DIGESTIBLE ENERGY STUDIES OF VARIOUS LEVELS OF CONCENTRATES IN PELLETED RATIONS FOR FATTENING LAMBS

by

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B. S., Kansas State University of Agriculture
and Applied Science, 1959

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Animal Husbandry

KANSAS STATE UNIVERSITY
OF AGRICULTURE AND APPLIED SCIENCE

1960

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INTRODUCTION

From the time the first pelleting machine appeared on the market, livestock producers and feed manufacturers have been interested in pelleting all or part of the ration for farm animals. Various advantages have been claimed for pelleted feeds. Among these are greater daily gains and increased feed efficiency. In addition to these direct effects on the animal, pelleting puts the feed in a form that is easy to handle and aids in reducing waste. In the case of the complete pelleted ration, the animal is forced to eat the ingredients that are placed before him in the ratio that they are intended.

Several reasons have been given for the increased growth and feed efficiency due to pelleting. Much of the response is, no doubt, simply due to the increased feed consumption usually found with completely or partially pelleted rations. Allred et al. (2) (3) believed that the increased growth response may have been due to the destruction of some unidentified growth depressing factor present in the grain part of the ration. However, this concept does not explain the growth increases and increase in feed efficiency found when roughage is pelleted for ruminants. Meyer et al. (61) suggest that fine grinding prior to pelleting is probably the major factor causing increased feed consumption of pelleted hay and that the pelleting process serves to put the fine, dusty feed in a more palatable form.

As early as 1937, Patton (67) discussed the use and advantages of pelleted rations for poultry. Neale (64), at New Mexico, pelleted low quality alfalfa for lambs, and found that in the pellet form, the low quality ration produced gains equal to high quality roughage in the nonpelleted form.

Studies with the complete pelleted ration point out that when the entire ration is pelleted, the level of roughage can be increased over the amount used in a nonpelleted ration, thereby making a saving in higher priced concentrates. This fact, and the observation that lower quality roughage in pellets produced results that were, in the main, equal to higher quality roughage in a nonpelleted ration, make the practice of pelleting look very promising to the livestock producer.

The purpose of this study was to determine digestible energy, digestible dry matter, protein digestion coefficients and nitrogen retention on various ratios of roughage to concentrate in complete pelleted rations. Nine lambs were placed in digestion crates, where complete feces and urine collections were made. Total nitrogen was determined by the Kjeldahl method (5) in the urine, feces, and feed. Dry matter was found with the Parr oxygen bomb calorimeter. From these analyses, digestible energy digestible dry matter, protein digestion coefficients, and nitrogen retention were calculated.

The author hopes that by becoming more familiar with the basic metabolic processes involved in the utilization of pelleted rations by lambs, knowledge will be gained that will aid in solving some of the problems concerned with practical applications of using pellets in the feed lot.

Blaxter and Grahm (14) concluded a study on the effect of grinding and pelleting on the utilization of the energy of dried grass by stating that:

"Physical factors which change the rate of passage of food through the gut, change the rate and nature of microbial fermentation, and cause variation in mechanical work involved in prehending, masticating and cudding food, are as important as the chemical composition of the food in determining its nutritive value."

REVIEW OF LITERATURE

Most of the work done on pelleting has compared pelleted and nonpelleted rations. Several articles have been written concerning the digestible energy of various feeds, but few of these deal with pelleted rations. This literature review attempts to summarize the work done with pelleted rations on the various classes of farm animals, with special emphasis on lambs and beef cattle. In addition, the author has reviewed references concerning the use of digestible energy as a measure of feed value, both in pelleted and nonpelleted rations.

Digestible Energy

Numerous references in the literature on nutrition and livestock feeding have been on the use of digestible energy as a criterion for evaluation of livestock feeds. In order to understand the literature concerning the utilization of energy, it is necessary for one to be thoroughly familiar with the terms used in discussing the various measurements of energy. According to Maynard and Loosli (55), gross energy, or the energy present in the injected feed, is divided into digested energy and fecal energy. The digested energy is further divided into the metabolizable portion and the energy lost in urine and combustible gasses. Metabolizable energy is then divided into net energy, or the energy actually available to the animal for growth, fattening, and reproduction, and the energy lost as heat, or heat increment.

Much of the early work on energy utilization by livestock was done in the respiration calorimeter at the Pennsylvania station. Armsby (4), as early as 1915, discussed this calorimeter and some of its uses. Gross energy in the ingested feed was determined by the bomb calorimeter. In the respiration calorimeter, it was possible to determine all the various classes of energy loss, including the energy lost by ruminants in the formation of methane, and the energy lost as heat increment. He also explained how the calorimeter was tested periodically using a standardized alcohol lamp.

Mitchell (62), in 1942, recommended that feeding values of various animal rations be determined on the basis of metabolizable energy and apparent digestibility of nitrogen in place of the more popular measure, total digestible nutrients. He stated that metabolizable energy could be determined with the bomb calorimeter by combustion of feed, feces, and urine. In the case of ruminants and horses, energy is lost by the evolution of methane gas. For determination of metabolizable energy in beef cattle, Mitchell suggested estimating the grams of gas given off from formulas developed by Kriss (41) in 1930. Two formulas were given; for roughage alone, $y = .0198\ x + 9$, and for a mixed ration, containing both roughages and concentrates, $y = .0225\ x + 18$, where y is equal to the grams of methane produced, and x is the grams of dry matter ingested. Mitchell stressed, however, that the complete proximate analysis is usually necessary for accurate evaluation of a particular ration or feed.

In 1944, Forbes et al. (32) published a paper discussing the effect of increased protein feeding on heat production of rats in a respiration calorimeter. These workers found that as the percent protein in the rat diet increased, the production of heat, and the metabolizable energy, decreased at a parallel rate. Diets were equal in total caloric content. The depression of heat production, therefore, was due to the decrease in fat and carbohydrates as the protein portion of the ration increased. It is evident from this experiment that protein determination is not necessary for the accurate evaluation of metabolizable energy in a ration.

Maynard (53), in 1944, published a method for converting the protein, fat, and carbohydrate portions of the complete proximate analysis into the caloric value for various feeds. He suggested multiplying percent protein and carbohydrate by four and the percent ether extract by nine. These factors were, at that time, considered to approximate the digestible energy, in calories, of a gram of these respective feed constituents. Maynard pointed out, however, that since these values were determined for the human diet on the basis of both animal and plant proteins and fats, they must be adjusted to the type of ration under consideration.

In another paper by Maynard (54) in 1953, he pointed out some of the errors in the use of 1814 calories per pound TDN. This figure, which had been used to estimate the calories per pound of TDN for over 30 years, apparently came from the calculation, four calories per gram times the number of grams per pound (4 cal/gm X 453.6 gm/lb. = 1814 cal/lb.). He pointed out that this value considerably underestimated the true digestible energy of the feed. Maynard emphasized that one of the errors inherent in using this system is that TDN as usually calculated actually measures the loss of protein energy in the urine as well as energy losses in the feces. A more recent formula for calculating TDN in its strictest sense involves multiplying digestible protein by 1.36, which is the caloric value of protein divided by the caloric value of carbohydrate. Maynard stated that a more accurate way of converting TDN to digestible energy was to multiply the pounds digestible carbohydrates, digestible protein, and digestible ether extract times their respective gross calorie values and add the results. This gives a figure of approximately 1987 calories of digestible energy per pound TDN, or a caloric value per gram of TDN of 4.38; proof that the earlier value of 1814 substantially underestimated the caloric value per pound of TDN.

Lofgreen (49) suggested another method of evaluating feeds in terms of digestible energy. His method concerned using the bomb calorimeter to determine energy values of feed and feces, and then converting these to TDN. This method preserved the usefulness of the feeding standards computed on the basis of TDN. Lofgreen's method consisted of determining moisture, ash, ether extract, and energy, and computing a conversion factor as follows:

$$F = \frac{OM}{100} + \underline{100 + (EE \times 2.25) - EE} .$$

In this formula, OM represents the percent organic matter in the feed, and EE represents the percent ether extract in the organic matter. The factor, F, is then multiplied times the percent digestible energy to give percent TDN. Digestible energy can also be computed from the values of standard feeding tables by the use of this formula. Values from the complete proximate analysis can be used to compute the conversion factor. TDN from the table is divided by the conversion factor to give the digestion coefficient for energy. This digestion coefficient for energy may then be multiplied by the heat of combustion, found by burning the sample in the bomb calorimeter, to give the digestible energy.

Lofgreen (50), in 1953, reported an even more rapid method for evaluation of rations. It concerned estimation of TDN from the amount of digestible organic matter. In this method, a standard digestion trial was conducted and moisture, ash and ether extract were determined on the feeds. Moisture and ash were determined on the feces. The digestibility of the organic matter was calculated, and a conversion factor, F, was computed from the formula: $F = M\ (.01 + .000125\ E)$, where M was the percent organic matter in the feed, and E was the percent ether extract in the organic matter. Finally, TDN was determined by multiplying the digestibility of the organic matter by the correction factor, F. This method appeared to be equally as accurate as complete proximate analysis and the method discribed by Lofgreen (49) in 1951 for estimation of TDN by the bomb calorimeter. The later method was, of course, much more rapid than either. Lofgreen stated, however, that protein in the ration and digestible protein should be determined because of their use in formulating rations.

Crampton et al. (25) found the average calories per gram TDN to be approximately 4.3. This was computed on various rations using the formula:

$$\text{Cal/gm TDN} = \begin{matrix} \%\ \text{protein} \times 5.65 \\ \%\ \text{fat} \times 9.3 \\ \%\ CH_2O \times 4.3 \end{matrix} \quad \times\ 1.018 - 0.0105\ (\%\ \text{fat})\ .$$

Swift (78) computed the calories per pound TDN and arrived at the figure of 2000. He measured calories per pound TDN on 100 percent roughage rations fed to sheep and cattle, and mixed rations fed to cattle. The mean of these values was 1999.4 calories and the difference between any two was nonsignificant at the .05 level.

Moore et al. (63) studied the relationship between TDN and net energy values for various feeds. They computed the regression equation, $Y = 1.393 X - 3463$, in which Y equals net energy and X equals TDN. A definate linear relationship was found to exist between net energy and total digestible nutrients. However, net energy decreased more rapidly than total digestible nutrients. Thus, net energy value per unit of concentrates is greater than the per unit value of forage. Regression equations calculated from three feeding tables (Morrison, Forbes, and Fraps) were quite similar.

Experimental work concerning digestible energy on pelleted rations has thus far been quite limited. Blaxter and Grahm (14), in 1956, published a study on the effect of the pelleting process on the utilization of the energy of dried grass. Energy retention was determined in the respiration calorimeter. Grass was fed in both the natural and pelleted state. Pelleting increased the fecal loss of energy and decreased the energy loss due to methane production in the rumen, with a net result that there was no significant difference in net energy between the two rations at either the low or high level of feeding. The increased loss of energy in the feces was apparently because of the decrease in carbohydrate digestibility especially crude fiber. Blaxter and Grahm stated that because of variations in energy needed for ingestion and mastication, and the differences between the heat increment of the various rations, digestible and metabolic energy sometimes fail to place rations in their true order of physiological usefulness.

Lindahl and Reynolds (47) studied the effect of pelleting on the chemical composition and digestibility of alfalfa meal. Chemical analysis of the rations showed that pelleting the alfalfa meal resulted in an increase in ether extract from 2.55 percent to 3.67 percent. When the pellets were ground, the ether extract portion remained essentially the same. Pelleting had no effect upon the gross energy content of the alfalfa meal. Digestibility studies showed highly significant increases in digestibility of the ether extract fractions, in both the pelleted and ground pellet rations in comparison to the meal form. No effect was observed on the digestibility of dry matter, crude fiber, nitrogen free extract, or gross energy. The increase in digestibility of ether extract was apparently due to the increase in ether extract in the diet, as the ether extract content of the feces on the meal, pelleted, and ground pellet rations was 3.7, 3.8, and 3.8 percent respectively.

Hopson (37) at the Kansas station determined digestible energy at various concentrate to roughage ratios in pelleted, pelleted plus hay, and nonpelleted rations. He found a small increase in digestible energy due to pelleting. However, when hay was added to the pelleted ration, there was a sharp drop in digestible energy. The data were not analyzed statistically. When digestible energy values were compared according to the roughage-concentrate ratio, there was a sharp increase between the 20 percent concentrate ration and the 30 percent concentrate ration, but only a slight increase from the 30 percent to the 50 percent concentrate rations. Hopson found an extremely high correlation between TDN determined by the bomb calorimeter. In general, TDN was correlated to digestible energy from .933 to .998, with most values falling near .990.

Techniques in Digestion Studies

In any experimental work concerning digestion studies, it is neces- to make certain that, as nearly as possible, the data collected are representative of the particular ration and the particular animal. Two of the most important considerations confronting the research worker conducting digestion studies involve the length of the preliminary feeding period following a change in rations, and the level of feed consumption.

Forbes et al. (31), at the Pennsylvania station, studied the energy metabolism of cattle in relation to the plane of nutrition. They worked with four nutritive planes providing twice the energy required for maintainence, one half more than the maintainence requirement, one half the maintainence requirement, and a maintainence allowance fed both as a mixed and an all roughage ration. They determined the digestibility of dry matter, organic matter, crude protein, crude fiber, ether extract, nitrogen free extract, carbon, and energy. In general, as the amount of feed consumed was decreased, the digestion coefficients of the various nutrients increased. Energy digestion increased from 69.6 percent on the ration providing twice the maintainence requirement to 73.1 percent on the ration that provided one half the maintainence requirement. When the maintainence ration was fed as a mixture containing 50 percent roughage and 50 percent concentrates, the digestibility coefficients were considerably higher than when the maintainence ration was fed as hay alone. Energy digested decreased from 74.3 percent on the mixed ration to 56.5 percent on hay alone.

Nicholson et al (66) conducted an experiment on the necessary preliminary period with steers fed changing roughage to concentrate ratios. They also studied one ration in which the amount of protein changed. Collections of feces were started immediately after the rations were changed and continued up to the 44th day. They found that although the proximate analysis showed cyclic variations in digestibilities, only from 16 to 30 days were needed for the feces from a steer to become representative of the ration being fed. The rations changed from 100 percent roughage down to 75, 50, and 35 percent roughage respectively. However when only the level of protein changed, seven days was adequate for the preliminary period.

Lloyd et al. (48), working at Macdonald College in Quebec, conducted a similar experiment with lambs. Four lambs were removed from pasture and placed in digestion crates on a ration of 100 percent roughage. Feces were collected and analized each day for 60 days. Then the lambs were changed to a ration of 65 percent hay, 21 percent oats, and 14 percent bran. Again, collections and analyses were carried out daily. Cyclic variations in digestibility of nutrients were found even up to 60 days. Precision gained by increasing the preliminary period to 60 days was nonsignificant. These authors stated that there was little justification for carrying out preliminary periods for longer than ten days, even under conditions where the roughage-concentrate ratio underwent a drastic change.

Pelleted Rations for Sheep

One of the first publications concerning pelleted rations for lambs was written by Neale (64), of the New Mexico station, who incorporated coarse, stemy, poor quality alfalfa into complete pelleted rations containing 50 and 60 percent roughage. These two rations were compared with an unpelleted ration containing fine stemmed medium grade alfalfa. The low quality alfalfa in pellets was equal or superior to the medium quality alfalfa in the nonpelleted ration. Later, Neale (65) repeated the study using 70 percent alfalfa in addition to the two previous rations. He found that the 70 percent alfalfa pellet produced more rapid, more efficient gains, and got the lambs to market several days sooner than the lower roughage rations.

Hopkins et al. (36) conducted an experiment in which alfalfa was fed ground, long, and in pellets, and corn was fed as pellets, and ground. These ingredients were fed to four lots in different combinations. Grinding hay increased feed intake and averaged daily gain ($P<.01$), and feed efficiency and dressing percent ($P<.05$). Pelleting the corn, hay, and entire ration caused no statistically significant differences but increased feed efficiency seven, five, and three percent respectively. In digestion studies, crude fiber digestion was decreased ($P<01$) and a decrease approaching significance was observed when the entire ration was pelleted. Of 90 lambs observed for rumen parakeratosis, 38 percent of the lambs fed pelleted feed were affected while only 4 percent of the lambs on nonpelleted rations were affected.

Much of the previous work with pelleted rations for lambs has involved pelleting the entire ration. Esplin et al. (30), Cate et al. (20), Bell et al. (12) (13), Joyce (40), Hopson (37), John (39), and Hays (34), all reported increased feed efficiency and daily gains due to pelleting. This seemed to be one of the most important advantages of pelleting lamb rations. Although greater gains and feed efficiency were produced on pelleted rations, the cost per pound of gain was higher in many cases, due to the cost of pelleting. This was true in feed lot studies on pelleting carried out by Thomas et al. (80), John (39), and Bell et al. (13). However, Neale (64) (65) found pelleting low quality roughage in a complete ration produced the most economical gain.

Cate (20) also stated that pelleting was more advantageous with low quality roughage. In a study comparing the effect of pelleting rations of varying roughage quality, he found that the greatest advantage for pelleted over nonpelleted rations occurred on a ration using timothy hay as the roughage. With timothy hay, feed consumption and daily gain were both increased significantly in relation to the nonpelleted rations. Pelleting alfalfa hay gave an increase in feed efficiency, but not so great as when timothy hay was used. Cate also reported that pelleting produced higher carcass grades on the timothy hay ration, but not on the alfalfa ration.

Esplin et al. (30) discussed the apparent preference of lambs for the pelleted ration. He reported an increase in feed consumption of the pelleted over the nonpelleted ration that was significant at the .01 level. He also found that when the animals were offered their choice in the same bunk, they consumed 213 pounds of pellets versus 42 pounds of the same ration in the meal form.

Brown and Caveness (18) conducted a similar study comparing corn, oats, milo, and wheat offered as whole grain, and in the finely ground, crimped, and pelleted states. There was no significant difference between preferences for the various grains, but the preference difference between the methods of preparation was significant ($P < .05$). The ewes consumed 94 percent of the finely ground grain, 90 percent of the crimped grain, and 88 percent of the pelleted grain, but only 60 percent of the whole grain.

In an experiment by Church and Fox (21), the effects of pellet size and fineness of grind of the roughage prior to pelleting were studied. A high roughage ration was used. Neither pellet size nor fineness of grind of the roughage produced a statistically significant effect upon daily gain.

Numerous authors have studied the effect of various roughage to concentrate ratios in complete pelleted rations for lambs. Cox (24), in 1948, reported the results of nine experiments which indicated that the optimum physical balance for lamb rations in the unpelleted form was 55 percent roughage to 45 percent concentrate. However, nearly all references concerning roughage to concentrate ratios for complete pelleted rations reviewed by the author indicate that more roughage can be fed than the amount determined by Cox for nonpelleted rations.

John (39) found that 65 percent roughage was significantly more efficient in the pelleted ration, while 55 percent roughage was significantly more effecient in the nonpelleted ration. On the other hand, Bell et al. (13) found that a ration of 55 percent roughage produced greater and more efficient gains in both the pelleted and nonpelleted form than did a ration with 65 percent roughage. Joyce (40) found that lambs on a pelleted ration containing 70 percent roughage made the most satisfactory gains among several roughage levels studied. Ross and Pavey (75) found that a pelleted ration containing 60 percent roughage produced significantly higher gains than did either the 40 percent or 50 percent roughage rations. However, the lambs on the 60 percent roughage ration had significantly lower carcass yields ($P<.01$). Hays (34) compared suncured and dehydrated alfalfa in addition to varying roughage to concentrate ratios, and found that rations containing 65 percent roughage consistantly produced slightly higher gains than when the 55 percent roughage ration was fed. He also found that suncured alfalfa produced more efficient gains than dehyrdated alfalfa in both the pelleted and nonpelleted form. He found no consistant differences in live market and carcass grades. Menzies et al. (59) found little difference in gaining ability between 60 percent roughage and 90 percent roughage rations. However, lambs on these rations all gained faster than those fed on 40 or 50 percent roughage. These workers found that feed efficiency increased as the percent concentrates increased. However, consumption was higher on the lower concentrate levels. They also found that lambs on the high roughage rations had a higher shrink. In this trial, high roughage pellets produced the cheapest gains. Hartman et al. (33) experimented with high and low roughage rations, both pelleted and nonpelleted, containing 59 and 29 percent roughage respectively. No appreciable differences in rate of gain were observed due to rations. However, lambs fed pellets tended to produce more oily carcasses. Pelleting the low roughage ration gave an advantage in gain and feed efficiency, but pelleting the high roughage ration resulted in greater consumption and daily gain, without affecting the efficiency. Neale (64) (65), in work cited previously, found that when using low quality alfalfa hay, the ration of 70 percent roughage, 20 percent sorghum grain, and 10 percent molassas produced the fastest gains with the greatest feed efficiency, and got lambs to market soonest with the least cost per hundred pounds of gain.

Pelleting has been found by Hopson (37), Bell et al. (11), Lindahl et al. (46), and John (39), to have very little effect upon TDN and digestible energy as determined by digestion studies. However, according to most of these workers, pelleting the ration decreased the digestibility of crude fiber and increased the digestibility of the ether extract portion. Results substantiating this statement were found by Joyce (40), Hopkins et al. (36), Bell et al. (11) (12), John (39), and Lindahl et al. (46).

On the other hand, Esplin et al. (30) found that no significant differences were apparent between pelleted and nonpelleted rations in regard to nitrogen balance and digestibility of dry matter, ether extract and crude fiber.

Hays (34), Woods et al. (85), and John (39) found increased nitrogen retention with lambs fed pelleted rations versus those fed nonpelleted rations. Joyce (40), on the other hand, found very little difference between the two preparations.

In general, grinding the ration lowered its digestibility, while pelleting following grinding restored the digestibility to its level in the natural feeds in experiments by Long et al. (51).

Woods et al. (85) state that digestibility of dry matter, organic matter, and cellulose was significantly depressed at the .05 level by pelleting both low and high roughage rations, but that digestible protein was not affected.

Several observations were made from the review of literature on pelleting rations for lambs: (1) Pelleting increased utilization of low quality roughages; (2) In complete pelleted rations, pelleting had a sparing action on grain, since equal or superior results were obtained when a high roughage pelleted ration was compared to a nonpelleted ration containing a higher level of concentrate; (3) The crude fiber digestion of most rations was depressed by pelleting, but there was little effect upon TDN; (4) There was, in general, an increase in daily rate of gain and feed efficiency on pelleted rations; and (5) Pelleting improved the palatability of the ration, thereby increasing consumption, and promoting more rapid gains. Pelleting can be considered an economical practice only if the value of the advantages due to feeding pellets, such as increased feed efficiency, higher daily rate of gain, greater convenience of feed handling, and earlier marketing of the lambs add up to more than enough to pay the cost of pelleting.

Pelleted Rations for Beef Cattle

The success of pelleting the grain or roughage portion, or the use of a complete pelleted ration for lambs has caused interest in pelleting rations for beef cattle in the past several years. Advantages from pelleting rations for beef cattle are not as consistant as those for pelleting lamb rations.

Pelleting the grain portion of the ration increased feed efficiency and daily rate of gain, according to Richardson et al. (74), Keltz (41), and Pope et al. (70). However, on a pelleted concentrate ration for creep feeding calves. Alexander et al. (1) found in one trial that the pelleted ration produced lower daily gains, probably because of decreased feed consumption. In another trial, pelleting caused no significant effect on either feed intake or weight gain. In the second trial, the pelleted ration produced a lower average slaughter grade. Pope et al. (71), working with milo and barley, found that although pelleting milo increased daily gains over dry rolling, steam rolling barley caused more rapid gains than pelleting. This may have been because the steam rolled barley was more palatable than the pelleted product. Richardson et al. (74) found that, in contrast to the results of Alexander et al. (1), the pelleted ration produced higher dressing percents and carcass grades.

Ray et al. (73) found in a preference study that calves showed a significant preference for pelleted over ground grain ($P<.01$).

Pelleting a roughage ration increased the daily gain according to two studies by Boren et al. (16) (17). In these experiments, alfalfa and forage sorghum were fed in a wintering ration for heifers. Alfalfa was fed as hay and as pellets. The forage sorghum was fed either as silage or as pellets made by dehydrating and grinding the entire plant. Since the whole plant was used, the ration contained a small amount of grain. These workers found that pelleting caused significant increases in daily gain with either alfalfa or forage sorghum. However, the advantage of pelleting the forage sorghum was greater than that from pelleting the alfalfa. These results agree closely with Neale (64), who used low quality roughage in a complete pelleted ration for lambs. Webb et al.

(82) found that pelleting the forage part of the ration (alfalfa and timothy) produced much greater feed efficiency than other preparations. Baled hay produced 115.5 pounds gain per ton of hay, chopped hay produced 116.2 pounds gain per ton of hay, and pelleted hay produced 220.7 pounds gain per ton of hay. Keltz (41) found no advantage for dehydrated pelleted grain sorghum when compared to the same forage in silage form.

McCroskey et al. (57) fed a pelleted roughage ration of equal parts average quality alfalfa hay and cottonseed hulls, with five percent molasses added. They found that the calves on the pelleted roughage produced lower gains than when roughage was fed in the nonpelleted form. However, in a preference study with the same ration, calves preferred the pelleted roughage 2.2 to 1.

Brown et al. (19) pelleted a roughage ration of grass hay and cottonseed hulls, and observed a depression in daily gain and feed efficiency.

A number of workers have studied the question of pelleting the entire ration for beef cattle, and several have found that the beneficial effects from pelleting depend upon the amount of roughage in the ration. Beardsley et al. (9) found that the gains of steers on pellets increased and gains on nonpelleted rations decreased as the amount of roughage was increased. These workers found that steers fed pellets regurgitated infrequently. Examination of stomachs upon slaughter revealed a high incidence of dark colored rumens from steers fed high roughage rations in the pelleted form. Histological studies revealed marked tissue changes including parakeratosis in steers on the high concentrate pelleted ration and the control ration, but not on the high roughage nonpelleted ration. No relationship was found between rumen parakeratosis and dark colored rumens. They observed the greatest gains on the 20 percent concentrate pelleted ration. Increases in the rate of gain and feed efficiency due to pelleting the 20 percent concentrate ration were significant at the .01 level. However, gains were decreased significantly at the .01 level when the ration containing 80 percent concentrate was pelleted. Pelleting increased the feed intake 14 percent on the low concentrate--high roughage ration, but decreased consumption 13 percent on the high concentrate ration.

Baker et al. (8), at the Kansas station, pelleted a ration containing 60 percent corn, 5 percent cottonseed meal, 10 percent molasses, and 25 percent alfalfa. The lots receiving the pelleted feed had a significantly lower growth rate than those on coarsely cracked corn and chopped hay. The growth depression was believed to be due to lowered consumption. Absence of regurgitation was noted, and late in the trial the animals developed a depraved appetite and began chewing on the board fences, apparently in an attempt to ingest coarse roughage.

Cmarik et al. (23) found in an experiment with various roughage to concentrate ratios in complete pelleted rations, that roughage can make up a high percent of the ration if fed in an acceptable form. No ill effects were found from fine grinding prior to pelleting.

Webb et al. (83) observed no significant difference in any age group of cattle studied when the concentrate was increased from 60 to 80 percent in a complete pelleted ration.

Weir et al. (84) noted that addition of 30 percent concentrates to an all hay pelleted ration produced no significant effect upon gains.

Daily intake was decreased and feed efficiency increased, thus tending to equalize TDN intake. However, when the concentrate level was increased to 60 percent, a decrease in feed consumption and daily gain occurred. This decrease was significant at the .05 level when compared with both the other concentrate levels in pelleted rations and the 60 percent concentrate level in the meal form.

Clanton et al. (22) reported on the efficiency of chopped and pelleted rations in both the growing and finishing stages. They fed the concentrate both cracked and pelleted and the roughage chopped and pelleted. The growing ration contained 1 part concentrate to 3.3 parts roughage, and the finishing ration, 2.5 parts concentrate to 1 part of roughage. In the growing phase, gains and feed efficiency were similar on both pelleted and chopped rations. In the fattening phase, the chopped roughage with pelleted concentrate produced the lowest gains and feed efficiency. Pelleting did not change the gains and feed efficiency in the growing phase. However, in the finishing phase, there was an undesirable effect from pelleting the roughage and a desirable effect from pelleting the concentrate.

In digestion studies conducted by Clanton et al. (22), during the growing phase, dry matter and energy were more digestible in the rations in which the roughage was chopped instead of pelleted. In the fattening phase, dry matter, energy, and protein were more digestible when the roughage was chopped and the concentrate pelleted.

Alexander et al. (1), in their study of pelleted creep rations, found very little difference between pelleted and nonpelleted rations in digestible protein and digestible energy.

Brown et al. (19) noted that when a roughage ration of grass hay and cottonseed hulls was pelleted, there was a highly significant decrease in the digestibility of the ether extract. This observation was in direct disagreement with ether extract digestion coefficients found by Joyce (40), Hopkins et al. (36), Bell et al. (11) (12), John (39), and Lindahl et al. (46), who worked with lambs.

It would appear from the review of literature on pelleted rations for beef cattle that there are some advantages for pelleting the roughage, concentrate, or the entire ration for beef cattle. However, advantages for pelleting appeared to be greater when a high roughage ration or a low quality roughage was fed. As with rations for lambs, the producer must carefully compare the cost of pelleting with the expected savings due to pelleting the ration. Even though some workers have claimed large gains in feed efficiency and growth, the producer should remember that numerous workers have found no advantage due to pelleting, and a few have experienced substantial decreases in efficiency and daily gains.

Pelleted Rations for Dairy Cattle

Most of the previous work done on pelleted dairy rations has been with the roughage part of the ration. Blosser et al. (15) reported on the comparative value of finely ground, chopped, and pelleted dehydrated alfalfa as a grain replacement for lactating dairy cows. Cows receiving the pelleted alfalfa produced significantly more four percent fat corrected milk than cows receiving their hay in the other forms. The increase was not related to the TDN consumed. Some of the increase may have been because cows fed pellets stayed on feed better than those receiving the ground ration. These authors concluded that pelleted alfalfa was definitely superior to finely ground alfalfa for dairy cows.

Porter et al. (72) used both field cured and artificially dried alfalfa in an experiment to determine their relative value in chopped, baled, ground, and pelleted forms. In the first trial, pellets increased the actual milk production but lowered the fat content. No significant effect was found in the amount of fat corrected milk. In the second trial, pelleting lowered hay consumption, fat content of the milk, and the amount of fat corrected milk. The decrease was attributed to the extreme hardness of the pellets.

Warren et al. (81) carried out a study to determine the lactation response from addition of dehydrated pelleted alfalfa to a ration of timothy-grass mixed hay and grain. As the amount of pelleted alfalfa fed increased, the ad lib. consumption of the timothy hay decreased, grain consumption increased, and dry matter, total digestible nutrients and net energy intake increased. The production of fat corrected milk increased, along with the carotene and vitamin A content of the milk. In spite of these advantages, the efficiency of milk production decreased.

One of the more recent studies on pelleting alfalfa hay for milk production was carried out by Magnor et al. (52). Cows on pelleted hay consumed more dry matter and produced more milk than those that received chopped hay. When the chopped hay was supplemented with 12 percent concentrates, the dry matter intake and production were on a comparable level with the pelleted hay ration. Supplementation of the pelleted hay ration at a similar rate did not show a significant increase in dry matter intake or milk production. The butterfat percentage of the milk was not affected by either of the pelleted hay rations.

Several workers have studied pelleted rations for dairy calves. In a study comparing field cured hay in bales and dehydrated alfalfa in both the chopped and pelleted form, Eaton et al. (29) found that consumption was highest on either the pelleted or chopped dehydrated hay. They noted that the calves grew faster on dehydrated hay than field cured hay, apparently because of the greater consumption. Dehydrated hay provided adequate carotene, while the field cured hay did not. The depletion times for vitamin A were 5.8 weeks for field cured hay, 7.7 weeks for pelleted hay, and 9.3 weeks for the chopped hay. These differences, however, were not statistically significant.

In a study concerning the nutritional merits of pelleting calf starters, Lassiter et al. (44) found that the physical preparation had no significant effect upon the average daily gain, skeletal growth, incidence of scours, hay or starter consumption, or feed efficiency. The starter was fed either in the pelleted form, meal form, or mixed. When offered a choice between preparations, the calves consumed significantly more of the pelleted starter. No nutritional advantages were found for pelleting the calf starter.

Pelleted Rations for Swine

Pelleted rations for swine have received relatively little attention as compared to the experimental work done on pelleted rations for other classes of livestock. However, most of the workers who have studied pelleted rations for swine have observed increased daily rate of gain and feed efficiency due to pelleting. This agrees with results on pelleted feeds for most other classes of livestock.

Jenson et al. (38) conducted five experiments using a total of 225 pigs weaned at two weeks of age. Although there was considerable variation between and within experiments, pelleting increased feed utilization in four of the five tests. There was only a slight difference in daily rate of gain. Proximate analysis revealed a consistant decrease in crude fiber in the ration following pelleting. In addition, studies on corn showed that the starch in corn was more succeptable to malt amylase following the pelleting process.

Thomas and Flower (79) carried out two experiments comparing the pellet and meal form for swine rations. In both rations there was a significant increase in daily rate of gain and feed efficiency. The pigs fed pellets reached market weight from 12 to 14 days faster than pigs on the meal ration. In this experiment, feed costs per hundred pounds gain were two dollars lower on the pelleted ration indicating that pelleting on this ration was a highly economical practice.

Aubel (6) (7), at the Kansas station, conducted two experiments comparing the free choice feeding of shelled corn and a protein supplement with the same ingredients in the pelleted form. In the first experiment, the pigs on the normal ration fed free-choice outgained the lot fed the same ration as pellets. The following year this situation was reversed, with the lot fed pellets showing greater gains. However, in both experiments, the feed efficiency was increased by pelleting the complete ration.

Dinusson and Bolin (26) compared a swine fattening ration fed as meal, crumbles, and pellets. In one lot, the pellets were ground and repelleted three times. These workers stated that there was less feed waste, increased palatability, increased density, and a saving in labor on the pelleted ration. In this study, when barley was pelleted, it was comparable in efficiency and daily gain to corn. Proximate analysis showed that pelleting consistantly decreased the crude fiber in the ration. This agrees with the results found by Jenson et al. (38). However, when the pelleted ration was reground and repelleted three times, there was no additional reduction in the crude fiber level. Neither was there any advantage in daily gain or feed efficiency due to the three extra pelletings. As with several other studies, this experiment showed that pigs on pelleted rations gained faster and more efficiently and reached market weight several days sooner. In this study, as in the one carried out by Thomas and Flower (80), the increased feed efficiency due to pelleting was enough to offset the cost of pelleting.

It would appear from the literature reviewed on pelleting swine rations that pelleting is definately beneficial, provided the increased feed efficiency lowers the cost per pound of gain enough to pay for having the feed pelleted.

Pelleted Rations for Poultry

No review of literature on pelleting would be complete without including a discussion of pelleted rations for poultry, since poultry rations were probably among the first rations commercially pelleted. Patton et al. (67) published a study of the relative merits of pelleted and mash poultry feeds in 1937. They found that chicks fed mash consumed 10.81 percent more feed per pound of gain than the chicks fed pellets. The chicks fed pellets gained 6.16 percent more rapidly than those on the mash ration. However, he observed that the chicks fed mash consumed 5.55 percent more feed than those fed pellets. Nearly all research work done with pelleted rations for poultry has shown that pelleting increased daily gains and feed efficiency, as is true with most other classes of livestock. Most of the material on pelleted rations for poultry has concerned either growing chicks or broilers, in which daily weight gain was the principal consideration. Increased gains and feed efficiency on pelleted rations were noted by Allred et al. (3) (4), Bearse et al. (10), Heywang and Morgan (35), Lanson and Smyth (43), and Patton (67).

In contrast to these results, Stewart and Upp (77) found no significant difference between mash, pellets, and crumbles on daily gains and feed efficiency. Preference was highest for pellets, and less feed was wasted in the pellet and crumble form.

Allred et al. (2) reported that a large part of the increased growth rate due to pelleting was the result of some chemical change instead of a simple change in the physical form of the ration. He believed that this change was perhaps the deactivation of some growth inhibitor present in the feed. In a later experiment, Allred et al. (3) concluded that the change was both chemical and physical. When individual ingredients of the ration were pelleted and reground, and incorporated into an otherwise nonpelleted ration, response was obtained only from corn and rye. Corn was subjected to steaming, autoclaving, and water soaking in an attempt to simulate changes undergone in the pelleting process. These treatments did not affect chick growth or feed efficiency.

Bearse et al. (10) studied the merits of pelleting chick rations of different fiber levels. They found that the beneficial effect of pelleting was increased as the amount of fiber in the ration increased. Fiber levels of 8, 13, and 18 percent were studied.

Dymsza et al. (28), working with various fiber levels (5, 10, and 15 percent) in turkey feed in the crumble (broken pellet) and mash forms found that crumbling was more effective on the higher fiber rations. This was partially attributed to the greater density of the crumbles, allowing wider adjustment of feed intake.

Pepper et al. (68) studied the effect of adding fat to pelleted and nonpelleted rations. They noted an increase in weight gains when fat was added to the mash ration. Increases in weight gains were significant when the ration was pelleted without fat, but as fat increased in the ration, the beneficial effect due to pelleting decreased. Thus, the authors concluded that pelleting had a sparing action on fat in the ration.

McGinnis and Stern (58) found that pelleting had no significant effect upon the action of procaine penicillin, diamine penicillin, and aureomycin fed to turkey poults. The antibiotics were added to the pelleted ration both before and after pelleting.

There has been a general opinion among poultry men that pelleted poultry rations tend to increase cannibalism. However, none of the work reviewed by the author showed a significant increase in cannibalism on pelleted rations over nonpelleted rations.

Few references were available on the effect of pelleting on egg production. Lee et al. (45) reported on a study carried out with 1200

Leghorn hens being fed with mechanical feeders. Half the hens received part of their ration in the pellet form and the remainder of the ration as mash. The other half received only mash. The experiment was continued for 630 days, during which time pelleting increased feed intake and feed conversion, and reduced the feed cost per dozen eggs.

DIGESTION STUDY

Experimental Procedure

Nine white-faced New Mexico wether lambs averaging 66 pounds were selected for this study from a larger group purchased for feed lot studies at the university sheep barn. Prior to being placed on experiment, the lambs were sheared and drenched with phenothiazine. The lambs were brought to the pens, several began showing symptoms of coccidiosis, whereupon the entire group was treated with a sulfa compound until the symptoms began to dissipate.

The lambs were started on an all-pelleted ration of 90 percent alfalfa hay and 10 percent sorghum grain as soon as they were brought to the pens. This ration was hand fed in individual feeding crates twice daily. An effort was made to adjust feeding levels to a point where the lambs would not completely satisfy their appetite. This was done in an attempt to keep the lambs from going off feed during the collection periods. Lambs were released from the crates when they had finished eating. They were removed from the pens and placed in digestion crates designed for the complete collection of feces and urine on December 1. A seven day preliminary period in the crates was allowed for the lambs to become accustomed to confinement before the actual collections were started. A total of 21 days on the 90 percent roughage--10 percent concentrate ration was allowed before the first collection, allowing time for the digestive tract to empty itself of previous feed, and for the feces and urine collected to become representative of the ration being fed.

Since this study was designed to deal only with the roughage to concentrate ratios in complete pelleted rations, all nine lambs received the same ration during each collection period.

The roughage to concentrate ratios fed the lambs on this study, and their respective collection periods were as follows:

90 percent alfalfa hay and 10 percent sorghum grain
December 7-14

80 percent alfalfa hay and 20 percent sorghum grain
January 2-9

70 percent alfalfa hay and 30 percent sorghum grain
January 18-25

60 percent alfalfa hay and 40 percent sorghum grain
February 3-10

50 percent alfalfa hay and 50 percent sorghum grain
February 19-26

40 percent alfalfa hay and 60 percent sorghum grain
March 8-15.

Throughout the remainder of the paper, the rations are referred to as 90-10, 80-20, 70-30, 60-40, 50-50, and 40-60.

Periods allowed for the lambs to adapt themselves to each new ration were as follows:

Ration	Days on preliminary feeding
90-10	21
80-20	18
70-30	9
60-40	9
50-50	9
40-60	11

Except for the first collection period, the lambs were placed in the crates three days prior to the start of collections.

Feces and urine were collected from each lamb every afternoon for seven consecutive days during the collection periods. Five percent of each lamb's daily urine excretion was placed in a glass jar under toluene, and stored under refrigeration, each day's aliquot being added to the previous aliquots. Feces were collected from each lamb and the wet weight recorded. Five percent of each day's collection was placed in a porcelainized pan and dried for 24 hours in an oven at 85-90 degrees centigrade. The following day, the pan was weighed and a five percent aliquot of that day's collection added to the previous sample. After the seven day collection period, another day was allowed for the final day's samples to dry, and all nine composite samples were taken to the nutrition laboratory. The samples were ground, using a 2 millimeter sieve, in a Wiley mill and stored in sealed glass jars. Part of each ground sample was further dried in a vacuum oven under vacuum of approximately 29 inches of mercury at 100 degrees centigrade to obtain a dry sample for analysis, and to determine the dry matter content. The samples were stored in desiccators until they could be analyzed for nitrogen and energy.

Near the end of each collection period, a random sample of the particular pelleted ration was obtained, ground in the Wiley mill, and dry matter determined. The feed samples were then stored in desiccators with the feces samples.

Nitrogen in the urine, feces, and feed was determined by the Kjeldahl method according to standard AOAC procedures (5). Energy was determined by combustion in the Parr oxygen bomb calorimeter. From these determinations, digestible energy, protein digestion coefficients, and nitrogen retention were calculated. Dry matter of feed and feces was used to calculate percent digestible dry matter.

Following each collection period, the lambs were removed from the metabolism crates and placed in pens, where they were immediately started on the next roughage to concentrate ratio.

Results and Discussion

Digestible energy studies on the various pelleted rations disclosed a roughly linear increase in percent digestibility of energy as the amount of concentrate in the ration increased. This would be expected, since the amount of fiber in a ration of this type decreases proportionately as the amount of concentrate increases. However, the results of this experiment did not agree with the results of Hopson (37), who conducted a similar study. Hopson found a rapid increase in percent digestible energy from the 80-20 ration to the 70-30 ration, and then a gradual leveling off to the 50-50 ration. Nicholson et al. (66) found the relationship between percent roughage and percent digestible dry matter was almost perfectly linear from 100 percent roughage to 50 percent roughage and 50 percent concentrates. However, when the roughage percentage was further reduced to 35 percent, digestibility tended to level off.

When the analysis of variance according to Snedecor (76) was applied to these data, a highly significant ($P < .01$) difference between treatments was found. Means were separated according to Duncan's New Multiple

Range test (27). This test indicated that each treatment mean was significantly different from the other treatment means at the .01 level. There was a significant difference between lambs at the .05 level, but not at the .01 level. However, this fact was not alarming considering the exceptionally small error term in the analysis of variance in table 1. When statistical analysis was applied to the graph of digestible

Table 1. Percent digestible energy
Analysis of variance

Source	DF[1]		SS[2]		MS[3]	F
Total	53		1738.44			
Rations	5		1603.91		320.78	139.47**
Linear		1		1581.12	1581.12	687.44**
Quadratic		1		2.05	2.05	.89NS
Cubic		1		17.73	17.73	7.71**
Quartic		1		.37	.37	.16NS
Qunitic		1		2.66	2.66	1.16NS
Lambs	8		42.37		5.30	2.30*
Error	40		92.15		2.30	

1. DF represents degrees of freedom
2. SS represents sums of squares
3. MS represents mean square
** represents highly significant values (P<.01)
* represents significant values (P<.05)

energy values (figure 1), the line was found to be principally linear, the linear relationship accounting for 98.58 percent of the sum of squares due to treatments. However, a highly significant (P<.01) improvement in

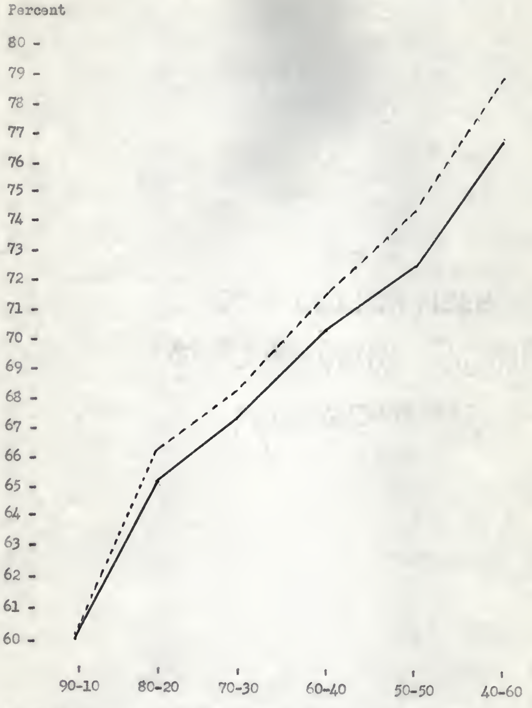

Figure 1. Percent digestible energy and percent digestible dry matter on various roughage to concentrate ratios in complete pelleted rations for lambs.

Digestible dry matter - - - - - - - -

Digestible energy ————————

the fit of the line was accounted for by fitting a cubic line to the data. This improved the fit of the line an additional 1.10 percent. The cubic configuration of the line may have been due to chance alone, or some unknown factor during the experiment.

Digestible dry matter was correlated with the digestible energy. All correlations were highly significant, and only the correlation on the 70-30 ration was below .900. These correlations are presented in table 2. It was intended to calculate an overall correlation between digestible dry matter and digestible energy, but the test for homogeniety of correlation showed the correlations to be nonhomogeneous.

Table 2. Correlation coefficients of digestible energy versus digestible dry matter, and digestible energy versus feed intake.

Ration	Digestible energy versus digestible dry matter	Digestible energy versus grams feed consumed
90-10	.909**	.082NS
80-20	.990**	.767*
70-30	.867**	-.047NS
60-40	.999**	.749*
50-50	.971**	.610NS
40-60	.976**	.277NS

* represents significant values (P<.05)
** represents highly significant values (P<.01)
NS represents nonsignificant values

Inspection of the correlation values indicated that the correlation on the 70-30 ration is the value that caused the correlations to be nonhomogeneous. It should be pointed out, however, than when calculating correlations on numbers of observations as small as those in this experiment, a slight experimental error could have easily influenced the resulting correlation to a high degree. One should expect a high correlation between digestible energy and digestible dry matter since they are both measures of the same biological function--namely that of food digestion.

Correlation coefficients were calculated between digestible energy and feed consumption in an effort to find out if there was a relationship between the grams of feed ingested and the utilization of the feed. The correlation coefficients ranged from .767 to -.047. Correlations for all six roughage to concentrate ratios are found in table 2. The correlations indicated that there was probably no relationship between these two measurements in this experiment, since only two correlations were significant at the .05 level. Certainly the correlations between rations were not homogeneous. Forbes et al. (31) demonstrated a relationship between the plane of nutrition and energy metabolism in dairy cattle. However, in their experiment, they varied the plane of nutrition from twice the maintainence level to one half the maintainence level. In the study at hand, the plane of nutrition was essentially the same throughout the trial, with differences in consumption within a collection period being due to certain lambs going off feed. The lambs were fed somewhat more than a maintainence ration, since they gained an average of 41 pounds during the study.

A definite tendency for certain lambs to go off feed during the collection periods was noted. These lambs did not completely refuse to eat, but simply exhibited a lack of appetite, whereupon the feed offered them was reduced until they cleaned up the amount placed before them.

In all but a few cases, the lambs were cleaning up the feed offered them at both the beginning and end of the collection period. Of the six collection periods, number five lamb consumed less feed than the others five times; number nine lamb, four times; and number three lamb three times. Number two and number seven lambs each consumed less feed than the others on one collection period. Percent digestible energy did not seem to be either consistantly higher or lower on the lambs that tended to go off feed. There seemed to be no definite relationship between low feed consumption and pounds of gain over the entire experiment from November 15 to March 15. Mean gain for the entire period was 41 pounds with a standard deviation of plus or minus 4.55 pounds.

Protein digestion coefficients were determined and it was found that the treatment mean digestion coefficients increased rapidly from 65.77 percent on the 90-10 ration to 72.03 percent on the 70-30 ration. From the 70-30 ration, the digestion coefficients tended to level off to the 40-60 ration, where digestible protein was 72.98 percent. Analysis of varience in table 3 indicated that there was no significant difference between lambs, but a highly significant difference between treatments.

Duncan's New Multiple Range test was used to find the significantly different treatment means. Statistically the 90-10 ration was equal to the 80-20 ration, and the 70-30, 60-40, 50-50, and 40-60 rations were all equal in protein digestion coefficients. However, the 80-20 and 90-10 rations were both statistically different from all the remaining rations. When analysis of variance was applied to the trend line, the linear configuration accounted for only 77.16 percent of the sum of

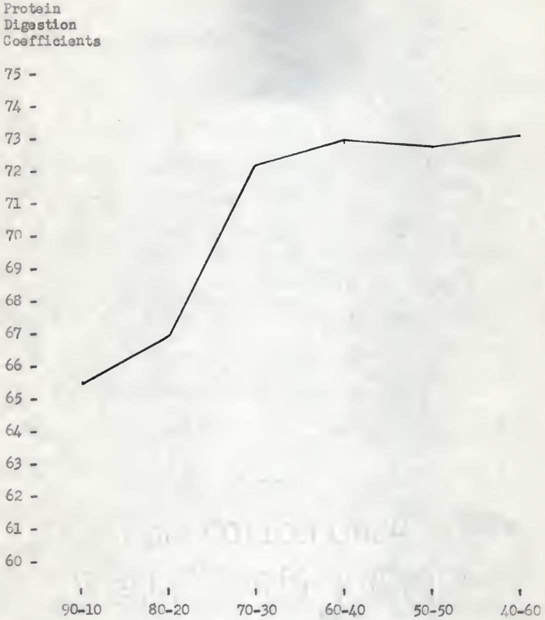

Figure 2. Protein digestion coefficients on various roughage to concnetrate ratios in complete palleted rations for lambs.

Table 3. Protein digestion coefficients
Analysis of varience

Source	DF	SS	MS	F
Total	53	814.68		
Rations	5	488.82	97.76	16.91**
Linear	1	377.15	377.15	65.25**
Quadratic	1	73.66	73.66	12.74**
Cubic	1	1.66	1.66	.29NS
Quartic	1	31.49	31.49	5.45*
Qunitic	1	4.85	4.85	.84NS
Lambs	8	94.51	11.81	2.04NS
Error	40	231.35	5.78	

** represents highly significant values ($P<.01$)
* represents significant values ($P<.05$)
NS represents nonsignificant values.

squares due to rations. An additional 15.07 percent was accounted for by the quadratic configuration. The improvement due to the quadratic configuration was highly significant ($P<.01$). An additional improvement of 6.44 percent, significant at the .05 level, was found when the quartic configuration was tested.

In work conducted by Joyce (40), the protein digestion coefficients decreased as the percent of roughage in the ration decreased. This was in direct disagreement with results found by the author. As with digestible energy, no relationship was evident between protein digestion coefficients and feed consumption of the lambs. The author found no experimental data other than work by Joyce in which protein digestibility coefficients on various roughage to concentrate ratios in pelleted rations were compared.

Nitrogen balance was computed from the nitrogen content of the feed, feces, and urine. Analysis of variance in table 4 showed no significant difference between lambs, but a highly significant difference ($P < .01$) due to treatments. There was no significant difference in the percent nitrogen retained on the 90-10 ration and the 80-20 ration. The 50-50 and 40-60 rations were statistically equal in nitrogen retention. In the collection period with the 90-10 ration, a slight negative mean percent nitrogen retained occurred. The 80-20 ration produced a slight positive mean percent nitrogen retention. An increase in the percent nitrogen retained occurred up to the 50-50 ration, where the trend line turned downward. Grams of nitrogen retained by the various lambs on each ration are given in table 7 (Appendix).

Analysis of variance applied to the trend line showed that 88.64 percent of the sum of squares for rations could be explained by a linear relationship. The quadratic configuration produced a 4.13 percent improvement in the fit of the line ($P < .01$) and the cubic relationship produced an additional highly significant improvement in the fit of the trend line of 6.38 percent ($P < .01$).

Inspection of the nitrogen retention data in table 7 indicates a wide variation in the percent and amounts of nitrogen retained between lambs on any given collection period, with more pronounced differences occuring on the high roughage rations. The author observed that, in

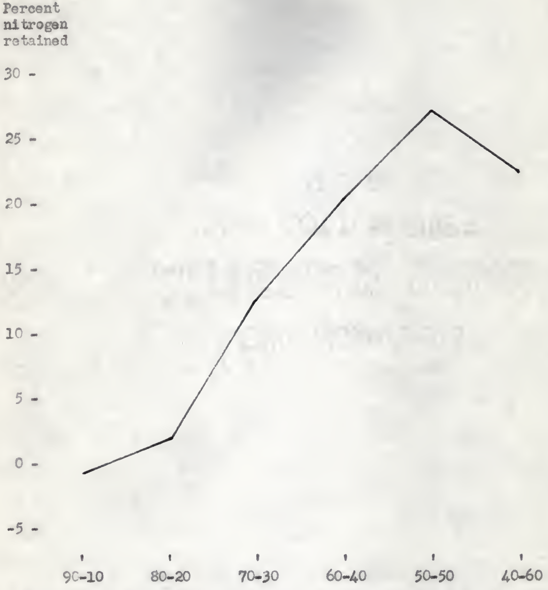

Figure 3. Percent nitrogen retained on various roughage to concentrate ratios in complete pelleted rations for lambs.

Table 4. Percent nitrogen retained (coded)[1]
Analysis of variance

Source	DF	SS	MS	F
Total	53	6869.16		
Rations	5	5873.37	1174.67	55.25**
Linear	1	5206.31	5206.31	244.88**
Quadratic	1	242.52	242.52	11.41**
Cubic	1	374.91	374.91	17.63**
Quartic	1	5.21	5.21	.25NS
Quintic	1	44.39	44.39	2.08NS
Lambs	8	165.19	20.65	.97NS
Error	40	850.60	21.26	

1. For purposes of simplifying the analysis if variance and removing negative values, the data were coded by adding 10 percent to each raw nitrogen retention percentage.

** represents highly significant values ($P < .01$)
* represents significant values ($P < .05$)
NS represents nonsignificant values.

general, when a lamb went off feed early in a collection period, and then returned to normal consumption, a high nitrogen balance occurred. However, if a lamb went off feed near the end of the collection period, there was usually a low nitrogen balance. Therefore, it would appear that nitrogen balance is more useful for diagnosing digestive disturbances or amount of feed consumed in individual lambs than in an evaluation of a particular ration. It would seem that there should be a significant difference due to lambs in the analysis of variance since there is so much difference within treatments. However, a lamb that was in a low nitrogen balance during one collection period often retained enough more nitrogen on subsequent collections to make the totals for the individual lambs fairly constant. An exception to this observation was lamb number nine, which was in a large negative nitrogen balance on both the 90-10 and 80-20 rations.

Early in the digestion study, it was discovered that several of the lambs consistantly produced copious amounts of urine. For example, on the 90-10 collection period, the amount of urine excreted during the seven day collection period ranged from about seven liters on lamb number three to over thirty liters from lamb number two. As the study progressed, urine output increased on certain lambs, until on the final collection period (40-60), number seven excreted 76.5 liters of urine--an average of almost 11 liters per day. During the same collection period, number eight excreted 4.9 liters, or an average of .7 liters per day--a difference between the two extremes of about 1400 percent. Neither the digestibility of the protein nor the percent nitrogen retention seemed to be affected by the excess urination, and the lambs appeared to be otherwise perfectly normal and healthy.

Lambs on this experiment showed signs of craving coarse roughage. They were observed to stand for hours chewing on the boards in their crates. Similar results were reported by Baker et al. (8), with steers fed an all pelleted ration.

Regurgitation in the lambs ceased soon after they were placed on the pelleted ration. Baker et al. (8) noted a similar occurence in beef cattle. However, since the lambs gained an average of 41 pounds during the study, and appeared normal and healthy at all times, it would seem that complete rations in the pelleted form had little, if any, adverse effects upon the lambs.

Table 5. Mean percent digestible energy, digestible dry matter protein digestion coefficients, and nitrogen retention, on various roughage to concentrate ratios in complete pelleted rations for lambs.

Ration	Percent digestible energy	Percent digestible dry matter	Protein digestion coefficient	Percent nitrogen retained
90-10	60.04	60.26	65.66	.16
80-20	65.14	66.22	67.00	1.80
70-30	67.44	68.24	72.04	13.51
60-40	70.46	71.74	72.92	20.31
50-50	72.83	74.36	72.55	27.18
40-60	77.00	78.82	72.98	23.50

The author realizes certain errors were introduced when the collection were carried out according to a nonrandom arrangement. However, it should be remembered that if the rations had been alloted at random for each collection period, certain lambs would have been forced to change from an extremely high roughage ration to an extremely low roughage ration. This procedure would not only bring about digestive disturbances, but would have necessitated longer preliminary feeding periods prior to the collection periods in order for the lambs to become accustomed to their radically changed rations. In the design of this experiment, the roughage percentages were reduced ten percent on each collection period--hardly enough to cause any serious digestive disturbances. The author believes that in this type of study, part of the error due to time, temperature changes, or other factors could have been partially overcome by starting five lambs on the 90-10 ration, and four lambs on the 40-60 ration. Then, the first group could have had their roughage intake reduced ten percent on each collection period and those in the second group could have had their roughage intake increased ten percent on each collection period.

SUMMARY AND OBSERVATIONS

Nine white-faced New Mexico wether lambs averaging 66 pounds were used in a digestion study to determine the digestion characteristics of various roughage to concentrate ratios in complete pelleted rations. Collection periods were seven days long. Preliminary feeding periods of from 9 to 21 days allowed the lambs to become accustomed to the rations, and the feces and urine to become representative of the ration being fed. The rations consisted of alfalfa hay and sorghum grain pelleted in the following roughage to concentrate ratios: 90-10, 80-20, 70-30, 60-40, 50-50, and 40-60. Digestible energy, digestible dry matter, protein digestion coefficients, and nitrogen retention were determined on each ration.

Statistical analysis of the digestible energy data showed a significant difference among lambs ($P<.05$), and a highly significant difference between rations ($P<.01$). The digestible energy in the rations increased as the percentage of roughage in the ration decreased, and the relationship between the two measures was principally linear, the straight line relationship accounting for over 98 percent of the sum of squares due to rations.

Dry matter digestibility was correlated with digestible energy, and the relationships were highly significant ($P < .01$).

Feed consumption was correlated with digestible energy. Within the limits of the nutritive plane used in this experiment, there was no relationship between the two. The lambs were on somewhat more than a maintainence ration throughout the experiment, as their mean weight gain was 41 pounds over the four month period.

Protein digestion coefficients increased rapidly as the percent concentrate in the ration increased from 10 percent to 30 percent. The trend line then leveled off from the 30 percent concentrate level to the 60 percent level. Analysis of variance showed no significant differences between lambs, but a highly significant ($P < .01$) difference due to rations. There was no significant difference between the 70-30, 60-40, 50-50, and 40-60 rations, or between the 90-10 and 80-20 rations but a highly significant difference ($P < .01$) between the 80-20 and 70-30 rations. The trend line was found to have a quadratic configuration at the .01 level.

Nitrogen balance data on the lambs were analyzed statistically, and a highly significant difference was found between the rations. There was no significant difference between lambs. Percent nitrogen retention increased from -.16 percent on the 90-10 ration to 27.07 percent on the 50-50 ration, and then decreased to 23.49 on the 40-60 ration. In this study, although there was no statistically significant difference between lambs, nitrogen retention appeared to be a better measure of the digestive condition of the lambs and the amount of feed consumed than an evaluation of the ration.

The lambs ceased regurgitation soon after the experiment was started, and displayed a craving for coarse roughage by chewing the boards in the digestion crates.

Polyuria was observed in several of the lambs, with one lamb excreting an average of 11 liters of urine per day over a seven day collection period. No adverse effects on growth, nitrogen retention, or general health were associated with polyuria, lack of regurgitation, or absence of coarse roughage in the ration.

As the amount of concentrate in the ration increased, feed consumption decreased. At the same time, the digestibility coefficient for energy increased. This tended to equalize the total caloric intake throughout the study. Protein digestibility coefficients were statistically equal in rations containing more than 30 percent concentrates. Thus, it would appear that since there were no adverse digestive effect on any of the roughage to concentrate ratios studied, the optimum ration for feeding lambs on a practical basis would depend upon the relative costs of the components of the ration, the cost of pelleting, the relative feed efficiency of the various rations, and the daily gains observed in the feed lot.

ACKNOWLEDGMENTS

The author wishes to express his sincere thanks and appreciation to his major advisor, Dr. Draytford Richardson for his assistance and advice in setting up the experiment and preparing the manuscript; to Dr. W. S. Tsien for assisting with the chemical analysis; and to Dr. Stanley Wearden for aiding in statistical analysis of the data.

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APPENDIX

Table 6. Digestible energy and digestible dry matter on various roughage to concentrate ratios in complete pelleted rations for fattening lambs.

Lamb	Grams Dry feed	Cal. per gm. dry feed	Total cal. fed	Cal. per gm. dry feces	Grams dry feces	Calories excreted	Percent D.E.[1]	Percent D. D. M.[2]
			90 percent roughage--10 percent concentrate					
1	8733	4.3340	37848.8	4.4141	3476.90	15347.4	59.45	60.19
2	8733	4.3340	37848.8	4.3809	3417.41	14971.3	60.44	60.87
3	7617	4.3340	33012.1	4.2092	3138.66	13211.2	59.98	58.79
4	8733	4.3340	37848.8	4.3823	3231.19	14160.0	62.59	63.00
5	8733	4.3340	37848.8	4.4350	3515.27	15590.2	58.81	59.75
6	8733	4.3340	37848.8	4.3846	3585.84	15722.5	58.46	58.94
7	8733	4.3340	37848.8	4.3573	3555.59	15492.8	59.07	59.29
8	8733	4.3340	37848.8	4.3410	3326.98	14442.4	61.84	61.90
9	7307	4.3340	31448.5	4.3252	2948.40	12752.4	59.73	59.65
Sum							540.37	542.38
Mean							60.04	60.26
			80 percent roughage--20 percent concentrate					
1	7654	4.3556	33338.8	4.5139	2673.37	12067.3	63.80	65.07
2	7654	4.3556	33338.8	4.5625	2526.27	11526.1	65.43	66.99
3	7654	4.3556	33338.8	4.4461	2619.98	11648.7	65.06	65.77
4	7654	4.3556	33338.8	4.4797	2600.44	11649.2	65.06	66.03
5	7381	4.3556	32148.7	4.5023	2495.40	11235.0	65.05	66.19
6	6743	4.3556	29369.8	4.5525	1992.39	9070.4	69.12	70.45
7	7654	4.3556	33338.8	4.4985	2613.35	11756.2	64.74	65.86
8	7654	4.3556	33338.8	4.4725	2566.08	11476.8	65.58	66.47
9	6142	4.3556	26752.1	4.4433	2265.17	10064.8	62.38	63.12
							586.22	595.95
							65.14	66.22

1. D. E. represents digestible energy
2. D. D. M. represents digestible dry matter

Table 6. (Continued.)

Lamb	Grams dry feed	Cal. per gm. dry feed	Total cal. fed	Cal. per gm. dry feces	Grams dry feces	Calories excreted	Percent D. E.[1]	Percent D. D. M.[2]
			70 percent roughage--30 percent concentrate					
1	6167	4.4491	27437.6	4.5881	2032.05	9323.2	66.02	67.05
2	6167	4.4491	27437.6	4.6638	1941.92	9056.7	66.99	68.51
3	6167	4.4491	27437.6	4.6379	1981.43	9189.7	66.51	67.87
4	6167	4.4491	27437.6	4.5811	1887.45	8646.6	68.49	69.39
5	5814	4.4491	25867.0	4.5205	1831.69	8280.2	67.99	68.50
6	6167	4.4491	27347.6	4.5223	1969.34	8905.9	67.54	68.07
7	6167	4.4491	27347.6	4.5257	1901.16	8604.1	68.64	69.17
8	6167	4.4491	27347.6	4.5280	1963.02	8888.6	67.60	68.17
9	5638	4.4491	25084.0	4.4829	1835.42	8228.0	67.20	67.45
Sum							606.98	614.18
Mean							67.44	68.24
			60 percent roughage--40 percent concentrate					
1	6204	4.4202	27422.9	4.6162	1794.57	8284.1	69.79	71.07
2	6204	4.4202	27422.9	4.6555	1661.20	7733.7	71.80	73.22
3	6204	4.4202	27422.9	4.6247	1687.58	7804.6	71.54	72.80
4	6204	4.4202	27422.9	4.6806	1694.14	7929.6	71.08	72.69
5	5584	4.4202	24682.4	4.6170	1579.51	7292.6	70.45	71.71
6	6204	4.4202	27422.9	4.6358	1689.39	7831.7	71.44	72.77
7	6204	4.4202	27422.9	4.5927	1766.10	8111.2	70.42	71.53
8	6204	4.4202	27422.9	4.6050	1814.40	8355.3	69.53	70.75
9	5628	4.4202	24876.9	4.5753	1736.43	7944.7	68.06	69.15
							634.11	645.69
							70.46	71.74

1. D. E. represents digestible energy
2. D. D. M. represents digestible dry matter

Table 6. (Concluded.)

Lamb	Grams dry feed	Cal. per gm. dry feed	Total cal. fed	Cal. per gm. dry feces	Grams dry feces	Calories excreted	Percent D. E.[1]	Percent D. D. M.[2]
			50 percent roughage--50 percent concentrate					
1	6245	4.3448	27133.3	4.6069	1722.30	7934.5	70.76	72.42
2	6245	4.3448	27133.3	4.7170	1569.56	7403.6	72.71	74.87
3	5977	4.3448	25968.9	4.6474	1587.07	7375.7	71.60	73.45
4	6245	4.3448	27133.3	4.5650	1623.73	7412.3	72.68	74.00
5	5353	4.3448	23257.7	4.5932	1601.52	7356.1	68.37	70.08
6	6245	4.3448	27133.3	4.6328	1488.39	6895.4	74.59	76.17
7	6245	4.3448	27133.3	4.5342	1433.18	6498.3	76.05	77.65
8	6245	4.3448	27133.3	4.5583	1587.94	7238.3	73.32	74.57
9	6245	4.3448	27133.3	4.5617	1461.72	6667.9	75.43	76.59
Sum							655.51	669.20
Mean							72.83	74.36
			40 percent roughage--60 percent concentrate					
1	6177	4.4400	27425.9	4.7279	1493.08	7059.1	74.26	75.83
2	5338	4.4400	23700.7	4.7769	1123.90	5368.8	77.35	78.95
3	5382	4.4400	23896.1	4.7795	1072.53	5126.2	78.55	80.07
4	6177	4.4400	27425.9	4.7857	1220.58	5841.3	78.70	80.24
5	4985	4.4400	22133.4	4.9867	1162.04	5794.7	73.82	76.69
6	6177	4.4400	27425.9	4.9817	1193.98	5828.7	78.75	80.67
7	6177	4.4400	27425.9	4.8722	1239.89	6041.0	77.97	79.93
8	6177	4.4400	27425.9	4.8275	1385.53	6688.6	75.61	77.57
9	6177	4.4400	27425.9	4.7531	1271.02	6041.3	77.97	79.42
Sum							692.98	709.37
Mean							77.00	78.82

1. D. E. represents digestible energy
2. D. D. M. represents digestible dry matter

Table 7. Protein digestion coefficients and nitrogen retention on various roughage to concentrate ratios in complete pelleted rations for lambs.

Lamb	Grams dry feed	Grams N per gram dry feed	Grams N ingest	Grams N per gram dry feces	Grams dry feces	Grams N Excreted in feces	Percent D. P.*	Grams N per ml. urine	Ml. urine excreted	Grams N excreted in urine	Percent N retained	Grams N retained
					90 percent roughage--10 percent concentrate							
1	8733	.0286126	249.87	.0257571	3476.90	89.55	64.16	.0129181	12330	159.28	.42	1.04
2	8733	.0286126	249.87	.0243684	3417.41	83.28	66.67	.0053953	30090	162.34	1.70	4.24
3	7617	0286126	217.94	.0257511	3138.66	80.82	62.91	.0212443	7095	150.73	- 6.24	-13.61
4	8733	.0286126	249.87	.0248772	3231.19	80.38	67.83	.0212338	7520	159.68	3.93	9.81
5	8733	.0286126	249.87	.0235255	3515.27	82.70	66.90	.0158051	10990	173.70	- 2.61	- 6.53
6	8733	.0286126	249.87	.0227899	3585.84	81.72	67.29	.0056379	29085	163.98	1.67	4.17
7	8733	.0286126	249.87	.0254231	3555.59	90.39	63.82	.0180749	8365	151.20	3.32	8.30
8	8733	.0286126	249.87	.0257380	3326.89	85.63	65.73	.0142779	10940	156.20	3.22	8.04
9	7307	.0286126	209.07	.0244015	2948.40	71.95	65.59	.0160247	9450	151.43	6.84	-14.31
Sum							590.90				- 1.45	1.15
Mean							65.66				- .16	.13
					80 percent roughage--20 percent concentrate							
1	7654	.0261911	200.47	.0259375	2673.37	69.34	65.41	.0125311	10590	132.70	- .78	- 1.57
2	7654	.0261911	200.47	.0248278	2526.27	62.72	68.71	.0069820	19960	139.36	- .80	- 1.61
3	7654	.0261911	200.47	.0275925	2619.98	72.29	63.94	.0220602	5480	120.89	3.64	7.29
4	7654	.0261911	200.47	.0278313	2600.44	69.77	65.20	.0157946	8250	130.31	.19	.39
5	7381	.0261911	193.32	.0240819	2495.40	60.09	68.92	.0096755	12915	124.96	4.28	8.27
6	6743	.0261911	176.61	.0252229	1992.39	50.25	71.55	.0060354	18090	109.18	9.73	17.18
7	7654	.0261911	200.47	.0255382	2613.35	66.74	66.71	.0130332	10180	132.68	.52	1.05
8	7654	.0261911	[illegible].47	.0247089	2566.08	63.41	68.37	.0142152	6660	123.10	6.96	13.96
9	6142	.0261911	160.87	.0254294	2265.17	57.60	64.19	.0168302	6860	115.46	- 7.57	-12.19
Sum							603.00				16.16	32.77
Mean							67.00				1.80	3.64

* D. P. represents protein digestion coefficient

Table 7 (Continued.)

Lamb	Grams dry feed	Gram N per gram dry feed	Grams N ingest.	Grams N per gram dry feces	Grams dry feces	Grams N excreted in feces	Percent D. P.*	Grams N per ml. urine	Ml. urine excreted	Grams N excreted in urine	Percent N retained	Grams N retained
					70 percent roughage--30 percent concentrate							
1	6167	.0284819	175.71	.0249304	2030.05	50.66	71.17	.0128762	7960	102.49	12.84	22.56
2	6167	.0284819	175.71	.0239364	1941.92	46.48	73.55	.0058890	18700	110.12	10.88	19.11
3	6167	.0284819	175.71	.0251461	1981.43	49.83	71.64	.0144871	6680	96.77	16.57	29.11
4	6167	.0284819	175.71	.0265751	1887.45	50.16	71.4[illegible]	.0153448	6540	100.35	14.34	25.20
5	5814	.0284819	165.65	.0241573	1831.69	44.25	73.29	.0082164	12360	101.55	11.98	19.89
6	6167	.0284819	175.71	.0250683	1969.34	49.37	71.90	.0038126	26245	100.06	14.96	26.28
7	6167	.0284819	175.71	.0256890	1901.16	48.86	72.19	.0086399	11740	101.43	14.47	25.42
8	6167	.0284819	175.71	.0250029	1963.02	49.08	72.07	.0155226	6630	102.91	13.50	23.72
9	5638	.0284819	160.64	.0252868	1835.42	46.41	71.11	.0139537	6800	94.89	12.04	19.34
Sum							648.37				121.51	210.63
Mean							72.04				13.51	23.40
					60 percent roughage--30 percent concentrate							
1	6204	.0262947	163.13	.0256619	1749.57	46.12	71.73	.0056484	15070	85.12	19.55	31.89
2	6204	.0264947	163.13	.0244474	1661.20	40.61	75.11	.0018117	50510	91.51	19.01	31.01
3	6204	.0264947	163.13	.0279572	1689.58	45.72	71.97	.0116525	7470	87.04	18.62	30.37
4	6204	.0264947	163.13	.0240628	1694.14	40.77	75.01	.0100521	8600	86.45	22.01	35.91
5	5584	.0264947	146.83	.0253859	1579.51	40.10	72.69	.0067335	10850	73.06	22.93	33.67
6	6204	.0264947	163.13	.0253716	1689.39	42.86	73.73	.0012364	68750	85.00	21.63	35.27
7	6204	.0264947	163.13	.0257804	1766.10	45.53	72.09	.0023222	38660	89.78	17.05	27.82
8	6204	.0264947	163.13	.0249028	1814.40	45.18	72.30	.0153135	5630	86.22	19.45	31.73
9	5628	.0264947	163.13	.0266310	1736.43	46.24	71.65	.0134202	5970	80.12	22.54	36.77
Sum							656.28				182.78	294.44
Mean							72.92				20.31	32.72

* D. P. represents protein digestion coefficient

Table 7. (Concluded.)

Lamb	Grams dry feed	Grams N per gram dry feed	Grams N ingest.	Grams N per gram dry feces	Grams dry feces	Grams N excreted in feces	Percent D.P.*	Grams N per ml. urine	Ml. urine excreted	Grams N excreted in urine	Percent N retained	Grams N Retained
					50 percent roughage--50 percent concentrate							
1	6245	.0249758	155.97	.0263704	1722.30	45.42	70.88	.0076777	8590	65.95	28.60	44.60
2	6245	.0249758	155.17	.0237562	1569.56	37.29	76.09	.0015502	38430	59.57	37.90	59.11
3	5977	.0249758	149.28	.0283394	1587.07	45.06	69.82	.0185770	3350	62.24	28.12	41.98
4	6245	.0249758	155.97	.0296501	1623.72	48.14	69.14	.0126699	5340	67.66	25.75	40.17
5	5353	.0249758	133.70	.0295614	1601.52	47.34	64.59	.0068931	6680	46.05	30.15	40.31
6	6245	.0249758	155.97	.0260612	1488.39	38.79	75.13	.0016339	47140	77.02	25.75	40.17
7	6245	.0249758	155.97	.0234159	1433.18	33.56	78.48	.0022343	45060	100.68	13.93	21.73
8	6245	.0249758	155.97	.0266584	1587.94	42.33	72.87	.0131064	5320	69.73	28.15	43.91
9	6245	.0249758	155.97	.0256320	1461.72	37.47	75.98	.0108575	7140	77.52	26.27	40.98
Sum							652.98				244.62	372.96
Mean							72.55				27.18	41.44
					40 percent roughage--60 percent concentrate							
1	6177	.0232392	143.55	.0330299	1493.08	49.32	65.64	.0026819	22880	61.36	22.90	32.87
2	5338	.0232392	124.05	.0311489	1123.90	35.01	71.78	.0018238	39850	72.68	13.20	16.36
3	5382	.0232392	125.07	.0311283	1072.53	33.39	73.30	.0101567	4970	50.48	32.94	41.20
4	6177	.0232392	143.55	.0306027	1220.58	37.35	73.98	.0129890	5330	68.96	25.94	37.24
5	4985	.0232392	115.85	.0270099	1162.04	31.39	72.90	.0048849	12720	62.14	19.27	22.32
6	6177	.0232392	143.55	.0293529	1193.98	35.05	75.58	.0012364	62900	77.77	21.41	30.73
7	6177	.0232392	143.55	.0277936	1239.89	34.46	75.99	.0010711	76500	81.94	18.91	27.15
8	6177	.0232392	143.55	.0286551	1385.53	39.70	72.34	.0120186	4900	58.89	31.32	44.96
9	6177	.0232392	143.55	.0278832	1271.02	35.44	75.31	.0111399	6410	71.41	25.57	36.70
Sum							656.82				211.46	289.53
Mean							72.98				23.50	32.17

* D. P. represents protein digestion coefficient

DIGESTIBLE ENERGY STUDIES ON VARIOUS LEVELS OF CONCENTRATES IN PELLETED RATIONS FOR FATTENING LAMBS

by

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B. S., Kansas State University of Agriculture and Applied Science, 1959

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Animal Husbandry

KANSAS STATE UNIVERSITY
OF AGRICULTURE AND APPLIED SCIENCE

1960

Pelleting all or part of the ration for lambs has become increasingly popular in the past several years. Numerous advantages have been associated with pelleted versus nonpelleted rations, among which are ease of handling, and increased daily gains, feed efficiency, and feed consumption. In addition, most workers have found roughage can make up a larger percent of the pelleted ration and that lower quality roughage can be used.

This experiment was designed to determine the digestion characteristics of various roughage to concentrate ratios fed as complete pelleted rations to lambs. Digestible energy, digestible dry matter, protein digestion coefficients, and nitrogen retention were determined. The rations contained the following ratios of alfalfa hay to sorghum grain: 90-10, 80-20, 70-30, 60-40, 50-50, and 40-60. Nine white-faced New Mexico wether lambs averaging 66 pounds were used in the study.

Complete collections of feces and urine were made on seven consecutive days on each of the six rations. Preliminary periods of from 9 to 21 days were allowed for the lambs to adjust to the rations, and for the feces and urine to become representative of the ration being studied.

Highly significant differences ($P<.01$) in digestible energy were found on the various rations, with digestible energy increasing in an almost perfect linear relationship with increasing concentrates in the ration. The linear configuration accounted for over 98 percent of the sum of squares due to treatments in the analysis of variance.

Digestible dry matter was correlated with digestible energy on each individual ration, and a highly significant relationship between the two measures was found. ($P<.01$).

Protein digestion coefficients increased from 65.66 percent on the

90-10 ration to 72.03 percent on the 70-30 ration, and then leveled off to 72.98 on the 40-60 ration. Statistical analysis showed no significant difference between the 90-10 and 80-20 rations, or between the 70-30, 60-40, 50-50, or 40-60 rations, but a highly significant difference between the 80-20 and 70-30 rations.

Analysis of variance on percent nitrogen retained showed a highly significant ($P<.01$) difference due to rations, with mean percent retention increasing from -.16 percent on the 90-10 ration to 27.07 percent on the 50-50 ration. This was followed by a decrease to 23.49 percent on the 40-60 ration. Wide variability of percent nitrogen retention between individual lambs on any given collection period pointed out the fact that nitrogen retention might not be an accurate measurement for the evaluation of a ration.

Lambs on the trial gained an average of 41 pounds, indicating that they were receiving more than a maintainence ration.

A craving for coarse roughage was apparent throughout the study, as the lambs were observed to stand for hours chewing the boards in the digestion crates.