	36.4	17.0

[a]All values on 95% dry matter basis.

Table 26. Chemical analysis of feces, trial 3, dry matter basis.[a]

Diet	Steer No.	Crude Protein %	NDF[b] %	Hemicellulose %	Cellulose %	Lignin %	Cell Wall Ash %	Ether Extract %	Total Ash %	NFE %	cal/g
Ground	144	7.8	70.6	16.8	28.3	15.2	10.5	1.3	15.5	15.3	4158
	24	8.2	69.2	14.8	28.2	14.5	11.0	1.4	17.2	15.0	4134
	8	7.8	70.7	16.9	28.3	15.0	10.5	1.5	14.9	15.7	4249
	22	8.3	70.7	17.4	30.2	15.2	9.2	1.3	14.4	14.5	4238
	27	7.6	71.1	17.7	28.9	14.7	9.9	1.5	15.2	14.5	4207
Pelleted	13	7.1	71.6	19.0	30.5	11.2	10.9	.71	15.5	16.0	4021
	139	7.2	72.5	18.2	32.1	11.2	10.9	.80	14.9	15.5	3998
	28	7.0	72.0	18.1	30.6	10.9	11.9	.76	16.2	17.9	4030
	1	7.0	70.4	18.3	30.2	11.2	11.9	.79	15.5	18.2	4059
	7	8.3	69.6	16.5	28.3	11.8	12.8	.75	18.5	15.7	3946

[a]Values were averaged from duplicate determinations.

[b]NDF refers to cell wall constituents (hemicellulose, cellulose, lignin, and cell wall ash).

Table 27. Feed intake and fecal output of steers during collection period, trial 4.

Pen No.	Steer No.	Treatment	Intake kg[a]				Feces kg[a]
			Straw	CSM	Starch	Total	
9	144	1	36.5	5.2	--	41.7	16.8
2	28	1	37.6	5.2	--	42.8	17.6
8	27	1	33.8	5.2	--	39.0	15.0
5	22	2	20.2	5.2	4.2	29.6	13.3
10	24	2	31.1	5.2	4.2	40.5	15.5
3	1	2	24.4	5.2	4.2	33.8	13.6
1	13	3	36.7	5.2	8.3	50.2	18.1
6	7	3	20.2	5.2	8.3	33.7	13.6
4	139	4	27.0	10.4	8.3	45.7	16.2
7	8	4	27.1	10.4	8.3	45.8	16.1

[a]All values on 95% dry matter basis.

Table 28. Chemical analysis of feces, trial 4, dry matter basis.[a]

Treatment No.	Steer No.	Crude Protein %	NDF[b] %	Hemicellulose %	Cellulose %	Lignin %	Cell Wall Ash %	Ether Extract %	Total Ash %	NFE %	cal/g
1	144	7.9	71.7	16.8	30.8	13.7	10.4	1.9	16.2	12.8	4036
1	28	7.7	72.0	16.8	30.3	14.3	10.6	1.8	15.9	13.2	4045
1	27	8.3	70.6	17.4	29.6	14.8	10.3	1.8	15.7	13.9	4067
2	24	8.3	73.4	18.0	31.3	14.2	9.5	1.8	16.0	10.0	4045
2	1	8.5	74.1	18.0	33.5	14.0	8.8	1.8	13.9	10.6	4111
2	22	9.4	72.2	19.6	33.8	12.2	8.5	1.8	13.6	11.5	4146
3	13	7.9	72.7	18.0	31.1	14.5	9.1	1.7	16.6	10.2	4020
3	7	9.5	72.4	19.7	33.3	12.1	7.3	1.6	13.7	10.1	4088
4	139	12.2	67.9	16.0	29.8	14.4	8.6	1.6	14.9	12.0	4155
4	8	11.8	66.1	15.5	30.7	14.4	8.6	1.7	14.5	14.5	4154

[a]Values were averaged from duplicate determinations.

[b]NDF refers to cell wall constituents (hemicellulose, cellulose, lignin, and cell wall ash).

Table 29. Steer weights kg during the four trials period[a] June 5, 1977-February 4, 1978.

Steer No.	June 5	June 29	Aug 2	Oct 3	Dec 3	Feb 4
1	257	265	263	247	262	300
2	260	270	264	--	--	--
4	259	254	268	234	--	--
7	248	256	255	223	225	269
8	233	239	242	235	228	288
13	268	291	289	274	274	309
22	213	219	217	203	202	237
24	260	268	271	262	280	296
27	232	242	242	213	229	247
28	254	252	251	246	259	302
139	275	272	274	256	273	343
144	279	286	290	281	280	302

[a]The period for each trial was: Trial 1--June 5-August 2; Trial 2--August 3-October 4; Trial 3--October 5-December 2; Trial 4--December 3-February 3.

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