THE INFLUENCE OF VARIOUS LEVELS OF READILY-AVAILABLE CARBOHYDRATES IN PURIFIED RATIONS ON CELLULOSE DIGESTIBILITY BY SHEEP

by

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INTRODUCTION

The ruminant has endured throughout history as a useful farm animal primarily due to the ability to utilize high fiber feeds in the production of meat, milk and wool. Although in recent production methods there has been increased use of grains in the production of cattle and sheep, under such regimes the ruminant, like the pig and chicken, becomes a competitor for feedstuffs which can be used as food for man. Such competition is needless since the ruminant, by virtue of the millions of microorganisms in the rumen, can convert a large portion of the vast amount of cellulose in grasses and other roughages to products useful to man. In order to obtain maximum performance on such high fiber rations, supplementation is usually necessary. Supplying the proper nutrients in suitable amounts to meet the nutrient requirements of rumen microorganisms is a prime requisite to obtaining maximum cellulose utilization in the ruminant.

The role of readily-fermentable carbohydrates in efficient roughage digestion is not clear. The addition of feeds rich in readily-available carbohydrates, such as starch and sugars, generally depresses fiber digestibility. However, it has been suggested that, under certain conditions, a small amount of readily-available energy supplied by readily-available carbohydrates is necessary for maximum cellulose degradation. The beneficial effects of low levels of soluble carbohydrates have been demonstrated *in vitro* but not *in vivo*. Research concerning the need for readily-fermentable carbohydrates for maximum cellulose digestion *in vivo* is limited.

Conventional protein supplements are among the more costly feedstuffs. Increasing the efficiency of utilization of protein in ruminants offers a valuable means of decreasing the cost of producing such animals. Under certain conditions, the level of readily-fermentable carbohydrates fed has been shown to influence nitrogen utilization in ruminants. This aspect of ruminant nutrition merits further investigation.

A high level of cellulose degradation can improve efficiency only if maintained over the entire feeding period. The present techniques used to measure digestibility and metabolism in the ruminant usually involves a 10-day preliminary or adjustment period followed by a 10-day collection period. Recent research tends to indicate adaptation to a ration change may take longer than the customary 10 days. It appeared advisable to determine the digestibility of purified rations containing different levels of readily-available carbohydrates as related to length of preliminary period.

In order to study further the effect of level of readily-available carbohydrates on cellulose digestibility, digestion and metabolism trials were conducted with sheep fed purified rations to investigate (1) the effect of low levels of readily-available carbohydrates and (2) the effect of high levels of readily-available carbohydrates. A third experiment was conducted to determine the effect of length of preliminary period on cellulose digestibility of rations containing 0, 8 and 32% readily-available carbohydrates. Also, regression analyses were conducted, using the data in these and previous trials to estimate the effect of level of readily-available carbohydrates on cellulose digestibility and nitrogen retention.

REVIEW OF LITERATURE

The Effect of Readily-Available Carbohydrates on Digestibility In Vivo

Patterson and Outwater (1907) reported increased dry matter and crude fiber digestibility when molasses was added to a mixed hay or grain mixture fed to steers.

The addition of molasses to hay or hay-grain rations markedly reduced dry matter digestibility in wethers in work reported by Lindsey and Smith (1910). They attributed the effect to inhibition of bacteria attacking cellulose, pentosans and gums by the lactic and butyric acids present in the rumen of animals fed molasses. They did not, however, determine if these acids were actually present.

Brooks (1954) reported a 10% increase in cellulose digestibility when 5% blackstrap molasses was added to a sheep ration composed of cottonseed hulls and casein. The digestion coefficient for cellulose was slightly less than for the basal level when 10% molasses was added to the ration.

El-Shazley _et al_. (1961) reported a decreased cellulose digestibility, as measured by the nylon bag technique, when corn replaced mixed hay in a sheep ration. When an all hay diet was fed, cellulose breakdown was 40%. When the hay to shelled corn ratio was 2:1 cellulose digestibility was decreased to 12%, addition of 16 gm. urea nearly alleviated the depression. At a hay to corn ratio of 1:1, 16 gm. of urea had little effect on the rate of cellulose digestion. Maximum breakdown was observed when 32 to

52 gm. urea were supplemented. Levels of urea up to 48 gm. had little effect when the hay to corn ratio was 1:2. This ratio of hay to corn inhibited cellulose breakdown almost completely.

Stone and Fontenot (1965) reported a significant decrease in crude fiber digestion when TDN was increased in steer rations from 58% to 60 and 63%. The rations were composed of 10% grass hay, corn, corn cobs and cottonseed meal. Corn and corn cobs were varied to obtain the desired TDN content.

McLaren _et al_. (1965) reported an 8% decrease in crude fiber digestibility for each 1000 kcal. of carbohydrates added to lamb rations. The rations were composed of chopped wheat straw, cane molasses, corn starch and dextrose in varying amounts. Urea, corn oil, minerals and vitamins were fed at a constant level in all rations. The influence of level of readily-available carbohydrates on crude fiber digestibility was measured by regression analysis.

It appears that in studying the effect of added carbohydrates on digestibility of nutrients it would be desirable to use purified sources of these carbohydrates. Several studies have been reported in which purified sources of readily-available carbohydrates have been added, usually, to natural rations.

Armsby and Fries (1918) found that the addition of starch to an alfalfa hay ration reduced crude fiber and crude protein digestibility in steers.

Mitchell et al. (1940) reported the addition of cerelose to steer rations containing timothy hay, ground corn and cottonseed meal reduced crude fiber digestion. As level of protein in the ration increased from 6 to 20%, the effect of cerelose on crude fiber digestibility was less pronounced. Crude fiber digestibility for the 6% and 20% rations was 51.7% and 35.7%, respectively. When cerelose was added to the rations, digestibility of crude fiber was 36.2 and 31.8%, respectively.

In studies reported by Hamilton (1942), cerelose added at levels of 20 to 30% to lamb rations reduced crude fiber digestibility 27%. Dry matter, nitrogen-free extract and total carbohydrate digestibility was increased in supplemented rations.

Swift et al. (1947) reported that the addition of 7% starch or cerelose to a lamb ration composed of mixed hay, corn and linseed meal resulted in a slight decrease in crude fiber and crude protein digestibility. A significant reduction in crude protein and crude fiber digestibility resulted when supplementation of cerelose was increased to 14% of the ration.

Hoflund et al. (1948) studied the effect of added sucrose on rate of cellulose digestion in sheep. Addition of 1 to 3% sucrose to a low-quality grass hay ration increased cellulose digestion temporarily, although digestion had decreased to 50% of the basal level within 4 weeks.

Burroughs *et al*. (1949b) found the addition of starch reduced dry matter digestibility of alfalfa hay only when protein content of the ration was below 7.5%. The authors concluded that the protein requirement for efficient roughage digestion was low when roughage supplies the carbohydrates in the ration. Rations composed of corn cobs and alfalfa hay with a crude protein content of 4.4% resulted in dry matter digestibility of 62.8%.

Fontenot *et al*. (1955) reported a reduction in crude fiber digestibility when graded levels of cerelose were added to steer rations composed of prairie hay and cottonseed meal and containing 8, 10 or 12% crude protein.

Woods *et al*. (1956) reported on studies with wethers fed timothy hay-soybean oil meal rations, containing 7, 11 and 14.5% crude protein, to which 0, 25 and 50 gm. of cerelose were added. The addition of 50 gm. cerelose resulted in slight decreases in crude fiber and crude protein digestibility at all protein levels. Dry matter digestibility tended to increase with increasing cerelose and protein levels.

Whiting *et al*. (1959) found that replacing 10% wheat straw with starch in a mixed diet for ewes reduced crude fiber digestibility only slightly. Replacing 30% oat hulls with 28% corn starch and 2% linseed meal reduced crude fiber digestibility 18%.

Increasing the level of cellulose in a semi-purified lamb ration increased cellulose digestibility, in studies reported by Ellis and Pfander (1958). Three levels of nitrogen, 1.65, 2.05

and 2.45%, and three levels of cellulose, 21.4, 31.4 and 41.6%, were used. Solka-floc and isolated soy protein replaced corn starch to give the desired nitrogen and cellulose levels.

Chappell (1964) reported that levels of readily-available carbohydrates of 33% or lower in purified sheep rations failed to affect cellulose digestibility significantly. Levels of 0, 8, 16 and 32% of a 1:1 mixture of cerelose and corn starch did not significantly alter cellulose digestibility, compared to a control ration containing no cerelose and starch. However, digestibility tended to be higher for the 8% level of readily-available carbohydrates. Isolated soybean protein, corn oil and minerals were supplied at constant levels of 11.1%, 3.9% and 7.2% of the rations, respectively. Readily-available carbohydrates were added to the ration at the expense of cellulose.

Addition of soluble carbohydrates to natural rations has generally resulted in a decrease in crude fiber (or cellulose) digestibility when levels of such carbohydrates are extremely high or protein level of the roughage was low. Addition of readily-available carbohydrates to high quality roughages such as alfalfa hay generally has had little or no effect on crude fiber digestibility. Levels of readily-available carbohydrates of 33% or lower in purified lamb rations have failed to significantly affect cellulose breakdown. In most cases, an increase in digestibility of dry matter resulted when readily-available carbohydrates were added to the ration.

The Effect of Readily-Available Carbohydrates on Cellulose Digestion In Vitro

Hoflund et al. (1948) observed a positive relationship between protein level in the media and the level of glucose necessary to decrease in vitro cellulose degradation. Maximum cellulose breakdown was obtained when glucose was added to the media at levels of 0.1 to 0.2%.

Arias et al. (1951) found low levels (9 to 20% of solids) of readily-available carbohydrates resulted in increased cellulose digestion in vitro while levels in excess of this amount tended to depress cellulose breakdown. Molasses was stimulatory at levels as high as 30% with only a slight depression in cellulose fermentation at the 45% level. The authors postulated that the low levels of readily-available carbohydrates were stimulatory to microbial cellulose breakdown since they may serve as an energy source until active fermentation of cellulose is progressing at a rate capable of supporting optimum growth and metabolism of the organisms.

Burroughs et al. (1951) reported on in vitro work conducted to determine which portion of molasses stimulated cellulose digestion. Their results indicated the ash portion of the molasses appeared to be the stimulating portion and tended to alleviate inhibition of cellulose breakdown by starch. A 50:50 mixture of dextrose and sucrose supplied at a level comparable to that found in molasses tended to depress cellulose breakdown.

Hunt *et al*. (1954) found starch was more inhibitory to *in vitro* cellulose breakdown in inoculum from steers fed timothy hay than in inoculum from steers fed alfalfa hay.

Belasco (1956), in studies conducted to determine the effect of level and type of readily-available carbohydrates on cellulose digestion *in vitro*, found 9% starch increased cellulose digestion 50%. Further additions of starch up to 48% failed to affect cellulose digestion; dextrose added at similar levels decreased cellulose degradation to levels below the control flask. When total carbohydrates were maintained at 48% of the solids, optimum cellulose degradation (90%) was obtained when the ratio of cellulose to starch ranged from 1:0.5 to 1:2.0.

Huhtanen and Elliott (1956), in work with ingesta from lambs fed a mixed grain and timothy hay ration, found n-valeric or isovaleric acid failed to stimulate *in vitro* cellulose degradation. Addition of 0.5% glucose inhibited digestion of timothy hay completely and depressed cellulose digestion in alfalfa hay 15 to 40%. Addition of 0.5% urea restored cellulose digestion in both roughages to near control levels.

Cline *et al*. (1958) conducted studies to determine if fermentation products resulting from the addition of starch were responsible for an increase in cellulose digestibility *in vitro* when starch was added to the system. The addition of 0.5% starch or 0.03% valeric acid increased cellulose digestion up to 150%. Valeric acid added in addition to the starch did not appear to be metabolized by the microorganisms. Valeric acid appeared to be used in protein synthesis since when the level of nitrogen in the media was increased, TCA insoluble nitrogen increased and valeric acid content of the media decreased.

El-Shazley et al. (1961) conducted studies to determine the nature of the inhibition of cellulose digestion by starch reported in earlier studies both in vivo and in vitro. Ground filter paper served as the substrate at a level of 2 gm./100 ml. Addition of 2 gm. starch or 1.5 gm. glucose to the fermentation flasks inhibited cellulose digestion completely. Tests showed the inhibiting substance was dializable. Fermentatation end-products were ruled out when they failed to affect digestion of cellulose when tested at the level found in the fermentation flasks. When urea was added to the media containing starch, it alleviated the inhibition of cellulose digestion nearly completely. These authors concluded the depression in cellulose digestion was the result of competition for essential nutrients with starch-digesting microorganisms proliferating preferentially.

Most studies on in vitro cellulose digestion have shown the beneficial effect of low levels of soluble carbohydrates on microbial cellulose degradation. In studies in which starch or sugar increased cellulose breakdown, the nitrogen source was ammonium salts or urea, readily-available energy was limited and pure cellulose served as substrate. When high quality roughages were the cellulose source, readily-fermentable carbohydrates tended to depress cellulose breakdown but not to the degree encountered when poor quality roughages were fermented.

The Effect of Energy Intake on Nitrogen Metabolism in Ruminants

Mitchell et al. (1940) found that the addition of 1200 gm. glucose daily to high-roughage rations containing 15 or 20% crude protein increased nitrogen retention in steers. This response was not noted when 6 or 10% rations were supplemented.

Lofgreen et al. (1951) reported increases in nitrogen retention of nearly 20% when non-nitrogenous TDN intake was increased in growing Holstein heifers from 1.45 to 1.77 kg. per day. As the animals grew larger, the effect was less pronounced. Increased energy intake did not affect nitrogen retention when protein intake was increased 60%.

The addition of starch to a sheep ration composed of wheat chaff containing 5% crude protein markedly increased the biological value of the protein in the work of Williams et al. (1953). Biological value was not affected when starch was added to the basal ration which had been supplemented with wheat bran and wheat gluten to give 10 or 13% crude protein.

Fontenot et al. (1953) reported higher nitrogen retention in steers, expressed as percent of consumed nitrogen, when prairie hay was supplemental with 0.91 kg. of 20% protein supplement than when 0.45 kg. of 40% supplement was fed. Fontenot et al. (1955) reported results of further studies with steer calves fed natural rations supplemented with various levels of cerelose. Cerelose supplementation of an 8% protein ration decreased nitrogen retention. Nitrogen retention was significantly increased when a 10% ration was supplemented with cerelose. When protein content of the basal ration was increased to 12%, cerelose supplementation did not significantly affect nitrogen retention. Generally, biological value was increased at all dietary protein levels by addition of cerelose.

Woods et al. (1956) reported the results of a study in which cerelose was added to high roughage lamb rations. The rations contained 7, 11 or 14.5% crude protein and 0, 25 or 50 gm. cerelose were fed at each protein level. Nitrogen retention tended to increase as cerelose supplementation increased but the differences were not significant.

Matsushima et al. (1957) found that nitrogen retention was not related to protein-energy ratio in beef cattle fattening rations. Three levels of crude protein and three levels of energy were fed yearling steers in a 3 x 3 factorial experiment. Protein and energy levels were adjusted with urea and stabilized beef tallow.

Winchester et al. (1957) found that, at the maintenance level of protein, nitrogen retention in beef calves increased 0.5 gm. for every one therm increase in net energy intake.

Brisson et al. (1957) observed that an increase in digestible energy intake resulted in increased nitrogen retention in bull calves fed purified and natural liquid diets ranging from 14.7 to 36.9% crude protein.

Urinary nitrogen decreased and nitrogen retention increased when corn starch was increased in semi-purified lamb rations at the expense of cellulose in work reported by Ellis and Pfander (1958).

Chappell (1964) reported a significant decrease in urinary nitrogen when the level of readily-available carbohydrates in purified sheep rations was increased from 0 to 32%. In one experiment the decrease in urinary nitrogen resulted in a significant increase in nitrogen retention. In a second experiment, which involved graded levels of readily-available carbohydrates, urinary nitrogen was significantly reduced at the 32% level compared to 0, 8 and 16%. The resulting increase in nitrogen retention was not significant. The protein level was 10% and with few exceptions all lambs were in positive nitrogen balance.

Stone and Fontenot (1965) found that increasing the digestible energy level in a 12% protein steer fattening ration from 2.50 to 2.56 kcal. per gm. resulted in an increase in biological value of the protein. Further increase to 2.69 kcal. digestible energy per gm. did not significantly further affect biological value.

In research reported by Albin and Clanton (1966), increasing the metabolizable energy from 1.65 megcal. per kg. dry feed to 1.94 megcal. per kg. increased daily nitrogen retention from 12.0 gm. to 18.9 gm. in steers. The steers were fed various combinations of brome grass hay, corn, corn starch and soybean meal. Dietary protein level was 11% and the steers were fed on the basis of metabolic size. The high energy ration was calculated to produce 0.45 kg. gain per head per day. The low energy ration furnished 82% of the high energy level.

It appears the conditions necessary to demonstrate the beneficial effect of readily-available carbohydrates on nitrogen retention in ruminants are critical. The results of previous studies suggest these conditions are low to medium levels of crude protein and low levels of energy intake.

The Effect of Adaptation to Ration on Digestibility

The true value of a ration can only be measured over the entire period of time it is being fed. In the conventional method for conducting digestion and metabolism trials a 10-day preliminary or adjustment period is followed by a 10-day collection period. An abnormal amount of variability has been observed in conventional metabolism trials with sheep fed purified rations (Chappell, 1964). Possibly, a 10-day preliminary period is not long enough for sheep fed this type of ration.

A 10-day preliminary period appeared to provide adequate time for adjustment in studies reported by Burroughs et al. (1950). Four steers were fed a basal ration composed of corn cobs, corn starch, dried skim milk, bone meal, salt and vitamins A and D. The steers were fed the ration a month prior to determination of digestibility of the dry matter of corn cobs, which was 34.4%. A water extract obtained from four pounds of alfalfa meal was then added to the rations daily and digestibility determined for three successive 10-day periods. Digestibility values for periods 1, 2 and 3 were 35.4%, 46.1% and 48.9%, respectively. After 30 days the extract supplementation was terminated and dry matter digestibility of the corn cobs was again measured for three successive 10-day periods. Apparent digestibility values of 48.4%, 34.4% and 36.6% were obtained for periods 1, 2 and 3, respectively. Although digestibility in the period immediately following change in the ration was similar to digestibility in the preceding period, digestibility values obtained in periods 2 and 3 were similar. The authors concluded from these data that a 10-day preliminary period provided adequate time for adjustment to ration changes of this type.

Hall and Woolfolk (1952) found that preliminary periods and collection periods as short as 3 days each gave results comparable to those obtained in digestion trials consisting of 10-day preliminary and 10-day collection periods. In these studies lambs were taken off pasture and immediately placed on chopped alfalfa hay rations. The average chemical composition of feces from trials differing in length of preliminary and collection periods never varied more than the maximum difference allowed by an analyst for duplicate samples of the same material. Differences in digestibility appeared to be due to variation in quantity of fecal excretion rather than differences in fecal composition.

In studies conducted to determine the effect of alfalfa ash or synthetic alfalfa ash on digestibility of prairie hay in lambs, Tillman _et al_. (1954) conducted digestion trials with lambs, in which a 7-day preliminary period and six 3-day collection periods were used. They found that collection periods of 3 days resulted in considerable variation between lambs within treatment. The average of three 3-day periods reduced such variation markedly.

Chappell _et al_. (1955) reported a 10-day preliminary period appeared to allow sufficient time for adjustment to rations similar to those of Tillman _et al_. (1954).

Lloyd _et al_. (1956) conducted digestion trials with sheep to determine the effect of change of ration on the required length of preliminary period. Four ewes were transferred from pasture to metabolism stalls and fed field-cured timothy hay for 70 days. They were then immediately changed to a ration composed of 65% roughage similar to that fed in the first trial and 35% concentrate (6 parts whole oat: 4 parts wheat bran). Daily fecal samples were collected and analyzed for 70 successive days beginning on the second day. In this manner it was possible to calculate digestion coefficients of various nutrients for preliminary feeding periods ranging from zero to 60 days. The conventional 10-day collection period following the 10-day preliminary period was used as a "standard" to establish a normal range. Apparent digestibility of dry matter, crude protein, crude fiber, ether extract and nitrogen-free extract of both rations showed rhythmic fluctuations. Since constant digestion coefficients were not obtained for nutrients even though the preliminary period was extended to 60 days and any increase in precision gained by extending the preliminary period appeared to be insignificant in practice, these authors concluded that a 10-day preliminary period was adequate for digestion trials with sheep.

Nicholson *et al*. (1956) reported that preliminary periods of 16 to 30 days were necessary when hay to grain ratios in rations fluctuate widely between trials. In their studies four rations were used. They were composed of 100% grass hay; 75% hay and 25% grain; 70% ground corn, 28% corn distillers dried grain with solubles, 1% iodized salts and 1% dicalcium phosphate; 50% hay and 50% grain; and 35% hay and 65% grain. The experimental design was a 4 x 4 latin square and each experiment lasted 49 days. Five day collection periods were conducted the last five days of the third, fifth and seventh weeks. Thus, 16-, 30- or 44-day preliminary periods preceded collection periods. The average crude fiber digestibility of the four rations (24.9%) was significantly higher ($P < .05$) after a 16-day preliminary period than after a 30-day (17.9%) or 44-day (18.7%) period. The difference between the 30-day and 44-day preliminary collection periods was not significant. In a second experiment where only protein source was varied and hay to grain ratio was held constant, a preliminary period of 7 days was adequate.

Kane *et al*. (1959) observed a significant effect of length of preliminary period on digestibility of alfalfa hay dry matter, when starch was supplemented. The cows had been on an all-hay ration for 11 days. Starch was added in the following manner: day 1, 1 lb.; day 2, 3 lb.; day 3, 5 lb.; days 4 to 6, 6 lb. Digestibility of dry matter for days 7 through 9 was similar to that of the all-hay ration. Mean dry matter digestibility for days 10 through 12 was significantly lower than when the cows had been fed for 26 days. Crude fiber digestibility was not affected by length of preliminary period.

Smith _et al_. (1960) reported a summary of research to study adaptation of sheep to diets containing urea. Although nitrogen retention was increased two percentage units of absorbed nitrogen for each 10-day increase in preliminary period up to 50 days, crude fiber digestibility in the ration was not influenced by length of preliminary period.

Gouws and Kistner (1965) studied the effects of changes in diet from lucerne hay (14% protein) to teff hay (3% protein) on the predominant types of cellulose digesting bacteria in the rumen of sheep. In sheep fed lucerne hay for 26 weeks _Ruminococcus albus_ was the predominant species appearing on cellulose agar film inoculated with rumen fluid. After an abrupt change to teff hay, a _Butyrivibrio_ species became established within 2 weeks in one sheep, within 4 weeks in another and was not completely established in 5 weeks in a third sheep. When the animals were changed again to the lucerne ration, _Ruminococcus albus_ became predominant in all sheep within 2 weeks.

The experiments conducted with ruminants have shown that a 10-day preliminary period was adequate when protein and mineral sources were studied. When the ration was altered only slightly in NFE and crude fiber level, any increase in accuracy gained by increasing the preliminary period was slight. Drastic changes in the level of readily-available carbohydrates in the ration may require a longer preliminary period for adjustment to the ration.

OBJECTIVES

The objective of these experiments was to study the effects of level of readily-available carbohydrates in purified sheep rations on cellulose digestibility. The digestibility of other ration constituents and efficiency of utilization of dietary nitrogen were also studied.

EXPERIMENTAL PROCEDURE

<u>Experiment 1B</u>

Two metabolism trials were conducted with 15 yearling wethers (av. wt., 32 kg.) to study the effects of low levels of readily-available carbohydrates. The 15 wethers were divided into three outcome groups of five each, based on weight. For each trial the five lambs within each outcome group were allotted at random to five rations, so there was a total of six observations per treatment. The wethers were kept in metabolism stalls similar to those of Briggs and Gallup (1949). Each trial consisted of a 10-day preliminary period followed by a 10-day collection period, during which total fecal and urine collections were made. The wethers had been used previously in a study involving purified rations, and they were fully adjusted to the stalls and purified rations. After being placed in the metabolism stalls at the start of the preliminary period, the wethers were not removed until the second trial was completed except for weighing the sheep and obtaining samples of rumen ingesta.

The composition of the rations used in experiment 1B is shown in table 1. Each ration contained 11.1% assay protein C-1, 7.2% minerals and 3.9% corn oil. The mineral was of the same composition as that of Oltjen et al. (1962). A vitamin A and D premix was added to supply 2700 and 350 U.S.P. units per head per day of vitamins A and D, respectively. Alpha-tocopherol was added to the corn oil in the rations at a level of 12.60 mg. per kilogram of ration. Ration M-1 contained 77.8% Solka-floc. A 1:1 mixture of cerelose and corn starch was incorporated at levels of 2, 4, 6 and 8%, at the expense of Solka-floc, in rations M-2, M-3, M-4 and M-5, respectively. An attempt was made to equalize the levels of dry matter, crude protein, ether extract and ash among rations. Cellulose content decreased linearly from 72.8% to 66.4% as the readily-available carbohydrates in the rations increased (table 1).

The wethers were fed 600 gm. of ration daily, 300 gm. at 6:30 a.m. and 300 gm. at 5:00 p.m. The rations were mixed immediately prior to each feeding from three portions. The first was a mixture of the corn oil (containing alpha-tocopherol), Solka-floc (10% of total Solka-floc in ration), isolated soybean protein, vitamins A and D and cerelose and starch (when contained in the ration). Since there was not a sufficient amount of solid ingredients, it was necessary to add 10% of the Solka-floc in the ration to obtain a mixture of desirable consistency. The remainder of the Solka-floc in the ration and the mineral mixture made up the

Table 1. Ingredient and Chemical Composition of Rations Fed in Experiment 1B.

Ration	M-1	M-2	M-3	M-4	M-5
Percent readily-available carbohydrates	0.0	2.0	4.0	6.0	8.0
Ingredient composition, %					
Solka-floc[a]	77.8	75.8	73.8	71.8	69.8
Cerelose[b]	0.0	1.0	2.0	3.0	4.0
Corn starch	0.0	1.0	2.0	3.0	4.0
Isolated soybean protein[c]	11.1	11.1	11.1	11.1	11.1
Minerals[d]	7.2	7.2	7.2	7.2	7.2
Corn oil[e]	3.9	3.9	3.9	3.9	3.9
Vitamins A and D[f]	+	+	+	+	+
Alpha-tocopherol[g]	+	+	+	+	+
Chemical composition, %					
Dry matter	93.3	93.2	93.3	93.2	93.3
Cellulose	72.8	71.0	69.7	67.6	66.4
Crude protein	9.4	9.4	9.2	9.6	9.3
Ether extract	3.7	3.8	3.8	3.8	3.8
Nitrogen-free extract	1.8	3.4	5.0	6.6	8.2
Organic matter	87.7	87.6	87.7	87.6	87.7
Ash	5.6	5.6	5.6	5.6	5.6
Gross energy Kcal./gm. dry matter	4.02	4.01	4.03	4.02	4.01

[a]A wood cellulose product. Brown Co., Berlin, N. H.
[b]A commercial preparation of glucose. Corn Products Refining Co., New York, N. Y.
[c]Assay Protein C-1. Skidmore Enterprises, Cincinnati, Ohio.
[d]Oltjen _et al_. (1962).
[e]Mazola Oil. Corn Products Refining Co., New York, N. Y.
[f]Fed to supply 2700 I.U. vitamin A and 350 I.U. vitamin D per sheep per day.
[g]Level was 12.60 mg. alpha-tocopherol per kg. of feed.

remaining two portions. Approximately 100 gm. water were added per 300 gm. portion to prevent dustiness in the ration and improve intake by the sheep. The rations were sampled at each feeding during the preliminary and collection periods. The wethers had access to water at all times except during the two daily 2-hour feeding periods. At the beginning and end of each trial the wethers were weighed individually.

The feces were collected in metal pans and picked up at 24-hour intervals. Each 24-hour collection was dried for 24 hours in a forced air oven set at approximately 50°C. The dried feces were then placed in cans with loosely-fitted lids and allowed to equilibrate with the atmospheric moisture. At the completion of each trial the composite of feces for each wether was weighed and sampled.

The urine was directed by a glass funnel placed under the grid in the floor of the stall into glass jars to which dilute sulfuric acid had been added (15 ml. 1:1 sulfuric acid and water in approximately 500 ml. water). The urine was collected every 24 hours and diluted to a constant weight. A 2% sample was taken and the composite for each wether was stored under refrigeration. The acid added to the collection jars was sufficient to maintain an acid pH during storage.

Feeds and feces were analyzed for cellulose by the method of Donefer *et al*. (1960). Urine was analyzed for nitrogen and feeds and feces were analyzed for dry matter, crude protein, ether extract and ash according to the methods of A.O.A.C. (1960). Gross energy of feeds and feces were determined in a Parr adiabatic oxygen bomb calorimeter.

At the completion of each trial samples of rumen fluid were taken by stomach tube 2 hours after the wethers were fed. The samples were strained through four thicknesses of cheesecloth. A 10 ml. sample of the filtrate was acidified with sulfuric acid and frozen until analyzed for volatile fatty acid content by the method of Bruno and Moore (1962).

The data were statistically analyzed by the analysis of variance method and differences between means were tested for significance using Duncan's (1955) multiple range test.

Experiment 2B

Two metabolism trials were conducted with 15 yearling wethers (av. wt., 35 kg.) to study the effects of high levels of readily-available carbohydrates. The experimental animals consisted of three outcome groups of five wethers each. The wethers in each group were allotted to the five rations prior to each trial. Thus, data were collected for six animals per treatment.

The ingredient and chemical composition of the rations is given in table 2. The basal ration contained no readily-available carbohydrates and was similar to ration M-1 in experiment 1B. Rations HC-2, HC-3, HC-4 and HC-5 contained 32, 40, 48 and 56% readily-available carbohydrates, respectively. The readily-available carbohydrates, consisting of equal parts starch and

Table 2. Ingredient and Chemical Composition of Rations Fed in Experiment 2B.

Ration	HC-1	HC-2	HC-3	HC-4	HC-5
Percent readily-available carbohydrates	0.0	32.0	40.0	48.0	56.0
Percent composition					
Solka-floc[a]	77.8	45.8	37.9	29.8	21.8
Cerelose[b]	0.0	16.0	20.0	24.0	28.0
Corn starch	0.0	16.0	20.0	24.0	28.0
Isolated soybean protein[c]	11.1	11.1	11.1	11.1	11.1
Minerals[d]	7.2	7.2	7.2	7.2	7.2
Corn oil[e]	3.9	3.9	3.9	3.9	3.9
Vitamins A and D[f]	+	+	+	+	+
Alpha-tocopherol[g]	+	+	+	+	+
Percent chemical composition					
Dry matter	95.6	94.7	94.5	94.3	93.8
Cellulose	74.2	44.3	36.8	29.3	21.5
Crude protein	9.4	9.4	9.8	9.5	9.4
Ether extract	3.9	4.0	4.0	4.1	4.4
Nitrogen-free extract	2.2	31.1	38.0	45.5	52.8
Organic matter	89.7	88.8	88.6	88.4	87.9
Ash	5.9	5.9	5.9	5.9	5.9
Gross energy					
Kcal./gm. dry matter	4.02	4.01	4.02	4.01	4.03

[a]A wood cellulose product. Brown Co., Berlin, N. H.
[b]A commercial preparation of glucose. Corn Products Refining Co., New York, N. Y.
[c]Assay Protein C-1. Skidmore Enterprises, Cincinnati, Ohio.
[d]Oltjen _et al_. (1962).
[e]Mazola Oil. Corn Products Refining Co., New York, N. Y.
[f]Fed to supply 2700 I.U. vitamin A and 350 I.U. vitamin D per sheep per day.
[g]Level was 12.60 mg. alpha-tocopherol per kg. of feed.

cerelose, replaced Solka-floc. The rations were similar in all other respects.

All other procedures used in experiment 2B were as described in experiment 1B.

Experiment 3B

A metabolism trial was conducted for 60 days with the 15 yearling wethers (av. wt., 35 kg.) used in experiment 2B. The three lambs on each of the rations used in the second trial in experiment 2B constituted an outcome group. The three lambs from each outcome group were allotted to three rations (five sheep per treatment).

The composition of the rations is given in table 3. The basal ration was similar to the basal ration used in the previous experiments. Rations Ad-2 and Ad-3 contained 8 and 32% readily-available carbohydrates, respectively. The rations were similar in all other respects. The values for chemical composition are the means of five analyses. The feed was sampled and feces and urine were collected as follows:

Period	Rations sampled	Feces and urine collected
1	Day 1 through day 18	Day 11 through day 20
2	Day 19 through day 28	Day 21 through day 30
3	Day 29 through day 38	Day 31 through day 40
4	Day 39 through day 48	Day 41 through day 50
5	Day 49 through day 58	Day 51 through day 60

Using this procedure it was possible to have trials with 10-, 20-, 30-, 40 and 50-day preliminary periods.

All procedures used in experiment 3B were as described in experiments 1B and 2B except that no rumen samples were taken.

Table 3. Ingredient and Chemical Composition of Rations Fed in Experiment 3B.

Ration	Ad-1	Ad-2	Ad-3
Percent readily-available carbohydrates	0.0	8.0	32.0
Ingredient composition, %			
Solka-floc[a]	77.8	69.8	45.8
Cerelose[b]	0.0	4.0	16.0
Corn starch	0.0	4.0	16.0
Isolated soybean protein[c]	11.1	11.1	11.1
Minerals[d]	7.2	7.2	7.2
Corn oil[e]	3.9	3.9	3.9
Vitamins A and D[f]	+	+	+
Alpha-tocopherol[g]	+	+	+
Chemical composition, %			
Dry matter	94.3	94.0	94.1
Crude protein	9.3	9.4	9.4
Ether extract	4.0	3.9	3.9
Cellulose	73.8	65.6	43.5
Nitrogen-free extract	1.3	9.2	31.5
Organic matter	88.4	88.1	88.2
Ash	5.9	5.9	5.9

[a]A wood cellulose product. Brown Co., Berlin, N. H.
[b]A commercial preparation of glucose. Corn Products Refining Co., N.Y.
[c]Assay Protein C-1. Skidmore Enterprises, Cincinnati, Ohio.
[d]Oltjen _et al_. (1962).
[e]Mazola Oil. Corn Products Refining Co., New York, N. Y.
[f]Fed to supply 2700 I.U. vitamin A and 350 I.U. vitamin D per sheep per day.
[g]Level was 12.60 mg. alpha-tocopherol per kg. of feed.

Experiment 4B

The effect of level of readily-available carbohydrates varying from 0 to 48% on cellulose digestibility and percent nitrogen retention was estimated by means of regression analysis. Data from four experiments, including 84 individual metabolism trials, were used. The data were obtained from experiments 1 and 2 reported by Chappell (1964) and from experiments 1B and 2B reported herein. A brief description of the data used for the regression analysis is given in table 4.

All rations contained 77.8% total carbohydrates. Readily-available carbohydrates, supplied by a 1:1 mixture of cerelose and starch, replaced Solka-floc in supplemented rations. Protein was supplied by 11.1% Assay protein C-1 in all cases. Other constant portions were 3.9% corn oil, 7.2% minerals, alpha-tocopherol and vitamins A and D.

Table 4. Summary of Data Used in Regression Analysis

Experiment	1[a]	2[a]	1B	2B
Daily feed intake (gm.)	800	600	600	600
Percent readily-available carbohydrates				
0.0	4[b]	5	6	6
2.0			6	
4.0			6	
6.0			6	
8.0		5	6	
16.0		6		
32.0		6		6
33.3	4			
40.0				6
48.0				6

[a]Chappell (1964).
[b]Values denote number of animals per treatment.

RESULTS

Experiment 1B

Apparent digestion coefficients for experiment 1B are given in table 5. Values for the individual wethers and statistical analysis of the data appear in appendix tables 1 and 2, respectively. The low levels of readily-available carbohydrates had no significant effect on digestibility. Cellulose digestion in all rations was higher than the previous studies. Although not statistically significant, the highest value for cellulose digestibility (70.5%) resulted when the ration contained 8% readily-available carbohydrates. Digestibility of cellulose in rations containing 0, 2, 4, and 6% readily-available carbohydrates was 66.6, 60.5, 66.0 and 63.9%, respectively.

Table 5. Effect of Low Levels of Readily-Available Carbohydrates on Apparent Digestibility. Experiment 1B.

Ration	M-1	M-2	M-3	M-4	M-5
Level of readily-available carbohydrates, %	0.0	2.0	4.0	6.0	8.0
Apparent digestibility, %					
Dry matter	65.6	61.5	66.7	64.1	70.8
Cellulose	66.6	60.5	66.0	63.9	70.5
Crude Protein	70.2	68.6	69.3	67.6	71.4
Ether extract	90.5	90.7	90.4	91.1	90.9
Energy	69.0	63.1	65.5	65.9	72.7

Dry matter and energy digestibility tended to follow the same pattern as cellulose digestibility. Differences in digestibility of protein and ether extract were small and inconsistent.

The nitrogen balance data for experiment 1B are shown in table 6. Values for individual wethers and statistical analysis of the data appear in appendix tables 3 and 4, respectively. Daily fecal nitrogen excretion tended to vary with cellulose excretion. For example, fecal nitrogen excretion was lowest for sheep fed ration M-5. Cellulose content was lowest, cellulose digestibility was highest and consequently the least amount of cellulose was excreted for these rations.

Table 6. Effect of Low Levels of Readily-Available Carbohydrates on Nitrogen Balance. Experiment 1B.

Ration	M-1	M-2	M-3	M-4	M-5
Level of readily-available carbohydrates, %	0.0	2.0	4.0	6.0	8.0
Nitrogen intake, gm./day	9.03	9.02	8.86	9.24	8.96
Nitrogen excretion, gm./day					
Fecal	2.69	2.81	2.74	2.91	2.56
Urinary	4.60	4.70	4.77	4.86	4.31
Total	7.29	7.51	7.51	7.77	6.87
Nitrogen retention, gm./day	1.74	1.51	1.35	1.47	2.09

Urinary nitrogen excretion values for rations M-1, M-2, M-3, M-4 and M-5 were 4.60, 4.70, 4.77, 4.86 and 4.31 gm. per day, respectively. The lowest value was for the ration which had the highest value for energy digestibility, but differences were not significant. The nitrogen retention values were not significantly different. However, the highest value (2.09 gm./day) was for the diet in which energy digestibility was highest.

The effect of level of readily-available carbohydrate in the ration on the volatile fatty acid content of the rumen fluid is shown in table 7. Data for the individual wethers and statistical analysis of the data appear in appendix tables 5 and 6, respectively. Average propionic acid content was higher for the ration containing the higher levels of readily-available carbohydrate (4, 6 and 8%). The value of 3.14 meq./100 ml. for the 4% level was significantly higher than the values of 1.81 and 1.59 meq./100 ml. for the 0 and 2% levels, respectively. The increased propionic acid resulted in a decrease in acetic to propionic ratio. Total volatile fatty acid content of the rumen fluid was considerably higher than in previous studies (Chappell, 1964). Such an increase appears to be due to increased acetic and propionic acid. This increase may reflect the higher cellulose digestibility observed in this study than in previous experiments.

Table 7. Effect of Low Levels of Readily-Available Carbohydrates on Volatile Fatty Acid Content (meq./100 ml.) of Rumen Fluid. Experiment 1B.

Ration	M-1	M-2	M-3	M-4	M-5
Level of readily-available carbohydrates, %	0.0	2.0	4.0	6.0	8.0
Rumen fluid levels					
Acetic acid	5.18	5.39	5.16	5.40	4.05
Propionic acid	1.81[a]	1.59[a]	3.14[b]	2.16[a,b]	2.94[a,b]
Butyric acid	0.31	0.34	0.45	0.35	0.59
Total	7.30	7.32	8.75	7.91	7.58
Acetic/propionic ratio	3.06	3.67	2.21	2.70	1.40

[a,b]Means on the same line bearing different superscript letters are significantly ($P < .05$) different.

Experiment 2B

Extreme difficulty was encountered in getting the wethers to consume ration HC-5 (56% readily-available carbohydrates). Only one wether in each of two trials ate the ration in amounts adequate to allow measurement of digestibility and nitrogen balance. Thus, the data for this ration were not used.

Table 8. Effect of High Levels of Readily-Available Carbohydrates on Apparent Digestibility. Experiment 2B.

Ration	HC-1	HC-2	HC-3	HC-4
Level of readily-available carbohydrates, %	0.0	32.0	40.0	48.0
Apparent digestibility, %				
Dry matter	65.0	67.7	68.3	72.1
Cellulose[a]	65.3	50.5	41.6	40.8
Crude protein	67.1	65.9	67.4	67.6
Ether extract[b]	88.0	88.7	85.9	88.0
Total carbohydrates[c]	62.8	67.2	65.0	72.7
Energy	66.5	68.0	70.1	72.2

[a]Value for ration HC-1 is significantly ($P < .05$) higher than for rations HC-2, HC-3 and HC-4. Value for ration HC-2 is significantly ($P < .05$) higher than for rations HC-3 and HC-4.

[b]Difference between the value for ration HC-2 and rations HC-3 and HC-4 was significant ($P < .05$). The value for ration HC-3 was significantly less than for ration HC-4 ($P < .05$).

[c]Difference between the value for ration HC-1 and rations HC-2, HC-3, and HC-4 approached significance ($P < .10$). Value for HC-3 was significantly less than for ration HC-4 ($P < .05$).

Apparent digestion coefficients for experiment 2B are given in table 8. Individual values and statistical analysis of the data are given in appendix tables 7 and 8, respectively.

Digestibility of cellulose for the basal ration (HC-1) was 65.3%. This value was significantly higher than values for the rations supplemented with high levels of readily-available carbohydrates. When the level of readily-available carbohydrates was increased from 32 to 40 and 48%, cellulose breakdown was reduced from 50.5% to 41.6 and 40.8%, respectively ($P < .05$). The difference between the two higher levels of readily-available carbohydrates was not significant.

Digestibility of total carbohydrates (cellulose and NFE) was 62.8%, 67.2%, 65.0% and 72.6% for rations HC-1, HC-2, HC-3 and HC-4, respectively. The difference between the basal ration and the supplemented rations approached significance ($P < .10$). Increasing the level of readily-available carbohydrate supplementation from 40 to 48% resulted in a significant increase ($P < .05$) in total carbohydrate digestibility.

Digestibility of ether extract was 88.0, 88.7, 85.9 and 88.0%, respectively. The difference between ration HC-2 and ration HC-3 and HC-4 was significant. Ether extract digestibility was significantly greater for ration HC-4 than for ration HC-3.

Dry matter and energy digestibility tended to increase as level of readily-available carbohydrates in the rations increased, but the differences were not significant. Crude protein digestibility varied only slightly among rations.

Nitrogen balance data for experiment 2B are given in table 9. Individual values and statistical analysis of the data are given in appendix tables 9 and 10, respectively.

Table 9. Effect of High Levels of Readily-Available Carbohydrates on Nitrogen Balance. Experiment 2B.

Ration	HC-1	HC-2	HC-3	HC-4
Level of readily-available carbohydrates, %	0.0	32.0	40.0	48.0
Nitrogen intake, gm./day	8.98	8.99	9.36	9.24
Nitrogen excretion, gm./day				
Fecal	2.95	2.99	3.05	2.85
Urinary	5.10	4.77	4.64	4.72
Total	8.05	7.76	7.69	7.57
Nitrogen retention, gm./day	0.93	1.23	1.67	1.67

There were no consistent trends in daily fecal nitrogen excretion. Urinary nitrogen tended to be lower and nitrogen retention higher in the readily-fermentable carbohydrate supplemented rations, but differences were not significant.

Volatile fatty acid data for experiment 2B are given in table 10. Individual values and statistical analysis of the data are given in appendix tables 11 and 12, respectively.

Butyric acid content of rumen fluid was significantly ($P < .05$) increased when readily-available carbohydrates were fed. This increase resulted in a trend toward increased total volatile fatty acids in rumen fluid for the supplemented rations (8.35 meq./100 ml. for ration HC-1 vs. 10.39, 9.10 and 11.61 meq./100 ml. for rations HC-2, HC-3 and HC-4, respectively).

Table 10. Effect of High Levels of Readily-Available Carbohydrates on Volatile Fatty Acid Content (Meq./100 ml.) of Rumen Fluid. Experiment 2B.

Ration	HC-1	HC-2	HC-3	HC-4
Level of readily-available carbohydrates, %	0.0	32.0	40.0	48.0
Rumen fluid levels[a]				
Acetic acid	4.88	5.64	4.03	4.86
Butyric acid[b]	0.72	2.24	3.32	2.72
Propionic acid	2.75	2.51	1.74	3.88
Total	8.35	10.39	9.10	11.61
Acetic/propionic ratio	2.16	2.36	2.74	1.30

[a]Average of values for the wethers per treatment.

[b]Value for ration HC-1 was significantly ($P < .05$) lower than for rations HC-2, HC-3 and HC-4.

Experiment 3B

Due to development of urinary calculi in two lambs (one each on rations Ad-2 and Ad-3), data from these lambs were discarded. After the first collection period the lamb on ration Ad-3 was replaced with a lamb which had received similar treatment previously. Only four observations were obtained for this lamb.

Apparent digestion coefficients with standard errors are given in table 11. Means of individual lambs are shown in table 13 of the appendix. Since the data could not be pooled, it was analyzed by analysis of variance within period. Level of readily-available carbohydrates in the ration failed to significantly affect digestibility of the ration components listed for any of the trials. In all periods cellulose digestibility tended to be lower for the supplemented rations.

Cellulose digestibility was maintained at a relatively constant level throughout the five periods for the ration containing no readily-available carbohydrates with a trend for an increase after the first period. Digestibility of cellulose for the 8% ration (Ad-2), followed a similar pattern although the variation was somewhat greater than for the basal ration. Cellulose digestibility for the 32% ration (Ad-3) did not follow a consistent pattern among trials.

Dry matter and organic matter digestibility tended to be slightly higher in the ration containing 32% readily-available carbohydrates. Crude protein digestibility did not follow any definite trend with

Table 11. Effect of Level of Readily-Available Carbohydrates on Apparent Digestibility Following Preliminary Periods of Differing Length. Experiment 3B.

Component	Period	Preliminary period (days)	Ration		
			Ad-1	Ad-2	Ad-3
Cellulose	1	10	63.5±8.9†	54.7±16.3	57.9±13.5
	2	20	68.5±8.5	62.8±10.6	56.5±15.7
	3	30	65.5±6.5	65.3±15.9	62.1± 9.7
	4	40	65.7±5.3	58.6±13.5	60.9±16.2
	5	50	68.0±8.4	60.8±11.5	58.7±15.3
Dry matter	1	10	63.7±6.5	61.3± 9.4	72.0± 5.9
	2	20	66.3±6.3	65.8± 8.5	70.6± 7.0
	3	30	65.6±5.3	68.2±10.1	73.0± 4.4
	4	40	64.9±3.4	63.6±10.0	71.9± 7.7
	5	50	66.4±6.4	63.1± 8.5	71.0± 8.4
Organic matter	1	10	63.3±6.9	60.6±11.7	72.0± 6.5
	2	20	66.6±6.8	65.7± 9.0	70.5± 7.5
	3	30	65.9±5.6	68.4± 9.4	73.7± 5.1
	4	40	65.5±4.0	63.8±10.5	72.6± 8.4
	5	50	67.5±6.7	63.2± 9.1	71.0± 7.7
Crude protein	1	10	70.8±4.4	67.3± 2.0	72.0± 8.4
	2	20	69.1±3.0	68.4± 2.4	66.9± 5.1
	3	30	70.0±1.2	70.0± 2.9	64.7± 5.7
	4	40	69.5±1.9	70.4± 4.4	66.3± 6.5
	5	50	70.6±3.7	65.5± 2.5	68.0± 5.6

†Mean ± standard error.

level of readily-available carbohydrate in the diet. There appeared to be no definite trends in digestibility of the above three constituents as related to length of preliminary period.

Nitrogen balance data for experiment 3B are given in table 12. Means of individual lambs are given in table 14 of the appendix. Fecal nitrogen excretion varied little among rations and between trials. Fecal nitrogen excretion values appeared to be the least variable data collected in this trial.

Urinary nitrogen excretion followed no definite trends with length of preliminary period or ration. In trial 2 urinary nitrogen excretion was less ($P < .05$) for wethers receiving the ration containing 8% readily-available carbohydrates than for the other rations. This decrease resulted in a significant increase in nitrogen retention for this ration. There were no significant differences in nitrogen retention among rations for any of the other trials.

Variation in digestion coefficients and nitrogen balance, measured by standard errors, appeared to be as great at the end of a 50-day preliminary (period 5) as it was at the initiation of these studies (period 1). In fact, the standard errors for a given measurement were of approximately the same magnitude for all trials.

Table 12. Effect of Level of Readily-Available Carbohydrates on Nitrogen Balance Following Preliminary Periods of Differing Length. Experiment 3B.

Item	Period	Preliminary period (days)	Ration		
			Ad-1	Ad-2	Ad-3
Fecal Nitrogen excretion gm./day	1	10	2.64±0.41[†]	2.81±0.11	2.59±0.25
	2	20	2.78±0.17	2.83±0.11	2.99±0.54
	3	30	2.69±0.10	2.62±0.25	3.10±0.53
	4	40	2.73±0.17	2.63±0.44	3.01±0.66
	5	50	2.67±0.34	2.90±0.25	2.90±0.51
Urinary Nitrogen excretion gm./day	1	10	5.07±0.43	4.01±0.70	4.95±0.92
	2	20	5.03±0.87[b]	3.43±0.64[a]	5.18±0.54[b]
	3	30	5.21±0.77	4.60±0.58	4.94±0.78
	4	40	5.19±0.45	5.30±0.50	4.46±0.71
	5	50	5.11±0.87	4.38±0.45	5.06±0.71
Nitrogen retention gm./day	1	10	1.25±0.59	1.77±0.70	1.42±0.54
	2	20	1.19±0.36[b]	2.68±0.76[a]	0.83±0.44[b]
	3	30	1.08±0.29	1.47±0.56	0.87±0.67
	4	40	1.05±0.50	0.82±0.19	1.46±0.35
	5	50	1.30±0.63	1.12±0.47	1.11±0.39

[†]Mean ± standard error

[a,b]Mean with different superscript letters are significantly ($P < .05$) different

Regression Analysis

A summary of the regression analysis is given in table 13. Cellulose digestion and nitrogen retention data used to estimate the influence of level of readily-available carbohydrates on cellulose digestion and nitrogen retention are given in table 14. Approximately 40% of the total variance in cellulose digestibility was due to percent readily-available carbohydrates in the ration. The influence of this variable was significant ($P < .001$).

Table 13. Effect of Level of Readily-Available Carbohydrates on Cellulose Digestibility and Nitrogen Retention as Estimated by Regression Analysis.

Statistical item	Percent cellulose digestibility (Y_c)	Percent nitrogen retention (Y_n)
Determination coefficient, R^2=	0.3955	0.0324
Mean square due to regression	5076.9493[a]	213.778
Mean square due to deviation about regression	94.6360	76.0445
Standard error of regression coefficient	0.0648	0.05745
Regression equation[b]	$Y_c = 64.8385 - 0.47426X$	$Y_n = 14.0264 + 0.09632X$

[a] $P < .001$.
[b] Y_c = Percent cellulose digestibility, Y_n = Percent nitrogen retention, X = Percent readily-available carbohydrates in ration.

The regression equation for percent cellulose digestibility was as follows:

$$Y_c = 64.8385 - 0.4746X$$

The equation indicates that, for each percent of increase in readily-available carbohydrate in the ration, cellulose digestibility is reduced approximately 0.47%. The treatment means of the pooled data and their relation to the regression line are shown in figure 1.

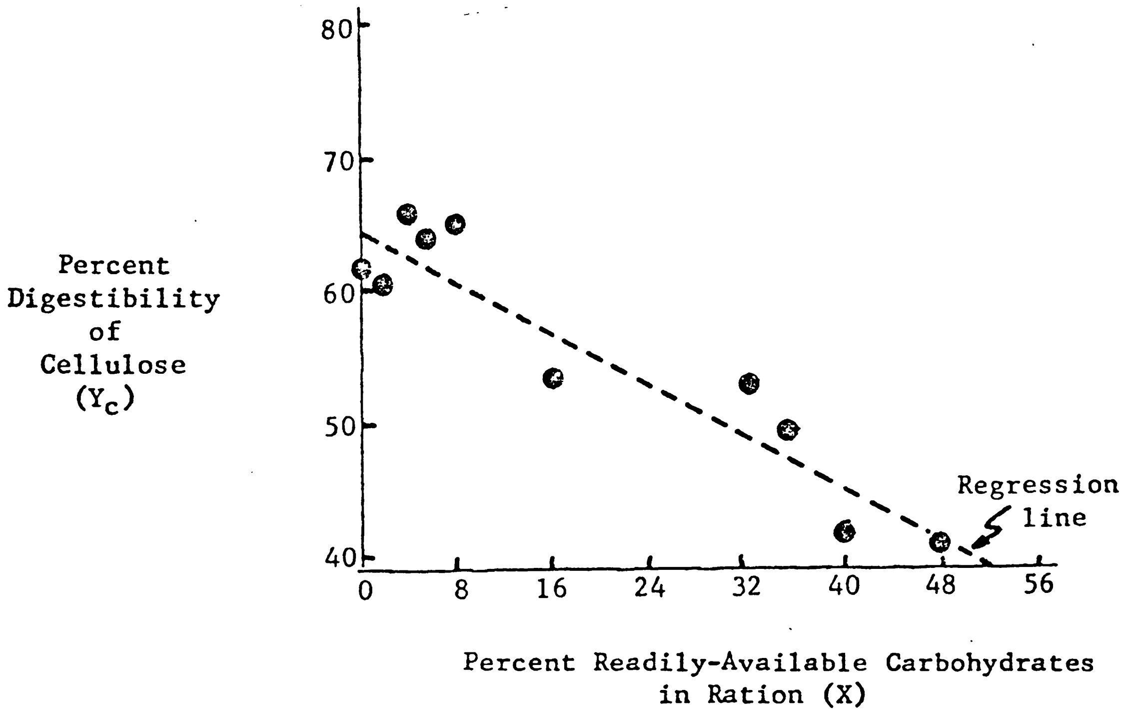

Figure 1. The Effect of Percent Readily-Available Carbohydrates on Cellulose Digestion.

Table 14. Influence of Level of Readily-Available Carbohydrates on Apparent Cellulose Digestibility (%) and Nitrogen Retention (% of Intake)

Percent readily-available carbohydrates	Digestibility (%) by experiment				Nitrogen retention by experiment			
	1[a]	2[b]	1B[b]	2B[b]	1[a]	2[b]	1B[b]	2B[b]
0.0	60.9(4)[c]	57.0(5)	66.6(6)	65.32(6)	9.20(4)[c]	6.85(5)	19.26(6)	11.22(6)
2.0			60.5(6)				16.74(6)	
4.0			66.0(6)				15.23(6)	
6.0			63.9(6)				15.90(6)	
8.0		59.6(5)	70.5(6)			11.90(5)	23.32(6)	
16.0		53.4(6)				17.80(6)		
32.0		55.1(6)		50.52(6)		20.42(6)		13.70(6)
33.3	49.5(4)				20.16(4)			
40.0				41.63(6)				18.69(6)
48.0				40.78(6)				14.74(6)

[a]Daily feed intake was 800 gm./day.
[b]Daily feed intake was 600 gm./day.
[c]Figures in parentheses refer to number of lambs per treatment.

The regression of percent readily-available carbohydrates in the ration on percent nitrogen retention was not significant. The regression equation was:

$$Y_n = 14.0264+0.093632X$$

When Y_n refers to percent nitrogen retention and X to percent readily-available carbohydrates in the ration, the trend for an increase in nitrogen retention with increased readily-available carbohydrates in the ration agrees with at least trends for increased nitrogen retention in the individual experiments.

DISCUSSION

In the studies reported here levels of readily-available carbohydrates of 8% of the ration or lower did not significantly affect cellulose digestibility. In experiment 1B, in which rations containing 0, 2, 4, 6 and 8% readily-available carbohydrates were used, there was a trend toward higher cellulose digestibility at the 8% level, but the difference was not significant. This is in agreement with earlier studies (Chappell, 1964) in which a trend for an increase at the 8% level of supplementation was observed. In these earlier studies levels of 16, 32 or 33% did not significantly affect cellulose digestibility.

Levels of readily-available carbohydrates of 32% and above generally resulted in decreases in cellulose digestibility in the present studies. The effect was significant in experiment 2B. In experiment 2B, increasing the level of readily-available carbohydrates from 32% to 40 and 48% caused a significant depression in cellulose breakdown. Such a decrease in cellulose breakdown when levels of readily-available carbohydrates in excess of 32% were fed is in agreement with earlier work with natural rations. A depression in cellulose or crude fiber digestibility has generally resulted when a source of readily-available carbohydrates was added to high fiber rations (Mitchell et al., 1940; Hamilton, 1942; Fontenot et al., 1955: Woods et al., 1956). Thus, it appears that cellulose digestibility in purified rations of the type used in these studies, is decreased when the approximate level of NFE usually found in roughage (about 30%) is exceeded.

There was no apparent beneficial effect of readily-available carbohydrates on cellulose digestibility even when lambs were maintained on the respective rations for up to 60 days. Cellulose digestibility for the basal ration in experiment 3B was 63.5, 68.5, 65.5, 65.7 and 68.0% after 10-, 20-, 30-, 40- and 50-day preliminary periods. The corresponding values for the rations containing 32% readily-available carbohydrates were 57.9, 56.5, 62.1, 60.9 and 58.7%, respectively. Thus, there was a trend for lower values for the supplemented ration for each trial and the magnitude of the difference was slightly greater for period 5 than for period 1. The wether showing the highest average level of cellulose breakdown (77.31%) had been on the ration containing no readily-available carbohydrates for 85 days at the completion of the experiment.

The results reported here are not in agreement with those obtained in *in vitro* studies. Arias *et al.* (1951) and Belasco (1956) reported increases of up to 50% in *in vitro* cellulose breakdown when small amounts of readily-available carbohydrates were added to the system. The difference between *in vitro* and *in vivo* responses may be due to the fact that in the *in vitro* work non-protein nitrogen was used as the nitrogen source in the media, whereas preformed protein was used in the present *in vivo* studies. Possibly, the rumen microorganisms used the isolated soybean protein as a source of readily-available energy. This aspect needs further study.

It appears, under the conditions of these experiments, that a dietary source of readily-available carbohydrate is not a prerequisite for maximum cellulose digestibility in the ruminant when a source of preformed protein is supplied.

Dry matter, energy and organic matter digestibility tended to increase in all experiments as level of readily-available carbohydrates in the ration increased. Such increases are in agreement with earlier studies in which sugar was added to natural (Hamilton, 1942; Swift et al, 1947; Woods et al., 1956) and semi-purified diets (Ellis and Pfander, 1958). In those experiments and in the present studies, an increase in NFE digestibility generally more than compensated for any decrease in cellulose digestion (if it occurred). This effect is well exemplified in experiment 2, in which digestibility of total carbohydrates (cellulose and NFE) for rations containing 0, 32, 40 and 48% readily-available carbohydrates was 62.5, 67.2, 65.0 and 72.6%, respectively.

In present studies, urinary nitrogen tended to decrease as level of readily-available carbohydrates in the ration increased, although the effect was not significant. Such a decrease is in agreement with earlier studies with natural (Hamilton, 1942; Fontenot et al., 1955) and purified diets (Chappell, 1964). Nitrogen retention tended to increase with readily-available carbohydrate supplementation in all experiments. These results are in agreement with those reported by Woods et al. (1956), who found nitrogen retention tended to increase with increasing levels of cerelose added to a natural lamb ration containing 11% crude protein. Chappell (1964) reported similar results when the level of readily-available carbohydrates in purified lamb rations was increased.

The trend for an increase in butyric acid and/or propionic acid in rumen fluid when level of readily-available carbohydrates in the ration is increased is in agreement with earlier studies (Chappell, 1964).

It is interesting to note that, when the level of cellulose breakdown was high (60 to 70% in experiment 1B) and low levels of readily-available carbohydrates did not significantly affect such digestion, the addition of readily-available carbohydrates tended to increase propionic acid levels. In experiment 2B, when cellulose breakdown was 65.3% for the basal ration, addition of high levels of readily-available carbohydrates significantly reduced cellulose breakdown and significantly increased butyric acid content of the rumen fluid.

Although the data obtained in experiment 3B could not be used to measure adaptation *per se*, since length of feeding was confounded with time, the trials did offer the opportunity to determine whether or not length of feeding (preliminary period) would affect the high degree of variability observed within rations in experiments 1B and 2B and in earlier work (Chappell, 1964). It appears that increasing the length of preliminary period did not reduce variation within treatment. A comparison of the treatment means and the standard errors shown in table 11 and individual lamb means and the standard errors in appendix table 13 tends to suggest that the variation within treatment is due primarily to differences among lambs. These results suggest that metabolism studies using purified rations should be conducted utilizing a latin square or reversal design. These methods compensate for variance due to individual lambs.

It appears from the limited amount of data obtained that a 10-day preliminary period is adequate for adjustment to rations containing a wide range of levels of readily-available carbohydrates. The lambs were allotted in trial 3B on basis of ration received in trial 2 of experiment 2B. Thus a wether receiving each of the high level carbohydrate rations (40, 48 and 56%) were allotted to each ration in experiment 3B. However, the 10-day preliminary period appeared adequate for adjustment to rations containing lower levels of readily-available carbohydrates (0, 8 and 32%). El-Shazley _et al._ (1961) observed that _in vivo_ cellulose degradation was nearly inhibited in wethers fed rations containing a hay to corn ratio of 1:2. When inoculum from these animals was used for _in vitro_ studies, cellulose digestion was 30% within 50 hours. If such an adjustment in fermentation patterns and/or bacterial numbers and types can be accomplished in such a short period of time, a 10-day preliminary period may be adequate for any dietary levels of readily-available carbohydrates.

The results of the regression analysis to estimate the effect of percent readily-available carbohydrates in purified rations on cellulose breakdown agree, in part, with the results of McLaren *et al*. (1965), obtained with sheep fed semi-purified rations. These workers observed a depression in crude fiber digestibility of 8 percentage units per 1000 kcal. of added readily-available carbohydrates. When calculated on the basis of kilocalories readily-available carbohydrates, the regression equation in the present studies indicated that a depression of 21 percentage units of cellulose digestibility resulted per 1000 kcal. of readily-available carbohydrates in the rations. However, a valid comparison of the two studies is impossible since methods used in the two studies differed greatly. The investigations of McLaren *et al*. (1965) involved natural roughage and readily-available carbohydrates were added to the basal ration. In the present studies purified rations were fed and total carbohydrates in the rations were constant.

SUMMARY

Two experiments were conducted to study the effect of level of readily-available carbohydrates on cellulose digestion in sheep fed purified rations. The level of readily-available carbohydrates was varied by replacing cellulose with a 1:1 mixture of cerelose and starch. In experiment 1B, levels of readily-available carbohydrates were 0, 2, 4, 6 and 8%. In experiment 2B, levels of 0, 32, 40 and 48% were used. All rations contained 11.1% isolated soybean protein, 7.2% of a mineral mixture and 3.9% corn oil. Vitamins A and D and alpha-tocopherol were included in the rations.

Cellulose digestibility was 66.6%, 60.5%, 66.0%, 63.9% and 70.5% in experiment 1B for rations containing 0, 2, 4, 6 and 8% readily-available carbohydrates. Differences among rations were not significant. In experiment 2B, cellulose digestibility was 65.3% for the basal ration. Addition of 32, 40 and 48% readily-available carbohydrates to the ration significantly ($P < .01$) decreased cellulose digestibility. The value was 50.5% for the 32% level of starch and cerelose. Increasing the level of readily-available carbohydrates from 32% to 40 and 48% reduced ($P < .05$) cellulose digestion to 41.6 and 40.8%, respectively.

Dry matter, organic matter and energy digestibility tended to increase as level of readily-available carbohydrates in the ration increased in experiment 1B. In experiment 2B, dry matter digestibility showed a similar trend and total carbohydrate (cellulose and

NFE) digestibility tended to be higher for the supplemented rations.

In both experiments, fecal nitrogen was not affected, urinary nitrogen tended to decrease and nitrogen retention tended to increase as level of readily-available carbohydrates in the ration increased.

Total volatile fatty acids in rumen fluid tended to increase in readily-available carbohydrate supplemented rations in both experiments. In experiment 1B, the increase was due primarily to an increase in proponic acid. In experiment 2B, butyric acid appeared to account for the slight increase in total volatile fatty acids for the rations containing readily-available carbohydrates.

In a third experiment lambs were fed rations containing 0, 8 and 32% readily-available carbohydrates for 60 days. There were five 10-day collection periods following a 10-day preliminary period. Increasing the length of preliminary period did not appear to change the pattern of digestibility or nitrogen utilization. There were no consistent significant differences in digestibility or nitrogen utilization among rations for any of the trials.

Regression analysis of data from four experiments involving 84 individual metabolism trials indicated that for each percentage increase in readily-available carbohydrates in the ration cellulose digestion was significantly reduced approximately 0.5 percentage unit. Similar analysis of nitrogen retention data showed a trend for an increase in nitrogen retention with increasing levels of readily-available carbohydrates but the effect was not significant.

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APPENDIX

Table 1. Apparent Digestion Coefficients. Experiment 1B.

Trial no.	Ration	Sheep no.	Apparent percentage digestibility: Dry matter	Crude protein	Ether extract	Cellulose	Energy
1	M-1	6	64.79	73.27	92.42	64.39	66.96
1	M-1	12	76.61	66.20	89.71	82.22	76.96
1	M-1	14	60.62	69.47	84.26	60.10	63.13
2	M-1	3	68.62	71.98	92.06	70.33	70.12
2	M-1	18	57.75	66.64	92.87	57.96	58.93
2	M-1	24	65.11	73.67	92.46	64.63	65.43
Average			65.60	70.20	90.60	66.60	66.90
1	M-2	1	66.14	63.52	90.51	67.75	68.45
1	M-2	2	53.40	68.22	86.32	49.15	56.70
1	M-2	36	62.13	73.61	89.68	59.34	64.02
2	M-2	1	67.02	69.36	93.41	67.96	69.08
2	M-2	5	57.32	64.38	91.93	55.42	59.13
2	M-2	32	63.36	72.72	92.17	63.28	64.98
Average			61.50	68.60	90.70	60.50	63.70
1	M-3	3	64.86	71.06	93.46	62.05	67.20
1	M-3	24	66.16	67.79	92.21	65.98	68.16
1	M-3	26	59.66	71.31	90.89	55.97	61.16
2	M-3	12	76.88	71.25	86.73	80.81	79.03
2	M-3	14	75.47	66.75	91.03	77.49	77.28
2	M-3	25	56.93	66.09	88.02	53.44	58.20
Average			66.70	69.3	90.40	66.0	67.50

Table 1. Apparent Digestion Coefficients. Experiment 1B. (continued)

Trial no.	Ration	Sheep no.	Apparent percentage digestibility				
			Dry matter	Crude protein	Ether extract	Cellulose	Energy
1	M-4	5	59.93	68.04	89.74	55.15	61.71
1	M-4	25	72.28	70.87	87.12	73.22	74.05
1	M-4	32	58.70	66.77	93.02	55.55	61.85
2	M-4	2	68.63	68.57	91.07	69.80	69.86
2	M-4	26	63.92	72.19	92.89	69.36	65.38
2	M-4	27	61.34	49.02	92.88	60.23	62.85
Average			64.10	67.6	91.10	63.90	65.90
1	M-5	7	74.52	69.41	92.12	76.99	76.78
1	M-5	18	72.27	71.06	86.47	72.82	74.26
1	M-5	27	64.24	64.41	92.85	62.96	67.01
2	M-5	6	70.67	74.51	88.39	67.31	71.83
2	M-5	7	79.58	74.89	93.24	84.83	80.54
2	M-5	36	63.20	74.19	92.57	57.90	64.06
Average			70.80	71.4	90.90	70.50	72.4

Table 2. Analysis of Variance for Apparent Digestion Coefficients. Experiment 1B.

Source	Degrees of freedom	Apparent percentage digestibility				
		Dry matter	Cellulose	Crude protein	Ether extract	Energy
		m.s.	m.s.	m.s.	m.s.	m.s.
Treatment	4	68.966	80.830	25.414	0.455	63.188
Outcome group	5	39.139	75.43	6.563	4.324	25.613
Trial	1	12.662	45.91	0.048	14.616	2.2963
Error	19	42.787	89.13	30.592	7.879	44.602
Total	29					

Table 3. Daily Nitrogen Balance. Experiment 1B.

Trial no.	Ration	Sheep no.	Nitrogen intake	Nitrogen excretion Fecal	Urinary	Total	Nitrogen balance
			gm.	gm.	gm.	gm.	gm.
1	M-1	6	8.98	2.40	4.04	6.44	2.54
1	M-1	12	8.98	3.04	3.87	6.91	2.07
1	M-1	14	8.98	2.74	5.27	7.91	0.97
2	M-1	3	9.08	2.54	4.46	7.00	2.09
2	M-1	18	9.08	3.03	5.26	8.29	0.79
2	M-1	24	9.08	2.39	4.70	7.09	1.99
Average			9.03	2.69	4.60	7.29	1.74
1	M-2	1	9.09	3.31	4.90	8.21	0.88
1	M-2	2	9.09	2.78	4.55	7.23	1.77
1	M-2	36	9.09	2.40	4.80	7.20	1.89
2	M-2	1	8.94	2.74	4.17	6.91	2.03
2	M-2	5	8.94	3.18	5.19	8.37	0.57
2	M-2	32	8.94	2.44	4.46	6.90	1.94
Average			9.02	2.81	4.70	7.51	1.51
1	M-3	3	8.86	2.56	3.72	6.28	2.58
1	M-3	24	8.86	2.85	5.10	7.95	0.91
1	M-3	26	8.86	2.54	5.00	7.54	1.32
2	M-3	12	8.85	2.55	4.80	7.35	1.50
2	M-3	14	8.85	2.94	4.21	7.15	1.70
2	M-3	25	8.85	3.00	5.78	8.78	1.07
Average			8.86	2.74	4.77	7.51	1.35

Table 3. Daily Nitrogen Balance. Experiment 1B. (continued)

Trial no.	Ration	Sheep no.	Nitrogen intake	Nitrogen excretion Fecal	Urinary	Total	Nitrogen balance
			gm.	gm.	gm.	gm.	gm.
1	M-4	5	9.37	3.00	4.90	7.90	1.47
1	M-4	25	9.37	2.73	4.66	7.39	1.98
1	M-4	32	9.37	3.11	5.05	8.16	1.21
2	M-4	2	9.10	2.86	4.84	7.70	1.40
2	M-4	26	9.10	2.53	5.29	7.82	1.28
2	M-4	27	9.10	3.25	4.41	7.66	1.44
Average			9.24	2.91	4.86	7.77	1.47
1	M-5	7	8.96	2.74	3.28	6.02	2.94
1	M-5	18	8.96	2.59	4.07	7.66	2.30
1	M-5	27	8.96	3.19	5.17	8.36	0.61
2	M-5	6	8.96	2.28	4.83	7.11	1.85
2	M-5	7	8.96	2.25	3.68	5.93	3.03
2	M-5	36	8.96	2.31	4.85	8.16	1.80
Average			8.96	2.56	4.31	6.87	2.09

Table 4. Analysis of Variance for Daily Nitrogen Balance. Experiment 1B.

Source	Degrees of freedom	Nitrogen excretion (gm.)		Nitrogen retention	
		Fecal	Urinary	Gm.	%
		m.s.	m.s.	m.s.	m.s.
Treatment	4	0.104	0.233	0.407	67.395
Outcome group	5	0.032	1.045	0.652	92.275
Trial	1	0.095	0.456	0.307	14.228
Error	19	0.112	0.324	0.379	53.595
Total	29				

Table 5. Volatile Fatty Acid Content of Rumen Fluid (meq./100 ml.). Experiment 1B.

Trial no.	Ration	Sheep no.	Acetic acid	Propionic acid	Butyric acid	Total	Acetic/ propionic ratio
1	M-1	6	3.99	1.53	0.25	5.77	2.61
1	M-1	12	4.77	1.23	0.14	6.14	3.88
1	M-1	14	6.37	1.52	0.57	8.46	4.19
2	M-1	3	3.21	2.72	0.13	6.06	1.18
2	M-1	18	4.72	1.74	0.29	6.93	2.71
2	M-1	24	8.00	2.10	0.49	10.59	3.81
Average			5.18	1.81	0.31	7.30	3.06
1	M-2	1	7.45	1.36	0.36	9.17	5.74
1	M-2	2	6.11	1.70	0.22	8.03	3.59
1	M-2	36	5.12	1.56	0.27	6.95	3.28
2	M-2	1	6.06	1.18	0.52	7.76	5.14
2	M-2	5	3.38	1.69	0.13	5.25	2.00
2	M-2	32	2.51	2.02	0.48	5.01	1.24
Average			5.39	1.59	0.34	7.32	3.67
1	M-3	3	4.79	3.53	0.48	8.80	1.86
1	M-3	24	3.58	2.64	0.54	6.76	1.36
1	M-3	26	5.31	4.84	0.75	10.90	1.10
2	M-3	12	3.34	3.31	0.27	6.92	1.01
2	M-3	14	6.19	1.52	0.30	8.01	5.27
2	M-3	25	7.75	2.97	0.35	11.07	2.61
Average			5.16	3.14	0.45	8.75	2.21

Table 5. Volatile Fatty Acid Content of Rumen Fluid (meq./100 ml.). Experiment 1B. (continued)

Trial no.	Ration	Sheep no.	Acetic acid	Propionic acid	Butyric acid	Total	Acetic/ propionic ratio
1	M-4	5	7.83	1.69	0.49	10.01	4.63
1	M-4	25	2.40	2.72	0.19	5.31	0.88
1	M-4	32	6.62	1.95	0.17	8.74	3.39
2	M-4	2	5.43	2.18	0.42	8.03	2.49
2	M-4	26	5.24	2.81	0.44	8.49	1.86
2	M-4	27	4.88	1.66	0.37	6.91	2.94
Average			5.40	2.16	0.35	7.91	2.70
1	M-5	7	3.81	3.25	0.57	7.63	1.17
1	M-5	18	4.42	3.10	0.82	8.34	1.13
1	M-5	27	3.51	2.45	0.44	6.93	1.80
2	M-5	6	3.50	2.15	0.68	6.33	1.63
2	M-5	7	3.76	3.23	0.60	7.59	1.16
2	M-5	36	5.27	3.45	0.42	9.14	1.53
Average			4.05	2.94	0.59	7.58	1.40

Table 6. Analysis of Variance for Volatile Fatty Acid Content of Rumen Fluid (meq./100 ml.). Experiment 1B.

Source	Degrees of freedom	Fatty acid content (meq./100 ml.) Acetic	Propionic	Butyric	Total	Acetic/ propionic ratio
		m.s.	m.s.	m.s.	m.s.	m.s.
Treatment	4	2.139	2.809*	0.078	2.640	4.423
Outcome group	5	2.351	0.386	0.015	1.360	1.464
Trial	1	0.250	0.004	0.003	0.267	0.843
Error	19	3.684	0.446	0.030	3.225	2.127
Total	29					

*P < .05.

Table 7. Apparent Digestion Coefficients. Experiment 2B.

Trial	Ration	Sheep No.	Apparent percentage digestibility: Dry matter	Crude protein	Ether extract	Cellulose	Energy	Total carbohydrates (cellulose & NFE)
HC-1	HC-1	42	66.82	63.83	82.59	69.94	67.35	66.43
HC-1	HC-1	44	60.35	65.23	78.82	58.81	62.96	58.02
HC-1	HC-1	506	65.81	67.40	88.01	67.59	66.98	64.02
HC-2	HC-1	42	69.25	66.66	92.38	69.84	70.63	65.58
HC-2	HC-1	45	66.35	70.32	92.02	66.37	68.09	64.81
HC-2	HC-1	46	61.14	69.18	93.91	59.39	62.95	58.19
Average			65.0	67.10	88.0	65.30	66.50	62.80
HC-1	HC-2	40	60.29	68.19	82.89	31.61	62.34	56.89
HC-1	HC-2	48	70.61	66.45	89.94	55.26	72.73	71.34
HC-1	HC-2	420	70.88	65.95	89.01	54.14	71.62	69.96
HC-2	HC-2	41	68.95	54.16	88.73	60.69	67.84	70.66
HC-2	HC-2	506	73.28	75.06	95.96	61.47	72.31	73.21
Average			67.7	65.90	88.7	50.50	68.0	67.20
HC-1	HC-3	41	66.08	68.57	64.51	37.59	66.52	66.16
HC-1	HC-3	46	70.57	60.14	89.49	48.27	70.52	53.04
HC-1	HC-3	49	62.20	67.83	84.25	27.58	64.83	60.08
HC-2	HC-3	40	64.38	68.17	90.70	30.11	65.18	64.37
HC-2	HC-3	48	79.12	71.46	93.44	66.00	81.60	79.06
HC-2	HC-3	464	67.44	68.11	92.84	40.20	72.00	67.14
Average			68.3	67.40	85.9	41.60	70.1	65.00

Table 7. Apparent Digestion Coefficients. Experiment 2B.(continued)

			Apparent percentage digestibility					
Trial	Ration	Sheep no.	Dry matter	Crude protein	Ether extract	Cellulose	Energy	Total carbohydrates (cellulose & NFE)
HC-1	HC-4	43	72.00	66.70	83.21	41.01	72.88	72.82
HC-1	HC-4	45	68.54	58.52	82.82	40.41	65.52	70.04
HC-1	HC-4	464	73.46	68.04	90.41	46.41	73.82	74.51
HC-2	HC-4	47	75.36	70.32	92.58	46.94	74.70	75.98
HC-2	HC-4	50	71.48	67.79	85.80	41.60	72.29	72.29
HC-2	HC-4	420	71.49	74.24	93.35	28.32	74.11	70.26
Average			72.1	67.6	88.0	40.80	72.2	72.70

Table 8. Analysis of Variance for Apparent Digestion Coefficients. Experiment 2B.

Source	Degrees of freedom	Apparent percentage digestibility: Dry matter	Cellulose	Total carbohydrates (Cellulose & NFE)	Crude protein	Ether extract	Energy
		m.s.	m.s.	m.s.	m.s.	m.s.	m.s.
Treatment	3	51.226	778.855**	106.650	3.4031	9.000	37.374
HC-1 vs. HC-2, HC-3, HC-4	(1)	73.622	1987.764**	132.736[a]	0.087	0.865	58.951
HC-2 vs. HC-3, HC-4	(1)	23.847	347.201*	10.480	9.975	11.560*	39.795
HC-3 vs. HC-4	(1)	56.210	1.600	176.724*	0.147	13.954*	20.010
Outcome group	5	28.159	163.022	35.747	23.893	24.657*	26.162
Trial	1	22.099	43.363	64.485	48.963	346.028	25.730
Error	14	17.0089	86.2527	31.581	21.0639	2.220	80.184
Total	23						

[a] $P < .10$.
*$P < .05$.
**$P < .01$.

Table 9. Daily Nitrogen Balance. Experiment 2B.

Trial no.	Ration	Sheep no.	Nitrogen intake	Nitrogen excretion Fecal	Urinary	Total	Nitrogen balance
			gm.	gm.	gm.	gm.	gm.
1	HC-1	42	8.98	3.25	5.55	8.80	0.28
1	HC-1	44	8.98	3.12	5.29	8.41	0.57
1	HC-1	506	8.98	2.93	5.00	7.93	1.05
2	HC-1	42	8.98	2.99	4.80	7.79	1.19
2	HC-1	45	8.98	2.66	4.70	7.36	1.62
2	HC-1	46	8.98	2.77	5.29	8.06	0.92
Average			8.98	2.95	5.10	8.05	0.93
1	HC-2	40	8.93	2.84	5.61	8.45	0.48
1	HC-2	48	8.93	3.00	5.19	8.19	0.74
1	HC-2	420	8.93	3.04	4.41	7.45	1.48
2	HC-2	41	9.05	4.15	4.02	8.17	0.88
2	HC-2	49	9.05	3.11	5.00	8.11	0.94
2	HC-2	506	9.05	2.01	4.36	6.37	2.68
Average			8.98	3.02	4.77	7.79	1.21
1	HC-3	41	9.36	2.94	4.02	6.96	2.42
1	HC-3	46	9.36	3.73	5.12	8.85	0.51
1	HC-3	49	9.36	3.01	5.19	8.20	1.16
2	HC-3	40	9.36	2.98	5.00	7.98	1.38
2	HC-3	48	9.36	2.67	4.70	7.37	1.99
2	HC-3	464	9.36	2.98	3.82	6.80	2.56
Average			9.36	3.05	4.64	7.69	1.67

Table 9. Daily Nitrogen Balance. Experiment 2B. (continued)

Trial no.	Ration	Sheep no.	Nitrogen intake	Nitrogen excretion			Nitrogen balance
				Fecal	Urinary	Total	
			gm.	gm.	gm.	gm.	gm.
1	HC-4	43	9.03	3.01	3.87	6.88	2.15
1	HC-4	45	9.03	3.75	5.10	8.85	0.18
1	HC-4	464	9.03	2.89	4.95	7.84	1.19
2	HC-4	47	9.19	2.73	5.29	8.02	1.17
2	HC-4	50	9.19	2.35	5.78	8.13	1.06
2	HC-4	420	9.19	2.37	4.41	6.78	2.41
Average			9.11	2.85	4.90	7.75	1.36

Table 10. Analysis of Variance for Daily Nitrogen Balance. Experiment 2B.

Source	Degrees of freedom	Nitrogen excretion (gm.)		Nitrogen retention	
		Fecal	Urinary	Gm.	%
		m.s.	m.s.	m.s.	m.s.
Treatment	3	0.105	0.239	0.620	58.028
HC-1 vs. HC-2, HC-3, HC-4	(1)	0.002	0.669	0.750	90.878
HC-2 vs. HC-3, HC-4	(1)	0.058	0.028	0.616	36.321
HC-3 vs. HC-4	(1)	0.258	0.021	0.492	48.886
Outcome group	5	0.234	0.359	0.454	68.526
Trial	1	0.7668	0.411	1.2015	163.9605
Error	14	0.2131	0.298	0.4259	52.862
Total	23				

Table 11. Volatile Fatty Acid Content of Rumen Fluid (meq./100 ml.). Experiment 2B.

Trial no.	Ration	Sheep no.	Acetic acid	Propionic acid	Butyric acid	Total	Acetic/ propionic ratio
2	HC-1	45	4.95	1.37	0.49	6.81	3.61
2	HC-1	42	5.03	4.02	0.54	9.59	1.25
2	HC-1	46	4.66	2.86	1.13	8.65	1.63
Average			4.88	2.75	0.72	8.35	2.16
2	HC-2	41	6.08	3.49	2.19	11.76	1.74
2	HC-2	49	6.30	2.23	2.70	11.23	2.83
2	HC-2	506	4.55	1.81	1.83	8.18	2.51
Average			5.64	2.51	2.24	10.39	2.36
2	HC-3	48	2.45	1.37	4.94	8.76	1.79
2	HC-3	40	4.49	2.51	3.42	10.42	1.79
2	HC-3	464	5.16	1.35	1.60	8.11	3.82
Average			4.03	1.74	3.32	9.10	2.47
2	HC-4	47	5.06	3.01	2.33	10.40	1.68
2	HC-4	50	4.58	4.49	1.65	10.72	1.02
2	HC-4	420	4.93	4.14	4.17	13.72	1.19
Average			4.86	3.88	2.72	11.61	1.30

Table 12. Analysis of Variance for Volatile Fatty Acid Content of Rumen Fluid (meq./100 ml.). Experiment 2B.

Source	Degrees of freedom	Acetic	Propionic	Butyric	Total	Acetic/ propionic ratio
		m.s.	m.s.	m.s.	m.s.	m.s.
Treatment	3	1.2972	2.3444	3.7037	6.2178	0.8482
HC-1 vs. HC-2, HC-3, HC-4	(1)	0.0028	0.0034	9.3432*	9.1507	0.0336
HC-2 vs. HC-3, HC-4	(1)	2.8720	0.1820	1.2220	0.0024	0.4576
HC-3 vs. HC-4	(1)	1.0168	6.8480*	0.5460	9.5004	2.0533
Outcome group	2	0.2172	1.1031	0.1821	1.2353	0.3726
Error	6	0.9278	0.8217	1.5453	3.0902	1.0127
Total	11					

*$P < .05$.

Table 13. Apparent Digestion Coefficients. Experiment 3B.

Ration	Percent readily-available carbohydrates	Lamb no.	Apparent digestibility (%) Dry matter	Cellulose	Organic matter	Crude protein
Ad-1	0.0	45	73.7±2.8	77.3± 3.8	74.8±2.8	68.7±2.2
Ad-1	0.0	47	65.6±3.0	66.5± 4.0	65.7±3.0	69.2±2.1
Ad-1	0.0	48	64.0±2.6	65.2± 4.0	64.6±3.2	70.9±1.9
Ad-1	0.0	49	59.4±1.7	59.3± 2.3	59.3±2.3	70.8±1.6
Ad-1	0.0	383	64.3±2.1	64.0± 3.8	64.4±2.7	70.5±5.5
Ad-2	8.0	40	65.3±6.3	62.6±10.8	65.2±6.9	65.7±0.7
Ad-2	8.0	41	55.6±4.2	47.7± 6.1	55.0±4.4	68.2±2.6
Ad-2	8.0	44	60.1±1.9	55.5± 3.1	59.7±2.2	65.8±2.8
Ad-2	8.0	46	76.6±2.0	76.8± 2.0	77.5±2.1	71.5±2.7
Ad-3	32.0	42	68.0±4.6	48.8± 2.7	67.8±4.8	76.0±4.6
Ad-3	32.0	420	64.5±1.9	44.6± 5.9	64.2±2.1	70.5±4.5
Ad-3	32.0	464	71.3±1.6	60.0± 3.0	72.0±1.7	62.6±4.0
Ad-3	32.0	503	79.4±2.4	74.0± 6.4	80.1±3.0	65.9±2.4
Ad-3	32.0	506	77.1±3.3	71.9± 3.7	77.6±2.3	62.4±2.0

Table 14. Daily Nitrogen Balance. Experiment 3B.

Ration	Percent readily-available carbohydrates	Lamb no.	Nitrogen excretion: Fecal	Nitrogen excretion: Urinary	Nitrogen balance	
			gm.	gm.	gm.	%
Ad-1	0.0	45	2.86±0.21[†]	4.95±0.70	1.40±0.58	15.56± 6.33
Ad-1	0.0	47	2.80±0.17	5.14±0.66	1.09±0.68	12.10± 7.15
Ad-1	0.0	48	2.62±0.16	5.53±0.52	0.85±0.55	9.42± 6.20
Ad-1	0.0	49	2.60±0.27	5.28±0.41	1.10±0.45	12.20± 5.00
Ad-1	0.0	383	2.61±0.50	4.89±0.44	1.44±0.50	16.05± 5.73
Ad-2	8.0	40	2.97±0.08	4.09±0.90	1.97±0.44	18.48±10.90
Ad-2	8.0	41	2.76±0.23	4.94±0.99	0.96±0.90	10.94±10.00
Ad-2	8.0	44	2.96±0.21	4.41±0.39	1.33±0.20	15.32± 5.56
Ad-2	8.0	46	2.73±0.55	3.96±0.74	1.98±0.22	22.76±13.70
Ad-3	32.0	42	2.09±0.43	5.50±0.19	1.15±0.56	13.12± 6.51
Ad-3	32.0	420	2.52±0.32	5.86±0.37	0.50±0.34	5.80± 3.26
Ad-3	32.0	464	3.37±0.36	4.40±0.51	1.24±0.51	13.84± 6.06
Ad-3	32.0	503	3.07±0.17	4.60±0.21	1.07±0.31	14.95± 2.99
Ad-3	32.0	506	3.39±0.17	4.30±0.42	1.32±0.55	14.67± 6.10

[†]Mean ± standard error.

THE INFLUENCE OF VARIOUS LEVELS OF READILY-AVAILABLE CARBOHYDRATES IN PURIFIED RATIONS ON CELLULOSE DIGESTIBILITY BY SHEEP

by

Guy Lee Monty Chappell

(ABSTRACT)

Three metabolism trials were conducted with wethers fed purified rations to study the effect of level of readily-available carbohydrates on cellulose digestibility. In the first experiment, two trials were conducted with fifteen wethers fed five rations. The basal ration contained 77.8% cellulose, 11.1% assay protein C-1, 7.2% minerals and 3.9% corn oil. Readily-available carbohydrates supplied by a 1:1 mixture of cerelose and starch replaced cellulose in the other rations to give levels of 2, 4, 6 and 8% readily-available carbohydrates. Level of readily-available carbohydrates in the ration failed to significantly affect digestibility of ration components and nitrogen balance. Cellulose digestibility tended to be higher for the 8% ration. Energy and dry matter digestibility tended to be higher for the supplemented rations. In experiment 2B, two metabolism trials were conducted with twelve wethers to study the effect of higher levels of readily-available carbohydrates on utilization of purified rations. The basal ration was of the same composition as that described above. Three additional rations contained 32%, 40% and 48% readily-available carbohydrates (levels were substituted for equal amounts of cellulose).

Cellulose digestibility was 65.3% for the basal ration. Addition of 32, 40 and 48% readily-available carbohydrates significantly reduced cellulose digestibility. Increasing the level of readily-available carbohydrates from 32 to 40 and 48% reduced digestibility of cellulose ($P < .05$). Digestibility of total carbohydrates (cellulose and NFE) was 62.8%, 67.2%, 65.0% and 72.7% for the 0, 32, 40 and 48% rations, respectively. The difference between the 40% and 48% rations was significant. Nitrogen retention tended to increase in the supplemented rations, but the effect was not significant. Butyric acid content of the rumen fluid was higher in the supplemented rations. In the third experiment, fifteen wethers were fed three rations to determine the effect of level of readily-available carbohydrates on cellulose digestibility following preliminary periods of different lengths. The composition of the basal ration was the same as in experiments 1B and 2B. The other two rations contained 8% and 32% readily-available carbohydrates. There was a 10-day collection period following preliminary periods of 10, 20, 30, 40 and 50 days. There were no significant differences in ration digestibility or nitrogen utilization, regardless of the duration of the preliminary period. Regression analysis of data from four experiments involving 84 individual metabolism trials indicated that for each one percentage increase in readily-available carbohydrates in the ration cellulose digestion was significantly reduced 0.5 percentage units and nitrogen retention was not significantly altered.