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MINERAL AND FAT INTERRELATIONSHIPS AS INFLUENCING RATION UTILIZATION BY LAMBS

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INTRODUCTION

Inedible lard and tallow became an agricultural surplus about 1947 which permitted fats to be used by the feed industry as a source of energy. By 1958 the feed industry ranked second to the soap industry in the consumption of inedible fats and oils (25). Approximately 460 million pounds of fats and oils were used in formula animal feeds in 1959 and 550 million pounds were used in 1958 (92) as compared to only 151 and 324 million pounds used in 1954 and 1956, respectively (3, 25). These 1958 and 1959 figures do not include fats added to alfalfa meal or to the oil meals. Most of this fat was used in poultry feeds with some going into dog foods. Only a small portion was used in beef, dairy and swine feeds.

Many advantages may be imparted to feeds by the addition of fat. Fat added in small quantities improves the texture and appearance, reduces dustiness, and at times may improve palatability of feeds. It also reduces wear on mixing and pelleting machinery. In addition to these advantages, a pound of fat contains approximately 2.25 times the energy of a pound of carbohydrate and approximately 2.6 times the productive energy of a pound of corn. The addition of this concentrated source of energy to livestock rations should enable livestock feeders to increase the efficiency of feed conversion and rate of gain. It is conceivable that fat may be digested, absorbed, resynthesized and then deposited in the tissues *per se*, thereby speeding the fattening process of cattle and lambs.

Ruminants have the ability to utilize large quantities of roughage in meeting their energy requirements. The digestible energy content of rations containing poor quality roughages such as corncobs, cottonseed hulls, prairie hay and straw is low but could theoretically be increased by the addition of fat. However, no increase in rate of gain or efficiency of feed conversion has been noted when fat was added to rations containing these roughages. Digestibility data indicate that rations containing poor quality roughages were poorly digested when fat was added. The poor utilization of the rations containing added fat apparently eliminates any benefits of adding the fat. Addition of alfalfa ash or calcium has been shown to increase the digestibility of rations containing fat. Fat additions have been shown to decrease apparent and true digestibility of calcium and to increase excretion of fecal soaps. The utilization of the energy in rations containing added fat is therefore questionable.

Experiments were conducted with lambs to study calcium-fat interrelationships in the digestion of energy. In light of these results, growing-fattening studies were initiated to determine the value of added fat in lamb rations. Mixtures of trace minerals were added to rations containing fat in an attempt to improve performance of fattening lambs. Systemic blood lipid levels were measured for an indication of fat absorption.

REVIEW OF LITERATURE

An attempt has been made to give a nearly complete review of all literature pertaining to the utilization of fat, or of rations containing fat, by ruminating beef cattle and sheep. This literature has expanded quite rapidly in recent years. Other literature is introduced when it pertains to the main purpose of this review.

Digestibility Studies with Added Fats

Lucas and Loosli (62) in studies with dairy cattle reported a decrease in digestibility of crude fiber and nitrogen free extract when the ether extract content of the ration was increased from 1 to 7 per cent by the addition of soybeans or solvent extracted soybean meal plus corn or soybean oil. Ether extract of rations containing soybean meal plus oil or fatty acids of soybean oil was more digestible than the ether extract of a ration containing soybeans. There was no difference in the digestibility of rations containing 1.6 and 2.6 per cent ether extract.

Swift _et al._ (87) in trials with sheep found that 3.6 per cent corn oil increased the digestibility of all ration components when added to a ration containing alfalfa-timothy hay, corn and linseed meal. The addition of 7 per cent corn oil decreased digestibility of all ration components except ether extract. In later work at the Pennsylvania station (85) the digestibility of dry matter and nitrogen free extract was decreased and the digestibility of ether extract was increased as the ether extract content of the ration was increased from 3 to 8 per cent by the addition of corn oil. The rations in this later study were held isocaloric by substituting corn oil for carbohydrate. Corn oil appeared to decrease digestibility of energy and decreased production of methane. The authors explained the increase in digestibility of ether extract as due to high digestibility of the corn oil.

The fat content of expeller or hydraulic processed soybean and cottonseed meals is 3 to 4 per cent higher than that of solvent processed meals. Gallup *et al.* (31), however, found no difference in the digestibility of rations containing hydraulic or solvent processed cottonseed meals, or of rations containing expeller or solvent processed soybean meals, by either steers or lambs fed maintenance or fattening type rations. The total fat content of these rations could not have been too different due to the relatively low levels of protein supplements added.

In digestion and calorimetric studies with sheep fed a ration containing 40.4 per cent corncobs and 5 per cent corn oil the apparent digestibility of crude fiber was increased from 43.0 to 53.8 per cent by the addition of alfalfa ash (86). This was accompanied by a slight increase in methane production. The net effect of the alfalfa ash was to increase the quantity of feed energy available to the animal. Tillman et al. (89) in later studies found that the addition of alfalfa ash increased digestibility of a semi-purified ration containing cottonseed hulls and corn oil. Lambs fed the basal semi-purified ration lost weight. The addition of the alfalfa ash or a synthetic alfalfa ash reversed this condition. Cobalt additions gave no response in these trials.

Brooks et al. (12) reported that corn oil reduced cellulose digestion *in vitro*. Corn oil or lard added to a sheep ration containing cottonseed hulls and casein greatly reduced cellulose digestion and lowered protein digestion slightly. Lard did not reduce cellulose digestion as much as corn oil. Alfalfa ash partially overcame the depressing effects of both fats. The rumen ingesta of the sheep fed corn oil had a putrid odor, a turbid color and a lowered volatile fatty acid content. Total number of bacteria present was not reduced but there was an increase in number of small cocci and a decrease in number of small rods. The addition of alfalfa ash, or a synthetic alfalfa ash, increased digestibility of the organic matter, ether extract, crude fiber and nitrogen free extract components of a ration containing 45 per cent corncobs and 3 per cent corn oil as reported by Chappel et al. (19). The addition of a mixture of NaCl, K, Mg, Mn, Fe, Cu and Zn had no effect in this respect.

Hale and King (42) studied levels of 0, 4, 8 and 12 per cent corn oil, tallow or hydrogenated animal fat upon digestibility of lamb rations. The 8 and 12 per cent levels of fat markedly decreased dry matter digestibility. Corn oil had the most detrimental effect. Apparent digestibilities of the fats when fed at the 12 per cent level were 92, 80 and 64 per cent for tallow, corn oil and hydrogenated animal fat, respectively. Erwin et al. (30) in studies with steers fed a ration containing straw found that 7 per cent fat decreased the digestibility of dry matter and crude fiber but increased digestibility of ether extract. Rhodes et al. (78) in studies with lambs fed rations containing cottonseed hulls reported that corn oil decreased digestibility of protein and cellulose which could be overcome by the addition of ash from alfalfa or distillers dried solubles. In later work at the Kentucky station (83), alfalfa ash overcame the depressing effects of corn oil on the digestibility of a ration containing corncobs.

Pfander and Verma (73) reported that corn oil, when added to cottonseed hulls and fed to sheep orally, decreased the digestibility of organic matter, cellulose and nitrogen but had no effect when added separately through a rumen fistula. A mixture of trace minerals partially overcame the effects of the corn oil. The corn oil was hydrogenated in the rumen within 5 hours after feeding.

The Oklahoma workers have conducted several trials with cattle and sheep in studying the relationship of minerals and fat in the utilization of rations containing low quality roughages (10, 51, 93). The addition of 2.6 or 10 per cent corn oil decreased weight gains and efficiency of feed conversion in growth trials with lambs (93). Alfalfa meal or ash of the alfalfa meal partially overcame the depressing effects of 10 per cent corn oil. Corn oil added at a level of 2.4 per cent did not affect digestibility of any ration component except ether extract. Ten per cent corn oil decreased digestibility of all ration components, except ether extract, and decreased nitrogen retention. Alfalfa ash partially overcame the effects of 10 per cent corn oil upon digestibility, increased nitrogen retention in the corn oil ration and slightly improved digestibility of the low fat basal ration. The addition of 15 per cent animal fat to a basal ration containing cottonseed hulls significantly reduced the digestibility of dry matter and organic matter and the weight gains of the lambs (10). Alfalfa ash, sodium bicarbonate or potassium bicarbonate did not improve weight gains of lambs fed the high fat ration. Both bicarbonates tended to depress appetite and weight gains. In another experiment, 10 per cent corn oil reduced gains regardless of whether it was absorbed by the concentrate or roughage portion of the ration prior to feeding. Corn oil did not seem to affect diurnal ruminal pH values of the sheep.

Alfalfa ash and the bicarbonates tended to reduce hydrogen ion concentration.

Work at the Kentucky station (94) showed that corn oil progressively decreased cellulose digestion during a 40 day trial. It took 17 days for digestibility to return to normal after the corn oil was removed from the ration. Alfalfa ash and calcium additions alleviated the effects of the corn oil. Phosphorus or trace minerals based on alfalfa ash had no effect in this respect. Tillman and Brethour (88), using Ca^{45} and P^{32}, found that the feeding of 7.5 per cent corn oil to lambs significantly reduced the apparent and true digestibility of calcium resulting in a decreased calcium retention but did not affect apparent digestibility, true digestibility, fecal endogenous or net retention of phosphorus. Hubbard _et al_. (51) later reported that corn oil increased fecal ash but did not alter calcium retention significantly in steers.

Work at the Iowa station (21) showed that corn oil saponified with potassium hydroxide decreased digestibility of a corncob ration by lambs to a greater extent than corn oil. The addition of calcium carbonate alleviated the effects of corn oil. Grainger and Stroud (39) and Grainger _et al_. (38) reported that corn oil, when fed in a semi-purified ration to lambs, decreased apparent and true digestibility of calcium, increased excretion of fecal soaps and decreased digestibility of cellulose. Addition of distillers dried solubles ash or calcium increased digestibility of cellulose in the corn oil ration. Iron partially alleviated the corn oil depression on cellulose digestibility but potassium further increased the corn oil effect. Magnesium and zinc caused the sheep to go off feed in 7 days.

In digestibility studies with lambs, 5 per cent corn oil, 5 per cent of a mixture of fatty acids, 5 per cent oleic acid, 5 per cent stearic acid and 1 per cent lauric acid decreased digestibility of dry matter, organic matter and cellulose and increased digestibility of ether extract (22). All but lauric acid decreased digestibility of ash. In studies conducted with rumen bacteria _in vitro_, butyric acid, valeric acid and glycerol increased cellulose digestion. Acetic and caproic acids had no effect while the saturated fatty acids from C_8 to C_{18}, oleic and linoleic acids decreased cellulose digestion. Hassinen _et al_. (44) showed that fatty acids of C_8 or above could inhibit growth of both gram-positive and gram-negative organisms. Nieman (71) says that the antibacterial activity of unsaturated fatty acids increases with the number of double bonds and that the antibacterial activity of saturated fatty acids is optimal at C_{12}. It was suggested that growth interference may be caused by changes in cell permeability by fatty acids adsorbed on the cell membrane. More recently, Camien and Dunn (16) suggested that the inhibitory effects may be due to the fatty acids exerting an antimetabolite effect. The inhibitory effects of fat upon ration digestibility by ruminants is probably due to the fatty acid components of the fat molecule.

Growth and Production Studies with Fats

Fat gave an increase in the average daily butterfat production but did not affect total milk yield when added as linseed oil, lard, corn oil, cottonseed oil, tallow or butterfat at the rate of 0.25 to 1.25 pounds per day to dairy rations (1). Byers _et al_. (14) found that a ration containing 5.2 per cent dietary fat did not increase milk production when compared to a ration containing 2.7 per cent dietary fat. However, a significant increase was observed in the per cent butterfat of the milk when the high fat ration was fed. The addition of 4 and 8 per cent stabilized animal fat to the grain mixture for dairy cows did not affect appetite, milk yield, milk test and butterfat composition or the carotene and vitamin A content of blood plasma or milk in an Illinois study (50). Alfalfa hay and corn silage or pasture and corn silage supplied the roughage for this study.

Various fats were added to skim milk, homogenized to form a product containing 3.5 per cent fat, and fed to dairy calves along with a low fat concentrate mixture, cod liver oil and alfalfa hay by Gullickson et al. (40). Butterfat, lard, tallow, coconut oil, peanut oil, corn oil, cottonseed oil and soybean oil were fed in this study. Calves fed butterfat excelled all other groups as measured by weight gains and general well being followed by calves fed lard and tallow. The calves fed corn, cottonseed or soybean oils were unthrifty, listless, emaciated, had a high mortality rate and a low average daily gain. Jacobson et al. (53) reported that a filled milk containing hydrogenated soybean oil produced growth in young dairy calves equal the growth of calves fed whole milk. Calves that were fed crude expeller soybean oil at the rate of 2 and 3 per cent and 3 per cent plus various B vitamins exhibited poor growth and severe scouring and had a high mortality rate.

Johnson et al. (56), in studies in which Holstein calves were fed a starter containing 0.0, 2.5, 5.0 and 10.0 per cent inedible stabilized tallow and alfalfa pellets, observed that calves fed starters containing tallow consumed more calculated total digestible nutrients which resulted in 5 to 6 per cent greater increases in weight gain. Efficiency of feed dry matter conversion was best for calves fed the tallow rations but total digestible nutrient utilization was not appreciably affected. The utilization of carotene and tocopherol was not affected by the addition of tallow. Digestibility and mineral balance studies with 8 of the calves and 4 lambs indicated that when tallow was fed, there was a decrease in the apparent digestibility of dry matter, organic matter, crude protein and nitrogen free extract in the ration fed the calves whereas the digestibility of ether extract was increased in the rations fed both species. Fecal calcium was increased in both species when tallow was fed.

Jones _et al_. (57) reported average daily gains of 1.76, 1.84 and 1.97 pounds in summarizing 3 experiments with steers fed 0.18, 0.58 and 0.98 pounds of cottonseed oil per day, respectively. High fat rations, 4.82 and 4.91 per cent cottonseed oil, resulted in a savings of about one pound of feed per pound of gain but exerted no influence on rate of gain or carcass grade in a later steer trial conducted at the Texas station (95). The fat significantly improved absorption and utilization of dietary carotene and increased the level of blood fat 3 fold.

Matsushima and Dowe (63, 64) found that a vitamin A supplement of 30,000 units per steer per day was not adequate to prevent symptoms of hypovitaminosis A when unstabilized tallow or corn oil was added to the ration. Three lots of steers were used in this study and received the following rations: Lot 1, ground shelled corn, soybean meal, vitamin A supplement and brome hay; Lot 2, ground ear corn, vitamin A, brome hay and pellets containing 5.53 per cent tallow and 68 per cent ground corncobs; Lot 3, same as Lot 2 with corn oil substituting for tallow. The average daily gains and feed per 100 pounds gain for Lots 1, 2 and 3 were 2.11, 986; 2.00, 1179; and 1.74, 1315, respectively. Tallow or animal grease improved feed efficiency when added to steer fattening rations that contained alfalfa hay in other Nebraska studies (65, 66, 67). Average daily gain tended to be increased if the level of fat did not exceed 5 per cent of the total ration, or 1 pound per steer per day. Higher levels of fat reduced average daily gain in the Nebraska trials.

In a study by Keith _et al._ (60), 2 per cent soybean oil did not increase rate of gain of steers fed a ration in which the roughage portion was alfalfa hay but it did save about 20 pounds of feed per 100 pounds gain. Hentges _et al._ (45) reported average daily gains of 1.8 and 2.3 pounds, respectively, for steers fed a basal ration or the basal plus 5 per cent raw ground waste beef fat. Feed efficiency followed a similar pattern. In another trial, 3 lots of steer calves were fed the following rations: basal, basal plus 5 per cent fat and basal plus 10 per cent fat. Average daily gains were 1.8, 1.9 and 1.5 pounds respectively for a 154 day period. Feed efficiency was greatest on the 5 per cent fat ration and poorest on the basal ration. The percentage of separable fat in the 9-10-11 rib cut was highest in the 5 per cent fat ration; however, no differences were noted in meat tenderness. There was no significant difference in dressing per cent or carcass grade in either of these two trials.

Erwin *et al.* (29) found that 7 per cent inedible animal fat significantly increased rate of gain of steers fed rations containing 82 per cent alfalfa hay and significantly decreased rate of gain of steers fed rations containing 82 per cent wheat straw. Seven per cent fat did not affect feed efficiency or rate of gain in a later study at the Washington State station (27). Fat decreased the digestibility of dry matter and crude fiber in a digestibility study with these same steers. The fat also had no effect on the liver stores of vitamin A. Fat fed at the 5 per cent level in an alfalfa hay ration increased rate of gain and feed efficiency in steer trials at the Nevada station (8); however, when fed at the 10 per cent level fat increased feed efficiency but only slightly increased the rate of gain.

Parham *et al.* (72) compared solvent extracted cottonseed meal with hydraulic extracted cottonseed meal for wintering beef cows. The type of cottonseed meal did not affect weight gains or carotene and vitamin A content of the blood. The hydraulic extracted meal significantly increased blood fat. Edwards *et al.* (28) studied the effect of dietary fat on the fatty acid composition of steer depot fat. The percentages of stearic and other saturated fatty acids of rib fat increased significantly with the addition of 2.5

and 5.0 per cent animal fat to the basal ration while the percentage of linoleic acid decreased significantly.

Bohman and Wade (7) studied the effects of rations containing 0, 5 and 10 per cent fat upon the composition of the blood, carcass and liver. Animal fat significantly increased the level of plasma fat and decreased the level of plasma carotene, plasma vitamin A, liver carotene and liver vitamin A. It also tended to increase the fat content of the carcass and temporarily decreased the level of plasma phosphorus. Bohman et al. (9) later studied dietary fat and alfalfa hay interrelationships as affecting rate of gain and blood constituents of 400 pound steers wintered on grass hay. One-half pound of animal fat daily did not affect rate of gain. Dietary fat increased plasma cholesterol from 100 mg. per cent initially to 225 mg. per cent at the end of the feeding period. The addition of 6 pounds of alfalfa hay with the fat held this increase in cholesterol to only 150-155 mg. per cent. Plasma fat, carotene and vitamin A paralleled plasma cholesterol but blood ketone level and hematocrit were not affected by dietary fat.

Dietary cottonseed oil tended to decrease the growth of rabbits as reported by Wooley and Mickelson (96). The addition of sodium, potassium and calcium increased the growth rate when added to the rations containing fat. Calcium produced a greater response than potassium but the addition of all 3 minerals together produced no greater growth than with sodium alone. The relationship observed here with cottonseed oil and minerals may have some bearing in ruminant rations.

The Texas workers (59) fed prime tallow at the 0, 5, 10 and 15 per cent level in rations containing 45 per cent alfalfa hay and found a greater feed efficiency for lambs fed rations containing 5 and 10 per cent tallow. There was no significant differences between gain and carcass weight for lambs fed 0, 5 and 10 per cent fat. The lambs fed 15 per cent fat had a significantly lower gain and carcass weight than any of the other groups. Hale et al. (41, 43) fed 3 per cent hydrogenated fat in one lamb fattening experiment and 5 and 9 per cent animal fat in another lamb fattening experiment. The fat did not markedly affect rate of gain or feed efficiency in either trial except for the 9 per cent fat group which had a lower feed consumption.

Jordan et al. (58) conducted 4 lamb fattening trials to determine the effect of adding 10 per cent stabilized tallow to the soybean oil meal portion of the ration. The rate of gain was not significantly affected; however, in 3 of the 4 trials the lambs fed the soybean oil meal with added fat gained slightly faster and required less feed per pound of gain than the control lambs. A non-legume hay was fed in these trials. In another trial, fattening lambs were fed grain rations consisting of whole soybeans, 50 per cent soybeans and 50 per cent corn, 25 per cent soybeans and 75 per cent corn, and 25 per cent flaxseed and 75 per cent corn. Alfalfa hay was the roughage in all rations. Rates of gain and feed consumption were not affected in the 25 per cent soybean or flaxseed rations but were greatly reduced in the other rations. The authors concluded that the high oil content of the soybeans caused the lowered feed consumption. The high fat rations had no effect on softness or color of carcass fat.

In summarizing all growing-fattening studies, the addition of up to 7 per cent fat to rations containing alfalfa hay as the roughage has resulted in an increased rate of gain, an improved efficiency of feed conversion, or both. When the roughage was other than alfalfa hay, rate of gain and efficiency of feed conversion were not improved and the animals in general consumed less feed.

Gastrointestinal Metabolism and Absorption of Fat

Lipid digestion, absorption and metabolism by ruminants have been recently reviewed by Garton (33). There are, however, some aspects of gastrointestinal metabolism and absorption that are of special significance to the area of research reported in this thesis.

In an early study, Maynard and McCay (69) reported that plasma fatty acid and cholesterol levels adjusted slowly, taking 7 to 8 days for any change ot occur, when grain mixtures containing 5.78 per cent and 0.66 per cent fat were alternately fed to lactating dairy cows or goats. Seshan (80) reported that the unsaturated fatty acids were better absorbed by cattle than the saturated fatty acids. Aylward and Blackwood (5) observed that the phospholipid content of blood obtained from the mammary vein decreased about 10 per cent when cows were fasted for 5½, 7½ and 10½ days; however, other blood lipid constituents did not change. The feeding of linseed oil increased phospholipid content of blood but did not alter other lipid constituents.

Aylward _et al_. (6) later studied the absorption of single doses of iodized fat by dairy cows and found that the concentration of iodized fat in the blood rose to a maximum by 1½ to 2 days and then decreased to essentially none by 5 days. The lipid components of the blood did not change in proportion or concentration during this time. It should be noted here that rumen microorganisms were recently found to be capable of removing I^{131} as iodide from labeled soybean oil (2) so the validity of Aylward's results may be questioned.

Total lipids, ester fatty acids, neutral fat, ester cholesterol and phospholipids were shown to increase from birth to 4 days of age in the blood plasma of dairy calves by Zaletel et al. (98). The free fatty acids and cholesterol content did not change. Jacobson et al. (54) demonstrated increases in total lipid, free cholesterol, ester cholesterol and ester fatty acids of calves fed whole milk and crude soybean oil, no change in calves fed butteroil or lard and a slight decrease in calves fed hydrogenated soybean oil. Hopkins et al. (48, 49) found that when a milk replacer composed predominately of skim milk was supplemented with tallow, coconut fat, grease or butter in the unhomogenized state, the fat was poorly digested by 2 to 3 week old dairy calves. The addition of crude soybean lecithin to the milk replacer improved the utilization of tallow, coconut fat and grease. Digestibility of coconut fat was improved to a greater extent than tallow or grease by the addition of lecithin.

Fat and the components of fat may undergo various reactions in the rumen. Garton et al. (36) demonstrated lipolysis (hydrolysis) of fat in the rumen of the sheep and in rumen contents incubated in vitro. Incubation of fat with saliva or autoclaved rumen contents did not result in hydrolysis. This hydrolysis with rumen microorganisms was further substantiated by Hill (46) and Hill et al. (47). Fractionating the rumen microorganisms by centrifugation indicated that the enzyme was primarily associated with the protozoa. Various compounds which were inhibitory to the protozoa also depressed the lipase activity. Garton *et al.* (37) incubated linseed oil, olive oil and cocoa butter (iodine values are 181, 80 and 40, respectively) with sheep rumen contents and obtained hydrolysis of 95, 70 and 40 per cent, respectively. This suggests that the extent to which triglycerides are hydrolyzed by rumen microorganisms may be related to the degree of saturation of its component fatty acids. These authors also reported a decrease in linolenic acid and an increase in stearic and palmitic acids during fermentation which suggests reduction of linolenic acid and the cleavage of a 2-carbon fragment from an 18-carbon fatty acid thereby producing palmitic acid. Hill's (46) studies indicate that the fatty acid molecule is not degraded, however. Sheep rumen contents and washed suspensions of rumen microorganisms were shown to hydrolyze phospholipids (23).

Rumen contents have also been shown to reduce linolenic acid (75). Reiser and Reddy (76) later showed that linoleic and linolenic acids were reduced to monoethenoid and saturated fatty acids in the rumen of the goat. Rumen contents of sheep were shown to reduce oleic, linoleic and linolenic acids to stearic acid as well as trans and positional isomers of the unsaturated acids by Shorland *et al.* (81). Acids with conjugated carbon-carbon double bonds were relatively stable to reduction by rumen microorganisms.

Obviously glycerol is liberated upon hydrolysis of fats. Johns (55) has shown glycerol to be fermented by rumen microorganisms *in vivo* and *in vitro* to yield primarily propionate. Garton (34) could not detect glycerol in the rumen contents of sheep or in the medium resulting from the incubation of rumen contents with linseed oil. Incubation of glycerol with rumen contents resulted in a rapid disappearance of glycerol and an increase in propionic acid. It therefore appears that glycerol is readily used as an energy source by rumen microorganisms.

There is considerable evidence that fat is hydrolyzed in areas other than the rumen of cattle. Itoh and Kayeshima (52) found little lipase activity in the stomach of the cow but found considerable activity in the pancreas. Lipase activity in the cow was similar to that of the pig but perhaps not as strong as that of man. Schonheyder and Volqvartz (79) found much lipase activity in the pancreas of the cow and that this enzyme exerted greatest activity for hydrolyzing tributyrin and lowest activity for hydrolyzing tristearin of the saturated triglycerides. The concentration of lipase activity in fresh pancreatic tissue from calf embryos, suckling calves and mature cows was shown to increase in this order (61). Esterase and lipase activity was found in the pancreas of the cow by Uchino and Mori (91); considerable esterase activity for triacetin was found in the mucosa of the small intestine but no activity was found for olive oil. Considerable esterase activity was found in tissues near the base of the tongue of the dairy calf by Ramsey *et al*. (74) but this activity diminished in older animals.

No data were found on the absorption of fatty acids by the cow or sheep; however, some were reviewed with respect to the rat and chicken. Saturated fatty acids from myristic to stearic acid are poorly absorbed by the rat (17, 18) and chicken (77, 97). Mono- and poly-unsaturated fatty acids are readily absorbed by both rat and chicken. It is interesting to note that stearic acid of distearin-monounsaturated or monostearin-diunsaturated triglycerides is almost completely absorbed by the rat but that stearic acid of tristearin is not absorbed (68). Young and Renner (97) present similar evidence with the chicken. It is possible that similar absorption patterns may be found in the ruminant.

DIGESTIBILITY STUDIES WITH LAMBS

The studies reported herein are a continuation of the studies of Davison (21) in 1959. In these earlier studies, fatty acids were shown to decrease digestibility of cellulose by rumen microorganism <u>in vitro</u> and to decrease digestibility of a ration containing 46 per cent corncobs by lambs. Corn oil and a mixture of fatty acids had similar effects upon ration digestibility. Calcium carbonate was shown to alleviate the effects of corn oil upon ration digestibility and to increase the utilization of energy in rations containing corn oil. The following studies were conducted to study the effects of calcium upon the utilization of rations containing an equivalent amount of energy added as corn oil or starch, to study the effects of corn oil and calcium upon digestibility of a ration containing alfalfa hay as the roughage and to compare the effects of calcium carbonate, calcium chloride and magnesium carbonate in alleviating corn oil depression of ration digestibility.

Experimental Procedure

<u>Trial 1</u>

Eighteen western crossbred wether lambs weighing an average of 60 pounds were randomly allotted to 6 groups of 3 lambs each and fed the following rations: (a) basal,

(b) basal plus 8 gm. $CaCO_3$, (c) basal plus 40 gm. corn oil, (d) basal plus 40 gm. corn oil plus 8 gm. $CaCO_3$, (e) basal plus 80 gm. corn starch and (f) basal plus 80 gm. corn starch plus 8 gm. $CaCO_3$. The basal ration, the composition of which is shown in Table 1, was mixed prior to starting the experiment. Daily allowance of the ration was 800 gm. fed in equal portions twice daily. Corn oil, starch and $CaCO_3$* were added at each feeding. Chemical composition of the basal ration is shown in Table 2. One lamb on each treatment was placed in a raised wire floor type metabolism stall in which feces were collected with a light harness and bag (32). Two lambs from each treatment were placed in all steel stanchion type metabolism stalls patterned after those described by Briggs and Gallup (11). The trial was repeated with the same lambs being randomly reallotted after a 10-day rest period in which they were fed alfalfa hay. A 10-day preliminary period immediately preceded a 10-day collection period.

Total daily fecal collections were dried in a forced draft oven for 48 hours at 70° C. The dried feces were permitted to equilibrate with moisture in the air until a constant weight was reached. The feces were then mixed, sampled and ground for chemical analysis. The urine was filtered through glass wool and collected in glass jars

*U.S.P. grade $CaCO_3$ was used in all digestibility studies.

Table 1. Percentage composition of the basal rations used in Trials 1, 3 and 4

Ingredient	Trial 1	Trials 3 and 4
Ground corncobs	46.0	46.0
Ground shelled corn	36.5	32.0
Soybean meal	16.0	--
Corn gluten meal	--	20.0
Salt	1.0	1.0
Dicalcium phosphate	0.5	1.0
Quadrex[a]	400 gm./ton in all trials	
$CoSO_4 \cdot 7H_2O$	200 mg./ton in all trials	

[a]Containing 10,000 I.U. of Vitamin A and 1,250 I.U. of D_2 per gram.

Table 2. Average chemical composition of the basal rations fed in the digestibility trials[a]

Component	Trial 1	Trial 2	Trial 3	Trial 4
Dry matter, %	89.3	89.4	92.9	88.7
Organic matter, %	86.2	85.1	89.5	85.6
Protein (Nx6.25), %	11.5	11.6	12.8	13.0
Cellulose, %	23.7	16.5	--	22.6
Ash, %	3.0	4.2	--	3.1
Nitrogen, %	1.84	1.85	2.06	2.08
Energy, Cal./gm.	4.05	4.06	--	--
Calcium, %	0.02	0.62	--	0.34

[a]In addition, corn oil contained 100% organic matter and 9.51 Cal./gm.; starch contained 87.4% organic matter and 3.73 Cal./gm.

containing acid (20 ml. of a mixture of equal parts HCl and water were added daily to each jar). The daily urine collection was diluted to the nearest 500 gm. and a 5 per cent aliquot was saved. Urine samples were stored under refrigeration until analyzed. Cellulose analysis for feed and feces was by the method of Crampton and Maynard (20). Gross energy of feed and feces was determined with a Parr oxygen bomb calorimeter equipped with an adiabatic jacket. Calcium was determined on feed and feces by the method of Diehl and Ellingboe (24) as modified by Tucker (90). Other chemical analyses were by accepted methods of AOAC (4). Statistical analyses of the data were conducted by analysis of variance and orthogonal comparisons (82).

Trial 2

Sixteen western crossbred wether lambs weighing an average of 78 pounds were randomly allotted to 4 groups of 4 lambs each and fed the following rations: (a) basal, (b) basal plus 10 gm. $CaCO_3$, (c) basal plus 50 gm. corn oil and (d) basal plus 50 gm. corn oil plus 10 gm. $CaCO_3$. The basal ration contained the following, in per cent: ground shelled corn, 50.0; alfalfa hay, 40.0; molasses, 7.0; soybean meal, 2.4; and salt, 0.6. In addition, the daily ration was supplemented with 400 I.U. vitamin A and 50 I.U. of vitamin D_2. Daily allowance of the basal ration was

1000 gm. All steel stanchion type metabolism stalls were used. Other procedures were similar to those of Trial 1.

Trial 3

Sixteen western crossbred wether lambs weighing an average of 71 pounds were randomly allotted to 5 groups, 4 groups of 3 lambs each and 1 group of 4 lambs (basal group), to which the following rations were fed: (a) basal, (b) basal plus 35 gm. corn oil, (c) basal plus 35 gm. corn oil plus 3.5 gm. $CaCO_3$, (d) basal plus 35 gm. corn oil plus 4 gm. $CaCl_2 \cdot 2H_2O$* and (e) basal plus 35 gm. corn oil plus 3 gm. $MgCO_3$*. Calcium and magnesium were added in equal molar equivalents. Daily allowance of the basal ration was 700 gm. Composition of the basal ration is given in Table 1. All steel stanchion type metabolism stalls were used. Other procedures were the same as those of Trial 1.

Trial 4

Trial 4 was identical in design to Trial 3. Lambs weighing an average of 86 pounds were fed a daily allowance of 800 gm. of the basal ration and 40 gm. of corn oil. Eight, twelve and seven gm. of $CaCO_3$, $CaCl_2 \cdot 2H_2O$ and $MgCO_3$, respectively, were added to the corn oil ration. A 12-day preliminary period immediately preceded a 7-day collection

*Reagent grade $CaCl_2 \cdot 2H_2O$ and $MgCO_3$ were fed.

period. Statistical analyses of the data were by analysis of variance (82) and multiple range test (26).

Results and Discussion

Trial 1

The results of Trial 1 appear in Table 3. Statistical analysis tables of all data appear in the Appendix. Corn oil and starch decreased ($P < 0.01$) digestibility of organic matter, protein and cellulose whereas calcium carbonate increased digestibility of these components and ash in all rations. Calcium carbonate increased digestibility of organic matter and cellulose to a greater extent in rations containing corn oil or starch than in the basal ration and completely counteracted the depressing effect of starch upon digestibility of organic matter. Corn oil had a greater depressing effect upon digestibility of organic matter and cellulose than starch; however, starch depressed protein digestibility more than corn oil. Fecal calcium was increased ($P < 0.05$) by the addition of calcium carbonate to the ration. Calcium carbonate additions increased retention of nitrogen ($P < 0.005$).

Calcium carbonate additions increased digestibility of energy in all rations ($P < 0.005$). Digested Calories were not increased by the addition of corn oil to the basal ration; however, digested Calories were increased when corn

Table 3. Average daily digestibility and balance data obtained from lambs fed corn oil, starch and $CaCO_3$

Component	0 $CaCO_3$			Plus $CaCO_3$		
	Basal	Corn oil	Starch	Basal	Corn oil	Starch
			Digestibility, %			
Organic matter	68.6	61.2	65.8	72.4	68.8	72.4
Protein	73.2	69.4	67.0	74.8	74.1	72.1
Cellulose	58.2	39.9	48.1	65.6	57.4	61.6
Ash	39.9	36.2	33.0	51.8	49.2	51.8
			Calcium intake and fecal excretion			
Intake, gm.	1.56	1.56	1.56	4.76	4.76	4.76
Fecal, gm.	1.92	2.02	1.86	3.99	4.10	4.17
			Nitrogen balance			
Intake, gms.	14.68	14.68	14.72	14.68	14.68	14.72
Fecal, gm.	3.89	4.47	4.84	3.67	3.78	4.10
Urinary, gm.	7.64	7.33	6.69	7.66	7.26	6.68
Retained, gm.	3.16	2.88	3.19	3.35	3.63	3.93
Feed N retained, %	21.5	19.7	21.7	23.0	24.7	26.6
Absorbed N retained, %	29.5	28.5	32.4	30.8	33.4	36.9
			Digestible energy			
Caloric intake	3240.0	3620.4	3538.4	3240.0	3620.4	3538.4
Digested Calories	2154.6	2162.6	2242.5	2274.1	2423.6	2484.7
Digestibility, %	66.5	59.7	63.4	70.2	66.9	70.4

oil was fed in combination with calcium carbonate. An increase occurred in digested Calories when starch was added to the basal ration ($P < 0.05$) which was further increased by calcium carbonate addition.

Trial 2

Table 4 presents the results of Trial 2. Corn oil and/or calcium carbonate additions to this alfalfa hay ration did not affect digestibility of organic matter, protein, cellulose or ash. Fecal calcium excretion was increased ($P < 0.005$) by calcium carbonate additions but not by corn oil additions. Nitrogen retention was similar for all treatments. There was an increase in Calories digested by lambs fed corn oil ($P < 0.005$), but the percentage digested did not change. These results with an alfalfa hay ration are in contrast to those in which corn oil and calcium were added to a corncob ration.

In a separate digestibility trial, lambs were fed a low-calcium, corncob ration to which both calcium carbonate and corn oil were added (see Davison (21) for description of this study). The calcium level of the low calcium ration was 0.06 per cent. Digestible energy and calcium data for this study are presented in Table 5. The addition of corn oil alone did not increase Calories digested in this study. The addition of calcium carbonate increased ($P < 0.05$) the

Table 4. Average daily digestibility and balance data obtained from lambs fed corn oil and $CaCO_3$ in an alfalfa hay ration

Corn oil, gm.	0		50	
Calcium carbonate, gm.	0	10	0[a]	10
	Digestibility, %			
Organic matter	77.3	76.7	76.5	77.3
Protein	68.6	68.2	66.4	68.2
Cellulose	55.0	55.0	55.0	56.1
Ash	48.4	44.3	47.4	45.1
	Calcium intake and fecal excretion			
Intake, gm.	6.19	10.12	6.20	10.25
Fecal, gm.	5.57	9.58	5.73	9.52
	Nitrogen balance			
Intake, gm.	18.36	18.34	18.42	18.50
Fecal, gm.	5.75	5.83	6.20	5.89
Urinary, gm.	8.29	8.62	8.17	8.22
Feed N retained, %	23.5	21.5	22.1	23.8
	Digestible energy			
Caloric intake	4032.8	4031.3	4511.7	4535.5
Digested Calories	3003.5	2990.9	3333.7	3401.6
Digestibility, %	74.5	74.2	73.9	75.0

[a]Average of only 7 lambs, 1 lamb removed because of feed refusal.

digested Calories in the basal ration but produced a further increase in the ration containing corn oil. Digestibility of energy of the high-calcium corn oil ration was nearly equal to that of the high-calcium ration. Fecal calcium was significantly increased ($P < 0.005$) by the addition of corn oil or calcium carbonate to the basal ration. These data indicate that there is definitely a relationship between

Table 5. Average daily calcium and energy digestibility data obtained from lambs fed corn oil and calcium in a low-calcium corncob ration[a]

Calcium carbonate, gm.	0		14	
Corn oil, gm.	0	40	0	40
	Calcium intake and fecal excretion			
Intake, gm.	0.51	0.52	6.12	6.11
Fecal, gm.	1.14	1.67	4.69	5.50
	Energy digestibility			
Caloric intake	3341.7	3712.8	3336.0	3726.1
Digested Calories	2246.6	2256.2	2477.6	2721.0
Digestibility, %	67.2	60.8	74.3	73.0

[a]Because of feed refusal, these values are averages of 7, 6, 8 and 6 lambs per treatment, respectively.

the calcium level of the ration and the utilization of energy supplied by corn oil. It should be pointed out that difficulty was encountered in getting lambs to consume their daily rations in this study with the exception of the lambs fed the high-calcium basal ration, which is the reason for the unequal number of lambs on the different ration treatments.

Trials 3 and 4

Difficulty was encountered in getting the lambs in Trial 3 to consume the desired level of feed, so a level of only 700 gm. of the basal ration was fed daily per lamb. The results of Trials 3 and 4 are shown in Table 6. Corn oil decreased ($P < 0.05$) digestibility of dry matter and organic

Table 6. Average daily digestibility and balance data obtained from lambs fed corn oil, $CaCO_3$, $CaCl_2$ and $MgCO_3$

	Basal	Corn oil	Corn oil		
			$CaCO_3$	$CaCl_2$	$MgCO_3$
Trial 3			Digestibility, %		
Dry matter	63.3	60.8	60.0	63.0	61.5
Organic matter	63.7	61.1	60.4	63.2	61.9
Protein	73.7	72.4	74.7	75.5	72.6
Trial 4					
Organic matter	72.2	68.3	72.7	71.7	67.4
Protein	77.1	77.3	78.6	77.3	74.8
Cellulose	61.4	48.7	58.7	57.9	47.7
Ash	42.8	41.9	48.0	47.2	48.8
			Calcium intake and fecal excretion		
Intake, gm.	2.68	2.68	5.88	5.94	2.68
Fecal, gm.	2.05	2.18	4.50	4.21	2.27
Retained, %	24.0	17.8	23.7	29.0	15.3
			Nitrogen balance		
Fecal, gm.	3.81	3.76	3.56	3.75	4.18
Urinary, gm.	9.57	8.86	8.95	9.71	8.55
Feed N retained, %	19.7	24.2	25.1	19.0	23.4

matter in Trial 3 but effects on digestibility of protein were not statistically different. Calcium chloride alleviated the effects of the corn oil. However, calcium carbonate and magnesium carbonate were not effective in alleviating the effects of corn oil. Other digestibility and balance measurements were not made. The effects of corn oil and calcium upon ration digestibility in Trial 3 were not as great as has been observed in past trials which is probably due to both a lowered feed consumption by the lambs and the low levels of calcium fed. For these reasons, this trial was repeated with higher levels of calcium and magnesium being fed.

In Trial 4, digestibility of organic matter and cellulose was decreased ($P < 0.01$) by the addition of corn oil. Calcium as the carbonate or chloride was equally effective in alleviating this corn oil depression on digestibility. Magnesium carbonate was not effective in preventing corn oil depression on organic matter and cellulose digestibility and decreased ($P < 0.05$) the digestibility of protein. Corn oil did not decrease protein digestibility. Feces of lambs fed the magnesium carbonate tended to be loose. If this looseness increased the rate of passage of ingesta, this might have caused a greater excretion of nitrogenous materials thereby lowering the apparent protein digestibility. Fecal calcium tended to increase with the addition of corn oil to the basal ration, but was greatly increased when corn oil and calcium carbonate or calcium chloride were added. Nitrogen retention was not significantly affected by ration treatments.

The addition of 5 per cent corn oil to rations containing corncobs has resulted in a decreased digestibility of organic matter, cellulose and, in one case, protein. Calcium additions, whether as the carbonate or the chloride, have alleviated these effects of corn oil. This indicates that the calcium ion is responsible for alleviating the effects of corn oil on ration digestibility and that the anion is of little importance. Magnesium, when fed as the carbonate, was not effective in alleviating corn oil depression on ration digestibility. When corn oil was added to a ration containing alfalfa hay, it did not alter ration digestibility. Calcium is probably one component of the alfalfa hay that prevented corn oil from depressing digestibility.

White _et al_. (94) suggested that it may be possible to explain this calcium-fat relationship as due to the formation of calcium soaps. Grainger and Stroud (39) and Grainger _et al_. (38) showed that corn oil decreased apparent and true digestibility of calcium and increased excretion of fecal soaps by lambs. The addition of more calcium to rations containing corn oil did not increase the excretion of fecal soaps. Tillman and Brethour (88) also reported that corn oil decreased digestibility of calcium. In Trials 1 and 4 corn oil tended to increase fecal calcium and corn oil significantly increased fecal calcium in the study with the low-calcium ration. Corn oil did not increase the excretion of calcium in Trial 2 in which alfalfa hay was part of the ration. More Calories were digested when lambs were fed corn oil in the alfalfa hay ration. When corn oil was added to the corncob basal rations the Calories digested were not increased; however, when calcium was added with the corn oil more Calories were digested. This suggests that the calcium-fat relationship is not simply due to the formation and excretion of soaps but that the calcium is beneficial in the utilization of the fat.

The energy from corn oil was at least 39 per cent utilized in the calcium plus corn oil ration of Trial 1 and was at least 62 per cent utilized in the calcium plus corn oil ration of the low calcium study. It should be pointed out that these are minimum values since the digestibility of other ration components was slightly lower when corn oil was fed. In the study with alfalfa hay the energy in corn oil was 75 per cent digested. Earlier studies by Davison (21) indicate that at least 70 per cent of the energy from corn oil was digested by lambs fed a ration containing corncobs.

Calcium increased digestibility of energy in all rations except the one containing alfalfa hay. Calcium or corn oil did not markedly affect nitrogen retention in these studies. Grainger _et al_. (38) experienced difficulty in getting lambs to eat a ration supplemented with magnesium carbonate. Similar difficulty was encountered in Trial 3. Summers _et al_. (83) showed that addition of starch decreased digestibility of cellulose and that this could be alleviated by addition of alfalfa ash or trace minerals. Starch decreased digestibility of organic matter, protein and cellulose in Trial 1 which was partially alleviated by the addition of calcium. Calcium also increased the utilization of energy from starch producing a similar interaction as with corn oil. Unfortunately the addition of an equivalent amount of energy from starch as from corn oil did not help explain the calcium fat relationship.

The following is suggested as a possible mechanism whereby calcium increases the digestion of rations containing fat by lambs. Fat is hydrolyzed in the rumen to fatty acids and glycerol (36). Glycerol is fermented to propionate (55). The fatty acids may act as antimetabolites to the bacteria (16), but in the presence of calcium the fatty acids are precipitated as calcium soaps. The remainder of the rumen ingesta is fermented normally. Passage of the calcium soaps through the abomasum results in dissociation to calcium and fatty acids. Garton (35) has shown that the pH of the abomasum and duodenum of sheep is approximately 3 and that solubility of calcium increases as it passes from the rumen into the abomasum. As the calcium and fatty acids pass into the small intestine, either the calcium is absorbed away from the fatty acids before the pH becomes neutral or alkaline and the fatty acids are absorbed farther on in the presence of bile, or the fatty acids are absorbed immediately upon passing from the abomasum. Some soaps undoubtedly escape in the feces. It is also likely that some fat escapes hydrolysis in the rumen and is digested by pancreatic lipase before being absorbed in the small intestine.

Summary

A series of digestibility trials were conducted to study the effects of corn oil, starch, $CaCO_3$, starch plus $CaCO_3$ and corn oil plus $CaCO_3$, $CaCl_2$, or $MgCO_3$ on ration digestibility by lambs. Corn oil or starch decreased digestibility of organic matter, protein and cellulose whereas calcium increased digestibility of these components in rations containing corncobs. Digestibility of organic matter, protein and cellulose was increased more by calcium additions in rations containing corn oil or starch than in control rations. Additions of calcium as either carbonate or chloride tended to increase the fecal excretion of calcium. Nitrogen retention was not affected by ration treatment. Calcium additions increased Calories digested from corn oil or starch additions to corncob rations. Corn oil or calcium did not alter digestibility of a ration containing alfalfa hay. The energy from corn oil was well utilized by lambs fed the alfalfa hay ration. Magnesium carbonate was ineffective in alleviating corn oil depression on ration digestibility.

GROWING-FATTENING STUDIES WITH LAMBS

Digestibility studies indicate that calcium carbonate additions improve the utilization of energy of corncob rations containing added corn oil but not of alfalfa hay rations containing added corn oil. The work reported herein was initiated to study the effects of corn oil and calcium carbonate additions to rations containing either corncobs or alfalfa hay upon performance of fattening lambs. In view of this first experiment, a series of trials were conducted to study any possible interrelationship of calcium and fat in enhancing performance of lambs fed a corncob ration.

Experimental Procedure

All lambs used in the following trials were crossbreds and were shipped in from the Range States. The lambs were given access to hay and water upon arrival at the Ruminant Nutrition Farm of Iowa State University. During the following 10 to 14 days the lambs were gradually accustomed to grain, and were ear tagged, vaccinated for enterotoxemia and contagious ecthyma, weighed and divided into relatively uniform weight groups. The lambs were individually weighed after being off feed and water for 12 hours at the beginning, every 2 weeks during the progress and at the end of the experiment. All lambs were individually fed and were permitted 2½ to 3 hours access to feed twice daily. The lambs, as a group, were penned outside on a concrete floor when they were not being fed. Iodized block salt and water were available free choice when the lambs were not eating. The data were statistically analyzed by analysis of variance (82) and the methods used for chemical analyses were those described in Trial 1 of the digestibility studies.

Trial 1

Forty-eight Idaho lambs weighing between 60 and 70 pounds were randomly allotted, 6 lambs per treatment, to a 2x2x2 factorial experiment. Treatment factors were 0 and 1 per cent $CaCO_3$ and 0 and 5 per cent corn oil added to basal rations containing either corncobs or alfalfa hay as the source of roughage. Composition of the basal rations is shown in Table 7. The chemical analyses of the basal and basal plus $CaCO_3$ rations are given in Table 8. Rations were mixed three different times during the experiment and calcium was added as feeding grade limestone during these mixings. Corn oil was mixed into the rations just prior to feeding. Six pounds of feed, including limestone and corn oil, were weighed out to each lamb and the lamb received no more feed until this was consumed or, if the lamb did not eat well, until the stale feed was weighed back which was at the feeder's discretion.

The lambs were shorn prior to the start of the experiment and were also individually fed their respective basal

Table 7. Percentage composition of the alfalfa hay and corncob basal rations fed in fattening Trial 1

Ingredient	Alfalfa hay	Corncob
Corncobs, 1/4" grind	--	40.0
Alfalfa hay, 3/4" grind	40.0	--
Ground corn	50.0	36.1
Soybean meal	2.4	16.0
Molasses	7.0	7.0
Salt	0.6	0.6
Dicalcium phosphate	--	0.3
Quadrex[a], gm./ton	40	40
$CoSO_4 \cdot 7H_2O$, mg./ton	--	200

[a]Containing 10,000 I.U. vitamin A and 1,250 I.U. vitamin D_2 per gram.

Table 8. Average percentage chemical analyses of the alfalfa hay and corncob basal and basal plus $CaCO_3$ rations fed in fattening Trial 1

	Corncob		Alfalfa hay	
$CaCO_3$ added	0	1%	0	1%
Dry matter	86.8	86.9	86.0	86.1
Ash	2.8	3.7	3.8	4.4
Protein (Nx6.25)	11.5	11.5	11.4	11.7
Calcium	0.24	0.70	0.62	0.96

rations for a 10 day standardization period. Duration of the experiment was 70 days. The lambs were slaughtered at a local plant and carcass weights and U. S. Government grades were then obtained. Chilled carcass weight was obtained by shrinking the warm carcass weight by 2 3/4 per cent. Dressing per cent was based on the chilled carcass weight and the shrink weight taken at the end of the experiment.

Trial 2

Forty-two South Dakota lambs weighing an average of 70 pounds were randomly allotted, 7 lambs per treatment, to a 2x3 factorial experiment. Treatment factors were 0.6, 0.8 and 1.0 per cent calcium in the total ration and 0 and 5 per cent added stabilized white grease. Composition of the basal ration is shown in Table 9. Chemical analyses of the rations containing various levels of calcium are shown in Table 10. Rations were mixed two different times during the experiment. Calcium levels were increased by adding ½ and 1 per cent limestone to the basal ration. Corn oil was fed the first 7 days of the experiment and stabilized white grease was fed thereafter. All lambs were drenched with phenothiazine after 3½ weeks on experiment since there were indications of worm infestation. The lambs were on experiment for 87 days with other procedures remaining the same

Table 9. Average percentage composition of the basal rations used in calcium and grease studies (fattening Trials 2, 3, 4 and 5)

Ingredient	Trial 2	Trial 3	Trial 4 and 5
Corncobs, ¼" grind	40.0	40.0	40.0
Ground corn	35.1	35.8	34.8
Soybean meal	16.0	16.0	16.0
Molasses	7.0	7.0	7.0
Limestone	1.0	0.3	0.3
Salt	0.6	0.6	0.6
Dicalcium phosphate	0.3	0.3	0.3
Quadrex[a], gm./ton	40	40	40
$CoSO_4 \cdot 7H_2O$, mg./ton	200	200	--
Grease	--	--	1.0

[a]Containing 10,000 I.U. vitamin A and 1,250 I.U. vitamin D_2 per gram.

Table 10. Average percentage chemical analyses of rations fed in fattening Trial 2

Limestone added, %	0	½	1
Dry matter	92.0	92.0	92.6
Ash	4.0	4.5	5.2
Protein (Nx6.25)	11.7	11.2	13.7
Calcium	0.60	0.94	1.10

as those of Trial 1.

Trial 3

Forty-two Montana lambs weighing an average of 74 pounds were randomly allotted, 7 lambs per treatment, to a 2x3 factorial experiment. Treatment factors were 0.3, 0.5 and 0.7 per cent calcium in the total ration and 0 and 5 per cent added stabilized white grease. All lambs were drenched with phenothiazine prior to the experiment. The lambs were group fed a ration containing 2 per cent grease for 1 week prior to starting the experiment. Duration of the experiment was 70 days. The composition of the basal ration is shown in Table 9 and the chemical analyses of the rations containing various calcium levels are shown in Table 11. Calcium levels were increased by adding ½ and 1 per cent limestone to the basal ration. Other procedures were the same as in Trial 1 except that the lambs were not shorn.

Trial 4

Forty-two California lambs weighing an average of 75 pounds were randomly allotted to 7 treatments of 6 lambs each. Treatments consisted of rations containing 0.3, 0.5 and 0.7 per cent calcium in the total ration and 1 and 6 per cent added stabilized white grease arranged in a

Table 11. Average percentage chemical analyses of rations fed in fattening Trial 3

Limestone added, %	0	½	1
Dry matter	90.4	90.1	90.3
Ash	3.6	3.9	4.2
Protein (Nx6.25)	12.5	12.2	12.3
Calcium	0.35	0.59	0.77

2x3 factorial, and an additional ration containing 0.5 per cent calcium, 6 per cent grease and a mixture of trace minerals. The trace mineral mixture supplied the following to the ration, in mg. per pound: Fe, 27.3; Cu, 2.9; Mn, 10.4; S, 22.8; and Co, 0.02. Composition of the basal ration is given in Table 9. Chemical analyses of the various rations are given in Table 12. Grease and calcium were added during the mixing of the rations. Up to 8 pounds of feed were given to the lambs at any one time. Duration of the experiment was 54 days. Other procedures were similar to those of Trial 1.

Trial 5

Forty-eight Utah lambs weighing an average of 71 pounds were randomly divided into 8 groups of 6 lambs each and assigned to a 2x2x2 factorial experiment. Treatment

Table 12. Average percentage chemical analyses of rations fed in fattening Trial 4

	Limestone added, %			Grease plus Ca plus T.M.
	0	½	1	
Dry matter	89.0	89.1	89.1	89.4
Ash	3.3	3.8	4.2	4.0
Protein (Nx6.25)	11.5	11.7	12.1	11.2
Calcium	0.32	0.57	0.76	0.53

factors were 0.3 and 0.6 per cent calcium in the total ration and 1 and 6 per cent stabilized white grease added to a ration with or without a trace mineral supplement. The composition of the basal ration is given in Table 9. The trace minerals added per pound of ration, in mg., were as follows: Fe, 15; Mn, 8; Zn, 2; Cu, 1; and Co, 0.03. Rations were mixed at two different times during the trial with grease, calcium and trace minerals being added at these mixings. The lambs were drenched with phenothiazine prior to the start of the experiment. Each lamb was given up to 8 pounds of feed at any one feeding. Chemical analyses of the various calcium and trace mineral rations are given in Table 13. Duration of the experiment was 63 days. Other procedures were the same as in Trial 1.

Blood samples were drawn by jugular puncture from all

Table 13. Average chemical composition of rations fed in fattening Trial 5

Trace minerals Limestone added, %	0 0	0 3/4	Plus 0	Plus 3/4
Dry matter	93.2	93.2	93.2	93.3
Ash	3.9	4.4	3.7	4.2
Protein (Nx6.25)	12.3	12.4	12.9	11.8
Calcium	0.36	0.66	0.34	0.62

lambs after 0, 10 and 50 days on experiment and total lipid in the plasma was determined. Potassium oxalate was used to prevent clotting of the fresh blood samples. The blood plasma was extracted from whole blood by centrifugation in an angle centrifuge at 12,000 r.p.m. for 15 minutes and was frozen until analyzed. Total lipid analysis was by the Mojonnier method (70) as described by Hill (46). The lipid from 5 ml. blood plasma was extracted with a mixture of hexane and ethyl ether. The hexane-ether-lipid mixture was decanted into tared beakers and the hexane-ether mixture was evaporated over a steam plate. Lipid was determined by difference in weight of the beaker.

Results and Discussion

Trial 1

The results of Trial 1 appear in Table 14. Addition of corn oil, or corn oil plus calcium carbonate, did not improve the rate of gain of lambs fed the corncob basal ration. Addition of calcium carbonate to the basal ration tended to increase rate of gain; however, none of the observations of lambs fed the corncob ration were statistically different at the 5 per cent level of probability. Calcium additions tended to increase daily feed consumption and carcass grade but did not increase efficiency of feed conversion or dressing per cent. The addition of corn oil did not measurably affect feed consumption, efficiency of feed conversion, dressing per cent or carcass grade.

The addition of corn oil to the alfalfa hay basal ration increased efficiency of feed conversion ($P<0.025$) and carcass grade ($P<0.05$). Differences, due to diet, in other factors measured were not statistically significant, but the addition of corn oil tended to increase rate of gain and dressing per cent of lambs fed the alfalfa hay ration. Calcium additions slightly decreased rate of gain but did not appreciably affect other measurements taken. Lambs fed the ration containing alfalfa hay tended to out perform lambs fed the ration containing corncobs.

Table 14. Averaged performance of lambs fed alfalfa hay or corncob rations containing added corn oil and/or calcium

Treatment	Daily gain (lb.)	Daily feed (lb.)	Feed per lb. gain (lb.)	Dressing per cent	Carcass grade[a]
Corncob basal	.42	3.32	7.83	50.0	5.0
plus corn oil	.43	3.35	7.74	49.2	4.8
plus calcium	.47	3.57	7.53	50.0	5.7
plus CO plus Ca	.42	3.62	8.64	50.8	5.5
Alfalfa hay basal	.49	3.46	7.02	50.5	5.7
plus corn oil	.54	3.37	6.26	52.4	6.4
plus calcium	.45	3.35	7.48	50.6	5.5
plus CO plus Ca	.54	3.38	6.31	52.8	6.7

[a]U. S. Government grade value; 4 equal low good, 5 equal av. good, 6 equal high good and 7 equal low choice.

Trial 2

Since feed consumption and carcass grade tended to be improved in lambs fed the corncob basal to which calcium carbonate or calcium carbonate plus corn oil was added, it was decided to further study this relationship using higher levels of calcium. Stabilized white grease replaced corn oil to make this study more practical. The results of Trial 2 appear in Table 15.

Rate of gain was not affected by addition of calcium carbonate or grease. Addition of calcium carbonate did not affect feed consumption, feed conversion, dressing per cent

Table 15. Averaged performance of lambs fed rations containing various fat and calcium levels (Trial 2)

Treatment	Daily gain (lb.)	Daily feed (lb.)	Feed per lb. gain (lb.)	Dressing per cent	Carcass grade[a]
Basal	.39	3.34	8.51	50.3[b]	5.0
plus ½% limestone	.37	3.21	8.62	49.3	5.1
plus 1% limestone	.38	3.20	8.40	47.5[c]	4.2[c]
Basal plus 5% grease	.40	3.03	7.62	48.7	5.1
plus ½% limestone	.35	2.95	8.37	49.6	4.7
plus 1% limestone	.40	3.05	7.54	49.8	5.3

[a]U. S. Government grade value; 4 equal low good, 5 equal av. good and 6 equal high good.

[b]Average of only 6 lambs; one value of 72.2% was considered in error so it was not included.

[c]Average of only 6 lambs, 1 lamb died in route to market.

or carcass grade. Feed consumption was decreased slightly by the addition of grease. Grease tended to improve feed conversion but did not improve carcass yield or grade.

Lambs fed the ration containing grease were slow in going on feed. They ate 0.5 pound less feed per day than lambs fed the rations without grease during the first 2 weeks of the trial. By the end of 6 weeks, lambs fed the rations containing grease were consuming feed at the same rate as the lambs not receiving grease. All lambs were wormed after 3½ weeks on experiment as some of the lambs were showing symptoms of worms.

Trial 3

The lambs were fed a ration containing 2 per cent grease for 7 days immediately prior to the experiment. This was an attempt to get the lambs that were to be fed 5 per cent grease rations on feed faster. The results of Trial 3 are shown in Table 16.

Performance of these lambs was highly variable. Gains of lambs fed rations containing fat and calcium additions varied from -1 to 39 pounds, whereas gains of lambs fed rations containing only calcium additions varied from 12 to 39 pounds. Because of this variation, differences in rate of gain and feed conversion were not statistically different. Calcium additions did not appreciably alter rate of gain, feed conversion, feed consumption or carcass yield and grade. The addition of grease tended to reduce rate of gain and reduced ($P < 0.10$) feed consumption. Daily feed consumption of lambs fed rations containing grease was 0.5 pound lower than the consumption of other lambs. The feeding of fat prior to the experiment was unsuccessful in getting the lambs on feed at a level similar to the control lambs. The addition of grease did not improve feed conversion, dressing per cent or carcass grade.

Table 16. Average performance of lambs fed rations containing various calcium and fat levels (Trial 3)

Treatment	Daily gain (lb.)	Daily feed (lb.)	Feed per lb. gain (lb.)	Dressing per cent[a]	Carcass grade[ab]
Basal	.38	3.15	8.26	46.8	6.3
plus ½% limestone	.39	3.18	8.08	48.0	7.0
plus 1% limestone	.42	3.04	7.31	48.6	6.6
Basal plus 5% grease	.31	2.57	8.24	48.2	6.5
plus ½% limestone	.31	2.61	8.53	48.3	6.8
plus 1% limestone	.30	2.72	9.02	48.1	6.0

[a]Average of 7, 7, 7, 6, 4 and 5 lambs. The remainder of these lambs were not heavy enough for market at the termination of the experiment.

[b]U. S. Government grade value; 6 equal high good, 7 equal low choice.

Trial 4

One per cent grease was added to the basal ration so that any grease flavor or odor would be imparted to the ration. It was thought that this may reduce the difference in feed consumption observed between lambs fed the control rations and those fed rations containing added grease. As can be seen by the results in Table 17, feed consumption was lower for lambs fed rations containing 6 per cent grease despite this effort.

The performance of the lambs in this trial was very good. Rate of gain and feed consumption were reduced by

Table 17. Average performance of lambs fed rations containing various calcium and fat levels (Trial 4)

Treatment	Daily gain (lb.)	Daily feed (lb.)	Feed per lb. gain (lb.)	Dressing per cent	Carcass grade[a]
Basal	.59	4.02	6.85	50.2	6.2
plus ½% limestone	.57	4.05	7.10	51.0	6.2
plus 1% limestone	.54	3.82	7.04	51.6	6.7
Basal plus 5% grease[b]	.56	3.50	6.25	51.3	6.2
plus ½% limestone	.56	3.87	6.94	51.6[c]	6.3
plus 1% limestone	.54	3.71	6.94	50.8	6.3
plus ½% limestone and trace minerals	.58	3.74	6.41	51.5	6.7

[a]U. S. Government grade value; 6 equal high good, 7 equal low choice.

[b]Average of 5 lambs, 1 lamb died of enterotoxemia during experiment.

[c]Average of 5 lambs, 1 lamb had a leg removed during slaughter.

the addition of 1 per cent limestone. Calcium additions did not improve efficiency of feed conversion, dressing per cent or carcass grade. Rate of gain, feed efficiency, dressing per cent and carcass grade of lambs fed rations containing grease were similar to those of lambs fed the basal rations. The addition of trace minerals did not improve performance of lambs fed a ration containing grease. It should be pointed out that none of the measurements made in this trial approached statistical significance.

Trial 5

The growing-fattening performance of the lambs of Trial 5 are shown in Table 18. Performance of these lambs was very poor. Two lambs refused feed and were removed from the trial. Ten of the 48 lambs exhibited a peculiar "stiff" condition during the experiment. This condition varied from a severe stiffness of one limb to a general stiffness where all four limbs were involved and appeared to be localized in the shoulder or leg. The feet and lower limbs were not sore. Other lambs from this same shipment exhibited a similar condition even though they were fed completely different rations. Two lambs exhibiting a severe general stiffness were taken to the Veterinary Clinic of Iowa State University for observation. They were then sacrificed and autopsied. The cause of the stiffness was not revealed by post-mortem examination or by tissue cultures. The lambs were also free of worms. The rate of gain, feed consumption and feed efficiency data do not fit any pattern attributable to treatments.

Total blood plasma lipid values obtained from the lambs of Trial 5 are shown in Table 19. Considerable individual variation was noted for lambs on the same ration treatment. Plasma lipid values changed very little between 0 and 10 days but increased ($P<0.005$) from 0 to 50 days on experiment. Total plasma lipids appeared to increase more in lambs fed

Table 18. Average performance of lambs fed rations containing 2 levels of calcium, fat and trace minerals (Trial 5)

Treatments	Daily gain (lb.)	Daily feed (lb.)	Feed per lb. gain (lb.)	Stiff lambs
Basal	.37	3.19	8.55	2
plus limestone[a]	.36	3.10	8.65	1
plus grease	.24	2.74	11.64	0
plus limestone plus grease	.23	2.70	11.75	3
Basal plus trace minerals	.29	2.85	9.97	0
plus limestone	.26	2.92	11.21	2
plus grease	.30	2.82	9.52	1
plus limestone plus grease	.19	2.47	12.98	1

[a]Average of 5 lambs, 1 lamb removed from trial.

rations containing fat than in the low fat rations; however, this difference was not statistically different. Plasma lipids of six lambs, one of which was fed a 6 per cent fat ration, actually decreased during this 50 day period.

In a separate study, three different lambs were given corn oil directly into the rumen by stomach tube and plasma total lipids were determined at various intervals up to 24 hours. Blood samples were drawn by jugular puncture. All three lambs were on a full feed of alfalfa hay, corn and soybean meal. Lamb 1 was given 430 gm. of corn oil and lambs 2 and 3 were given 440 gm. of corn oil. The lambs weighed 94, 97 and 98 pounds, respectively. The

Table 19. Average total plasma lipid values obtained from lambs fed rations containing 2 levels of calcium, fat and trace minerals (Trial 5)[a]

Treatment	Days on treatment 0[b]	10	50[b]	Day 50 minus day 0
Basal	92	83[c]	121	29
plus calcium	100[d]	83	107[d]	7
plus grease	85	89[d]	139	54
plus Ca plus grease	92[d]	108	154	62
Basal plus trace minerals	95	75	114	19
plus calcium	92	86	115[d]	23
plus grease	85	85[d]	131	46
plus Ca plus grease	83	85	129	46

[a]Expressed as mg./100 ml. plasma.

[b]Range for all samples, 49 to 176 mg. % on day 0 and 84 to 196 mg. % on day 50.

[c]Average of 4 values.

[d]Average of 5 values.

results of this study are given in Table 20. There was no indication of fat absorption by any of these lambs. Lamb 2 had a markedly higher plasma lipid level than lambs 1 and 3. No adverse effects from the fat were noted in lamb 1. Lambs 2 and 3 began scouring about 8 hours after the feeding of corn oil and were off feed that evening and the following morning.

These studies indicate that plasma fat levels respond very slowly, if at all, to the feeding of fat to fattening

Table 20. Effect of feeding large quantities of corn oil by stomach tube upon circulating plasma total lipids of lambs[a]

Hours post feeding of fat	Lamb 1	Lamb 2	Lamb 3
0	126	228	---
2	104	204	111
3	136	---	---
4	126	217	131
5	125	---	---
6	---	215	117
7	136	---	---
8	---	206	126
10	---	174	120
24	---	198	121

[a]Expressed as mg./100 ml. plasma.

lambs and are in agreement with the response observed with dairy cows (6, 69) and goats (69) to various dietary fat levels. Plasma lipid levels of the young dairy calf have been shown to respond to the addition of various fats in a milk replacer (54). Work at the Texas (95) and Nevada stations (7) has shown that the feeding of animal fat or cottonseed oil to steers will result in a marked rise in the plasma fat level over a 4 to 5 month period. It should be pointed out that little or no information is available on the rate of fat absorption or fat tolerance of the ruminant. More information along these lines would give more meaning to the present data.

The differences in performance of lambs fed corn oil in the ration containing corncobs versus those fed corn oil in the ration containing alfalfa hay are not fully understood. Certainly the difference in level of calcium of these two rations does not explain this difference in performance. Other factors in the alfalfa hay must assist the lamb in utilizing energy supplied by the addition of fat. It appears that the energy supplied by corn oil was not utilized by the lambs fed the corncob ration.

A summary of the performance of all lambs fed rations with or without 5 per cent stabilized white grease is shown in Table 21. Lambs fed the rations containing grease gained at a slightly slower rate and consumed about 0.3 pound less feed per day. Efficiency of feed conversion was not improved by the addition of grease. It would appear that the energy of the added grease was utilized in this series of trials. However, the lambs fed the rations containing grease gained 7.3 per cent less and consumed 8.2 per cent less feed than the control lambs. The daily Caloric consumption, using 4.1 Calories per gram for the basal ration and 4.4 Calories per gram for the basal plus grease ration, was 6160 and 6070 Calories per lamb, respectively; or it was 1.5 per cent less for the lambs fed grease. Maintenance energy expenditure would have been similar for all lambs. The percentage reduction in rate of gain is nearer the percentage reduction

Table 21. Summary of four trials in which lambs were fed rations with or without stabilized white grease

Ration[a]	Daily gain (lb.)	Daily feed (lb.)	Feed per lb. gain (lb.)
Basal	.41	3.31	8.07
Basal plus grease	.38	3.04	8.00

[a]Average of 82 and 90 lambs for the basal or basal plus grease rations, respectively.

in feed consumption than the percentage reduction in Caloric intake which would indicate that the energy in grease was not being efficiently utilized by the lambs fed these corn-cob rations. This is not in agreement with the digestibility studies and is difficult to explain.

Lambs fed rations containing grease were slower than control lambs in going on feed; but as the trial progressed, this difference in feed consumption decreased. It is possible that the reduction in feed intake early in the fattening period accounts for the apparent disparity between the growing-fattening and digestibility studies in the utilization of fat. Since the lambs were on a reduced feed intake during this period, their maintenance requirement would use a larger portion of the energy in the grease rations than in the control rations thus making them less efficient in converting energy to gain. It would appear that the addition of animal grease to a ration containing corncobs results in a ration that is unpalatable to lambs.

Summary

A growing-fattening experiment was conducted to compare performance of lambs when calcium and/or corn oil were added to rations containing corncobs or alfalfa hay. A series of experiments followed to study calcium, stabilized white grease and trace mineral interrelationships on performance of fattening lambs. The addition of 5 per cent corn oil to a ration containing 40 per cent alfalfa hay resulted in a savings of approximately 1 pound of feed per pound of gain and tended to increase rate of gain, carcass grade and dressing per cent. Corn oil additions did not improve performance of lambs fed rations containing corncobs. Calcium additions tended to increase rate of gain of lambs fed a corncob ration containing 0.24 per cent calcium but did not improve performance of lambs fed rations containing added fat or higher levels of calcium. The addition of 5 per cent stabilized white grease to rations containing corncobs tended to decrease rate of gain, feed consumption and efficiency of feed conversion. The addition of grease did not improve dressing per cent or carcass grade. Blood lipid values increased with fattening of the lambs but were

not appreciably changed by the feeding of grease. The feeding of large quantities of corn oil by stomach tube did not change total blood lipids in a 24-hour period.

GENERAL DISCUSSION

The data in this thesis clearly indicate that corn oil decreases digestibility of corncob rations by lambs. The depression in digestibility caused by corn oil was alleviated by the addition of calcium carbonate which is in good agreement with earlier studies conducted at this and other stations (21, 94). Calcium carbonate not only alleviated the depressing effects of corn oil upon ration digestibility but it increased digestibility of the energy supplied by the corn oil as well. Magnesium carbonate did not alleviate the effects of corn oil upon ration digestibility. Grainger _et al_. (38) at the Kentucky station observed that additions of magnesium carbonate would cause lambs fed semi-purified rations to go off feed. Calcium chloride was as effective as calcium carbonate in alleviating corn oil depression upon ration digestibility. It was therefore concluded that the calcium ion was alleviating the corn oil depression on ration digestibility. The anion was apparently of little value in this respect.

Calcium also increased digestibility of the basal corncob rations. Byers (13) reported that calcium as the carbonate increased digestibility of alfalfa hay by steers but calcium supplied as dicalcium phosphate did not. Calcium carbonate or corn oil additions did not alter digestibility of a ration containing 40 per cent alfalfa hay by lambs. The energy of corn oil was well utilized by lambs fed this alfalfa hay ration.

Fecal calcium tended to be increased when corn oil was added to rations containing corncobs but not when added to rations containing alfalfa hay. Fat has also been shown to increase fecal calcium of the monogastric animal (15, 84). The addition of calcium greatly increased fecal calcium excretion by lambs but feeding a combination of corn oil and calcium did not cause an excretion of calcium in excess of that expected by a summation of the individual corn oil and calcium effects. Similar results were reported by the Kentucky station (39). The mechanism of this calcium-fat interrelationship has been discussed earlier in this thesis.

Alfalfa ash (12, 78, 83, 93), distillers dried solubles ash (78), synthetic alfalfa ash, cobalt (89), trace minerals equivalent to those in alfalfa ash (73, 94), sodium and potassium bicarbonate (10), potassium hydroxide (21), potassium chloride, iron, zinc, magnesium (38), calcium (21, 94) and phosphorus (94) have all been studied as possible factors in alleviating the depressing effects of fat on ration digestibility. Alfalfa ash (12, 78, 83, 93) and calcium (21, 94), however, have been the only factors shown to completely alleviate the fat effects.

The performance of fattening lambs was improved when corn oil was added to a ration containing alfalfa hay which was in good agreement with the digestibility study. However, performance of fattening lambs was not improved by the addition of corn oil, stabilized white grease or fat and calcium combinations to a ration containing corncobs. This does not agree with the digestibility studies. As stated in the review of literature, the addition of up to 7 per cent fat to rations containing alfalfa hay has improved performance of cattle and lambs but this has not been the case when the ration did not contain alfalfa hay. This disparity between the results of growing-fattening studies and digestibility studies with fat and calcium additions is confusing. A possible explanation for the calcium effects may be due to the lower level of feed intake by lambs in the digestibility studies as compared to lambs in the fattening studies with a resultant lower total calcium intake. The animal's calcium requirement may be a constant quantity regardless of the level of feed intake.

In these digestibility trials, and in earlier trials (21), an intake of approximately 0.6 per cent calcium in the ration gave maximum digestibility of energy. This was a total consumption of 4.8 gm. of calcium per lamb per day. In the growing-fattening studies the basal ration, with the exception of those in Trial 1, contained 0.3 per cent calcium which gave a daily intake of 4.2 gm. The total calcium requirement for optimum digestibility and that fed in the basal rations of these growing-fattening experiments are very similar. This would suggest that the fattening lamb needs approximately 4 gm. of calcium daily for optimum rumen and other metabolic functions.

A lower manganese level in the corncob ration appeared to be the only major difference in trace mineral content between the corncob and alfalfa hay rations. Supplementing a 40 per cent corncob ration containing grease with all minerals to a level comparable to that supplied by 40 per cent alfalfa hay did not improve performance of lambs.
If the ability of the lamb to utilize fat is associated with the mineral content of alfalfa hay, it must be due either to the chemical form or to the availability of the minerals. The possibility still exists that some organic component of alfalfa hay may enhance utilization of added fat.

These fattening rations with added fat contain only about 6 per cent ether extract. Garton (33) has pointed out that fresh forages consumed by cattle and sheep contain up to 6 per cent total lipids on a dry matter basis, 4 per cent of which could be neutral fat. This would amount to a consumption of about 1 pound of fat daily by a cow and about 0.2 pound daily by a lamb. The addition of 5 per cent fat to the ration therefore does not seem to be unreasonable.

The stabilized grease was apparently unpalatable to the lamb as measured by feed consumption. In Trials 4 and 5 the grease was mixed along with the other ingredients so it is apparent that molasses will not mask the odor or taste. Other attempts to accustom the lambs to the fat were unsuccessful. A reduced feed consumption when animal fat was added has been noted by other workers (10, 29). Corn oil, however, did not affect feed consumption. It would be interesting to study the effect of 5 per cent stabilized white grease on the consumption of a ration containing alfalfa hay by lambs.

Another interesting area of study would be the rate of absorption of fat by cattle and lambs. The data in this thesis indicate that fat is absorbed slowly by the lamb. Limited data on the cow and goat indicate that fat is absorbed slowly by other ruminants (6, 69). Ruminants must have a very good lipostatic mechanism as circulating blood lipids of the cow were resistant to change even under fasting conditions (5). Apparently adequate lipase activity is present from microorganisms in the rumen of cattle and sheep (36, 46) and from pancreatic secretions in the small intestine of cattle (52, 61, 79, 91) to digest most dietary fats. It, therefore, would not seem unreasonable to assume that fat could be absorbed by the sheep.

There was no information found on the rate of fat oxidation by the lamb. The addition of alfalfa ash to a ration containing 5 per cent corn oil increased methane production in the rumen slightly but the net effect was to increase the quantity of feed energy available to the sheep (86); however, there were no low-fat control diets fed in this study. The liver may remove fat from the blood, but livers were not checked in any of the trials reported in this thesis. Deposition of fat in other tissues would also aid in holding blood fat at a constant value. It is doubtful, however, that deposition of fat in the lamb carcass was a major factor in clearing the blood lipids of lambs fed grease as these carcasses did not grade higher than control carcasses.

A more direct measure of fat absorption than that used in this thesis is needed. Sampling from or near the thoracic lymph duct would be a better technique and would remove errors caused by removal or oxidation of fat from the blood by the liver and other tissues. Once this sampling is mastered, the rate of absorption of various fats and fatty acids as well as factors aiding in their absorption could be studied. A study of the fate of fat after absorption would logically follow.

SUMMARY

A series of digestibility and growing-fattening trials were conducted to study the effects of fat and mineral additions upon the performance of lambs fed rations containing alfalfa hay or corncobs.

The addition of 5 per cent corn oil to rations containing 46 per cent corncobs decreased digestibility of organic matter, protein and cellulose. Total Calories digested were not increased by the addition of corn oil. Calcium, as the carbonate or the chloride, increased digestibility of all components measured when added to the basal ration but greatly increased digestibility of rations containing corn oil. Total Calories digested were greatly increased when calcium was added to rations containing corn oil which was interpreted as an increased utilization of the corn oil. Magnesium did not increase digestibility of a ration containing corn oil.

The addition of 5 per cent corn oil and/or 1 per cent calcium carbonate did not alter percentage digestibility of a ration containing 40 per cent alfalfa hay. Lambs fed this alfalfa hay ration containing corn oil digested approximately 500 more Calories daily than control lambs. The addition of corn oil saved about 1 pound of feed per pound of gain and tended to improve rate of gain, carcass grade and dressing per cent of lambs fed the 40 per cent

alfalfa hay ration in a growing-fattening study. The addition of 5 per cent corn oil to a ration containing 40 per cent corncobs did not improve rate of gain, feed efficiency, carcass grade or dressing per cent. Rate of gain, feed efficiency, carcass grade and dressing per cent of lambs were not improved when 5 per cent stabilized white grease was fed in combination with various calcium and trace mineral levels in corncob rations.

Calcium additions tended to increase rate of gain of lambs fed a 40 per cent corncob ration containing 0.24 per cent calcium. Calcium, or trace mineral, additions did not improve performance of fattening lambs fed rations containing 0.3 per cent or more calcium.

Within the limits of this study, the feeding of 5 per cent stabilized white grease or of large intraruminal doses of corn oil did not appreciably alter total systemic blood lipids of lambs.

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APPENDIX

Table 22. Analysis of variance of digestibility and balance data obtained from lambs fed corn oil, starch and $CaCO_3$ (digestibility Trial 1)

Source of variation	D.F.	Mean square					
		Organic matter	Protein	Cellulose	Fecal calcium	Digested Calories	Gm. N retained
Total	35						
Trial	1	129.20	189.53	159.60	1.00	135301	0.96
Treatment	(5)	110.11	53.85	539.79	8.37	111396	0.84
Basal vs. starch and corn oil	1	96.84	90.90	825.89	0.06	103922	0.19
Starch vs. corn oil	1	101.27	28.39	226.93	0.01	29822	0.55
Calcium	1	223.34	127.69	472.00	41.67	387797	2.85
Interaction	2	64.54	11.13	587.07	0.05	17720	0.31
Trial x treatment	5	18.52	6.36	57.28	0.10	18629	0.27
Remainder	24	6.04	3.54	32.88	0.07	7207	0.26

Table 23. Analysis of variance of digestible energy and fecal calcium data obtained from lambs fed corn oil and $CaCO_3$ in an alfalfa hay ration (digestibility Trial 2)

Source of variation	D.F.	Mean square Digested Calories	Fecal calcium
Total	30		
Trial	1	52398	4.43
Treatment	(3)	364390	39.45
Calcium	1	11562	118.23
Corn oil	1	1075319	0.03
Interaction	1	20686	0.03
Trial x treatment	3	9611	0.00
Remainder	23	7932	0.29

Table 24. Analysis of variance of digestible energy and fecal calcium data obtained from lambs fed corn oil and $CaCO_3$ in a low calcium, corncob ration (digestibility Trial 2)

Source of variation	D.F.	Mean square Digested Calories[a]	Fecal calcium
Total	30		
Trial	1	130010	.48
Treatment	(3)	292917	2.64
Calcium	1	94002	4.74
Corn oil	1	738128	1.94
Interaction	1	46276	0.00
Trial x treatment	3	3873	0.00
Remainder	23	8572	0.02

[a]Only 26 total degrees of freedom, lambs that did not consume all their ration were not considered.

Table 25. Analysis of variance of digestibility data obtained from lambs fed corn oil, $CaCO_3$, $CaCl_2$ and $MgCO_3$ (digestibility Trial 3)

		Mean square	
Source of variation	D.F.	Organic matter	Protein
Total	31		
Trial	1	1.67	5.95
Treatment	4	12.74	10.30
Trial x treatment	4	0.38	4.47
Remainder	22	3.49	4.52

Shortest significant ranges

Organic matter:

p:	(2)	(3)	(4)	(5)	
R_p:	2.93	3.08	3.17	3.24	
Treatments:	1	4	5	2	3
Means:[a]	63.7	63.2	61.9	61.1	60.4

Protein: Treatment effects not significant at 0.05 level of probability.

[a]Any two means not underlined by the same line are significantly different at the 0.05 level of probability.

Table 26. Analysis of variance of digestibility and balance data obtained from lambs fed corn oil, $CaCO_3$, $CaCl_2$ and $MgCO_3$ (digestibility Trial 4)

Source of variation	D.F.	Mean square: Organic matter	Protein	Cellulose	% feed N retained
Total	31				
Trial	1	0.01	44.42	17.85	130.01
Treatment	4	36.66	11.46	252.87	48.90
Tr. x treat.	4	2.55	0.24	20.55	19.45
Remainder	22	5.44	4.07	34.58	19.19

Shortest significant ranges

Organic matter:

p:	(2)	(3)	(4)	(5)	
R_p:	2.8	2.9	3.0	3.1	
Treatments:	5	2	4	1	3
Means:[a]	67.4	68.3	71.7	72.2	72.7

Protein:

p:	(2)	(3)	(4)	(5)	
R_p:	2.4	2.5	2.5	2.6	
Treatments:	5	1	2	4	3
Means:[a]	74.8	77.1	77.3	77.3	78.6

Cellulose:

p:	(2)	(3)	(4)	(5)	
R_p:	9.1	9.5	9.8	10.0	
Treatments:	5	2	4	3	1
Means:[b]	47.7	48.7	57.9	58.7	61.4

Feed N retained: Treatment effects not significant at 0.05 level of probability.

[a]Any two means not underlined by the same line are significantly different at the 0.05 level of probability.

[b]Any two means not underlined by the same line are significantly different at the 0.01 level of probability.

Table 27. Analysis of variance of performance of lambs fed rations containing alfalfa hay, corncobs, $CaCO_3$ and corn oil (fattening Trial 1)

Source of variation	D.F.	Mean square Gain	Daily feed	Feed per lb. gain	Dressing per cent	Carcass grade
Total	47					
Treatments	(7)	67.47	0.074	4.73	8.37	2.50
Roughage	1			15.40		
Corn oil	1			0.88		
R x CO	1			10.46		
Calcium	1			1.10		
R x Ca	1			0.22		
CO x Ca	1			1.03		
R x CO x Ca	1			4.04		
Remainder	40	61.41	0.242	1.67	5.78	1.27

Table 28. Analysis of variance of performance of lambs fed rations containing added grease and limestone (fattening Trial 2)

Source of variation	D.F.	Mean square Gain	Daily feed	Feed per lb. gain	Dressing per cent[a]	Carcass grade[b]
Total	41					
Treatments	5	1.84	1113.40	1.95	2.90	1.07
Remainder	36	3.99	652.22	1.40	2.97	0.78

[a]Only 39 total degrees of freedom.

[b]Only 40 total degrees of freedom.

Table 29. Analysis of variance of performance of lambs fed rations containing added grease and limestone (fattening Trial 3)

Source of variation	D.F.	Mean square: Gain	Daily feed	Dressing per cent[a]	Carcass grade[a]
Total	41				
Treatments	5	88.84	2617.9	2.44	0.716
Remainder	36	90.41	1233.8	3.19	0.446

[a]Only 35 total degrees of freedom.

Table 30. Analysis of variance of performance of lambs fed rations containing added grease, limestone and trace minerals (fattening Trial 4)

Source of variation	D.F.	Mean square: Gain	Daily feed	Feed per lb. gain	Dressing per cent	Carcass grade
Total	40					
Treatments	6	6.67	593.74	0.493	1.64	0.285
Remainder	34	34.87	354.47	0.816	3.22	0.406

Table 31. Analysis of variance of blood lipid values obtained from lambs fed rations containing grease, limestone and trace minerals (fattening Trial 5)

Source of variation	D.F.	Mean square
Total	91	
Day 0 vs. day 50	1	30897.87
Ration treatments	7	614.88
Day x ration	7	866.03
Remainder	76	626.17