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Environmental Protection Technology Series

INFLUENCE OF RECYCLING BEEF CATTLE WASTE ON INDIGESTIBLE RESIDUE ACCUMULATION

Robert S. Kerr Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Ada, Oklahoma 74820

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INFLUENCE OF RECYCLING BEEF CATTLE WASTE ON INDIGESTIBLE RESIDUE ACCUMULATION

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FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the agency's effort involves the search for information about environmental problems, management techniques and new technologies through which optimum use of the nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

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This report contributes to the knowledge essential if the EPA is to meet the requirements of environmental laws that it establish and enforce pollution control standards which are reasonable, cost effective and provide adequate protection for the American public.

William C. Galegar, Director
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ABSTRACT

Studies were conducted to investigate the effect of feces recycling in beef cattle diets (rations) on the digestibility of various dietary nutrients and on the accumulation of indigestible residues. Feces were refed in three successive phases based primarily upon the quantity of feces produced in the previous phase. Several different roughage levels in high concentrate rations were considered. An attempt was made to investigate the digestibility of various nutrient parameters in feces when refed and the roughage value of feces. Mineral retention data and the accumulation of various minerals in the fecal and urinary residues were studied. Varying levels of feces in growing/maintenance rations were investigated along with the efficiency of urinary nitrogen (N) as a supplemental N source.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

ADF	--acid detergent fiber	ml	--milliliter
ad lib	--*ad libitum*	NDF	--neutral detergent fiber
C.P.	--crude protein	NPN	--non protein nitrogen
CSH	--cottonseed hulls	O.M.	--organic matter
Dig.	--digestibility	Per	--period (division within a phase)
DM	--dry matter		
g	--gram	Ph	--phase
hr	--hour	SEM	--standard error of mean
I.U.	--International Unit	Supp	--supplement
kg	--kilogram		

SYMBOLS

Ca	calcium
Cl	chlorine
$kg^{0.75}$	metabolic weight
N	nitrogen
Na	sodium
NE_g	net energy for gain
NH_3	ammonia
P	phosphorus
$\bar{X}$	mean

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SECTION I

INTRODUCTION

In large cattle feedlots, feedlot waste is produced in huge quantities and must be disposed of by some means. Moreover, unless managed properly, beef waste can be a potential pollutant in our environment. With today's trend toward intensive production systems, efficient and economical alternatives must be found for effective disposal of animal waste materials. Traditionally, in many areas animal waste has been placed on land as a source of plant nutrients. This method may not be practical, however, in many instances because of the large quantities of land which may be required, expense, potential air and/or groundwater pollution, and other considerations.

Recycling of feedlot waste as livestock feed merits investigation as a potentially useful source of feed nutrients and as a means of lowering the disposable waste load. Either partial or continuous recycling of waste as feed should reduce the total amount of disposable waste and also the biological oxygen demand associated with decomposition of waste through the loss of organic matter. Animal waste may provide useful nutrients such as fiber, nitrogen, energy and/or minerals in the diets of ruminants. Therefore, studies were conducted herein to evaluate the following overall objectives:

1) Evaluate the effect of continuously recycling solid beef cattle waste on the digestibility of waste and on the accumulation of indigestible residues.

2) Determine the influence of roughage level in high concentrate rations on residue accumulations during recycling.

3) Determine the influence of recycling beef cattle waste on digestibility of ration nutrients, ration palatability and animal performance.

4) Determine the efficiency of nitrogen utilization from dried urine as a supplemental nitrogen source.

SECTION II

CONCLUSIONS

Ration digestibility was decreased by inclusion of feces in the ration. Feces produced on high concentrate rations were recycled (refed) in 4 consecutive phases through steers. Total disposable waste load was reduced by refeeding, indicating some further digestion or utilization of feces when refed. Calculated digestibility values for the feces component in a ration (diet) indicate a low to moderate, but variable digestibility for various nutrient parameters in feces being refed. Dry matter digestibilities ranged from 27 to 61% with protein, fiber and ash values usually being lower than this. Digestibility of fiber components tended to increase with each recycling. Feces in diets containing either zero or very low levels of roughage appear to have some roughage value and produce positive, associative effects, increasing ration digestibility. The composition of feces was altered by continuous refeeding such that the feces produced were slightly higher in protein, fiber and ash content. Recycling of feces in the feed produced an accumulation of Ca, but resulted in no material buildup of Na, Cl or P. Normal mineral retention values were observed in animals.

Physiological or nutritional status of an animal appears to influence digestive efficiency and efficiency of nitrogen (N) retention. Young lambs which were placed on a low nitrogen depletion diet for 4 weeks showed higher ration digestibilities and more efficient nitrogen retention during the first 2 weeks following the depletion period than 3 to 5 weeks following N depletion.

Urinary N appears to be readily utilized for microbial protein synthesis in the rumen. Diets containing either 0, 25 or 50% of the supplemental N from urine (soybean meal served as the control N source) promoted approximately equal efficiencies of N retention in young, N depleted lambs. When 75% of the supplemental N was supplied by urine only a slight decrease in N retention was observed. After N reserves were repleted (by fifth week), no treatment differences were observed.

Increasing the level of dried feces (0, 20, 40, 60%) in a ration caused a general reduction in total ration digestibility, but produced normal mineral retention. Dietary intakes on rations containing an increasing level of feces were very acceptable. Growth data with both lambs and cattle indicate that high feces rations are low in energy, but appear to be very acceptable for maintenance type programs.

SECTION III

RECOMMENDATIONS

Feces produced from cattle on high concentrate finishing rations can be refed or recycled in cattle diets. Feces will have a low to moderate nutrient digestibility and can be best used as a major dietary component in maintenance type rations which do not require a high caloric density or energy (Total Digestible Nutrient or Net Energy) value. In such rations, rather high levels (perhaps 50%+) can be included. Adaptation to such diets and acceptable feed intakes can be achieved in a relatively short time--perhaps several weeks or less.

In high concentrate finishing diets, feces may be included because of its apparent roughage replacement value. In zero roughage diets, feces also produce favorable associative effects, enhancing digestibility.

Recycling of feces can be practices to decrease the total disposable waste load. Further digestion appears to occur when feces are recycled. Fiber, in particular, appears to undergo more complete digestion when recycled.

Although feces were dried and ground prior to reincorporation in the diet in these studies, systems which incorporate wet feces (e.g. ensiling programs) would logically provide a more energy conserving approach. The feeding (nutritive) value of feces under field conditions would likely depend upon various factors. For one, any compositing which occurred would greatly lower potential energy value for feeding purposes. Moreover, if sand, dirt, etc. were included any potential feeding value would decrease accordingly. If conditions favored very high starch digestibilities in the grain fed, the resulting feces would have a lower refeeding value and conversely. Most field situations would probably result in poorer ration starch digestibilities (in zero feces rations) than observed in the studies reported herein. Hence, under field conditions, feces would probably have a somewhat higher starch content and potential refeeding value than in the studies reported here.

The crude protein in feces appeared to have a relatively low digestibility, but the efficiency of N utilization from urine appeared more favorable. Hence, urine in particular, might serve as a source of supplemental dietary N in some cases. Refeeding waste does not appear to create any problems with normal mineral retention in animals.

More definitive studies are needed in which 1) feces are recycled over more successive refeeding phases, 2) feces are included at varying levels in recycling test diets, 3) time is not a variable when comparing digestibilities in one refeeding phase vs another, 4) both feces and urine are included simultaneously for refeeding purposes, and 5) more types of diets are studied in recycling programs.

SECTION IV

LITERATURE REVIEW

EARLY RECYCLING WORK WITH CATTLE FECES

Pioneering work on the feasibility of refeeding steer manure was done by Anthony and Nix (1962) and Anthony (1966). In these initial trials, the solid portion of manure was separated from the liquid portion by vibrating screens or by adding additional water, allowing the solids to settle and decanting the water. The solid portion was then mixed in fattening rations in a 2:3 ratio, as-is, and fed to steers. However, on a dry matter basis the manure would have composed a much smaller fraction of the ration (approximately 20%). In a subsequent trial, cooked, washed and unwashed manure were compared (Anthony, 1970). It was concluded that neither cooking or washing of manure resulted in any improvement in feeding value. Anthony observed manure to have no negative effects on ration digestibilities of dry matter, crude protein or cellulose. This suggested manure to be of some nutritive value for productive purposes.

Ensiling Manure and Recycling

Refeeding fresh manure will only partially alleviate waste disposal problems. In Anthony's (1970) studies, only about one-half of the manure collected daily was refed and the remainder discarded. Thus, the concept of wastelage was developed by Anthony (1966, 1967, 1968, 1969) and Bandel and Anthony (1969). Wastelage was a term coined by Anthony to describe a combination of fresh manure mixed with ground grass hay (e.g. 57 kg of hay/43 kg of wet manure on an as-is basis) with the mixture being stored in a silo until fed. Fermentation occurs, and the product develops a silage odor while much of the manure odor disappears. Such a method of processing manure might effectively permit utilization of feedlot waste as feed and reduce disposal problems.

When Anthony (1969, 1971) combined 40% wastelage (wastelage consisted of approximately 80% hay and 20% manure on a dry matter basis) with 60% corn on an as-is basis and fed the mixture as a finishing ration to steers, average daily gains were equivalent to those on either a convential high concentrate finishing ration or a conventional high concentrate ration containing 40% fresh (as-is) untreated manure (Anthony, 1971). Anthony (1968) further reported corn silage fed cattle to be out-gained by wastelage fed cattle in two trials. However, the differences were not significant.

Breeding ewes and beef cattle have been adequately maintained on wastelage for up to a year when supplemented with Vitamin A (Anthony, 1967, 1979). During this period, the animals went through breeding, gestation and lactation. The wastelage fed ewes were reported to be in better physical condition than hay fed control ewes at the end of the second lambing. In addition, the average daily hay saving per wastelage fed ewe was reported at 0.79 kg.

Moore and Anthony (1970) anaerobically fermented cattle manure with ammonia and thereby increased the crude protein content from 17.0 to 43.3% (DM basis). The increase in protein content was mainly the result of increased bacterial protein and ammonium lactate. McClure et al. (1973) fed fermented manure containing straw bedding to steers ad libitum, and the steers were able to maintain their body weight for 60 days. They also reported that when manure containing corn stover bedding plus 10% ground shelled corn was fermented, and additional ground shelled corn was added to equal the grain in corn silage, average daily gain and dry matter intake were better than when corn silage was fed alone. When Cereco silage, a fermented processed feed made from feedlot manure, was fed to steers in a digestion study, dry matter and crude protein digestion coefficients were similar to those for cattle fed corn silage (Ward et al., 1974). Cereco silage was as palatable as corn silage when fed as 25 to 50% of the ration.

Chemical Treatment of Manure

A large portion of the undigested feed residues in feces is composed of cell walls consisting of cellulose, lignin and hemicellulose. If the cell wall portion of the feces could be made available to the rumen microbes, then additional nutrients would be available for use by the animal. Maximum response in improving cell wall digestion was noted when feces was treated with 3-4% sodium hydroxide or sodium peroxide (as-is basis) in in vitro studies conducted by Smith et al. (1969). This improvement in cell wall digestion was the result of chemical solubilization and/or bacterial cell wall digestion, depending on the substrate. When Smith and coworkers evaluated chemically treated manure via in vivo studies, they found significant improvements in cellulose and hemicellulose digestibilities for the chemical treated manure as compared to untreated manure. However, nitrogen digestibility remained unchanged.

When the digestion coefficients for the chemically treated and untreated feces were calculated, dry matter and cellulose digestibilities doubled, cell wall digestibility was enhanced four fold and hemicellulose digestibility was improved ten fold by chemical treatment of the feces. Nitrogen digestibility was improved from 0% for the untreated feces to 18% for the chemically treated feces. However, the low fecal nitrogen digestibility value suggests recycling of feces from forage fed animals to be of little value for further nitrogen utilization.

Smith et al. (1971) reported that the effect of chemical treatment on feces to be dependent upon the composition of the feces. They observed higher cell wall digestibility for manure uncontaminated with sawdust than

for manure having sawdust bedding and urine contamination. Sawdust influenced the results in these studies as it was less responsive to chemical treatment than feces.

Composition of Feces

The dry matter content of cattle manure usually varies from 20-30% as reported by Anthony (1969, 1971). Values for crude protein content of feces are reported to range from 13 to 27% by Anthony (1971), Linnimit et al. (1972), Johnson et al. (1972) and Lucas et al. (1975). Anthony (1971) noted that urea contributes up to 2-4% of the crude protein in feces.

Cell wall content values vary from 22 to 71% on a dry matter basis (Anthony, 1971, Johnson, 1972 and Lucas et al., 1975). Johnson (1972) and Lucas et al. (1975) have reported acid detergent fiber to be from 17-45%, cellulose 16 to 30%, and lignin 5 to 9% on a dry basis. Hemicellulose content of feces was reported to be 26% by Lucas and coworkers (1975).

Contamination of feces with dust, sand or soil during the collection process can bias the fecal ash value upward (Johnson, 1972). As a result of soil contamination, Johnson (1972) reported fecal ash values to be around 40% while Lucas et al. (1975) and Anthony (1971) reported ash content to be from 5-12% in feces on a dry basis.

Fecal calcium and phosphorus values on a dry basis range from 0.2 to 0.9% and 0.5 to 1.6%, respectively, as reported by Anthony (1971). Anthony also found magnesium content to be the highest of all minerals at 0.7 to 3.1%. Potassium ran between 0.5% to 0.9%, and copper, iron, manganese and zinc were all present in minute amounts.

Feces as a Source of Supplemental Nitrogen

Anthony (1971) found urea to be inferior to wastelage in supplementing a corn diet. Moreover, Tinnimit et al. (1972) found nitrogen retention data to favor soybean meal over feces as the supplemental source of nitrogen for lambs, whether intakes were restricted or unrestricted. However, the lambs fed the feces diets remained in positive nitrogen balance for the four week trial, and their nitrogen balance and utilization values were remarkably high (1-5 g of nitrogen retained per day) considering that 40 to 65% of the dietary nitrogen was of fecal origin. Soybean meal control lambs retained one to nine grams of nitrogen per day. Lucas and coworkers (1975) observed higher fecal nitrogen excretions for steers receiving a diet containing 20% feces as compared to a basal diet even though nitrogen intake favored the basal ration. This reflects poor nitrogen digestibility of the feces portion of the ration. As a result, nitrogen retention, expressed as grams per day, percent of nitrogen intake or percent of absorbed nitrogen was significantly higher for the basal ration as compared to the feces ration.

Johnson (1975) substituted feedlot feces for the majority of the soybean meal in a standard high concentrate feedlot ration on an iso-nitrogenous basis and found average daily gain to be reduced and feed to be less

efficiently utilized for the feces ration as compared to the soybean meal ration. His results were perhaps influenced, however, by lower intake of the feces ration.

Feces as a Roughage Source

When feedlot feces were substituted for cottonseed hulls at levels of 25 and 40% in a high roughage ration, ration dry matter digestibilities were lower for the feces containing rations while organic matter digestibilities were similar for both basal and feces rations (Johnson, 1972). Nitrogen digestibilities were consistently higher for the feces ration while ash digestibilities were lowered by the addition of feces to the rations. Johnson further reported the theoretical digestibilities of fecal dry matter and organic matter to be in the range of what many low quality roughages would be.

In a later study, Johnson et al. (1975) substituted feedlot waste for cottonseed hulls in a high concentrate feedlot type ration. The treatments compared were 1) a control containing 15% cottonseed hulls, 2) feedlot waste as a total replacement for cottonseed hulls and 3) 10% feces plus 5% cottonseed hulls. Apparently, feedlot waste in this trial was not a good roughage source as lamb growth performance data was the poorest for the lambs receiving feces as a total replacement for cottonseed hulls. The control fed lambs were the fastest gainers and most efficient feed converters.

Effect of Increasing Levels of Feces in Ration on Ration Digestibility

When dried caged layer feces were incorporated into a standard basal ration at 20, 40, 60 and 80% levels, and the proportion of corn cobs to corn starch was held constant, overall ration digestibilities of dry matter and organic matter decreased linearly with each increasing level of feces (Tinnimit et al., 1972). Regression equations predicted dry matter and organic matter digestibilities of dried poultry waste to be 53 and 65%, respectively.

Albin and Sherrod (1975) compared levels of 0, 20, 40 and 60% of dry feedlot waste in a high concentrate ration and found a significant linear decrease in dry matter, organic matter, apparent and true protein, cell solubles and cell wall ration digestibilities with increasing levels of feces. The apparent digestion coefficients for feedlot waste increased linearly with each higher percentage of feces level. The authors suggested that this could indicate an associative effect between the feces and the remainder of the ration.

Apparent Digestibility of Nutrients in Feces

Feedlot feces incorporated into low energy-low protein rations were observed by Albin and Sherrod (1975) to have higher digestion coefficients, except for cell walls, than feces incorporated into high energy-adequate protein rations. Differences between the two types of rations in fecal protein digestibility were the most obvious.

Table 1 shows some apparent digestion coefficients of feces as calculated by difference.

TABLE 1. THEORETICAL DIGESTIBILITIES AS CALCULATED BY DIFFERENCE FOR FECES PRODUCED BY ROUGHAGE AND FEEDLOT RATIONS

	Source of Feces	
	Roughage Ration %	Feedlot Ration %
Dry matter	16-22[a,d]	33-50[b,c]
Organic matter	14[d]	35-56[b,c]
Crude protein	0-26[a,d]	26-71[b,c]
Cell walls	15-18[a,d]	16-29[c]
Acid detergent fiber	5[d]	------
Cellulose	12-34[a,d]	------
Hemicellulose	10-28[a,d]	------

[a] Smith et al. (1969)

[b] Johnson (1972)

[c] Albin and Sherrod (1975)

[d] Lucas et al. (1975)

Fecal digestion coefficients for all nutrients are consistently higher when a feedlot type of ration is the source of feces as opposed to feces from a high roughage ration.

Continuous Recycling of Feces

Anthony (1970) refed cattle manure which was collected from cows that were fed manure themselves and noted no build-up of indigestible fecal residues at least as indicated by moisture content. The moisture content of the feces was higher at the end of the second cycle. However, the quantitative dry matter output, etc. was not determined. Albin and Sherrod (1975) reported results of a study by Ferrell and Garrett (1973) in which their data suggest no increase in fecal minerals and lignin content due to recycling. They also reported that only about 26% of the dry matter in manure was digested by recycling on their rations.

Flegal et al. (1972) studied the effect of long term recycling in poultry of dehydrated poultry waste on the composition of feces and on bird performance. Feces were collected for 12 days, dehydrated and refed at levels of 12.5 and 25% as a replacement for corn in a standard cage laying ration for 31 successive cycles. The crude protein, crude fiber and ash composition of the dehydrated poultry waste varied from cycle to cycle, but appeared to be unrelated to the number of successive cycles. Calcium seemed unrelated to cycle at the 12.5% level but seemed to increase with each successive recycling when fed at the 25% level. Fecal phosphorus increased with successive recycling after about the tenth cycle when feces were fed at either level. However, after 31 cycles, both feces rations had similar proximate analyses. Hen housed egg production, daily feed per bird and mortality figures favored the hens fed the 12.5% dehydrated poultry waste over the hens fed the control or 25% feces rations. However, all of these values reflect fecal composition values only and not total fecal output as well. Differences likely existed in the quantity of fecal output with repeated cycling.

SECTION V

TRIAL 1--RECYCLING DIGESTION TRIAL WITH STEERS

SUMMARY

Feces which were produced on a 90% concentrate ration in phase 1 were recycled in three consecutive phases (2,3,4) through beef cattle to determine the effect of feces recycling on the accumulation of indigestible residues and on nutrient digestibility. Feces from one phase (1,2,3) were refed in the next phase (2,3,4). In phases 2, 3 and 4, feces (15%) from the previous phase were then substituted for either all of the roughage (10% cottonseed hulls, CSH) and 5% corn (T1) in the basal ration or for 15% of the complete basal ration fed in phase 1 (T2).

Total indigestible residue excretions increased 60.8% (T1) to 72.4% (T2) when feces were recycled the first time. Additional recyclings, however, produced no further increase in total residue excretion. Excretion of most fractions, particularly fibrous components, was slightly greater on T2 than T1, reflecting the absence of CSH in T1.

Total ration dry matter digestibility decreased from 85.6% in phase 1 (no feces fed) to 76.1-78.3% in phases 2, 3 and 4, with the values being only slightly higher (~1%) for T1 than T2 in the three refeeding phases. Feces appeared to provide an adequate roughage replacement for CSH. Digestibility values for various nutrient parameters in feces (calculated by difference) when feces were refed in phases 2, 3 and 4 were generally quite low. Digestibility of the feces increased with each successive recycling, indicating possible adaptation. Crude protein and ash content of the feces tended to increase with each recycling.

Recycling feces three consecutive phases reduced the disposable waste load by 34%. Data in this experiment indicate that feces can be recycled three times without any material buildup of Na, Cl or P residues. Calcium, however, showed a definite accumulation. There were no detrimental effects upon mineral retention when feces were recycled.

INTRODUCTION

Digestion studies with steers were conducted in Trial 1 in which feces were recycled (refed) in three successive phases. The objectives of this trial were:

1) To determine the influence of recycling beef cattle feces on ration nutrient digestibility.

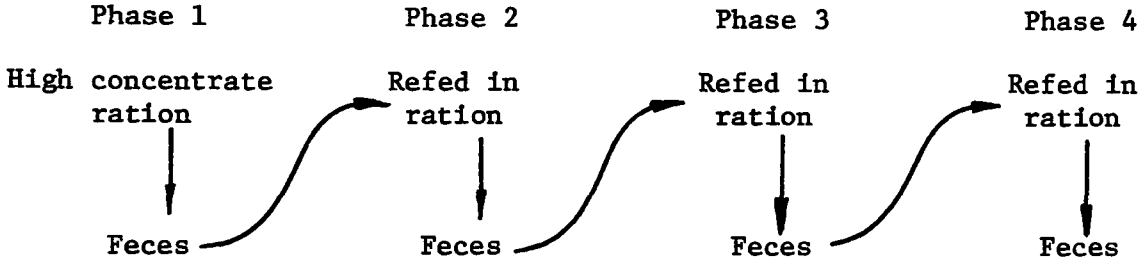
2) To determine the accumulation of indigestible residues in feces as a result of recycling through cattle three consecutive phases.

3) To study the effect on digestibility of replacing the roughage with feces in a high concentrate ration.

GENERAL PROCEDURES

Experimental Design

The overall experimental design can be depicted graphically as follows:



Feces produced in phase 1 were refed in phase 2; that produced in phase 2 were refed in phase 3, etc. A high concentrate ration (Table 2) was fed in phase 1 to produce feces for refeeding in phase 2. Hence, there was only one treatment in phase 1 (84.0% corn, 10.0% cottonseed hulls, 6.0% supplement). This is termed a basal ration. In this trial, feces were reincorporated (phase 2,3,4) at a level of 15% (DM basis) in the ration. Since the ration had a DM digestibility of nearly 85% in phase 1, this represented nearly complete feces reincorporation, particularly in the early phases. In phases 2, 3 and 4 there were two treatments as follows:

T1) Feces (15%) from the previous phase replaced the 10% cottonseed hulls (CSH), plus 5% corn in the basal ration fed in phase 1.

T2) Feces (15%) replaced 15% of the basal ration fed in phase 1 (i.e. ration was 85% basal + 15% feces from previous phase).

The ration formulae are shown in Table 2. Since final dry matter (DM) values differed slightly from the preliminary estimated DM values, the final formulae actually fed (as shown in Table 2) contained 15.4% feces rather than 15.0%. The same was true for the other ration ingredients, and this accounts for the slight difference noted between the desired formulae (15% feces) and those actually fed (15.4% feces).

Animals Used in Digestion Studies

Twelve Hereford X Angus crossbred yearling steers (approximately 400 kg) raised in the University herd were selected from a large group on the basis of uniformity, age and conditioning to establish a "pool" of animals for use

in conducting the recycling trials. Due to the time required to complete these trials, it was necessary to have sufficient steers available to permit periodic rotation and resting of animals. When steers are maintained in digestion stalls for prolonged periods, leg problems (swollen and sore knees and hocks, stiffness, etc.) can develop unless there is an opportunity for periodic exercise. To permit this, steers were removed from digestion stalls when it appeared desirable at the termination of a collection period. When not in the digestion stalls, the steers were maintained on the same ration but placed in a large. concrete floor pen for at least several weeks. Other steers from the "pool" of experimental animals could then be rotated or placed in the digestion stalls for collection purposes during this time.

TABLE 2. COMPOSITION OF RATIONS FED IN TRIAL 1

Ingredient[1]	Phase 1	%	
Ground corn, 4-02-935		83.5	basal ration
Cottonseed hulls, 1-01-599		10.2	
Supplement[2]		6.3	
Soybean meal, 5-04-604	3.6%		
Urea	0.6%		
Wheat middlings, 4-05-205	1.1%		
Calcium carbonate, 6-02-632	0.6%		
Dicalcium phosphate, 6-01-080	0.2%		
Salt, trace mineral	0.2%		
	6.3%		

	Phases 2, 3, 4		
Ingredient	T1 %	T2 %	
Ground corn	78.3	70.6	84.6% basal
Cottonseed hulls	----	8.6	
Supplement	6.3	5.4	
Feces[3]	15.4	15.4	

[1] Dry matter basis.

[2] 3,300 I.U. Vitamin A/kg.

[3] Feces from the previous phase.

Procedure for Conducting Digestion Trials

Four steers were selected at random from the pool of steers and assigned to individual digestion stalls. During phase 1, all four steers were fed the basal ration for at least 10 weeks to assure an ample supply of feces for the

following phases. A one week ration adaptation period was followed by total daily collections of feces and urine. No feces were saved during adaptation (first week). Thereafter the feces and urine samples for all four steers were composited daily and dried in a 60°C forced air oven for 48 hours for later refeeding. The dried feces were then ground in a hammermill, without a screen, for incorporation into diets T1 and T2 of phase 2. The urine was dried to a molasses consistency and stored frozen until needed later in Trials 3 and 5. Approximately the fourth week, digestion study data were collected on the four individual steers for a seven day period to ascertain digestibility. Individual steer outputs of feces and urine were weighed daily, and 10% of each day's output was frozen in individual containers. The daily samples were then composited by steer at the end of the 7 days, and sub-samples were taken and frozen for laboratory analyses.

In phase 2, four more steers were chosen at random from the pool and used for the remainder of the trial. Two were assigned to each of T1 and T2 in a switchback design consisting of two periods (see diagram in Figure 1 for illustration). The first period lasted for a period of 4-5 weeks wherein the procedure was the same as described for phase 1 except compositing of daily fecal collections for refeeding was done by treatment. At the end of the first period, the steers switched rations so every steer consumed each of the two rations, giving 4 observations per treatment (T1 and T2). The second period was handled in the same manner as the first period. The completion of the second period marked the end of phase 2. As illustrated in Figure 2, feces from periods 1 and 2 were combined by treatment for refeeding into their respective rations in phase 3. Phases 3 and 4 followed the same procedure as phase 2.

Water was available at all times during the digestion trials. The steers were fed at a level slightly above maintenance, 2.24 kg per steer twice per day (total of 4.48 kg DM/day). There were no feed weighbacks as the rations were readily consumed by the steers. When steers were reversed from one treatment to another to complete the switch back design, (T1→T2 or vice versa) after the completion of a period within a phase, feces were not saved for later refeeding during the first 5 days for adjustment.

Laboratory Analyses

Dry Matter and Ash

The dry matter content of wet feces was determined by drying approximately 600 g of steer feces from each animal in a forced draft oven at 60°C to a constant weight (48 hr). The samples were removed from the oven, allowed to equilibrate with the air for 24 hr and then reweighed. The steer feces were ground through a 1 mm screen in a large Wiley mill. Dry matter was determined on a two gram sample of the ground feces, and the 100% dry matter of the wet feces was thus calculated by multiplying the two dry matters. The two gram dry matter sample was then ashed in a 600°C furnace for four hours and reweighed. The residue in the crucibles was digested in 20% hydrochloric acid and diluted to volume with demineralized water for mineral analysis (Na, Ca, Cl). Dry matter and ash on the rations were determined by AOAC (1965) procedures.

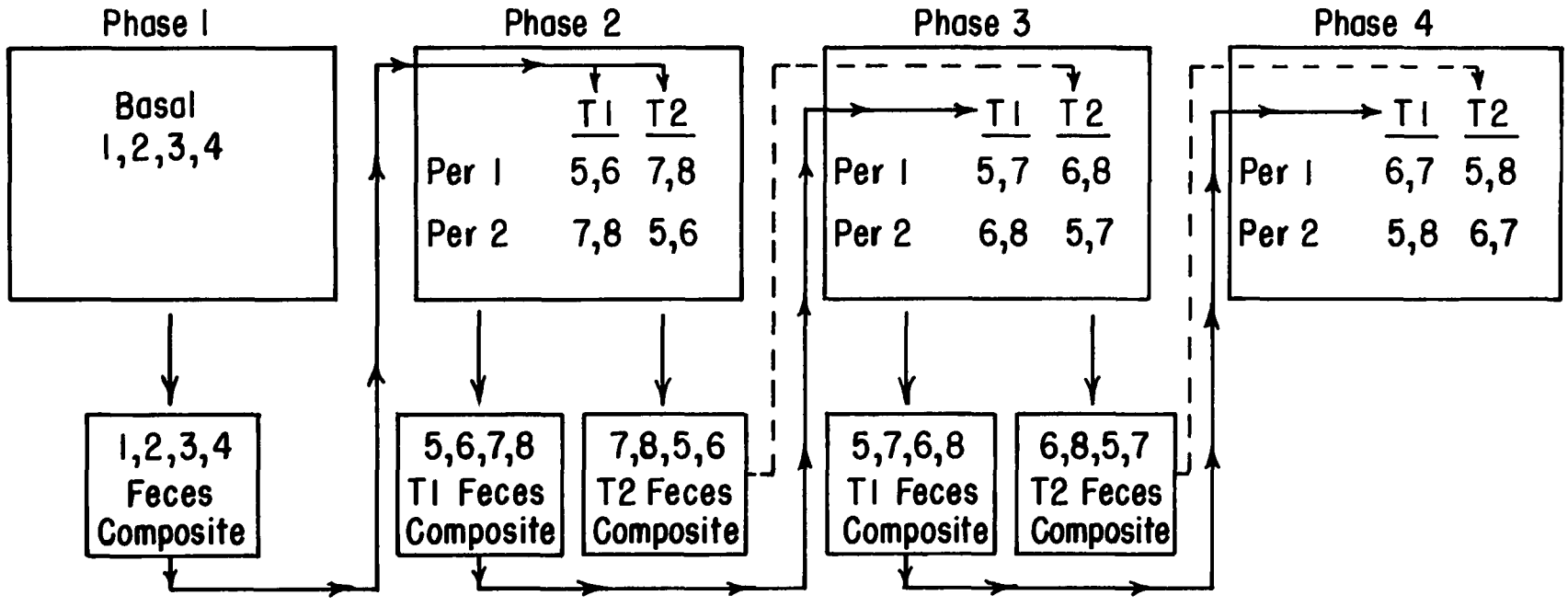


FIGURE 1. SCHEMATIC DIAGRAM OF THE EXPERIMENTAL DESIGN USED IN TRIAL 1. Numbers 1 to 8 represent steers. Per=period within a phase used for switchback purposes.

Crude Protein

Crude protein was determined on rations, urine, and dried feces according to AOAC (1965) methods. Crude protein was also determined on wet steer feces by placing an 80 g sample of wet feces in a Waring blender along with 250 ml of water and blending for two minutes. Duplicate ten gram samples of the homogenate were analyzed for nitrogen content by the Kjeldahl procedure. Dry matter was also determined on the homogenate. Since the crude protein values on the wet steer feces were consistently higher (approximately 10%) than on the dried steer feces, the values on the wet steer feces were used in determining the crude protein digestion coefficients.

Fiber

Acid-detergent fiber (Van Soest, 1963), lignin and cellulose (Van Soest and Wine, 1968) were determined on rations and dried feces. Total cell walls (NDF) were determined by a modification of the Van Soest and Wine (1967) procedure. Ashless filter paper (Whatman #541) was used instead of the recommended Gooch crucible for filtering NDF's due to the filtering difficulty encountered with the feces samples.

Minerals

Calcium and sodium were determined on the acid-digested ash samples using an atomic absorption spectrophotometer. Phosphorus was determined on a color spectrophotometer using ammonium molybdate as a color developer. Chlorine was analyzed according to AOAC (1965) methods. Calcium analysis in Trial 1 showed that most, 99%+, of the calcium excretion to be in the feces, thus, making accurate calcium determinations in the urine difficult, if not impossible and totally meaningless.

Calculations

Apparent digestibilities of dry matter, organic matter, crude protein, cell walls, acid-detergent fiber, lignin and cellulose in dried steer feces were calculated by-difference (Crampton and Harris, 1969). The by-difference method assumes in the calculations that the digestibility of the basal portion of the ration (ration component other than feces) remains the same when feces are included as when the basal ration is fed alone. That is to say, if a basal ration has a digestibility of 80% when fed alone, the basal ration component is assumed to still have a digestibility of 80% when fed with feces. Thus, if a ration contained 90% basal + 10% feces, the digestibility contribution from the basal portion would be 72% (90% X 80% = 72%). Coefficients of digestion were calculated in the conventional manner (i.e. Intake-excretion/Intake X 100 = % digestibility).

Statistical Analyses

The data were analyzed by analysis of variance and differences among means were tested by the least significant difference test (Snedecor and Cochran, 1967).

RESULTS AND DISCUSSION

Digestibilities of Complete Rations

Dry Matter

Ration dry matter digestibility decreased from 85.6% for the basal ration in phase 1 to 76.8% and 75.4%, for T1 and T2, respectively, in phase 2 (Table 3). In each consecutive phase (2,3,4), a slightly higher dry matter digestibility was obtained (P>.05) within each treatment. Moreover, in every phase, dry matter digestibility for T1 was slightly higher (P>.05) than for T2, averaging 77.7 for T1 vs 76.6% for T2 in the three phases. The slightly lower digestibilities observed for T2 can be attributed to the presence of 8.5% CSH in T2 vs 0% in T1. Interestingly, the differences might have been anticipated to be greater than actually observed. Recall that feces replaced CSH as the roughage source in T1 and appeared to provide an adequate roughage replacement.

Organic Matter

The inclusion of feces into the basal ration resulted in a decrease of approximately 9% in organic matter digestibility (Table 3). However, as with dry matter, organic matter digestibility increased slightly (P>.05) with each additional recycling of feces. No significant differences (P>.05) were observed between treatments within a phase or among phases within a treatment.

Ash

Ash digestibility in phase 2 was 44.9 (T1) and 42.9% (T2), as compared to 57.2% for the basal in phase 1 (Table 3). This is a net reduction of 21.5 (T1) and 25.0% (T2) in ash digestibility after the first recycling of feces. Within each treatment, ash digestibilities increased (P>.05) with each additional recycling of feces after the first. Differences between treatments within a phase were not significant. Such a percentage reduction can be accounted for largely by the increased total mineral intake in that net retention expressed on a gram or quantity basis remained about the same as in phase 1.

Crude Protein

Although not significant, crude protein digestibility was slightly higher for T1 than T2 in every phase (Table 3). Phase differences within each treatment were not significant for protein digestibility. The first recycling of feces resulted in a decrease of 12.8 and 14.7% in crude protein digestibility for T1 and T2, respectively as compared to the basal ration. The average protein digestibility for phases 2 thru 4 was approximately 58% vs 68.2% in phase 1.

Acid Detergent Fiber

Acid detergent fiber (ADF) digestibility was markedly lower (45.5%) for T1 in phase 2 as compared to the basal ration (Table 4). Also, in phase 2 ADF digestibility for T2 was 24.5% less than for the basal ration. ADF digestibility for T1 decreased from 28.7% in phase 2 to 19.5% in phase 4, while T2 increased from 39.8% to 45.0% over the same period. In phases 2, 3, and 4, ADF digestibilities were higher for T2 than for T1 (39.8% vs

TABLE 3. APPARENT RATION DIGESTIBILITIES OF DRY MATTER, ASH AND CRUDE PROTEIN IN TRIAL 1

		Rations				
		Basal	T1	T2	Means	SEM[1]
		----------%----------				
Dry matter[2,3]	Phase 1	85.6			85.6	
	2		76.8	75.4	76.1	1.3
	3		77.6	76.7	77.2	1.4
	4		78.8	77.8	78.3	1.1
	SEM		1.5	0.7		
Organic matter	Phase 1	86.8			86.8	
	2		78.7	77.2	78.0	1.2
	3		79.6	78.3	79.0	1.3
	4		80.4	82.8	81.6	1.1
	SEM		1.6	0.6		
Ash	Phase 1	57.2			57.2	
	2		44.9	42.9	43.9	3.5
	3		45.2	49.8	47.5	2.6
	4		50.1	52.8	51.4	2.4
	SEM		3.3	4.7		
Crude protein	Phase 1	68.2			68.2	
	2		59.5	58.2	58.8	2.4
	3		61.4	55.8	58.6	1.7
	4		59.8	57.1	58.4	1.5
	SEM		1.8	2.3		

[1] Standard error treatment mean.

[2] Phase 1 was not included in the statistical analyses.

[3] Values represent the mean of four observations per treatment.

28.7%, 42.3% vs 24.8% and 45.0% vs 19.5%) reflecting the presence of CSH in the ration. These differences were significant (P<.05) in phases 3 and 4.

Lignin

There were no differences (P>.05) between treatments within a phase or among phases within a treatment in lignin digestibilities (Table 4). The addition of feces to the ration decreased lignin digestibility from 52.3%

TABLE 4. APPARENT RATION DIGESTIBILITIES OF ACID-DETERGENT FIBER, LIGNIN, CELLULOSE AND NEUTRAL DETERGENT FIBER IN TRIAL 1

		Rations				
		Basal	T1	T2	Means	SEM
		----------%----------				
ADF[1,2,3]	Phase 1	52.7			52.7	
	2		28.7	39.8	34.2	3.7
	3		24.8[a]	42.3[b]	33.6	3.7
	4		19.5[a]	45.0[b]	32.2	3.6
	SEM		4.3	2.0		
Lignin	Phase 1	52.3			52.3	
	2		33.5	38.0	35.8	3.5
	3		38.1	39.3	38.7	3.6
	4		36.7	39.5	38.1	3.4
	SEM		2.5	1.2		
Cellulose	Phase 1	62.7			62.7	
	2		34.6	47.6	41.1	4.3
	3		37.2	51.1	44.2	3.7
	4		33.8[a]	55.6[b]	44.7	2.9
	SEM		4.8	2.3		
NDF	Phase 1	77.8			77.8	
	2		63.5	66.7	65.1	3.2
	3		65.6	66.9	66.2	2.1
	4		64.6	67.7	66.2	1.8
	SEM					

[1] Phase 1 was not included in the statistical analyses.

[2,a,b] Values within phase with different superscripts differ significantly ($P<.05$).

[3] Values represent the mean of four observations.

for the basal ration to 33.5% for T1 and 38.0% for T2 in phase 2. T2 tended to have slightly higher lignin digestibilities than T1 in every phase, again reflecting the presence of CSH.

Cellulose

Cellulose digestibility was higher in T2 than T1 in every phase by approximately 13-18% with the difference being significant (P<.05) in phase 4 (Table 4). Cellulose digestibilities were 34.6% and 47.6% for T1 and T2, respectively, as compared to 62.7% for the basal ration. This is a decrease in cellulose digestibility of 44.8% for T1 and 24.1% for T2. The second and third recyclings of feces produced no significant change in cellulose digestibility for T1 or T2.

Neutral Detergent Fiber

Neutral detergent fiber (NDF) favored (P>.05) T2 over T1 in every phase (Table 4). The first recycling of feces reduced NDF digestibility by 18.4% for T1 and 14.3% for T2. No differences (P>.05) were noted among phases 2, 3 and 4 within either treatment.

Average of Treatments by Phase

Since phase X treatment was not significant for any of the parameters, digestion coefficients for T1 and T2 were averaged for each phase (Table 3). Digestion coefficients for all the nutrients were lower in phase 2 as compared to phase 1. When averaged across treatments, ration digestibilities increased slightly with the first, second and third recycling of feces as follows: dry matter--76.1, 77.2 and 78.3%; organic matter--78.0, 79.0 and 81.6%; and ash--43.9, 47.5 and 51.4%. Crude protein digestibilities for the rations were about 58% during all three recycling phases. Lignin, cellulose and NDF digestibilities showed a similar pattern. It appears that perhaps some gradual adaptation to improved digestion of feces occurred with prolonged feeding. Ferrell and Garrett (1973) reported that the more digestible nutrients in a 50% feces ration tended to decrease during recycling while the less digestible components tended to increase.

Apparent Digestibility of Fecal Nutrients

There was a calculated disappearance of 19% for fecal dry matter with one recycling (Table 5). Similar values have been reported by Lucas *et al.* (1975) and Smith *et al.* (1971) for dry matter digestibility of feces when feces were included at 20 and 25%, respectively, in high roughage rations. Albin and Sherrod (1975) observed that about 33% of the dry matter in manure disappeared with one recycling when manure constituted 40% of a feedlot ration for cattle. However, they stated that digestion coefficients for fecal nutrients were lower when feces were refed at a level of 20% than 40% in the ration; similarly inclusion at a 60% level produced higher disappearance values than the 40% level. This suggests an associative effect. Dry matter digestibility of the feces in phases 3 and 4 was slightly higher, but still rather low being 27.7 and 34.3%, respectively. Thus in this experiment, after 3 recyclings, the amount of disposable manure would appear to be reduced by approximately one-third. Ferrell and Garrett (1973) refed cattle manure at a level of 50% in a high roughage pelleted ration and reported dry matter digestibilities for manure to be 26.6, 15.1 and 15.7% during the first, second and third recycling of manure, respectively. The differences in trends may be attributed to numerous variables, including the type of ration into which feces were incorporated--e.g., high roughage *vs* high concentrate.

TABLE 5. APPARENT DIGESTION COEFFICIENTS FOR CATTLE FEEDLOT WASTE--CALCULATED BY DIFFERENCE

Number of recyclings	PH 2 1	PH 3 2	PH 4 3	Means
	----------	----------	%	----------
Apparent digestibilities:[1]				
Dry matter	19.0	27.7	34.3	27.0
Organic matter	24.9	31.4	60.6	39.0
Ash	-35.5	9.1	28.6	0.7
Crude protein	3.7	-12.2	-4.9	-3.2
ADF	-31.3	-14.6	2.0	-14.6
Lignin	-40.7	-31.7	-31.9	-34.7
Cellulose	-35.4	-12.5	15.7	-10.7
NDF	5.6	7.1	11.4	8.0

[1] Calculated by difference as outlined by Crampton and Harris (1969).

All fecal nutrients, except crude protein and lignin, showed increased digestibility with each successive recycling of feces. This increase in digestibility of fecal components for each successive recycling of feces could indicate that the rumen microbes are undergoing some sort of adaptation over time in response to the presence of feces in the ration. However, traditionally any adaptation response would be expected to occur much more rapidly. For the most part, digestion coefficients were low for all nutrient parameters in the feces. The negative digestibilities that appear in the table for some items were unexpected and perhaps suggest a negative associative effect between feces and the remainder of the ration.

The low digestibility values for crude protein in feces in this experiment suggest limited potential for feces as a supplemental protein source in feedlot rations. However, the urine was not included and may effect the results in that manure normally includes nitrogen or protein contributions from both feces and urine.

Composition of Feces

The dry matter content of feces as excreted in Trial 1 ranged from 23.4% to 25.7% (Table 6) and showed little difference with recycling. The

ash content of feces tended to be several percent higher when the ration contained feces (phases 2,3,4) than when it did not (phase 1). The crude protein content of feces also tended to increase somewhat in each recycling phase (average of 22.2% in phase 2 vs 25.6% in phase 4).

The percent sodium in the feces produced by steers consuming feces (phases 2,3,4) was lower (0.11 to 0.24%) than in the feces produced by steers fed the basal ration (0.42%). Although the differences were small, chlorine content of feces, on the other hand, was higher in refeeding phases 2, 3, and 4 than with the basal ration (phase 1). Calcium content in feces tended to be higher when feces were recycled, and phosphorus lower than in phase 1. However, one must remember that the percentage composition is also a function of output when considering total residue excretion. Total residue excretions are presented later.

Composition of Urine

The percent crude protein in urine was slightly higher for T2 than for T1 in all phases (Table 7) with the average content being approximately 4%. Although the urinary sodium content on both T1 and T2 was higher in phase 2 than for the basal in phase 1 (0.18 vs 0.10%), the urinary sodium level decreased in phases 3 and 4 (0.12 and 0.10%, respectively) which were similar to those in phase 1. Chlorine content in urine was highest for steers fed the basal ration (0.54%) and declined with each successive recycling of feces in each treatment (0.21 to 0.14% for T1 and 0.26 to 0.15% for T2). The percent phosphorus in urine for the basal ration was 0.08%. In phases 2, 3 and 4, the respective values were: 0.17, 0.15, 0.07% for T1 and 0.23, 0.15 and 0.11% for T2.

Residue Excretions

The total indigestible fecal dry matter produced daily on the basal ration was 575.2 g compared to an average of 925.2 g (T1) and 991.4 g (T2) in phase 2 (Table 8). This represents an increase of 60.8% for T1 and 72.4% for T2 in indigestible dry matter excretion when feces are recycled once. The second and third recyclings (phases 3 and 4) resulted in a slight decrease in the accumulation of total indigestible residues.

The first recycling of feces resulted in a 40-90% increase over the basal ration in the accumulation of indigestible ash, ADF, lignin, cellulose and NDF residues, with the increase being larger for T2 than T1, particularly for all of the fiber fractions. This observation can be explained by the absence of CSH in the T1 ration. As with dry matter, the accumulation of indigestible residues associated with the second and third recyclings of feces (phases 3 and 4, respectively) tended to either remain stable or to decline as compared to the first recycling (phase 2). The large increases in indigestible residues when feces are recycled confirms the rather low digestibilities noted for the various fecal fractions. However, a portion of the feces are digested when recycled as evidenced by the fact that indigestible residues did not double when there was essentially complete fecal reincorporation. Moreover, the general decrease in total daily indigestible residue excretions from phases 2 through 4 suggest some adaptation to fecal

TABLE 6. COMPOSITION OF FECES IN TRIAL 1

Rations		Basal	T1	T2	Means
		%			
Dry matter [1,2]	Phase 1	25.7			
	2		25.0	24.2	24.6
	3		25.8	24.6	25.2
	4		23.4	24.5	24.0
Ash	Phase 1	11.5			
	2		13.4	12.6	13.0
	3		13.9	11.6	12.8
	4		12.8	12.6	12.7
Crude protein	Phase 1	24.4			
	2		23.1	21.2	22.2
	3		23.5	24.3	23.9
	4		25.0	26.1	25.6
ADF	Phase 1	32.1			
	2		28.8	34.9	31.8
	3		26.4	34.8	30.6
	4		28.9	31.6	29.8
Lignin	Phase 1	11.7			
	2		11.8	12.8	12.3
	3		10.4	13.8	12.1
	4		10.8	13.1	12.0
Cellulose	Phase 1	21.0			
	2		18.2	21.9	20.0
	3		15.3	21.2	18.2
	4		16.6	18.2	17.4
NDF	Phase 1	48.8			
	2		45.0	46.8	45.9
	3		42.3	48.7	45.5
	4		46.4	44.9	45.6
Sodium	Phase 1	0.42			
	2		0.24	0.18	0.21
	3		0.11	0.14	0.12
	4		0.18	0.20	0.19
Chlorine	Phase 1	0.20			
	2		0.23	0.28	0.26
	3		0.25	0.26	0.26
	4		0.23	0.24	0.24

Table continued

TABLE 6 (Cont'd). COMPOSITION OF FECES IN TRIAL 1

Rations		Basal	T1	T2	Means
		----------	%	----------	
Calcium	Phase 1	2.22			
	2		2.52	2.24	2.38
	3		2.59	2.15	2.37
	4		2.63	2.69	2.66
Phosphorus	Phase 1	1.10			
	2		1.04	0.91	0.98
	3		0.90	0.77	0.84
	4		0.88	1.07	0.98

[1] All nutrients, except dry matter, are on a 100% dry matter basis.

[2] Values represent the mean of four observations per treatment.

TABLE 7. COMPOSITION OF URINE IN TRIAL 1

Rations		Basal	T1	T2	Means
		----------	%	----------	
Crude protein[1]	Phase 1	3.90			
	2		3.87	4.34	4.10
	3		4.25	4.29	4.27
	4		2.84	4.90	3.87
Sodium	Phase 1	0.10			
	2		0.18	0.17	0.18
	3		0.13	0.10	0.12
	4		0.07	0.14	0.10
Chlorine	Phase 1	0.54			
	2		0.21	0.26	0.24
	3		0.20	0.17	0.18
	4		0.14	0.15	0.14
Phosphorus	Phase 1	0.08			
	2		0.17	0.23	0.20
	3		0.15	0.15	0.15
	4		0.07	0.11	0.09

[1] Values represent the mean of four observations per treatment.

digestion or a diminishing of negative associative effects. However, the indigestible nutrients (Table 8) in the rations containing feces were always higher than in the basal ration. Indigestible dry matter, ADF, lignin, cellulose and NDF were higher in T2 than in T1 for every phase. This is related to the presence of cottonseed hulls in T2 and their absence in T1. Cottonseed hulls are rather indigestible due to a high cell wall content which is measured by ADF (ADF values include lignin and cellulose content of cell walls) and NDF values.

TABLE 8. INDIGESTIBLE FECAL RESIDUES IN TRIAL 1

	Rations	Basal	T1	T2
		g/day		
Dry matter[1]	Phase 1	575.2		
	2		925.2	991.4
	3		898.3	932.4
	4		854.3	890.6
Ash	Phase 1	65.9		
	2		122.9	125.1
	3		124.7	108.3
	4		108.2	102.4
ADF	Phase 1	184.2		
	2		265.2	345.7
	3		236.7	324.7
	4		238.5	304.2
Lignin	Phase 1	66.9		
	2		108.4	126.2
	3		93.6	128.3
	4		92.3	126.5
Cellulose	Phase 1	121.0		
	2		169.0	217.6
	3		137.5	197.5
	4		141.6	177.4
NDF	Phase 1	208.2		
	2		418.9	465.2
	3		380.3	454.7
	4		395.8	438.2

[1] Values represent the mean of four observations per treatment.

Crude protein, sodium (Na), chlorine (Cl), calcium (Ca) and phosphorus (P) are nutrients which are excreted in the feces and urine (Table 9). Crude protein excreted in the feces was 141.0 g per day for steers fed the basal

ration as compared to fecal excretions of 212.4 (T1) and 210.4 g (T2) in phase 2. Daily urinary excretions of protein in phase 2 were 171.7 (T1) and 165.9 g (T2) vs 191.0 g on the basal ration (phase 1). The lower urinary excretions in phase 2 reflect the lower ration protein digestibilities when feces were fed. Thus, the total excretion of protein (feces and urine) after one recycling was higher for both T1 (15.7%) and T2 (13.3%) than for the basal ration. In general, total excretion of protein continued to rise still further during phases 3 and 4, again reflecting the low protein digestibility in the recycled feces.

TABLE 9. RESIDUES FROM TRIAL 1 EXCRETED IN THE FECES AND URINE

	Basal			T1			T2		
	Feces	Urine	Total	Feces	Urine	Total	Feces	Urine	Total
	g/day								
				Crude Protein[1]					
Phase 1	141.0	191.0	332.0						
2				212.4	171.7	384.1	210.4	165.9	376.3
3				210.6	259.4	470.0	225.8	225.5	451.3
4				213.4	188.9	402.3	219.7	257.8	477.5
				Sodium					
Phase 1	2.4	6.4	8.8						
2				2.0	7.9	9.9	1.8	5.5	7.3
3				1.0	7.9	8.9	1.3	6.3	7.6
4				1.5	4.6	6.1	1.6	7.6	9.2
				Chlorine					
Phase 1	1.2	29.5	30.7						
2				2.2	9.2	11.4	2.8	10.3	13.1
3				2.2	12.9	15.1	2.4	10.1	12.5
4				1.9	10.0	11.9	1.9	8.2	10.1
				Calcium					
Phase 1	12.8	0.4	13.2						
2				23.2	0.0	23.2	22.3	0.0	22.3
3				23.1	0.0	23.1	20.0	0.0	20.0
4				22.4	0.0	22.4	19.0	0.0	19.0
				Phosphorus					
Phase 1	6.4	6.9	13.3						
2				9.6	7.2	16.8	8.9	8.2	17.1
3				8.2	7.8	16.0	7.1	7.9	15.0
4				7.4	4.3	11.7	6.9	5.2	12.1

[1] Values represent the mean of four observations per treatment.

Sodium and chlorine excretions occur mainly in the urine while Ca is excreted almost entirely in the feces. Phosphorus is excreted about equally via the urine and feces. In general, total Na excretion showed little change during recycling. Total Na excretion rose slightly in phase 2 on T1 from 8.8 to 9.9 g per day, but declined on T2 from 8.8 to 7.3 g per day. Total Cl excretion, however, decreased markedly (in excess of 50%) in phases 2, 3 and 4 compared to phase 1. All of the feces-containing rations had less total excretion of Cl than the basal ration. This may have been influenced by the presence of only feces and not urine (source of most Cl excretion) in phases 2, 3 and 4. However, the decreases appear much larger than anticipated since only 15% feces were incorporated in the ration.

Steers fed the basal ration excreted a total of 13.2 g of Ca per day as compared to total excretions of 23.2 and 22.3 g per day for steers fed T1 and T2, respectively in phase 2. Additional recyclings of feces (phases 3 and 4) produced no further build-up of Ca. Ca levels in urine are very low and difficult, if not impossible, to quantify.

Phosphorus excretions in both the feces and urine rose when feces were recycled the first time. However, at the end of the third recycling, total P excretion was nearly the same (approximately 12 g) as that observed on the basal ration in phase 1 (13.3 g).

The data in this experiment indicate that feces can be recycled three times without any material build-up of Na, Cl or P residues. Phosphorus residues were higher after the first recycling but lower after the third as compared to the basal. However, more recyclings (phases) would be helpful in determining P build-up in the residues. Calcium was the only mineral to show a definite accumulation with recycling. Refeeding both the feces and urine might have altered the mineral excretion patterns for Na, Cl and P.

Mineral Retention

Sodium (Table 10), chlorine (Table 11), calcium (Table 12) and phosphorus (Table 13) retention data showed no particular trends and no significant differences either between treatments within phase or across phases when feces were recycled. The large negative chlorine retention observed during phase 1 (basal ration fed) is questionable. In general, the daily net mineral retention values were small and averaged approximately 1.62 g for Na, 1.52 g for Cl, 7.09 g for Ca and 0.18 g for P. These retention figures represented approximately 16.4% of the mineral intake for Na, 10.6% for Cl, 25.7% for Ca and 1.2% for P. In general, there appeared to be no detrimental effects upon mineral retention when feces were recycled.

TABLE 10. UTILIZATION OF SODIUM IN TRIAL 1

	Intake	Fecal Excretion	Urine Excretion	Net Retention	SEM
	g/day				
Phase 1	10.03	2.40	6.37	1.26[1,2]	
Phase 2, T1	9.13	2.04	7.94	-0.85	1.5
Phase 2, T2	10.89	1.81	5.54	3.54	1.5
Phase 3, T1	10.42	1.02	7.93	1.47	1.5
Phase 3, T2	9.24	1.34	6.28	1.62	1.5
Phase 4, T1	10.34	1.50	4.60	4.24	1.3
Phase 4, T2	9.18	1.60	7.55	0.03	1.3

SEM for T1:1.7
SEM for T2:1.0

[1] Phase 1 was not included in the statistical analyses.

[2] Values represent the mean of four observations.

TABLE 11. UTILIZATION OF CHLORINE IN TRIAL 1

	Intake	Fecal Excretion	Urine Excretion	Net Retention	SEM
	g/day				
Phase 1	13.87	1.15	29.52	-16.80[1,2]	
Phase 2, T1	15.02	2.15	9.18	3.69	0.6
Phase 2, T2	13.60	2.76	10.30	0.54	0.6
Phase 3, T1	15.00	2.17	12.90	-0.07	1.8
Phase 3, T2	13.98	2.44	10.07	1.47	1.8
Phase 4, T1	14.89	1.94	10.05	2.90	1.2
Phase 4, T2	13.42	1.87	8.17	3.38	1.2

SEM for T1:2.0
SEM for T2:1.3

[1] Phase 1 was not included in the statistical analyses.

[2] Values represent the mean of four observations.

TABLE 12. UTILIZATION OF CALCIUM IN TRIAL 1

	Intake	Fecal Excretion	Urine Excretion	Net Retention	SEM
	g/day				
Phase 1	17.79	12.75	0.41	4.63[1,2]	
Phase 2, T1	26.67	23.20	0.01	3.46	2.1
Phase 2, T2	24.95	22.34	----	2.61	2.1
Phase 3, T1	32.54	23.12	0.01	9.41	0.3
Phase 3, T2	28.05	19.97	0.01	8.07	0.3
Phase 4, T1	30.73	22.40	0.02	8.31	2.5
Phase 4, T2	32.12	18.95	0.01	13.16	2.5

SEM for T1:1.5
SEM for T2:1.8

[1] Phase 1 was not included in the statistical analyses.

[2] Values represent the mean of four observations.

TABLE 13. UTILIZATION OF PHOSPHORUS IN TRIAL 1

	Intake	Fecal Excretion	Urine Excretion	Net Retention	SEM
	g/day				
Phase 1	12.42	6.40	6.92	-0.90[1,2]	
Phase 2, T1	16.75	9.60	7.15	0.00	0.3
Phase 2, T2	15.94	8.94	8.24	-1.24	0.3
Phase 3, T1	14.08	8.25	7.83	-2.00	1.2
Phase 3, T2	14.58	7.14	7.94	-0.50	1.2
Phase 4, T1	14.77	7.45	4.34	2.98	1.6
Phase 4, T2	15.01	6.93	5.17	2.91	1.6

SEM for T1:0.8
SEM for T2:1.5

[1] Phase 1 was not included in the statistical analyses.

[2] Values represent the mean of four observations.

SECTION VI

TRIAL 2--RECYCLING DIGESTION TRIAL WITH STEERS

SUMMARY

Recycling studies were conducted with steers to determine the influence of roughage level (0, 7, 14, 21% Cottonseed hulls, CSH) in high concentrate rations on digestibility and accumulation of indigestible residues when feces were recycled from such rations in three successive phases. Feces were reincorporated in each successive phase (2,3,4) based upon the percent of feces dry matter voided on each treatment in the previous phase (1,2,3). In each treatment (0, 7, 14, 21% CSH), feces replaced an equal amount of the complete basal ration which was fed in phase 1-providing complete feces reincorporation in phases 2, 3 and 4.

Ration DM digestibility in phase 1 (no feces fed) was nearly identical (~85.6%) on the 0, 7 and 14% CSH rations, suggesting strong favorable associative digestibility effects for low levels of CSH. However, digestibility was lower, 82.1%, on the 21% CSH ration. Declines in digestibility with feces reincorporation were less pronounced than in Trial 1. The total ration DM digestibilities averaged across all four treatments were 84.8, 82.5, 78.6 and 80.3% in phases 1, 2, 3 and 4, respectively.

In general, feces had a low to moderate, but variable digestibility when refed. Feces appeared to have roughage associative effects on digestibility when the ration contained 0% CSH. Calculated digestibility values for the refed or recycled feces fraction, averaged across all four treatments and refeeding phases (2,3,4), was 60.8% for dry matter, 64.5% for organic matter, 31.6% for ash, 41.7% for crude protein and 42.8% for acid detergent fiber. Digestibility of fiber components tended to increase with each successive recycling.

In general, the composition of the feces produced changed from phase 1 to 4 such that there was a small, but consistent increase on the order of 2-4% in the dry matter, ash, protein and fiber content. Phase 2 (first recycling) produced a 15% increase in total residue excretions over phase 1; in phase 3, residue excretion showed a further rise of 21% over phase 2; phase 4 showed no further increase. As in Trial 1, feces recycling produced no material buildup of Na, Cl or P, but produced an accumulation of Ca. Inclusion of urine in the diet may have altered the results for Na, Cl and/or P. Recycling produced normal mineral retention values.

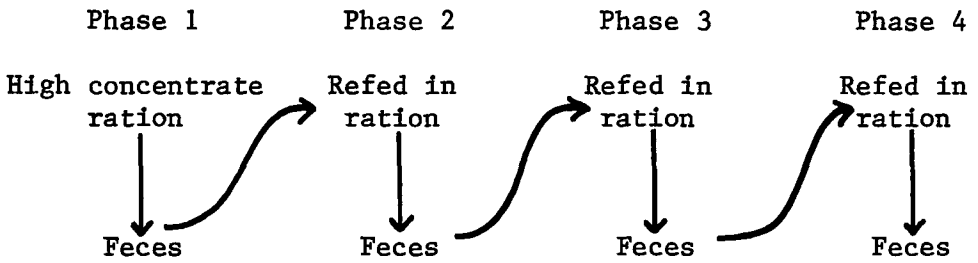
INTRODUCTION

Digestion studies were conducted in this trial to determine the effect of variable roughage levels (0, 7, 14, 21%) in high concentrate rations on ration digestibility and on the accumulation of indigestible residues when feces were recycled from such rations three times. The quantity of feces reincorporated in each recycling period was based upon the amount voided in the previous phase (total reincorporation, not a constant level of 15% as in recycling Trial 1).

GENERAL PROCEDURES

Experimental Design

The overall experimental design in this trial was somewhat similar to that in Trial 1 as depicted by the following:



There were 4 treatments in each phase. The major ways in which the design in Trial 2 differed from Trial 1 were:

1) There were 4 treatments (roughage levels of 0, 7, 14, 21% cottonseed hulls) in phase 1 as follows:

	T_1	T_2	T_3	T_4	
CSH	0	7	14	21	Referred to as basal rations
Corn	94	87	80	73	
Supp	6	6	6	6	
	100	100	100	100	

2) Feces were reincorporated into the 4 basal rations (treatments T1→T4) in phases 2, 3 and 4 based upon the amount of feces voided in the previous phase as follows:

Phases 2, 3 and 4

% Basal (basal rations same as in phase 1 for T1→T4)
+
% Feces (based on % voided in previous phase)

As noted above, feces simply replaced a corresponding percentage of the basal ration. Therefore, the level of feces in the rations was not constant from phase to phase as in Trial 1. As in Trial 1, the actual formulae fed (Table 14) in phase 1 differed only slightly from the 0, 7, 14, 21% CSH

levels intended due to the fact that the final dry matter values of the feeds actually fed differed slightly from the preliminary dry matter estimates.

TABLE 14. COMPOSITION OF RATIONS FED IN TRIAL 2

Rations[1]	T1 0	T2 7	T3 14	T4 21
	----------%----------			
	Phase 1 (Basal)			
Ground corn, 4-02-935	93.8	86.7	79.6	72.5
Cottonseed hulls, 1-01-599	----	7.1	14.2	21.3
Supplement	6.2	6.2	6.2	6.2
	Phase 2			
Basal	85.3	86.1	86.0	82.7
Feces[2]	14.7	13.9	14.0	17.3
	Phase 3			
Basal	85.5	84.4	83.0	79.0
Feces	14.5	15.6	17.0	21.0
	Phase 4			
Basal	80.9	80.0	78.3	74.0
Feces	19.1	20.0	21.7	26.0

[1] Dry matter basis.

[2] Percent reincorporation was equal to the percent voided in the previous phase for each respective ration.

Procedure for Conducting Digestion Trials

Eight steers were randomly chosen from the same pool of steers used in Trial 1 and randomly assigned to the four treatments in phase 1, giving 2 steers/treatment. Due to a limitation on available collection facilities not more than 8 digestion trials (2 animals/treatment) could be conducted simultaneously. All steers were accustomed to digestion stalls and a feces diet, permitting rotation to digestion stall or diet when desirable. Each phase (except phase 2) consisted of three periods, and each period had two steers/treatment to give a total of six observations/treatment within each phase. There were only 2 periods in phase 2, however, giving 4 observations per treatment. This was because the original intent was to obtain only 4 observations per treatment in phases 2, 3 and 4. Later, this was revised in phases 3 and 4 when it was apparent that sufficient feces were available to obtain 2 additional observations/treatment. Steers were rerandomized at the end of each period. During the first 5 days of each period (within a

phase) feces were not saved for future refeeding (to allow for adjustment). Thus, each succeeding phase was somewhat shorter than the previous due to the fact that feces produced during the adjustment periods could not be saved for later refeeding. Each period was usually a minimum of four to five weeks to permit ample feces production for refeeding in succeeding phases. Digestion trials were conducted near the completion of each period after cattle had been on the specific ration for several weeks. The steers were fed as in Trial 1. Rations were consumed readily, and there were no feed weighbacks.

Sample Collection and Laboratory Analyses

Methods of collecting and drying feces and urine for refeeding (urine dried for later use in Trials 3 and 5), sampling procedures for feces and urine, laboratory analyses, calculations and statistical analyses were the same as reported in Trial 1.

RESULTS AND DISCUSSION

Digestibilities of Complete Rations

Dry Matter

Apparent dry matter digestion coefficients (Table 15) in phase 1 for the 0, 7, 14, and 21% CSH basal rations were 84.9, 86.5, 85.5 and 82.1%, respectively. Since CSH normally have a rather low digestibility (about one-half of corn or less), the dry matter digestibility of a complete ration should, in theory, decrease as the level of CSH increases. Interestingly, the DM digestibilities were essentially identical for the 0, 7 and 14% CSH diets, suggesting strong favorable associative effects on enhanced digestibility for low levels of CSH. Possibly the rate of passage is reduced by low levels of CSH, increasing digestive efficiency. When feces were added to the basal ration (phase 2), dry matter digestibility for T1 (0% CSH) remained the same as in phase 1, while dry matter digestibility for T2, T3 and T4 decreased from 2.6 to 3.6%. Small additional decreases ranging from 0.5-5.4% were observed in phases 3 and 4. In general, T4 always had the lowest digestibility in all phases ($P<.05$ in phases 2, 3 and 4). This can be attributed to the high CSH level. Again, the differences were smaller than anticipated for the T1, T2 and T3 rations. When averaged across all four treatments (within a phase), the average DM digestibilities were 84.8, 82.5, 78.6 and 80.3% in phases 1, 2, 3 and 4, respectively. The declines in digestibility with the first, second and third feces recyclings (phases 2, 3, 4) were less pronounced than in Trial 1 and smaller than expected.

Organic Matter

The organic matter digestibility means (Table 15) of the four treatmetns within each phase followed a pattern similar to DM, being 85.8, 83.8, 80.3 and 81.8% in phases 1, 2, 3 and 4, respectively. There were no significant differences across phases within treatment. Within a phase, T4 was generally lower ($P<.05$) than T1, T2 and T3, with little difference among T1→T3.

TABLE 15. APPARENT DIGESTIBILITIES OF DRY MATTER, ORGANIC MATTER ASH AND CRUDE PROTEIN IN TRIAL 2 RATIONS

Rations	T1 0	T2 7	T3 14	T4 21	Means	SEM
			%			
			Dry Matter			
Phase 1	84.9[1,2]	86.5	85.5	82.1	84.8	1.2
2	85.2[a]	83.9[a]	82.4[a]	78.5[b]	82.5	0.9
3	79.8[a]	80.7[a]	79.1[a]	75.0[b]	78.6	0.9
4	81.2[a,c]	82.2[a]	79.7[b,c]	78.0[b]	80.3	0.7
SEM[3]	1.3, 1.6	1.4, 1.7	1.8, 2.1	2.2, 2.8		
			Organic Matter			
Phase 1	86.0	87.8	86.3	83.0	85.8	1.2
2	86.7[a]	85.3[a]	83.6[a]	79.6[b]	83.8	1.0
3	81.7[a]	82.4[a]	80.7[a]	76.4[b]	80.3	0.9
4	82.8[a,c]	83.8[a]	81.2[b,c]	79.5[b]	81.8	0.8
SEM	1.1, 1.3	1.3, 1.6	1.7, 2.0	2.1, 2.6		
			Ash			
Phase 1	59.1	56.9	66.7	61.9	61.2	2.3
2	55.4	59.2	58.0	57.6	57.6	1.9
3	43.9[a]	54.1[b]	53.9[b]	60.8[b]	53.2	2.6
4	58.0	59.9	57.0	56.6	57.9	1.0
SEM	4.7, 5.7	4.2, 5.1	3.2, 3.9	4.6, 5.7		
			Crude Protein			
Phase 1	74.0	75.8	74.4	70.1	73.6	1.6
2	71.4[a]	70.8[a]	69.8[a]	63.3[b]	68.8	1.4
3	65.4[a]	66.2[a]	63.5[a]	57.6[b]	63.2	1.6
4	67.0	69.9	66.2	65.3	67.1	1.1
SEM	2.2, 2.7	1.9, 2.4	2.5, 3.0	3.2, 4.0		

[1abc]: Values within phase with different superscripts differ significantly ($P<.05$).

[2] Values represent the mean of six steers in phases 1, 3 and 4 and four steers in phase 2.

[3] The first number is the standard error of treatment mean (SEM) for phases 1, 3 and 4 of each treatment and the second number is the SEM for phase 2 of each treatment.

Ash

Ash digestibility ranged from 56.9 to 66.7% (P>.05) in phase 1 and from 43.9 to 60.8 in phases 2, 3 and 4. In general, the lowered ash digestibility during recycling can be attributed to the increased ash intake via the feces. In phase 3, T1 had the lowest (P<.05) ash digestion coefficient. Ration ash digestibilities were similar (P>.05) in phase 4. There were no significant differences (P>.05) among phases 1 to 4 within any of the treatments in ash digestibility.

Crude Protein

Digestion coefficients for crude protein were very similar among T1, T2 and T3 in all four phases, but T4 was always lowest (P<.05 in phases 2 and 3). Protein digestibility, averaged across all treatments, was 73.6, 68.8, 63.2 and 67.1% in phases 1, 2, 3 and 4. The largest decline was apparent the first time feces were incorporated, but changed much less thereafter. In general, the protein digestibility followed the pattern observed for dry matter and organic matter; however, the depression in digestibility was greater for protein when feces were recycled.

Acid Detergent Fiber

T1 had the lowest acid detergent fiber (ADF) digestibility within all four phases, being significantly lower (P<.05) than the other rations in phases 2, 3 and 4 (Table 16). Generally, the highest values were obtained on T4 (21% CSH). This is in contrast to the other parameters discussed thus far. The mean ADF digestion coefficients for phases 1 thru 4 were 47.4, 47.3, 41.9 and 52.3%, respectively, reflecting little or no change (in contrast to decreases for other parameters cited previously). This implies that some cellulose and/or lignin in feces is further digested when recycled.

Lignin

In phase 1, lignin digestibility (Table 16) increased as the percent roughage increased (8.0, 25.4, 26.1 and 28.3%). Correspondingly, lignin digestibilities were generally higher (P>.05) when feces were included in the ration for recycling. Within each treatment, lignin digestion coefficients were higher for the feces containing rations than for the basal ration. The treatment averages (T1-T4) for lignin digestibility in phases 1, 2, 3 and 4 were 22.0, 40.1, 30.3 and 38.2%. Normally, lignin is regarded as having an extremely low digestibility (perhaps 0-25%). Lignin digestibilities in the 30-40% area would be considerably above usual reported values and perhaps suggest more extended microbial degradation of lignin when it is recycled through a ruminant one or more times. In general, cellulose (the largest component of ADF) digestion followed the pattern reported for ADF. While a few significant differences existed among treatments in phases 3 and 4, generally there was little change in cellulose digestibility across phases when feces were reincorporated into the ration (60.9, 52.9, 52.2 and 59.4% in phases 1, 2, 3, 4, respectively). Again this suggests some further digestion of previously indigested cellulose when it is recycled. The percent of cellulose in the diet or total grams of cellulose presented to the animal when feces are included would be considerably greater than in the basal ration; hence, if the digestibility (%) is the same for feces rations, previously indigested cellulose appearing in the feces would be partially, further digested the first, second or third time

TABLE 16. APPARENT DIGESTIBILITIES OF ACID DETERGENT FIBER, LIGNIN, CELLULOSE AND NEUTRAL DETERGENT FIBER IN TRIAL 2 RATIONS

Rations	T1 0	T2 7	T3 14	T4 21	Means	SEM
	%					
			Acid Detergent Fiber			
Phase 1	41.0[1,2]	50.3	48.6	49.6	47.4	4.5
2	42.2[a]	48.7[b]	49.1[b]	49.2[b]	47.3	1.6
3	28.3[a]	45.8[b]	47.1[b]	46.4[b]	41.9	1.9
4	42.2[a]	54.2[b]	55.4[b]	57.5[b]	52.3	1.3
SEM[3]	4.6, 5.6	5.2, 6.3	4.3, 5.2	4.9, 6.0		
			Lignin			
Phase 1	8.0	25.4	26.1	28.3	22.0	7.1
2	32.7[a]	38.2	38.8[a]	50.8[b]	40.1	2.8
3	22.5[a]	32.6[b]	41.0[c]	25.2[a]	30.3	1.6
4	33.6[a]	45.7[c]	35.7[a,b]	38.0[b]	38.2	1.4
SEM	6.7, 8.2	7.7, 9.4	5.5, 6.8	5.2, 6.3		
			Cellulose			
Phase 1	56.3	64.4	61.2	61.8	60.9	3.5
2	57.7	60.0	58.6	55.2	57.9	1.4
3	42.1[a]	58.2[b]	54.7[b]	53.9[b]	32.2	1.8
4	48.9[a]	59.7[b]	63.1[b,c]	65.8[c]	59.4	1.1
SEM	4.0, 4.9	3.7, 4.5	3.6, 4.4	4.1, 5.0		
			Neutral Detergent Fiber			
Phase 1	77.6[r]	78.7	76.0	72.1	76.1	2.0
2	77.5[a,r]	75.4[a]	72.7[b]	68.9[b]	73.6	1.4
3	65.9[s]	70.1	68.4	63.9	67.1	1.7
4	69.8[s]	73.3	70.8	70.1	71.0	1.4
SEM	1.9, 2.3	2.3, 2.8	2.4, 2.9	3.1, 3.8		

[1]abc: Values within phase with different superscripts differ significantly (P<.05). rs: Values within treatment with different superscripts differ significantly (P<.05).

[2] Values represent the mean of six steers in phases 1, 3 and 4 and four steers in phase 2.

[3] See Table 15.

since cellulose in feces are recycled.

Neutral Detergent Fiber

When feces were included in the ration (phase 2), neutral detergent fiber (NDF) digestibility (Table 16) remained unchanged for T1 but decreased (P>.05) by approximately 4% for T2, T3 and T4. Slight additional decreases were observed in most cases during phases 3 (second recycling) and 4 (third recycling). The treatment means during phases 1, 2, 3 and 4 were 76.1, 73.6, 67.1 and 71.0%. In general, the NDF digestibility values were quite high in all cases.

The overall digestibility of the rations (T1→T4) cited in Tables 15 and 16 decreased from phase 1 (no feces) to phase 2 (first recycling) and phase 3 (second recycling) as expected. For unknown reasons, however, the values in phase 4 (third recycling) were slightly higher than in phase 3. Moreover, the decrease in ration digestibility from one phase to the next was smaller than expected (implying a higher digestibility of the feces component) and less than observed in Trial 1. Ferrell and Garrett (1973) reported a similar trend in ration dry matter digestibility when feces were refed three consecutive times at a 50% level.

Apparent Digestibility of Fecal Nutrients

The apparent digestibility of nutrients in feces, calculated by difference, followed the same general pattern as the ration digestion coefficients in that there was a decrease in the digestibility of fecal nutrients from phase 2 to 3 (first to second recycling) and an increase in phase 4 (third recycling) as shown in Table 17. The dry matter digestibilities for feces indicated a dry matter disappearance of 61.3 to 87.0% with the first, 47.6 to 49.6% with the second and 58.6 to 66.3% with the third recycling of feces. In general, the highest values were observed on T1 (0% CSH), but the differences were not profound. Organic matter digestibility in feces was approximately 3 to 4 percentage units higher than the corresponding fecal dry matter digestibility. This can be attributed to the reduced digestibility noted for the increased ash intake or load when feces were incorporated (OM = DM - ash). Digestion coefficients for fecal crude protein, after one recycling, were 65.4, 51.9, 40.4 and 40.2%, respectively, for the 0, 7, 14 and 21% CSH rations. During the second recycling of feces (phase 3) protein digestibility in the feces was only about one-half (20.0-29.3%) of that in the first recycling. During the third recycling, values were similar (42.3-56.1%) to those in the first. Fiber components (ADF, lignin, cellulose and NDF) were generally high and quite variable. The overall fecal digestibility means (combining all treatments in recycling phases 2, 3 and 4) for various nutrient parameters in feces are summarized in Table 18. It is apparent that the nutrient digestion coefficients for the various fecal parameters are much higher than observed in Trial 1. The corresponding fecal digestion values in Trial 1 were: DM, 27.0; O.M., 39.0; Ash, 0.7; crude protein, -3.2; ADF, -14.7%. The reasons for the higher fecal digestibilities are not readily apparent, but it should be noted that the calculation of fecal digestibilities by difference is a highly leveraged calculation, particularly when only 15-20% feces are incorporated into a ration. The average DM digestibility of the 10% CSH basal ration (0%

TABLE 17. DIGESTIBILITY OF FECES AS CALCULATED BY DIFFERENCE FOR TRIAL 2

Rations		T1 0	T2 7	T3 14	T4 21	Mean
Apparent digestibility, %[1]						
	Phase 2	87.0	67.9	63.4	61.3	69.9
Dry matter	3	49.6	49.2	47.6	48.5	48.7
	4	65.6	64.9	58.6	66.3	63.8
	Mean					60.8
	Phase 2	91.1	69.9	67.2	63.2	72.8
Organic matter	3	56.8	53.0	53.0	51.3	53.5
	4	69.2	67.7	62.5	69.5	67.2
	Mean					64.5
	Phase 2	33.6	73.7	4.9	36.8	37.2
Ash	3	-45.6	39.3	-8.5	56.8	10.5
	4	53.1	72.1	22.0	41.4	47.2
	Mean					31.6
	Phase 2	65.4	51.9	40.4	40.2	49.5
Crude protein	3	25.2	29.3	20.0	24.1	24.6
	4	49.8	55.6	42.3	56.1	51.0
	Mean					41.7
	Phase 2	49.3	38.8	52.3	47.2	46.9
ADF	3	-46.6	21.8	40.0	34.2	12.4
	4	47.5	69.7	79.8	79.9	69.2
	Mean					42.8
	Phase 2	129.3	106.9	117.1	158.2	127.9
Lignin	3	60.7	62.6	113.8	13.6	62.7
	4	108.0	120.2	70.2	65.6	91.0
	Mean					93.9
	Phase 2	65.6	32.7	42.9	24.0	41.3
Cellulose	3	41.9	24.6	22.9	24.1	28.4
	4	17.6	41.1	70.1	77.1	51.5
	Mean					40.4
	Phase 2	76.7	54.8	52.2	53.4	59.3
NDF	3	-3.3	23.6	31.5	33.1	21.2
	4	36.4	51.6	52.1	64.4	51.1
	Mean					43.9

[1] Calculated by difference as outlined by Crampton and Harris (1969).

feces in phase 1) in Trial 1 was 85.6% as compared to a mean DM digestibility of 84.8% for the four basal rations (0, 7, 14, 21% CSH) in phase 1 of Trial 2.

TABLE 18. DIGESTIBILITY OF FECES COMPONENT WHEN RECYCLED

Item	Ration Digestibility in Phase 1	Ration Digstibility in Phases 2, 3, 4	Digestibility of Feces (by difference)
	$\bar{X}$(T1-T4)	$\bar{X}$(T1-T4)	$\bar{X}$
	%	%	%
D.M.	84.8	80.5	60.8
O.M.	85.8	82.0	64.5
Ash	61.2	56.2	31.6
C.P.	73.6	66.3	41.7
ADF	47.4	47.2	42.8

Thus, the basal ration (0% feces) digestibilities were very similar in both trials. In Trial 1, the mean ration DM digestibility in phases 2, 3 and 4 was 76.6 vs 80.5% in Trial 2. Hence, even a small increase in total ration digestibility (as noted in Trial 2) can have a rather large increase on the calculated fecal digestibility when modest levels of feces are involved. The method for calculating fecal digestibility by difference in Trial 1 can be illustrated as follows:

Dig. of basal in phase 1 = 85.6%
Dig. of feces ration in phases 2,3,4 = 76.6%
85% of Dig. in phase 1 (85.6 X 85%) = 72.7

$$76.6 - 72.7 = \frac{3.9\%}{15.0\% \text{ feces}} = 26.0\% \text{ D.M. Digestibility}$$

Hence, to illustrate the leverage factor, had the mean digestibility in phases 2, 3 and 4 of Trial 1 been 80.5 instead of 76.6 (a difference of only 3.9%), the calculated fecal DM digestibility would have doubled (e.g. 7.8/15.0 = 52.0%).

Johnson (1972) reported the average calculated theoretical dry matter, organic matter and crude protein digestibility of feedlot feces to be from 40-50%, 42-56% and 60-71%, respectively, with one recycling of feces at a 25 and 40% level. Fecal dry matter, organic matter, protein and NDF digestibility values were observed by Albin and Sherrod (1975) to be much lower than those in this trial when feces were refed once at a 20% level. In general, the digestibility values for the nutrients in the feces produced by Trial 2 tended to be high and, particularly so, for the fibrous components of feces--ADF, lignin, cellulose and NDF.

Composition of Feces

The dry matter content of feces, averaged across treatment, increased from phase 1 to 4 as follows: 24.1, 25.7, 26.4 and 26.9% (Table 19). Percent ash in feces increased more during recycling, being 10.8% ash in phase 1 (no feces in ration) vs 13.8 and 13.7% in phases 3 and 4. Protein and fiber components (ADF, lignin, cellulose and NDF) also showed a small, but consistent increase on the order of 2-4%. All fiber components showed a substantial increase in the feces as the roughage level was increased from T1 to T4. This was true in all phases. Again it must be recalled that total residue excretions are a function of the quantity of feces X its composition.

The sodium and phosphorus content in feces tended to decrease slightly with each successive phase (1 to 4) while chlorine and calcium tended to remain stable. The percent of each fecal nutrient (except minerals) in Trial 2 was higher within each treatment in phases 2, 3 and 4 than in phase 1. The chemical composition of the feces (excluded minerals) in Trial 2 agrees closely with those previously reported by Anthony (1969, 1971), Johnson (1972), Lucas et al (1975) and Tinnimit et al (1972) and those reported in Trial 1.

Ferrell and Garrett (1973) reported similar trends for calcium, phosphorus and sodium concentrations in feces when feces were recycled three times. They observed calcium to make up approximately 2.5% of the feces; in this trial the Ca level ranged from 3.18 to 6.15%. Their phosphorus and sodium contents in feces were similar to those reported in Trial 2 with phosphorus being approximately 0.7 to 1.0% and sodium being approximately 0.5%.

TABLE 19. COMPOSITION OF FECES IN TRIAL 2

	Rations	T1 0	T2 7	T3 14	T4 21	Means
		----------	----------	%	----------	----------
Dry matter[1,2]	Phase 1	26.2	24.2	22.6	23.4	24.1
	2	26.2	26.0	24.7	26.0	25.7
	3	26.2	25.8	27.2	26.2	26.4
	4	26.7	26.6	28.1	26.3	26.9
Ash	Phase 1	10.8	13.4	9.7	9.5	10.8
	2	14.6	13.5	11.6	10.0	12.4
	3	14.4	14.1	13.3	13.3	13.8
	4	13.7	14.9	13.2	13.1	13.7
Crude protein	Phase 1	22.2	23.2	22.1	20.3	22.0
	2	26.3	25.0	22.9	22.6	24.2
	3	24.5	24.4	23.4	22.3	23.6
	4	26.0	24.6	23.3	22.8	24.2

TABLE 19. CONT'D. COMPOSITION OF FECES IN TRIAL 2

	Rations	T1 0	T2 7	T3 14	T4 21	Means
		----------%----------				
ADF	Phase 1	17.6	31.0	43.3	45.4	34.3
	2	22.0	36.1	45.5	49.5	38.3
	3	25.8	35.8	44.4	49.8	39.0
	4	28.4	35.6	43.9	47.7	38.9
Lignin	Phase 1	7.0	12.0	16.4	17.1	13.1
	2	9.1	14.7	16.8	16.5	14.3
	3	9.7	15.6	16.3	19.7	15.3
	4	12.0	14.3	20.3	22.5	17.3
Cellulose	Phase 1	10.7	18.3	26.5	27.8	20.8
	2	12.4	20.6	28.1	32.5	23.4
	3	14.6	19.1	26.5	27.4	21.9
	4	15.9	20.4	25.4	26.5	22.0
NDF	Phase 1	36.4	45.8	55.1	57.4	48.7
	2	40.7	48.8	55.2	59.0	50.9
	3	46.2	50.3	55.6	62.0	53.5
	4	46.7	49.3	55.4	59.2	52.6
Sodium	Phase 1	0.42	0.60	0.65	0.58	0.56
	2	0.57	0.53	0.50	0.46	0.52
	3	0.47	0.64	0.43	0.56	0.52
	4	0.40	0.48	0.38	0.47	0.43
Chlorine	Phase 1	0.22	0.22	0.28	0.30	0.26
	2	0.23	0.22	0.34	0.34	0.28
	3	0.34	0.25	0.31	0.32	0.30
	4	0.24	0.28	0.25	0.29	0.26
Calcium	Phase 1	4.26	5.56	3.18	3.61	4.15
	2	6.15	5.28	3.77	3.22	4.60
	3	5.19	5.11	4.72	4.05	4.77
	4	4.83	4.42	4.46	3.97	4.42
Phosphorus	Phase 1	1.05	1.25	0.84	0.71	0.96
	2	1.35	1.02	0.61	0.54	0.88
	3	0.88	0.84	0.64	0.57	0.73
	4	0.78	0.71	0.60	0.87	0.74

[1] Values represent the mean of six observations per treatment in phases 1, 3 and 4 and four observations per treatment in phase 2.

[2] All nutrients, except dry matter, are on a 100% dry basis.

Composition of Urine

The percent crude protein in urine (Table 20), averaged within phase, increased almost two-fold in phases 2, 3 and 4 compared to phase 1 (1.90, 3.79, 4.61, 4.69%). Sodium and chlorine content in urine was also higher within each treatment when feces were included in the rations (phases 2, 3 and 4). The percent phosphorus in urine followed a similar pattern.

TABLE 20. COMPOSITION OF URINE IN TRIAL 2

Rations		T1 0	T2 7	T3 14	T4 21	Means
		%				
Crude protein[1]	Phase 1	2.33	2.08	1.45	1.75	1.90
	2	3.25	4.68	3.80	3.43	3.79
	3	5.24	5.56	4.46	3.19	4.61
	4	5.08	3.82	4.74	5.13	4.69
Sodium	Phase 1	0.08	0.08	0.04	0.04	0.06
	2	0.09	0.14	0.09	0.09	0.10
	3	0.18	0.17	0.15	0.09	0.15
	4	0.20	0.16	0.18	0.16	0.18
Chlorine	Phase 1	0.14	0.15	0.10	0.10	0.12
	2	0.17	0.20	0.16	0.15	0.17
	3	0.28	0.30	0.24	0.16	0.24
	4	0.29	0.23	0.25	0.24	0.25
Phosphorus	Phase 1	0.10	0.06	0.05	0.06	0.07
	2	0.07	0.14	0.14	0.12	0.12
	3	0.18	0.14	0.17	0.14	0.16
	4	0.19	0.13	0.22	0.21	0.19

[1] Values represent the mean of six observations per treatment in phases 1, 3 and 4 and four observations per treatment in phase 2.

Residue Accumulations

Indigestible dry matter excretions (Table 21) on the 0, 7, 14 and 21% basal rations were 600.0, 535.8, 577.5 and 713.9 g per day, respectively, as compared to 590.1, 640.9, 702.4 and 860.4 in phase 2 (first recycling). The nearly identical excretions in phase 1 and 2 on the 0% CSH diets suggest that feces served as an effective roughage replacement and produced positive associative effects on digestibility. On an average, phase 2 produced about a 15% increase in total residues over phase 1. In phase 3 the average residue excretion was approximately 21% higher than in phase 2. Phase 4 showed no further increase. In all cases, the most profound differences were observed on T4, which can be accounted for by the high roughage level.

Phase averages for indigestible ash residues were 64.4, 84.8, 117.2 and 109.8 g per day for phases 1 thru 4, respectively. No consistent trends were observed among treatments within a phase in ash accumulations. This is logical in that total ash content of the rations within a phase differed little.

TABLE 21. INDIGESTIBLE NUTRIENTS EXCRETED IN FECES IN TRIAL 2

Rations		T1 0	T2 7	T3 14	T4 21	Means
		g/day				
Dry matter[1]	Phase 1	600.0	535.8	577.5	713.9	606.8
	2	590.1	640.9	702.4	860.4	698.4
	3	806.7	771.5	836.7	1002.4	854.3
	4	760.8	723.3	828.5	902.5	803.8
Ash	Phase 1	64.5	70.3	56.2	66.4	64.4
	2	86.0	86.0	81.3	85.9	84.8
	3	116.0	107.6	110.9	134.1	117.2
	4	104.3	107.6	108.4	119.0	109.8
ADF	Phase 1	105.8	164.5	248.3	320.2	209.7
	2	129.6	229.4	318.5	425.1	275.6
	3	206.5	277.6	370.0	498.7	338.2
	4	215.1	256.5	361.0	429.5	315.5
Lignin	Phase 1	42.4	64.1	93.0	119.2	79.7
	2	53.4	93.2	117.7	141.3	101.4
	3	77.6	120.6	135.7	195.4	132.3
	4	91.0	103.0	166.0	202.2	140.6
Cellulose	Phase 1	64.0	96.2	152.8	197.8	127.7
	2	72.7	131.4	196.5	279.9	170.1
	3	117.0	148.2	221.2	272.4	189.7
	4	120.5	147.2	208.4	238.0	178.5
NDF	Phase 1	218.2	243.7	314.8	412.2	297.2
	2	240.5	311.5	387.0	507.0	361.5
	3	373.1	388.8	465.6	618.9	461.6
	4	355.1	357.4	458.8	532.5	426.0

[1] Values represent the mean of six observations per treatment in phases 1, 3 and 4 and four observations per treatment in phase 2.

ADF, lignin, cellulose and NDF residues, expressed as grams per day, increased within each phase as the percent of roughage increased in the

rations. This trend was expected since these are the major constituents of roughage. Moreover, indigestible fiber components showed a sizeable increase in the first recycling with some additional increase in phases 3 and 4.

Crude protein and minerals are excreted in both the feces and urine (Table 22). Total indigestible crude protein in the feces (grams per day) increased by 5.4% with one recycling (phase 1 to 2) for T1 and 12-20% for T2, T3 and T4. The second recycling of feces (phase 3) resulted in total indigestible protein residue increases of 18.0 (T1), 11.5 (T2), 2.9 (T3) and 2.0% (T4) over the first recycling (phase 2). Values in the third recycling (phase 4) were similar to those in the second.

Daily sodium (Na) excretion, averaged across phase, was very similar for all four phases (8.8 to 10.5 g). Except for T1, total grams of chlorine (Cl) excreted daily (as in Trial 1) were less for steers fed the feces rations (phases 2, 3, 4) than for those fed the basal ration (phase 1). This was likely due to the fact that most chlorine is excreted in the urine, and not feces. Moreover, feces replaced a portion of the basal ration and feces are low in Cl. Calcium (Ca) was analyzed only in the feces in Trail 2 as Ca levels in the urine are so low that accurate determinations are difficult to make. Total grams of Ca excreted daily increased with the first and second recycling of feces (phase 2 and 3), but showed no further increase with the third recycling (phase 4). Total phosphorus (P) excretion averages for phases 1 to 4 were 12.3, 11.7, 12.9, and 13.2 g per day, respectively. As in Trial 1, phosphorus excretion occurred about equally between feces and urine; whereas, Na and Cl were excreted to a greater degree in the urine. Except for Ca, recycling as conducted in this study, produced no buildups in mineral residues. Had the urine been refed, the answer may have been different. However, this could be corrected by altering mineral formulation in the diet. Of all the nutrients, Na, Cl and P showed the least tendency to accumulate when recycling feces three consecutive times. However, if feces were recycled ten consecutive times with the roughage levels spaced out more, overall trends in residue accumulations could be much better established.

Mineral Retention

Grams of sodium (Table 23), chlorine (Table 24), calcium (Table 25) and phosphorus (Table 26) retained per day tended to increase with the first recycling (phase 2), decrease with the second recycling (phase 3) and increase again with the third recycling of feces (phase 4). However, the differences were not great. The high retention values for calcium in phase 4 were surprising especially since there were negative or small retention values in the other three phases. The average daily retentions of sodium, chlorine, calcium and phosphorus were 5.87, 4.84, 4.22 and 7.06 g, respectively. These retention values represented approximately 38.1% of the mineral intake for sodium, 28.8% for chlorine, 11.4% for calcium and 36.0% for phosphorus. These values are somewhat higher than in Trial 1.

General Conclusions in Recycling Trials 1 and 2.

1. Total ration nutrient digestibility decreased when feces were refed

TABLE 22. RESIDUES WHICH ACCUMULATED IN FECES AND URINE ON TRIAL 2

Rations	T1 0			T2 7			T3 14			T4 21			Means		
	Feces	Urine	Total	Feces	Urine	Total	Feces	Urine	Total	Feces	Urine	Total	Feces	Urine	Total
							g/day								
							Crude Protein[1]								
Phase 1	123.6	199.6	323.2	118.1	180.3	298.4	118.9	149.7	268.6	136.7	169.8	306.5	124.3	174.8	299.1
2	139.3	201.4	340.7	147.0	202.6	349.6	155.8	167.8	323.6	179.4	165.1	344.5	155.4	184.2	339.6
3	179.4	222.6	402.0	172.0	217.9	389.9	180.6	152.3	332.9	201.6	149.8	351.4	183.4	185.6	369.0
4	173.6	198.2	371.8	164.5	168.0	332.5	179.6	171.3	350.9	192.6	150.9	343.5	177.6	172.1	349.7
							Sodium								
Phase 1	2.5	7.0	9.5	3.3	7.3	10.6	3.9	3.9	7.8	4.3	4.1	8.4	3.5	5.6	9.1
2	3.3	5.7	9.0	3.5	5.9	9.4	3.5	3.9	7.4	3.9	5.1	9.0	3.6	5.2	8.8
3	3.8	7.6	11.4	4.9	6.6	11.5	3.7	5.5	9.2	5.5	4.5	10.0	4.5	6.0	10.5
4	3.2	7.8	11.0	3.5	6.2	9.7	3.2	6.2	9.4	4.3	4.9	9.2	3.6	6.3	9.9
							Chlorine								
Phase 1	1.3	11.7	13.0	1.2	14.0	15.2	1.6	10.5	12.1	2.1	10.4	12.5	1.6	11.6	13.2
2	1.4	10.9	12.3	1.4	8.5	9.9	2.4	7.2	9.6	2.9	7.7	10.6	2.0	8.6	10.6
3	2.7	11.4	14.1	1.9	12.8	14.7	2.6	8.5	11.1	3.1	7.9	11.0	2.6	10.2	12.8
4	1.8	11.6	13.4	2.0	9.5	11.5	2.1	8.7	10.8	2.6	7.3	9.9	2.1	9.3	11.4
							Calcium								
Phase 1	25.6	----	25.6	29.1	----	29.1	18.4	----	18.4	24.9	----	24.9	24.5	----	24.5
2	36.0	----	36.0	33.5	----	33.5	26.1	----	26.1	27.8	----	27.8	30.8	----	30.8
3	41.6	----	41.6	39.2	----	39.2	39.5	----	39.5	40.2	----	40.2	40.1	----	40.1
4	37.1	----	37.1	31.9	----	31.9	37.1	----	37.1	36.2	----	36.2	35.6	----	35.6
							Phosphorus								
Phase 1	6.[illegible]	[illegible].1	14.6	7.2	6.1	13.3	4.8	5.1	9.9	5.1	6.4	11.5	5.9	6.4	12.3
2	8.3	4.8	13.1	6.5	6.4	12.9	4.3	5.9	10.2	4.6	6.3	10.9	5.9	5.8	11.7
3	7.3	8.1	15.4	6.4	5.8	12.2	5.4	6.1	11.5	5.7	6.7	12.4	6.2	6.7	12.9
4	6.0	7.8	13.8	5.2	6.7	11.9	5.0	8.2	13.2	7.9	6.0	13.9	6.0	7.2	13.2

[1] Values represent the mean of six observations per treatment for phases 1, 3 and 4. Phase 2 had four observations per treatment.

in the ration, but decreases were less than expected.

2. In general, feces appeared to have a low to moderate, but rather variable digestibility when refed. Average calculated digestibility values for different nutrient parameters in recycled feces in Trial 1 were: D.M. 27.0; O.M. 39.0; Ash 0.7; C.P. -3.2; ADF -14.7%. The values were higher in Trial 2 being: D.M. 60.8; O.M. 64.5; Ash 31.6; C.P. 41.7 and ADF, 42.8%.

3. Low levels of roughage appear to produce desirable associative effects on ration digestibility in high concentrate rations.

4. Feces in 0% roughage rations appear to have roughage value and produce positive associative effects on ration digestibility.

5. Recycling appears to enhance digestibility of fiber components in feces; the less digestible components (cellulose, lignin) in feces tended to increase with each successive recycling.

6. Feces would appear to be a low energy feed which has potential in maintenance type programs or as a source of fiber in 0% roughage rations.

7. Indigestible residues accumulated in feces during recycling, but not at the rate expected. Moreover, the change from phase to phase was smaller and more erratic than anticipated.

8. Fecal composition was altered during recycling; dry matter content increased several percent, and on a dry matter basis, the feces became higher in C.P., ash and fiber, particularly during the first recycling. Less change occurred thereafter during the second and third recyclings.

9. Feces can be recycled three times without any material buildups of Na, Cl or P. Ca, however, showed a definite accumulation. Refeeding both feces and urine might have altered observations on Na, Cl and/or P.

10. Recycling produced normal mineral retention values.

Recommendations for Improval of Trial Design

Based upon the evidence obtained in these studies modifications in trial design might have been helpful to provide more definitive data.

1. More phases (recyclings). If feces were refed more consecutive times (e.g. 8-10), a more meaningful relationship could have been established between number of recyclings and ration digestibilities, nutrient digestibility in feces, residue accumulations, composition of feces and urine, mineral retention and overall acceptance by the animals to feces in the diet when fed over prolonged periods of time. This would have permitted regression and correlation analyses of the data to be conducted in a meaningful way.

TABLE 23. SODIUM RETENTION IN TRIAL 2

	Rations	T1 0	T2 7	T3 14	T4 21	Means	SEM
		g/day[2]					
Phase 1	Intake	14.98	15.02	15.07	15.12	15.05	
	Fecal excretion	2.50	3.32	3.91	4.30	3.51	
	Urine excretion	6.98	7.30	3.87	4.07	5.56	
	Net retention	5.50[a,b]	4.40[a]	7.29[b]	6.75[b]	5.98	0.7
Phase 2	Intake	14.47	15.29	16.73	15.95	15.61	
	Fecal excretion	3.34	3.46	3.50	3.93	3.56	
	Urine excretion	5.73	5.93	3.94	5.07	5.17	
	Net retention	5.40[a]	5.90[a]	9.29[b,c]	6.95[a,c]	6.88	0.8
Phase 3	Intake	14.91	15.13	15.25	15.33	15.16	
	Fecal excretion	3.81	4.88	3.74	5.50	4.48	
	Urine excretion	7.58	6.61	5.51	4.54	6.06	
	Net retention	3.52[a]	3.64[a]	6.00[b,c]	5.29[a,c]	4.61	0.6
Phase 4	Intake	15.24	19.14	13.67	15.17	15.80	
	Fecal excretion	3.20	3.48	3.18	4.29	3.54	
	Urine excretion	7.80	6.22	6.17	4.87	6.26	
	Net retention	4.24[a]	9.44[b]	4.32[a,c]	6.01[c]	6.00	0.6
	SEM[3]	1.6, 2.0	1.6, 1.9	1.0, 1.2	1.2, 1.4		

[1abc]: Values within phase (across treatments) with different superscripts differ significantly ($P<.05$).

[2] Values represent the mean of six observations per treatment in phases 1, 3 and 4 and four observations per treatment in phase 2.

[3] See Table 15.

2. Wider spread of roughage levels. Since ration digestibilities did not decrease significantly as level of roughage increased (due to the levels being spaced too closely), regression lines and correlations would have been meaningless. Ration digestibilities would have shown more decrease if the roughage levels were spread out more (e.g. 0, 14, 28, 42%, etc.), thereby allowing extrapolation by regression for residue accumulations, etc. in feces and urine when feces are being recycled over a broader range of rations. Different kinds of roughages or diets may also give different results. The digestibility of feces may also be a function of the amount in the diet and the nature of other dietary ingredients.

3. Change of experimental design. The length of time required to complete the animal collection portion of Trial 2 was tremendous--approximately 8 months. Therefore, time could have influenced or confounded the results

TABLE 24. CHLORINE RETENTION IN TRIAL 2

	Rations	T1 0	T2 7	T3 14	T4 21	Means	SEM
		g/day[2]					
	Intake	18.06	18.08	18.10	18.12	18.09	
Phase 1	Fecal excretion	1.31	1.19	1.60	2.06	1.54	
	Urine excretion	11.66	13.98	10.48	10.39	11.63	
	Net retention[1]	5.09	2.91	6.02	5.67	4.92	0.9
	Intake	16.66	16.59	16.78	16.50	16.63	
Phase 2	Fecal excretion	1.38	1.44	2.45	2.86	2.03	
	Urine excretion	10.92	8.47	7.24	7.71	8.58	
	Net retention	4.36	6.68	7.09	5.93	6.02	0.9
	Intake	16.39	16.30	16.67	16.20	16.39	
Phase 3	Fecal excretion	2.74	1.89	2.61	3.12	2.59	
	Urine excretion	11.37	12.80	8.50	7.93	10.15	
	Net retention	2.28	1.61	5.56	5.15	3.65	1.2
	Intake	15.90	16.04	16.16	16.69	16.20	
Phase 4	Fecal excretion	1.84	2.04	2.09	2.65	2.16	
	Urine excretion	11.64	9.50	8.72	7.30	9.29	
	Net retention	2.42[a]	4.50[a,b]	5.35[b,c]	6.74[c]	4.75	0.7
	SEM[3]	1.6, 2.0	1.5, 1.8	1.2, 1.5	1.2, 1.5		

[1abc]: Values within phase (across treatments) with different superscripts differ significantly ($P<.05$).

[2] Values represent the mean of six observations per treatment in phases 1, 3 and 4 and four observations per treatment in phase 2.

[3] See Table 15.

to some degree since the basal ration digestibilities (baseline or bench mark values) were determined at the beginning. An alternative experimental design might be to collect enough feces for each treatment in phase 1 such that ample feces could be stored for refeeding in a separate digestion study to be conducted at a later date to determine residue accumulation with one recycling and still have feces left from phase 1 to refeed in phase 2. Likewise, a portion of the feces produced at the end of phase 2 could be stored for refeeding at a later date to determine residue accumulation with two recyclings and part could be used for refeeding in phase 3. Similarly, a portion of the feces produced in phase 3 could be saved for refeeding in a later digestion trial, etc. while the remainder is fed in phase 4. This procedure could be followed for the number of cycles desired. If there were 4 treatments/phase and 3 recycling phases, at this point, there would be 16 rations to compare (4 basal, 12 feces containing ones). The stored

TABLE 25. CALCIUM RETENTION IN TRIAL 2

	Rations	T1 0	T2 7	T3 14	T4 21	Means	SEM
		g/day[2,3]					
Phase 1	Intake	21.85	22.11	22.37	22.64	22.24	
	Fecal excretion	25.56	29.11	18.36	24.90	24.48	
	Net retention	-3.71[a]	-7.00[a,r]	4.01[b]	-2.26[a]	-2.24	1.8
Phase 2	Intake	35.68	38.07	33.07	35.19	35.50	
	Fecal excretion	36.03	33.51	26.10	27.76	30.85	
	Net retention	-0.35	4.56[r]	6.97	7.43	4.65	1.8
Phase 3	Intake	41.58	40.89	38.34	36.34	39.29	
	Fecal excretion	41.58	39.20	39.49	40.16	40.11	
	Net retention	0.00	1.69[r]	-1.15	-3.82	-0.82	1.9
Phase 4	Intake	52.04	54.22	46.59	50.66	50.88	
	Fecal excretion	37.12	31.90	37.12	36.20	35.58	
	Net retention	14.92	22.32[s]	9.47	14.46	15.29	3.7
	SEM[4]	4.9, 6.0	3.2, 4.0	3.1, 3.8	4.6, 5.6		

[1abc]: Values within phase (across treatments) with different superscripts differ significantly (P<.05). rs: Values within treatment (across phase) with different superscripts differ significantly (P<.05).

[2] Values represent the mean of observations per treatment in phases 1, 3 and 4 and four observations per treatment in phase 2.

[3] Calcium was not analyzed in the urine since over 99% of the excretion is in the feces.

[4] See Table 15.

feces from phase 1 would be incorporated into the basal rations based on the indigestible dry matter production for each treatment in phase 1. Likewise, the feces stored from phases 2, 3 etc. could be reincorporated into the basal rations based on the indigestible dry matter produced during the appropriate phases. By such an arrangement, all rations could be compared at once in a randomized block design (blocked on time for replication) with 4-6 replications per treatment. Thus, time would be eliminated as a variable in comparing residue accumulations from recycling feces since all recycling treatments could be represented simultaneously. Another and perhaps more desirable alternative would be to include feces from each recycling phase at the same level (e.g. 50%) or two different (e.g. 25 and 50%) levels in the digestion trial rations. Other design possibilities exist (e.g. 2 basal treatments in phase 1, followed by 8 recyclings of each; or 1 basal treatment followed by 8 or 10 recyclings; or 4 X 4 or 6 X 6 Latin square

possibilities could be used). In any event, a design whereby time could be removed as a variable would be advantageous. Moreover, conduction of more replicates/treatment simultaneously to delete the need for periods or to reduce the number of periods within a phase would likely add some precision to digestibility estimates. Incorporating higher levels of feces in digestion trial studies would also tend to reduce any leverage factor in estimating fecal digestibility parameters.

4. Incorporation of both feces and urine. Protein digestibility and mineral residue excretion patterns may differ somewhat if both feces and urine were reincorporated during recycling.

TABLE 26. PHOSPHORUS RETENTION IN TRIAL 2

	Rations	T1 0	T2 7	T3 14	T4 21	Means	SEM
		g/day[2]					
	Intake	19.71	18.98	18.25	17.52	18.62	
Phase 1	Fecal excretion	6.49	7.20	4.77	5.12	5.90	
	Urine excretion	8.06	6.11	5.06	6.35	6.40	
	Net retention[1]	5.16	5.67	8.42[r,s]	6.05	6.32	1.5
	Intake	20.71	20.53	19.94	17.82	19.75	
Phase 2	Fecal excretion	8.29	6.54	4.29	4.63	5.94	
	Urine excretion	4.78	6.38	5.89	6.31	5.84	
	Net retention	7.64	7.61	9.76[r]	6.88	7.97	1.0
	Intake	21.18	19.92	18.42	18.32	19.46	
Phase 3	Fecal excretion	7.31	6.39	5.42	5.69	6.20	
	Urine excretion	8.08	5.83	6.10	6.69	6.68	
	Net retention	5.79	7.70	6.90[s,t]	5.94	6.58	0.6
	Intake	20.53	21.48	18.22	22.00	20.56	
Phase 4	Fecal excretion	5.99	5.19	4.95	7.86	6.00	
	Urine excretion	7.81	6.73	8.22	5.99	7.19	
	Net retention	6.73[a,c]	9.56[b]	5.05[a,t]	8.15[b,c]	7.37	0.7

[1]abc: Values within phase (across treatments) with different superscripts differ significantly (P<.05). rst: Values within treatment (across phase) with different superscripts differ significantly (P<.05).

[2] Values represent the mean of six observations per treatment in phases 1, 3 and 4 and four steer observations per treatment in phase 2.

SECTION VII

TRIAL 3--NITROGEN DEPLETION-REPLETION STUDY

SUMMARY

Urine collected from steers in Trials 1 and 2 was evaluated as a supplemental nitrogen (N) source in Trial 3. Iso-nitrogenous rations containing 0, 1.6, 3.2 or 4.9% dried urine as a replacement for 0, 25, 50 and 75% of the supplemental N supplied by soybean meal were compared in a N depletion-repletion study with young, growing lambs. The lambs were placed on a low N depletion ration for 4 weeks, following by a 5-week repletion period on the test diets.

Ration dry matter digestibility averaged approximately 6.6% higher and crude protein digestibility about 8.1% higher on all treatments during the first 2 weeks of the repletion period than during the last 3 weeks. This suggests that physiological or nutritional status may influence digestive efficiency. Moreover, greatest N retention efficiency was noted during the first several weeks following depletion when the lambs still had a rather depleted N status. During the first week, N retention, expressed either as % absorbed or % consumed N retained, was higher ($P<.05$) on the 0, 1.6 and 3.2% urine diets than on the 4.9% urine diet. The same pattern was noted during the second week. By the fifth week, the lambs had repleted their N reserves to the point that N response parameters were the same on all 4 treatments. Treatment differences were most profound during the first week, decreased thereafter and equalized by the end of the fifth week. Urinary N appeared to be readily available for utilization and promoted better N retention efficiencies than anticipated. The average daily protein retention per kg of metabolic body weight during the entire 5-week period was 5.2, 5.6, 6.1 and 4.8 g on the 0, 1.6, 3.2 and 4.9% urine diets, respectively ($P<.05$).

INTRODUCTION

Urine contains nitrogen (N) and thus should have merit as a supplemental N source. A relatively new technique has been developed to evaluate efficiency of N utilization. First, young lambs are fed a diet which is very low in N for a period of 3 to 4 weeks to deplete their N reserves. At this point, the lambs will be in a negative N balance, which means they will be excreting more N than what they are consuming. The next stage is the repletion phase where the lambs are assigned either to rations which contain graduated levels of the N test source or different nitrogen sources. Efficiency of N utilization is measured by the net amount of N retained.

Therefore, the purpose of this trial was to evaluate the efficiency of N utilization from steer urine by using the N depletion-repletion procedure with young, growing lambs.

MATERIALS AND METHODS

Experimental Design

Sixteen young (12-week-old), crossbred Western lambs averaging about 20 kg were fed a N-depletion ration for four weeks (Table 27). Then the lambs were placed in digestion stalls and randomly assigned to one of four N-repletion rations (Table 28). The N-repletion rations consisted of 20% dried steer feces, along with 0, 2, 4 or 6% partially dried steer urine (0, 1.6, 3.2 and 4.9% urine on DM basis) which were obtained from Trials 1 and 2. The composition of the feces and urine is shown in Table 29. The N from the urine replaced 25, 50 and 75%, respectively, of the total supplemental N supplied by soybean meal (control). The lambs were fed once daily at a level equal to 90 $g/kg^{0.75}$ initial body weight at the beginning of the repletion phase. This represented a rather high level of daily intake (in excess of 4.0% of body weight). Feed weighbacks were recorded weekly. The repletion phase was conducted for five weeks. Feces and urine were collected and weighed daily during the repletion phase. The total individual daily collections were frozen and composited weekly by lamb. Aliquots were taken for laboratory analyses. The lambs were weighed at the beginning and end of the trial. Water was available at all times.

TABLE 27. NITROGEN-DEPLETION RATION FED IN TRIAL 3

Ingredient[1]	%
Cottonseed hulls, 1-01-599	45.1
Dried molasses, 4-04-695	15.4
Corn starch	9.9
Ground corn, 4-02-935	28.5
Calcium carbonate, 6-02-632	0.4
Dicalcium phosphate, 6-01-080	0.4
Trace mineral salt	0.2
667 I.U. Vitamin A/kg	+
67 I.U. Vitamin D/kg	+

[1] Dry matter basis.

Laboratory Analyses

Dry Matter

A 300 g sample of wet sheep feces was placed in a 60° forced air oven for 48 hours. The samples were removed and allowed to equilibrate with air for 24 hr before weighing. The samples were then ground through a 20 mesh screen in a small laboratory mill, and dry matters were determined on the dried feces according to AOAC (1965).

TABLE 28. NITROGEN-REPLETION RATIONS FED IN TRIAL 3

Ingredient[1]	T1	T2	T3	T4
	----------	----------	%	----------
Cottonseed hulls, 1-01-599	8.9	8.9	8.9	8.9
Dried feces	18.5	18.5	18.5	18.5
Dried molasses, 4-04-695	13.7	13.7	13.7	13.7
Soybean meal, 5-04-604	10.7	8.0	5.4	2.7
Ground corn, 4-02-935	28.0	28.8	29.7	30.6
Dried urine[2,3]	----	1.6	3.2	4.9
Corn starch	8.8	8.8	8.8	8.8
Calcium carbonate, 6-02-632	0.4	0.4	0.4	0.4
Dicalcium phosphate, 6-01-080	0.4	0.4	0.4	0.4
Trace mineral salt	0.2	0.2	0.2	0.2
667 I.U. Vitamin A/kg	+	+	+	+
67 I.U. Vitamin D/kg	+	+	+	+
Composition:				
Dry matter	89.5	89.3	89.1	89.0
Crude protein[1]	14.2	14.1	14.0	13.9

[1] Dry matter basis.

[2] Added at levels to keep all treatments iso-nitrogenous.

[3] N Composition--Dry matter basis.
total N - 10.17%
soluble N - 9.52%
non-protein N - 7.73%
urea N - 5.16%

TABLE 29. COMPOSITION OF FECES AND URINE USED IN TRIAL 3 REPLETION RATIONS

Item	Feces	Urine
	----------	% ----------
Dry matter	92.4	81.3
Ash[1]	10.5	----
Crude protein[1]	18.6	63.6
Acid-detergent fiber[1]	34.0	----

[1] Dry matter composition.

Crude Protein

Kjeldahls were done on the feces and urine samples for N determination according to AOAC (1965) methods. At first, Kjeldahls were done on both the wet and dry sheep feces. However, since there was little difference in the results between the two samples, Kjeldahls were discontinued on the wet samples. Thus, all the calculations are based on the crude protein values obtained on the dry feces samples.

Calculations

Digestion coefficients were calculated in the conventional manner. Nitrogen balance data was calculated on the basis of metabolic weight, $kg^{0.75}$, to minimize any error resulting from differences in lamb size.

Statistical Analyses

Statistical analyses were done by analysis of variance, and differences among means were tested by least significant differences according to Snedecor and Cochran (1967).

RESULTS AND DISCUSSION

Week 1.

Dry matter and crude protein intakes (Table 30) were slightly higher on the 4% urine ration, although the differences were not significant ($P>.05$). Dry matter and crude protein digestibilities, crude protein absorbed and crude protein excreted were similar among treatments. However, the 4% urine treatment had the most favorable values for all these parameters, while the 6% urine treatment had the least favorable. Thus, grams of protein retained per day, per unit of metabolic weight, were higher ($P<.05$) on the 0 and 4% urine rations than on the 6% urine ration (6.7 and 8.0 vs 4.9 g/day, respectively). Lambs on the 2% urine ration retained an intermediate amount, 6.4 g/day ($P>.05$). Nitrogen (N) retention, expressed either as % absorbed or % consumed N retained, was higher ($P<.05$) for lambs fed the 0, 2 and 4% urine rations as compared to lambs fed the 6% urine ration. In general, during the first week of the repletion phase, the lambs utilized N most efficiently from the 4% urine ration and least efficiently from the 6% urine ration. This might be attributed to the slightly greater intakes on the 4% treatment.

Week 2.

Although there were no significant ($P>.05$) differences among the rations in week 2 (Table 31) for any of the N balance parameters, dry matter and protein intakes were slightly higher on the 0 and 4% urine rations as were the grams of absorbed protein. The grams of protein retained daily were slightly lower in week 2 on the 0, 2 and 4% urine rations, but similar to week 1 on the 6% urine ration. Lambs fed the 0, 2, 4 and 6% urine rations retained 5.9, 6.0, 6.6 and 5.0 g per day in week 2 vs 6.7, 6.4, 8.0 and 4.9 g per day in week 1. The percent absorbed and consumed N also decreased slightly in week 2, except on the 6% urine treatment. In general,

the lambs consuming the 0 and 4% urine rations were still the most efficient, and the lambs consuming the 6% urine ration the least efficient. But, the differences as illustrated in Figures 2 and 3 were somewhat less.

TABLE 30. N BALANCE FOR WEEK ONE OF TRIAL 3

Item[4]	T1	T2	T3	T4	SEM[1]
Dry matter intake, $g/kg^{0.75}/day$[2,3]	86.7	83.3	89.1	83.4	
Dry matter digestibility, %	79.8	82.2	86.2	78.2	2.6
Crude protein intake, $g/kg^{0.75}/day$	12.4	11.8	12.5	11.6	
Crude protein digestibility, %	73.6	76.2	78.7	65.1	3.8
Crude protein absorbed, $g/kg^{0.75}/day$	9.1	9.0	9.8	7.6	0.6
Urinary crude protein excreted, $g/kg^{0.75}/day$	2.3	2.5	1.8	2.8	0.2
Crude protein retained, $g/kg^{0.75}/day$	6.7^{a}	$6.4^{a,b}$	8.0^{a}	4.9^{b}	0.5
% Absorbed N retained	$74.0^{a,c}$	71.9^{a}	81.3^{c}	62.2^{b}	3.0
% Consumed N retained	54.7^{a}	55.0^{a}	63.9^{a}	41.1^{b}	4.2

[1] Standard error of the mean.

[2] Values represent the mean of four lambs per treatment.

[3abc]: Values in a row with different superscripts differ significantly ($P<.05$).

[4] T1, T2, T3, T4 represent 0, 2, 4 and 6% urine, respectively.

Week 3.

Although daily dry matter and crude protein intakes in week 3 (Table 32) were identical to week 2 for each corresponding ration, dry matter and crude protein digestibilities were lower (4-7% and 7-10%, respectively). As a result, the grams of absorbed protein were also lower in week 3. Since the grams of protein excreted in the urine were similar for weeks 2 and 3, net protein retention (grams) in week 3 was 10-20% lower on the 0, 2 and 4% urine rations and 4% lower on the 6% urine ration. The percent absorbed and consumed N retained was lower in week 3 than in week 2 for all the rations except the 6% urine ration. The 4 % urine ration showed the greatest decrease in both of these parameters, likely due to the higher

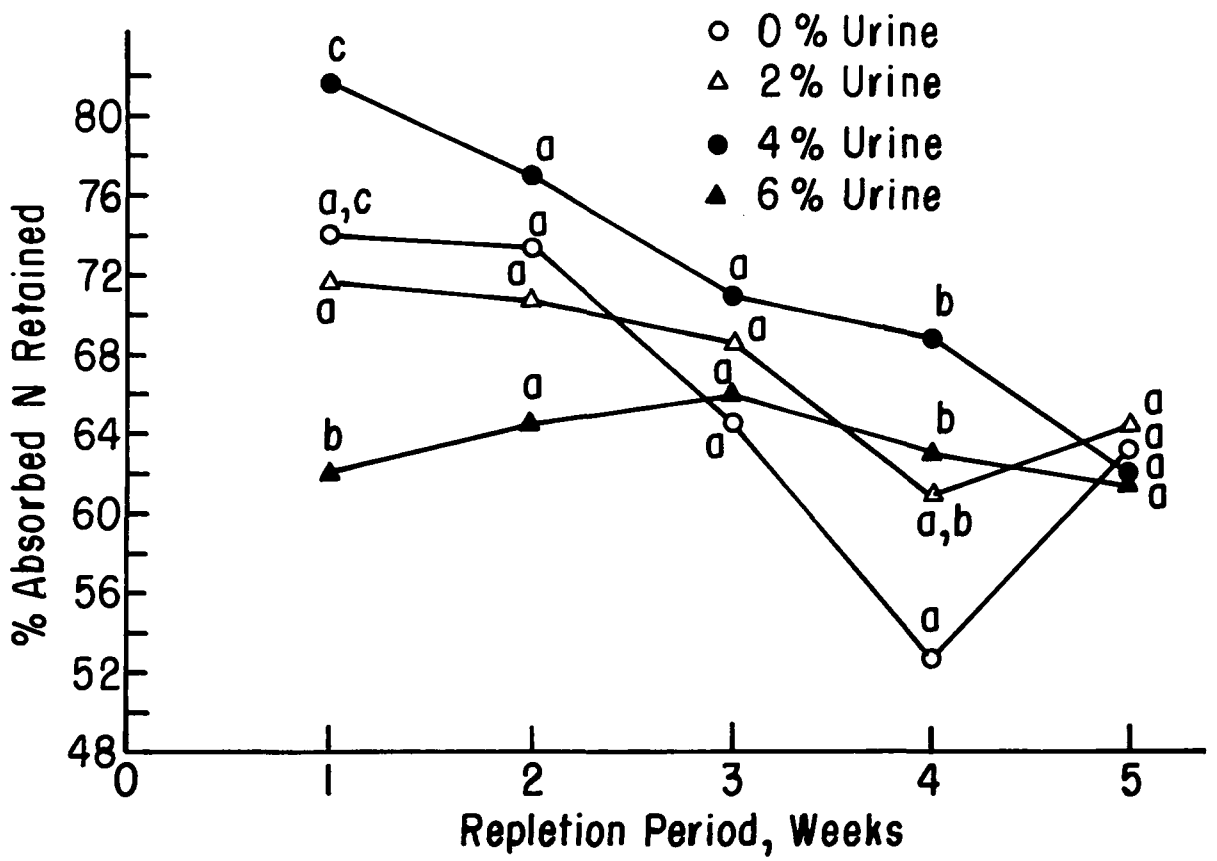


FIGURE 2. PERCENT ABSORBED N RETAINED
abc: Points within each week differ significantly ($P<.05$).

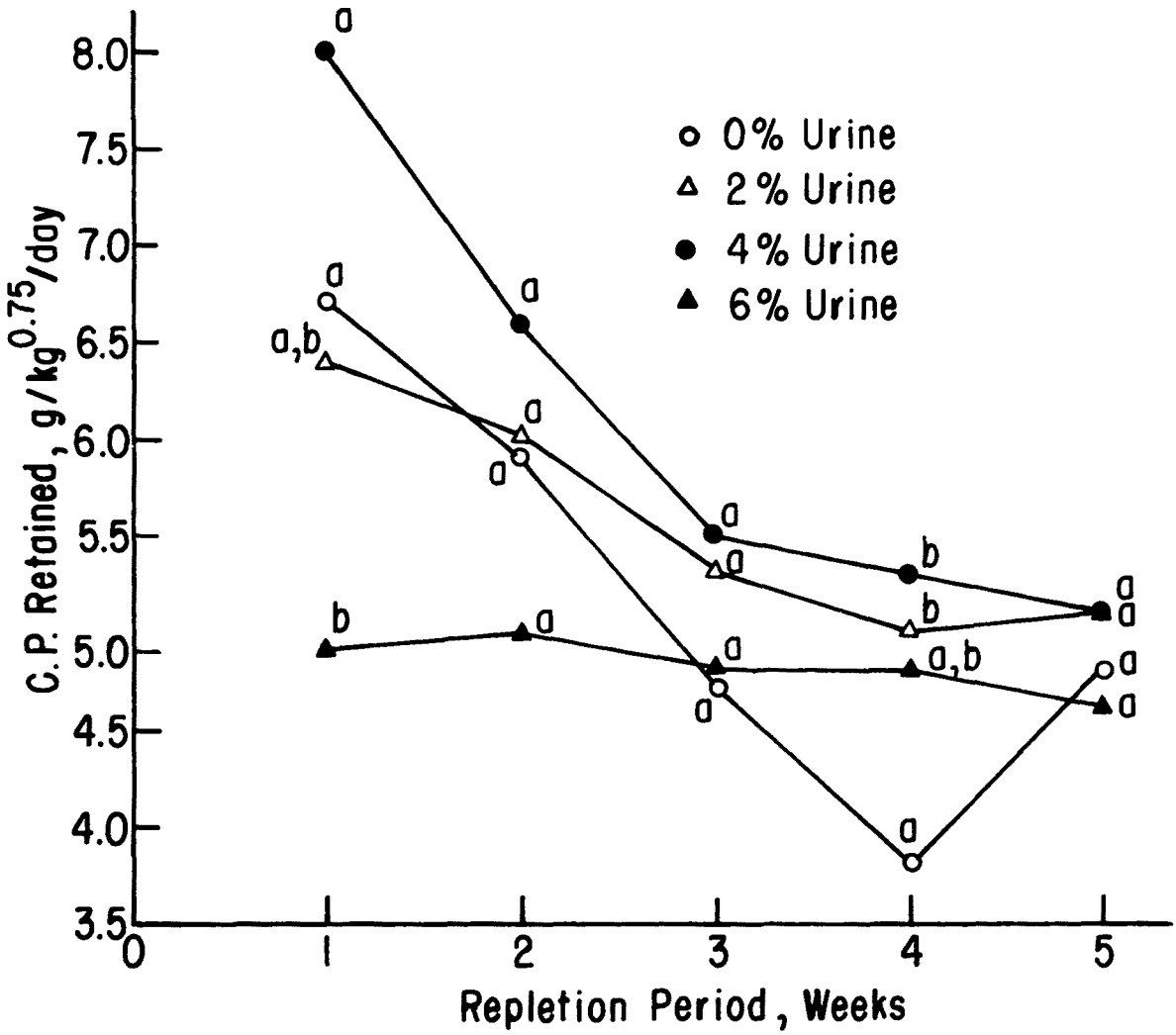


FIGURE 3. GRAMS OF PROTEIN RETAINED
ab: Points with different letters within each week differ significantly (P<.05).

TABLE 31. N BALANCE FOR WEEK TWO FOR TRIAL 3

Item	T1	T2	T3	T4	SEM
Dry matter intake, $g/kg^{0.75}/day$	87.1	84.2	89.1	84.2	
Dry matter digestibility, %	75.3	79.1	78.3	78.0	2.4
Crude protein intake, $g/kg^{0.75}/day$	12.4	11.9	12.5	11.7	
Crude protein digestibility, %	64.6	70.4	68.8	65.8	3.1
Crude protein absorbed, $g/kg^{0.75}/day$	8.0	8.4	8.6	7.7	0.4
Urinary crude protein excreted, $g/kg^{0.75}/day$	2.1	2.4	2.0	2.7	0.3
Crude protein retained, $g/kg^{0.75}/day$	5.9	6.0	6.6	5.0	0.6
% Absorbed N retained	73.6	70.9	77.0	64.5	4.5
% Consumed N retained	47.9	50.0	53.1	42.6	4.5

TABLE 32. N BALANCE FOR WEEK THREE OF TRIAL 3

Item	T1	T2	T3	T4	SEM
Dry matter intake, $g/kg^{0.75}/day$	87.1	84.2	89.1	84.2	
Dry matter digestibility, %	69.8	74.2	73.3	74.9	2.3
Crude protein intake, $g/kg^{0.75}/day$	12.4	11.9	12.5	11.7	
Crude protein digestibility, %	58.0	65.0	61.7	61.0	3.1
Crude protein absorbed, $g/kg^{0.75}/day$	7.2	7.7	7.7	7.2	0.5
Urinary crude protein excreted, $g/kg^{0.75}/day$	2.5	2.4	2.2	2.4	0.3
Crude protein retained, $g/kg^{0.75}/day$	4.7	5.3	5.5	4.8	0.6
% Absorbed N retained	64.6	68.7	70.9	66.0	4.4
% Consumed N retained	37.7	44.8	44.0	40.7	4.2

retention values noted in the previous weeks. Although there were no significant differences (P>.05) among any of the treatments in efficiency of N utilization, lambs fed the 2 and 4% urine rations retained the most protein whether expressed as grams per day, % absorbed or % consumed N retained. Lambs fed the 0 and 6% urine rations retained similar amounts of N.

Week 4.

Treatments did not differ (P>.05) in dry matter and crude protein intakes or digestibilities in week 4 (Table 33). The grams of net protein retained during week 4 on the 0, 2, 4 and 6% urine rations were (P<.05) 3.8, 5.0, 5.3 and 4.8 g per day, respectively. These would compare with 4.7, 5.3, 5.5 and 4.8 g per day, respectively, in week 3. The percent of absorbed and consumed N retained was also lower for all treatments in week 4. This was likely due to the increased positive protein status of the animals by this time. Lambs fed the 2, 4 and 6% urine rations retained a (P<.05) higher percentage (39.8, 43.0 and 39.9%, respectively) of consumed N than lambs fed the 0% ration (31.0%). Percent absorbed N retained appeared similar to consumed N retained. In general, N utilization was still slightly more efficient for lambs fed the 4% urine ration.

TABLE 33. N BALANCE FOR WEEK FOUR OF TRIAL 3.

Item	T1	T2	T3	T4	SEM
Dry matter intake, $g/kg^{0.75}/day$	86.2	89.3	88.3	86.4	
Dry matter digestibility, %	70.4	74.3	71.5	73.1	2.2
Crude protein intake, $g/kg^{0.75}/day$	12.3	12.6	12.4	12.0	
Crude protein digestibility, %	59.2	65.1	62.0	61.4	2.6
Crude protein absorbed, $g/kg^{0.75}/day$	7.3	8.2	7.7	7.4	0.4
Urinary crude protein excreted, $g/kg^{0.75}/day$	3.4^{a}	$3.2^{a,c}$	2.4^{b}	$2.6^{b,c}$	0.2
Crude protein retained, $g/kg^{0.75}/day$	3.8^{a}	5.0^{b}	5.3^{b}	$4.8^{a,b}$	0.3
% Absorbed N retained[1]	52.6^{a}	$61.2^{a,b}$	69.1^{b}	65.2^{b}	2.9
% Consumed N retained[1]	31.0^{a}	39.8^{b}	43.0^{b}	39.9^{b}	2.4

[1]abc: Values in a row with different superscripts differ significantly (P<.05).

Week 5

By the fifth week, all of the lambs had repleted their N reserves to a

point that was near normal for their physiological growth status (Table 34). Therefore, as noted in Table 34 and Figures 2 and 3, N response parameters were essentially the same on all treatments. All rations were about equally efficient in meeting the daily N requirement, and differences in N retention were less apparent than in the preceding four weeks.

TABLE 34. N BALANCE FOR WEEK FIVE OF TRIAL 3

Item	T1	T2	T3	T4	SEM
Dry matter intake, $g/kg^{0.75}/day$	86.2	89.3	88.3	86.4	
Dry matter digestibility, %	72.6	72.8	74.9	73.7	2.6
Crude protein intake, $g/kg^{0.75}/day$	12.3	12.6	12.4	12.0	
Crude protein digestibility, %	63.3	63.8	65.7	62.1	3.2
Crude protein absorbed, $g/kg^{0.75}/day$	7.8	8.0	8.1	7.4	0.5
Urinary crude protein excreted, $g/kg^{0.75}/day$	2.9	3.0	3.1	2.8	0.4
Crude protein retained, $g/kg^{0.75}/day$	4.8	5.1	5.1	4.6	0.5
% Absorbed N retained	62.4	63.4	62.1	61.5	4.4
% Consumed N retained	39.3	40.3	41.0	38.5	3.5

Five Week Summary

Figure 2 shows the treatments to differ widely during the first week of the repletion phase in percent absorbed N retained, but to equalize by the end of the fifth week. Grams of protein retained per day followed a similar pattern (Figure 3). When the N balance data was averaged over the five week repletion phase (Table 35), daily dry matter and crude protein intakes for the 0, 2, 4 and 6% urine rations were 86.7, 86.1, 88.0 and 84.9 g/day, respectively for dry matter and 12.3, 12.2, 12.4 and 11.8 g/day, respectively, for protein. Dry matter digestibilities ranged from 73.6 to 76.9% ($P>.05$). The 6% urine ration had a lower ($P<.05$) protein digestibility (63.1%) than the 2 (68.1%) and 4% (67.4%) urine rations. Protein digestibility on the 0% urine ration (63.8%) was lower ($P<.05$) than on the 2% urine ration. Lambs fed the 6% urine ration absorbed less ($P<.05$) protein (7.5 g/day) than lambs fed the 2 (8.2 g/day) and 4% (8.4 g/day) rations. Although protein excretion in the urine did not differ ($P>.05$) among rations, the 4% urine ration was the lowest. Grams of protein retained per day were higher ($P<.05$) on the 2 and 4% urine rations than on the 6% urine ration (5.6 and 6.1 vs 4.8 g/day). Lambs fed the 4% urine ration retained a higher ($P<.05$) percentage of absorbed (72.1%) and consumed N (49.0%) than lambs fed the 0 (65.5 and 42.1%) and 6% urine rations (63.9 and 40.5%).

In general, the 5-week treatment averages were less profound than in the early weeks, but the trends were the same.

TABLE 35. N BALANCE SUMMARIZED OVER THE FIVE WEEK PERIOD

Item	T1	T2	T3	T4	SEM
Dry matter intake, $g/kg^{0.75}/day$[1,2]	86.7	86.1	88.0	84.9	
Dry matter digestibility, %	73.6	76.5	76.9	75.6	1.1
Crude protein intake, $g/kg^{0.75}/day$	12.3	12.2	12.4	11.8	
Crude protein digestibility, %	$63.8^{a,c}$	68.1^{b}	$67.4^{b,c}$	63.1	1.4
Crude protein absorbed, $g/kg^{0.75}/day$	$7.9^{a,c}$	$8.2^{b,c}$	$8.4^{b,c}$	7.5^{a}	0.2
Urinary crude protein excreted, $g/kg^{0.75}/day$	2.7	2.7	2.3	2.6	0.1
Crude protein retained, $g/kg^{0.75}/day$	$5.2^{a,b}$	$5.6^{b,d}$	$6.1^{c,d}$	4.8^{a}	0.2
% Absorbed N retained	65.5^{a}	$67.2^{a,c}$	$72.1^{b,c}$	63.9^{a}	1.8
% Consumed N retained	$42.1^{a,b}$	$46.0^{b,c}$	49.0^{c}	40.5^{a}	1.7

[1] Values represent the mean of 20 observations per treatment.

[2] abc: Values in a row with different superscripts differ significantly ($P<.05$).

General Conclusions

1. For unknown reasons, ration digestibility was greatest during the first two weeks following the depletion phase. This implies that physiological or nutritional status of the animal may influence digestive efficiency--greatest efficiency being observed in thin animals in poor condition.

2. Greatest N retention efficiency was observed during the first two weeks when the lambs were still in a very depleted N state.

3. In general, the greatest N retention efficiency was observed on the 4% urine ration, particularly during the first several weeks. Nevertheless, the differences were not great between the 0, 2 and 4% urine rations.

4. In general, the 6% urine ration promoted the poorest N retention efficiency especially during the first several weeks. Little difference was noted, however, by the end of the fifth week. This was due to the fact

that N retention efficiency on the 6% urine diet tended to remain constant over the 5 week period while N retention on the other three treatments declined. This response may be an indication of an adaptation response, but more likely merely reflects compensatory N repletion in that the 6% treatment produced the poorest N retention during the first two weeks; thus, these animals merely took longer to replete their N reserves.

5. It is not clear why the responses were slightly better throughout most of the study on the 4% urine treatment. Since there were only 4 lambs/treatment, possibly by chance more vigorous, genetically superior animals in growth rate (hence, greater ability to store or retain protein in muscle growth, etc.) were allotted at random to this treatment, biasing the results.

6. When the lambs had repleted their protein reserves by the fifth week, there were no differences or trends evident in N efficiency among treatments.

7. Urinary N appears to be readily available for incorporation into microbial protein synthesis in the rumen. Certainly, it was not anticipated that the N retention efficiencies from urine would look as favorable as they did.

8. Since these lambs were fed ad lib they likely consumed small quantities of feed at any one time and ate frequently (nibblers) throughout the day. In theory, such a feeding arrangement would favor better NPN utilization since low levels of the NPN source (in this case urine) would be consumed at one time. This would result in moderately low, relatively constant NH_3 levels in the rumen, rather than having large peaks in NH_3 concentration (and resulting wasteage) shortly after feeding as when lambs are fed one or two times daily (meal eaters). A low, continuous supply of NH_3 would be more favorable for efficient incorporation of NH_3 into microbial protein synthesis and result in reduced NH_3 losses via absorption into the blood, reconversion of absorbed NH_3 to urea in the liver and excretion of urea via the urine. Moreover, it should be noted that the diet used in these studies contained a reasonably good source of readily available carbohydrates or energy, providing for favorable microbial protein synthesis from NPN. Nevertheless, it is somewhat surprising that the N retention data looks as favorable as it does on the urine diets, particularly the higher levels. Possibly the favorable N retention data (relative to soybean meal) can be explained by the manner of feeding. It would be interesting to ascertain N response parameters under different feeding arrangements.

SECTION VIII

TRIAL 4--DIGESTION AND GROWTH STUDY WITH LAMBS

SUMMARY

Trial 4 was a growth and metabolism study comparing rations containing 0, 20, 40 and 60% feces as a roughage source for lambs.

In general, dry matter, organic matter, ash, crude protein, acid detergent fiber, cellulose and neutral detergent fiber digestibilities decreased with increasing feces levels although the differences were not always significant. Dry matter digestibilities were 45.3, 40.7, 37.0 and 29.2% on the 0, 20, 40 and 60% feces rations, respectively ($P<.05$).

There were no significant ($P>.05$) differences among treatments in chlorine and phosphorus retention. Calcium and phosphorus intake and excretion increased with feces level in the diet. All of the mineral retention values appeared normal.

Daily dry matter intakes were slightly higher ($P<.05$) for lambs fed the control ration (1.17 kg) as compared to those fed the 20% (1.06 kg), 40% (1.07 kg), and 60% (1.07 kg) feces rations. In general, intakes and palatabilities of the feces rations appeared much better than anticipated. Average daily gain decreased ($P<.05$) slightly with each higher increment of feces. The values were 0.06, 0.03, 0.01 and -0.02 kg gain per day (89 days) on the 0, 20, 40 and 60% feces rations, respectively. Although the data herein suggest that feces are low in energy, all of the levels of feces used in this trial appeared acceptable for maintenance type programs.

INTRODUCTION

The purpose of this trial was to determine the effect of increasing levels of feces upon nutrient digestibility, ration palatability and lamb growth rate.

EXPERIMENTAL PROCEDURES

The rations used in this trial are shown in Table 36. Dried steer feces were incorporated into four lamb growing rations (treatments) at levels of 0, 20, 40 and 60% as a replacement for 10% dehydrated alfalfa and 10% cottonseed hulls for each 20% increment in feces level. Forty-eight young, Western lambs weighing an average of 23.4 kg were randomly allotted to one of the four treatments making a total of twelve lambs per treatment. The

lambs were adapted over a two week period to the rations which was followed by a 89-day growth study. The lambs were fed ad libitum daily in individual pens, and feed weighbacks were recorded weekly. Water was always available.

After the seventh week on trial, four lambs were chosen at random from each of the treatments and placed in individual digestion stalls. Daily feed levels were adjusted to a constant daily ad libitum intake. After a 10-day adjustment in the stalls, a 7-day digestion study was conducted. During the digestion study, total outputs of feces and urine were collected, weighed and sampled daily. The individual daily samples for each lamb were then composited. The feces samples were dried and ground as described in Trial 3. Laboratory procedures were as outlined in Trial 1 except Kjeldahls were done only on the dried feces.

Ration digestion coefficients and growth performance data were calculated in the conventional manner. Statistical analyses were done using analysis of variance with significant differences among means being tested by least significant differences (LSD).

TABLE 36. COMPOSITION OF THE RATIONS FED IN TRIAL 4

Ingredient[1]	Feces Level 0	20	40	60
	%			
Dehydrated alfalfa meal, 1-00-025	65.5	55.1	44.8	34.7
Cottonseed hulls, 1-01-599	34.3	24.3	14.4	4.7
Dried feces	----	20.4	40.5	60.4
Traced mineral salt	0.2	0.2	0.2	0.2
Proximate Analysis:				
Dry matter	93.6	92.8	93.4	93.6
Ash	12.0	13.2	18.7	26.7
Crude protein	14.3	15.5	16.5	17.0
Acid-detergent fiber	42.9	40.9	40.9	47.5
Lignin	11.0	15.1	14.0	12.9
Cellulose	30.8	28.6	25.0	20.4
Neutral detergent fiber	58.5	57.8	56.7	59.3
Sodium	0.49	0.30	0.55	0.45
Chlorine	0.64	0.53	0.68	0.59
Calcium	1.24	1.30	1.56	1.66
Phosphorus	0.27	0.40	0.59	0.72

[1] Dry matter basis.

RESULTS AND DISCUSSION

Ration Digestibilities

Dry matter digestibility for the 0% feces control ration (45.3%) did

not differ (P>.05) from the 20% ration (40.7%), but was higher (P<.05) than for the 40% (37.0%) and 60% (29.2%) feces rations (Table 37). Moreover, the dry matter digestibility of the 40% feces ration was significantly higher (P<.05) than the 60% feces ration. The 0% feces ration had the highest (P<.05) ash digestibility (34.2%). Ash digestibility for the 40% feces ration (12.2%) was similar (P>.05) to the 20% feces ration (7.1%) but higher (P<.05) than the 60% (-2.4%) feces ration. The low ash digestibilities on the feces rations can be attributed to the high ash content in the feces. Rations did not differ (P<.05) in organic matter or crude protein digestibility. Digestibilities for these parameters were approximately 40-48% for all treatments.

Acid detergent fiber (ADF) digestibilities were similar on the 0 and 20% feces rations (24.0 and 18.7, respectively), but the 0% feces ration was higher (P<.05) than the 40% (14.7%) and 60% (10.7%) feces rations. As in Trial 2, lignin digestibility (-2.2%) was the lowest (P<.05) for the 0% feces ration, but the 20, 40 and 60% feces rations did not differ (P>.05) in lignin digestibility (approximately 20%). There were no significant (P>.05) differences in cellulose digestibility, but neutral detergent fiber (NDF) digestibility decreased (P<.05) with increasing feces level in the diet. In general, dry matter, organic matter, crude protein, ADF and NDF digestibilities decreased with each increase of feces in the ration.

TABLE 37. APPARENT DIGESTIBILITIES OF RATIONS IN TRIAL 4.

	Feces Level				
	0	20	40	60	SEM
	%				
Apparent digestibilities					
Dry matter[1,2]	45.3[a]	40.7[a,b]	37.0[b]	29.2[c]	2.4
Ash	34.2[a]	7.1[b,c]	12.2[b]	-2.4[c]	4.5
Organic matter	46.7	45.6	42.6	40.4	2.2
Crude protein	48.2	46.0	44.7	43.4	2.1
Acid detergent fiber	24.0[b]	18.7[a,b]	14.7[a]	10.7[b]	2.9
Lignin	-2.2[a]	23.5[b]	20.1	18.6	4.2
Cellulose	40.4	43.1	40.5	36.0	2.4
Neutral detergent fiber	37.2[c]	33.0[b,c]	27.6[b]	18.2[a]	3.0

[1abc]: Values with different superscripts in a row differ significantly (P<.05).

[2] Values represent the mean of four lambs.

Mineral Retention and Excretion

Sodium retention (Table 38) was highest (P<.05) on the 0% feces ration (2.26 g/day). Each higher increment of feces, after 20%, resulted in a higher (P<.05) retention of sodium. Sodium retention for the 20, 40 and

60% feces ration was -1.42, 0.44 and 1.15 g/day, respectively. There were no significant (P>.05) differences among treatments in chlorine and phosphorus retention, but tended to be slightly higher on the control diet (0 feces). In general, there was a slight negative Ca retention on the three feces diets. All of the mineral retention data, however, would be regarded as normal values. There were no substantial differences in sodium and chlorine intake and/or fecal excretion regardless of treatment. This should be expected since those are normally excreted predominately in the urine. For Ca and P, however, both intake and fecal excretion increased as feces in the diet increased. This is logical and as should be expected considering the normal avenues of excretion as discussed in Trial 2.

TABLE 38. MINERAL RETENTION DATA IN TRIAL 4

	Feces Level				
	0	20	40	60	SEM
	g/day				
			Sodium		
Intake	5.78	3.46	6.33	5.03	
Fecal excretion	1.03	1.02	1.24	1.37	
Urine excretion	2.49	3.86	4.65	2.51	
Net retention	2.26[d]	-1.42[a]	0.44[b]	1.15[c]	0.2
			Chlorine		
Intake	7.62	5.99	7.86	6.50	
Fecal excretion	0.31	0.41	0.54	0.70	
Urine excretion	6.69	5.96	7.00	5.46	
Net retention	0.62	-0.38	0.32	0.34	0.2
			Calcium[3]		
Intake	14.64	14.82	17.98	18.35	
Fecal excretion	13.49	16.44	18.76	19.19	
Urine excretion	-----	-----	-----	-----	
Net retention	1.15[b]	-1.62[a]	-0.78[a]	-0.84[a]	0.5
			Phosphorus		
Intake	3.15	4.58	6.76	7.99	
Fecal excretion	2.52	4.38	5.52	6.51	
Urine excretion	0.39	0.40	0.86	1.07	
Net retention	0.24	-0.20	0.38	0.41	0.2

[1abcd]: Values with different superscripts in a row differ significantly (P<.05).

[2] Values represent the mean of four lambs.

[3] Calcium was not analyzed in the urine as the majority is excreted in the feces.

Growth Performance

Daily dry matter intake was highest (P<.05) on the 0% ration (1.17 kg/day), as shown in Table 39. The three feces rations produced about 0.10 kg lower (P<.05) intakes, being 1.06 (20), 1.07 (40) and 1.07 kg (60) dry matter intake/day. Average daily gain (89 days) on the 4 treatments were 0.06, 0.03, 0.01 and -0.02 kg on the 0, 20, 40 and 60% rations, respectively. Each additional level of feces cause a significant (P<.05) decrease in gain, although the actual magnitude of decrease was very small. The growth data in this study suggests that the energy content of feces is low, but that rather large amounts of feces could be incorporated into maintenance type rations. No adverse problems were encountered in achieving satisfactory intakes on the feces diets. This was evidenced by intakes in excess of 4.0% of body weight on all diets. Adaptation to such diets was successfully achieved in about one week. The ground feces used in this study were very dry and dusty. Perhaps, even better acceptance might be obtained if the feces rations were pelletted.

TABLE 39. GROWTH DATA ON LAMBS IN TRIAL 4

	Feces Level				
	0	20	40	60	SEM
Number of lambs	12	12	12	12	
Beginning weight, kg	23.3	23.6	23.6	23.3	
Ending weight, kg	28.9	26.6	24.1	21.3	
Dry matter intake, kg/day	1.17[a]	1.06[b]	1.07[b]	1.07[b]	17.5
Average daily gain, kg/day	0.06[a]	0.03[b]	0.01[c]	-0.02[d]	.01

labcd: Values with different superscripts in a row differ significantly (P<.05).

SECTION IX

TRIAL 5--HEIFER GROWTH TRIAL

SUMMARY

A 109-day feedlot growth trial was conducted with heifers to compare three treatments: T1) basal containing 88% concentrate, T2) basal plus 15% dried steer feces and, T3) basal plus 15% dried steer feces and 1% partially dried steer urine. The feces were substituted for corn in the basal ration, and the urine was substituted for soybean meal on an iso-nitrogenous basis.

Heifers fed the control, basal ration (T1) consumed slightly more feed (P>.05) than heifers fed the 15% feces (T2) and feces plus urine (T3) rations (6.03 vs 5.70 and 5.75 kg, respectively). The respective average daily gains were 1.13, 0.87 and 0.92 kg. The feed/gain values were 5.33, 6.59 and 6.28 on T1, T2 and T3, respectively.

INTRODUCTION

The purpose of this trial was to determine the feedlot performance of growing cattle fed high concentrate rations containing feces or feces plus urine.

EXPERIMENTAL PROCEDURES

Twenty-seven 6-8 month old heifer calves weighing an average of 177.8 kg were randomly assigned to one of three treatments with nine heifers per treatment (three pens per treatment and three heifers per pen). The treatments compared (Table 40) were: T1) basal ration containing 88% concentrate, T2) basal ration plus 15% dried steer feces, and T3) basal ration with 15% feces plus 1% partially dried steer urine (T3). In T2 and T3 feces and/or urine were substituted for corn in the basal ration. The nitrogen in the urine replaced an equivalent amount of supplemental nitrogen supplied by soybean meal. All rations were intended to be iso-nitrogenous. A three week ration adaptation period was followed by a 109-day growth trial. The heifers were fed ad libitum, and feed weighbacks were taken weekly on each pen. Water was always available.

RESULTS AND DISCUSSION

Heifers fed T1 consumed slightly more feed (P>.05) than heifers fed T2 or T3 (6.03 vs 5.70 and 5.78 kg day, respectively) as shown in Table 41. Average daily gain was higher (P<.05) for heifers fed T1 (1.13 kg/day) than

those fed T2 or T3 (0.87 and 0.92 kg/day, respectively). Although there were no significant differences (P>.05) among treatments in feed efficiency, heifers fed the control required less feed per kilogram of gain (5.33, 6.59 and 6.28 on T1, T2 and T3, respectively).

When calculating the amount of ration other than feces and/or urine (non-feces portion) required/unit of gain, it is evident that about the same amount of non-feces ration was required whether feces were added or not (5.33, 5.54 and 5.28 for the control (T1), feces (T2) and feces plus urine treatments (T3), respectively). Thus, in this particular case, feces did not contribute materially to a reduction in the amount of basal ration required per kilogram of gain. However, it must be pointed out that lower gains (as obtained on T2 and T3) automatically result in some increase in feed requirements/unit gain since maintenance energy costs (although fixed) are not diluted over as much gain/day. Hence, maintenance energy feed requirements will increase/unit of gain as gain is reduced since maintenance is a fixed cost/day. Moreover, feces replaced corn which is higher in energy (NE_g) than the remaining basal ration components. Hence, these two factors can bias the data if they are not considered, resulting in the impression that feces have a lower energy value than it may have actually had or that the feces made less contribution in feed energy replacement than it really did.

TABLE 40. COMPOSITION OF RATIONS FED IN TRIAL 5

Ingredient[1]	T1	T2	T3
	----------%	----------	
Ground corn, 4-02-935	78.8	63.1	63.6
Cottonseed hulls, 1-01-599	7.6	7.5	7.5
Dehydrated alfalfa meal, 1-00-025	5.2	5.1	5.1
Liquid molasses, 4-04-696	1.9	1.9	1.9
Soybean meal, 5-04-604	5.1	5.0	3.5
Dried feces	----	15.9	15.9
Dried urine	----	----	1.0
Calcium carbonate, 6-02-632	0.9	0.8	0.8
Dicalcium phosphate, 6-01-080	0.3	0.3	0.3
Salt	0.3	0.3	0.3
Aurofac-50	+	+	+
Vitamin A	+	+	+

[1] Dry matter basis.

Although the rations were consumed readily, it can be concluded that overall growth performance was lowered somewhat when feces were included at a 15% level in a feedlot growing ration for heifers. In this experiment, the corn was ground rather fine, and the feces were also finely ground and somewhat dusty. Such factors can cause reductions in intake. Had the corn and feces been rolled or ground to give a large particle size, better in-

takes and gains might have been achieved on the feces diets. When feces are added to a high corn diet as in this instance, perhaps it is utilized with a different efficiency (lower) than when combined into lower quality rations (e.g. roughage). Source of the feces is also undoubtedly important. The feces in this study were obtained from rations in which the starch digestibility in steers was experimentally determined to be 99%+. In this respect, starch digestibilities under field conditions would normally be lower than this (perhaps 85-94%), and hence, the feces from high concentrate rations would normally be expected to be somewhat higher in indigested starch content than in this study--resulting in a higher potential refeeding value.

TABLE 41. GROWTH DATA ON HEIFERS IN TRIAL 5

Rations[1]	T1	T2	T3	SEM
Number of heifers	9	9	9	
Beginning weight, kg	178.1	177.8	177.6	
Ending weight, kg	301.6	273.0	276.4	
Daily feed intake, kg/day				
Basal[2]	6.03	4.79	4.86	
Feces	-----	0.91	0.92	
Total[3]	6.03	5.70	5.78	0.37
Average daily gain, kg/day				
Basal	1.13	0.73	0.77	
Feces	-----	0.14	0.15	
Total	1.13[a]	0.87[b]	.92[b]	0.06
Feed efficiency, kg feed/kg gain				
Basal	5.33	5.54	5.28	
Feces	-----	1.05	1.00	
Total	5.33	6.59	6.28	0.41

[1] T1 is the control, T2 contains feces and T3 contains feces plus urine.

[2] In T2 and T3, feces replaced corn rather than a percentage of the basal ration.

[3ab]: Values with different superscripts in a row differ significantly ($P<.05$).

SECTION X

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16. ABSTRACT

Studies were conducted to investigate the effect of feces recycling in beef cattle diets (rations) on the digestibility of various dietary nutrients and on the accumulation of indigestible residues. Feces were refed in three successive phases based primarily upon the quantity of feces produced in the previous phase. Several different roughage levels in high concentrate rations were considered. An attempt was made to investigate the digestibility of various nutrient parameters in feces when refed and the roughage value of feces. Mineral retention data and the accumulation of various minerals in the fecal and urinary residues were studied. Varying levels of feces in growing/maintenance rations were investigated along with the efficiency of urinary nitrogen (N) as a supplemental N source.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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