A COMPARATIVE STUDY OF THE ENERGETICS, FAT METABOLISM AND COMPOSITION OF PLASMA FATTY ACIDS IN GROWING GOATS AND LAMBS

by

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SUMMARY

1) This work studied the effect of feeding patterns on growth and body composition of goats from 9 days to 5 months and sheep from 1 month to 6 months of age.

In addition, the effects of age and feeding frequency on patterns of fat mobilization and plasma fatty acid composition were determined at monthly intervals. Diurnal variation in plasma FFA and triglycerides over a 24-hour period was examined in 7 week-old goats. The response to infusion of a lipolytic agent, adrenaline, was examined when animals were 7 months old.

Body composition and water turnover rates were estimated using the dilution of injected tritiated water of a known radioactivity every 4 weeks.

Fasting metabolic rate was estimated at monthly intervals by measuring the rate of oxygen consumption using an open circuit metabolimeter.

After extraction of plasma lipids and separation into FFA and triglycerides, quantitation of their individual long chain fatty acids was achieved by GLC.

2) During milk feeding, goats gained relatively more body weight/day than after weaning. Goats fed twice daily had slightly higher growth rate both before and after weaning than those fed once daily.

Between 2 and 7 months of age, a linear relationship existed between food consumption and age; lambs consumed 15% more than goats fed the same diet at the same age. Goats, although smaller than lambs between 2 and 7 months, grew 21% faster, ate relatively more feed/kg Bwt and had higher feed conversion efficiency. Goats and lambs had similar efficiency in the digestibility of nitrogen and energy, and utilization of dietary energy as metabolizable energy,

but goats retained more of the dietary protein than lambs (35.8% and 27% respectively).

3) Three major body components, fat, protein and water, increased as the animals grew. The proportion of fat increased with age in both species, but declined slightly immediately after weaning. Lambs were found to be slightly fatter than goats at the same age. The increase in body fat per increase in body weight was significantly higher in lambs (270g/kg) than in goats (218g/kg). Multiple regression analyses showed that body weight had a greater influence on body fat than did age in lambs, while in goats, age had a greater influence than body weight. Lambs fed twice daily deposited more fat than the other two groups but this difference was not observed in goats.

Although total body water increased with age, its proportion to body weight declined.

Body protein increased with age and was significantly correlated to body weight in both species. The proportion of body protein to body weight was relatively constant with age and showed a slight decline at the age of 6 months in lambs and 5 months in goats.

Plasma protein in both species increased significantly with age to near adult values at 3 and 4 months. Lambs grazing in the paddocks had higher plasma protein than pen fed groups.

4) Higher fasting metabolic rates were observed during milk feeding in both species, and this decreased significantly at weaning. Goats generally had lower fasting metabolic rates than lambs. Feeding patterns had no significant effect on fasting metabolic rates in both species.

5) Water turnover rates were higher during milk feeding, decreasing significantly at 1 month of age in goats. Immediately after weaning, there was a decrease in water turnover, followed by a subsequent increase.

Grazing lambs had significantly higher water turnover during winter and early spring. Goats had lower water turnover rates than lambs.

6) The fasting plasma FFA concentration in goats and lambs was high during the first 2 months of life, reaching a peak after weaning. This was followed by a significant decrease from 3 months of age onwards. Feeding patterns had no significant effect on the concentration of plasma FFA in goats or lambs fed in pens, while the grazing lambs had a higher concentration of plasma FFA at 4 months which was coupled with a decrease in feed availability in the paddock. Lambs were found to mobilize more fat than the goats at all times.

The concentration of oleic acid was highest at 2 months of age followed by a decline in subsequent months. Its proportion to total FFA in both species declined with age, while that of stearic acid increased. This inverse relationship is associated with functional rumen development. Palmitic acid was highest during milk feeding, decreased immediately after weaning, then increased as the animals grew older. Palmitoleic and myristic acids were also higher during milk feeding and decreased with age. Linoleic acid did not change significantly with age in lambs, while it was highest in goats at 2 months of age. Goats were found to have lower saturated to unsaturated fatty acids ratios and lower stearic to oleic acid ratios than lambs.

Feeding once daily was found to increase the proportion of plasma unsaturated free fatty acids in the two species.

7) Fasting plasma triglyceride changed little with age in goats, while in lambs the concentration was significantly higher at 1 and 2 months and then decreased.

The individual triglyceride fatty acids in both species showed a close similarity to the fatty acid composition of plasma FFA.

8) Little diurnal variation in plasma FFA was observed in the two groups of goats. Feeding milk twice daily resulted in two peaks of plasma FFA. Individual plasma fatty acids also showed no diurnal variation. A steady increase in the concentration of plasma triglyceride to a peak 14 hours after feeding was observed in the group of goats fed milk once daily. Feeding milk twice daily resulted in the formation of two triglyceride concentration peaks resulting from the absorption of morning and evening feeds, but there was no variation in the concentration of individual triglyceride fatty acids at these times.

9) Saline infusion induced a slight increase in the concentration of plasma FFA in lambs and a significant increase in goats.

Adrenaline infusion (10 μg/kg body weight) for 30 min. increased the concentration of plasma FFA significantly in both species. Lambs showed a higher response to adrenaline infusion than goats.

A decrease in plasma FFA concentration 30 min. after cessation of adrenaline infusion was observed in the two species. The decline was faster in goats than in lambs.

At rest and during saline infusion, the highest proportion of the total FFA in lambs was stearic acid, whereas in goats it was oleic acid. Goats had a higher proportion of unsaturated fatty acids than lambs.

Adrenaline infusion in both species produced a significant increase in the concentration of five of the main fatty acids, in the following order:- oleic > stearic > palmitic > linoleic > and palmitoleic. Some minor fatty acids also increased.

The proportion of stearic acid to total plasma FFA decreased with adrenaline infusion, while that of oleic acid increased in both species. The proportion of palmitic acid increased in lambs and

decreased in goats. The ratio of total saturated to unsaturated fatty acids decreased significantly during adrenaline infusion.

The concentration of each fatty acid decreased significantly on the termination of adrenaline infusion with the exception of stearic acid, which increased in lambs. The proportion of oleic acid to total fatty acids decreased rapidly to pre-adrenaline infusion levels, while that of stearic acid increased to pre-adrenaline infusion levels in goats, but was found to be even higher in lambs.

The proportion of saturated fatty acids increased in both species to pre-adrenaline infusion levels, while that of unsaturated fatty acids decreased.

Feeding patterns had no effect on the response to adrenaline infusion in the two species.

DECLARATION

I certify that this thesis does not incorporate, without acknowledgement, any material previously submitted for a degree or diploma in any university, and that to the best of my knowledge and belief it does not contain any material previously published or written by another person, except where due reference is made in the text.

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ABBREVIATIONS

FFA - Free fatty acids

TG - Triglycerides

GLC - Gas liquid chromatography

TLC - Thin layer chromatography

Cyclic AMP - Cyclic adenosine monophosphate

CHAPTER ONE

INTRODUCTION

1.1 General

Domestic sheep (Ovis aries) and goats (Capra hircus) belong to the family Bovidae of hollow-horned ruminants. These two species can be distinguished by their tail characteristics since the tail of the goat turns upwards while that of the sheep does not. Sheep have lachrymal face glands and interdigital foot glands while goats do not. Male goats generally have beards and a strong odour contrary to male sheep.

Sheep were first domesticated about 11,000 years ago, and goats about 10,000 years ago in south-western Asia (Reed, 1961). With both species, their small size, tractability and their ability to produce fibre, milk, meat and hides, have led to their wide spread around the world.

Both genera vary in size, colour, horns, meat characteristics and length and shape of tails. They also vary in length, fineness and density of wool or hair covering, reproductive rates, milk production and lactation curve.

Domestic sheep (about 1 billion) extend from the Arctic Circle in Iceland and Europe to the southernmost tips of South America and New Zealand. The heaviest concentrations are found in the warmer portions of the temperate zones, particularly in the southern hemisphere, with fewer in the tropical areas of South America, Africa and India.

About 377 million domestic goats are kept around the world (FAO Year Book, 1967). Goats thrive in a variety of climates, but they are concentrated much more in the drier tropical and subtropical areas than are sheep. Goats have the widest ecological range of all domestic livestock, ranging from extremes of tropical rainforests to dry deserts where sheep cannot exist (Epstein, 1965).

The ability of each of these species to survive and produce in different environmental conditions, depends on their evolutionary adaptability to harsh environmental conditions such as low water, scarce feed and extreme temperatures. Those animals, whose metabolic rate and water turnover rate are low, can survive and produce better in the semi-arid regions of the world.

Goats are widely distributed because of their ability to survive, and often to thrive, on sparse vegetation unsuitable for the satisfactory feeding of other domestic animals, in both temperate and tropical regions, and also because of their capacity to withstand dry environmental conditions better than cattle and sheep. Goats are known to be sensitive to cold due to low insulation, but can withstand high temperatures. Goats sweat little at low temperatures and less than sheep at high temperatures (French, 1970).

Goats are known to have lower water turnover than sheep (Macfarlane, 1964) but similar glomerular filtration rate and the same ability to reduce glomerular filtration rates during dehydration (Maloiy, 1974). Goats can digest high fibre diets better than sheep (Devendra, 1978).

As meat animals, these two species have equal prospects. Although goat meat is not very popular in the Western countries except France, it is very important in the hot dry areas and it is considered a delicacy in places like Africa, the Middle East, India and South East Asia where the price of goat meat can be higher than that of beef.

The demand for fat in beef and sheep meat has been falling and important influences are the lower caloric requirements brought about by more sedentary occupations and recognition of health problems caused by the consumption of highly saturated fats. Goat meat might attract more attention because in terms of carcass composition, goats

have less fat than cattle or lambs (Fehr et al., 1976).

Among domesticated ruminants in my own country, Tanzania, the cattle population is the highest, followed by goats and then sheep. Almost all rural and some urban families keep a few goats which provide meat and milk. In most cases, however, goats are kept for ritual purposes. The largest population of goats is found in the semi-arid areas where they are kept by nomadic tribes.

Tanzanian goats consist of different nondescript indigenous breeds known collectively as East African dwarf goats. Some are of medium size, with well-fleshed body and moderate udder development, with the adult liveweight ranging from 40-45kg. For the small goats, the adult liveweight ranges from 25-30kg.

Goat improvement in Tanzania is being achieved by crossbreeding the indigenous varieties with large exotic meat types such as Boer and Jamnapari, and with dairy breeds such as Saanen and Toggenburg.

Assessment of the growth and reproductive performance of meat goats in Tanzania has shown that they produce kids all the year round with peak fertility during the rains. Dressing percentage of adult goats was found to be 45% (Kyomo, 1978, unpublished finding).

The sheep industry in Tanzania is mainly on large State farms in the high altitude areas where exotic breeds are kept for meat which is exported to Zambia and other neighbouring countries.

However, indigenous breeds of sheep, mainly the red haired Masai sheep and the black head fat rump sheep, are kept by individual herdsmen. These animals provide mutton which is not as popular as goat meat in the butchery.

1.2 Physiology of Goats and Sheep

Changes in body composition as animals grow have been well documented (Searle and Graham, 1970; Reid, 1972; Kellaway, 1973; Searle and Hilmi, 1977).

However, of the ruminant species, sheep and cattle have been studied most, and the results obtained for lambs are assumed to be applicable to goats. On the other hand, species differences in body composition at the same body weight and age do exist (Ledger, 1968; Pitts and Bullard, 1968).

Adult goats were compared with sheep by Panaretto and Till (1963) to evaluate the indirect estimation of body composition using the tritiated water dilution technique. They concluded that the body composition of goats was the same as that of sheep and thus the equations used for predicting body composition in sheep would be applicable to goats. Little has been done, however, on the body composition of growing kids.

Similarly other physiological parameters associated with ruminant development are based on lambs, and the results obtained are assumed to be applicable to other ruminants. Plasma lipids and their fatty acids composition have been studied practically in the three ruminants, goats, sheep and cattle, both in adults and in newly born animals (Leat 1966; Garton and Duncan, 1964; Masters, 1964a). However, changes in plasma lipids and their fatty acid composition in growing ruminant animals have been reported for lambs from birth to five months (Masters, 1964; Leat 1967) and for calves from birth to six weeks (Wood et al., 1971b) or to six months (Shannon and Lascelles, 1966), but not for goats.

Effects of feeding on body composition and other physiological parameters have been studied using different planes of nutrition and

feed composition, particularly protein levels, but little has been done on the effect of feeding frequency.

Reid et al., (1968) showed that there was little difference in body composition of adult sheep in studies of feeding frequency. The theoretical postulation of Black (1974) indicated that there could be an increase in fat content, no effect, or a decrease in body fat, depending on the plane of nutrition and the time interval between meals.

As far as plasma lipids are concerned, little work has been done in ruminants to compare the effect of feeding frequency on their concentration, although much has been done in non-ruminant species. The available information is that of Basset (1974) on lambs and that of Wood et al. (1971b) on calves.

In view of the overall lack of published information relating to goats, and of their importance in the provision of animal protein for the people of Tanzania, present work was designed to study the effect of feeding frequency on growth and body composition and to compare the responses of goats and sheep. Rates of water turnover and oxygen consumption were measured at intervals of 4 weeks to assess general metabolic status.

In addition, the effects of age and feeding frequency on patterns of fat mobilization and plasma fatty acid composition were determined and the response to infusion of a lipolytic agent adrenaline, examined. In this respect, the goat-sheep comparison was of particular interest since goats are usually reported as having less body fat, particularly in the subcutaneous region (Eggen et al., 1973), and might therefore be expected to show a different fat mobilizing pattern from that of sheep.

CHAPTER TWO

LITERATURE REVIEW

2.1 Growth and body composition of ruminants

Introduction

The growth and development of animals can be defined as an increase in size or weight. According to Fowler (1968) growth has two aspects. The first is measured as an increase in mass (weight) per unit time, of body organs and tissues which occurs by hyperplasia, cell hypertrophy and the addition of intracellular and extracellular material. The second involves changes in form and composition resulting from the differential growth of the component parts of the body.

Gross liveweight changes are relatively easily measured by expressing live weight gain per unit time. For this method to be an accurate measure of the economic worth of farm animals, some standardization of methods of weighing has been suggested. Reid et al. (1968) proposed that animals should be weighed after 24 hours without feed, but with water, to minimize errors due to stomach fill, or weighed several times on successive days and the average weight used. However the second method is not always practical.

In meat animals, one is primarily concerned with growth of the major body tissues, muscle, fat and bone, and with the proportions of these three in the carcass. Relative growth (in the sense of body composition changes) is more difficult to appraise than body weight, since there is no absolute method available for obtaining quantitative measurements of body components or tissues in the live animal. A method used in several studies of relative compositional growth is serial slaughter of random samples over a range of live weights or ages, followed by physical dissection of the carcass into its several tissues (Butterfield and May, 1966; Butterfield and Berg, 1966). From these measurements it was possible to assess changes in the component tissues during growth, with comparisons also between animals

of different breeds, sexes and from differing nutritional treatments.

Although this procedure provides some information for assessing carcass composition in terms of commercial values, it is poor in assessing the chemical composition of the animal since muscle tissue contains some fat as well as protein, water and ash, and adipose tissue is not pure chemical fat but has protein and water as well.

Patterns of growth and development of chemical constituents of the body and the tissues have been used to assess carcass quality in meat animals. Much of the information on chemical composition has been obtained from chemical analyses of whole bodies or carcasses. The results obtained from these analyses have been used as a major criterion of animal response to various influences, particularly nutritional treatments. In this way it has been possible to quantify what the animal does with the chemical nutrients of feed in building up its body (Reid et al., 1968).

Indirect methods of estimation of chemical composition in living animals have largely replaced the laborious work of dissection and have encouraged more investigations in this field. The indirect technique provides more information as the growth of a particular animal can be followed at various stages by estimating chemical composition repeatedly. This is more useful in the selection of breeding stock and it allows assessment of response to nutritional treatment in individual animals which is not possible with comparative slaughter and whole body analyses.

The most productive and promising indirect procedures for the quantitation of body composition are based on the dilution of injected water labelled with a hydrogen isotope, usually tritium (TOH) (Searle, 1970a, b; Panaretto, 1968). This method estimates the total body water of an animal, and from that the proportions of other components

are calculated. Because of the relatively constant composition of the fat free mass, the use of multiple regression equations with liveweight and TOH space as predictors for each of the main components is possible (Panaretto, 1963; Keenan et al., 1969; Searle, 1970a).

Growth and body composition of animals as measured by either the proportion of muscle, fat and bone or the proportion of protein, water, fat and ash, is the combined function of genetic and environmental interplay, under hormonal and nervous control. Of the four major chemical components of the body, protein, fat, ash and water, fat is the most variable, and manipulation of body composition by genetic or nutritional means depends largely on controlling the proportion of fat, which, in turn, affects the proportions of other components (Berg and Butterfield, 1976; Black, 1974; Reid et al. 1963).

2.2 Factors which affect body composition (with special reference to fat) include:

1) age
2) nutrition
3) species, breed and sex
4) climate.

2.2.1 Age

(a) Water

As animals grow and develop, the proportional concentration of water in the fat-free body decreases and that of protein and ash increases before reaching values which are fairly constant for the species (Reid et al., 1963).

Water is the major component of the body comprising from 60-70% of live weight. The young of a species contain relatively more water and less fat than older fattened animals. This has been demonstrated

in sheep by Searle et al. (1972) and in Friesian calves and young buffaloes by Kamal and Seif (1969). The latter authors have suggested that the change with age is consequent upon replacement of the more hydrated functioning protoplasmic mass with less hydrated tissues containing fat and collagen.

(b) Protein

During the early growth phase, protein shows a steady increase relative to live weight as does ash. Its proportion compared to total body weight drops slightly as fattening proceeds. Protein increases with age as its components, sarcoplasmic protein, fibrillar protein, extracellular protein nitrogen in muscle and protein of all other tissues including blood increase (Dickerson and Widdowson, 1960).

Searle and Graham (1972) observed a higher proportion of protein in growing lambs during the milk feeding phase and the period of rumen development, while the proportion decreased during the fattening phase.

The absolute increase in protein in cattle was found to follow the growth curve of an animal. That is, initially the protein increased rapidly and then at a progressively slower rate relative to increments in body weight up until approximately 160kg (Moulton, 1923).

(c) Body fat

Lipids combined with structural protein form the membranes which are essential to life in all cells. Adipose tissue is vital in supplying these structural lipids and in providing caloric homeostasis. Fat is found in adipose tissues which are differentiated from mesenchymal tissue during embryo growth. This embryonic kinship with connective tissue confers the ability to accumulate fat with age. Fat makes up a small amount of the carcass at birth, compared to the

proportion found in adults. In newborn lambs lipids constitute about 3% of body weight, whereas ewes might contain 28% fat (Alexander, 1962; Jagusch et al., 1970a).

This amount is known to increase slowly with age until, given an adequate plane of nutrition, a fattening phase sets in and fat is deposited at an increasing rate. Initiation of this fattening phase is mainly determined by the body weight attained (Searle and Graham, 1970). In cattle, all fat deposits increase in weight during fattening with the greatest gains occuring in the intermuscular depots followed by the subcutaneous and finally the intramuscular depots (Johnson et al., 1972).

2.2.2 Nutrition of the animal

Plane of nutrition, chemical composition of the diet and feeding frequency can all have major effects on the body composition of animals, as seen when comparisons are made between animals of the same age. However, these differences are substantially reduced when comparisons are made between animals of the same body weight. Reid et al. (1968) hold that for animals of the same breed and sex, body composition is determined by body weight and is virtually independent of nutritional history. This theory contends that as the animal grows, the chemical components accumulate in the body in fixed patterns which are determined by the net amount of growth. If growth is slower the whole process is merely delayed in time and slow growth would be expected to result in exactly the same chemical composition at the same empty body weights (live body weight less gut content), as more rapid growth.

Several workers, however, maintain that although the proportion of muscle and bone, or of protein, water and ash, have a constant

relationship to the weight of the fat free body, the amount of fat can be affected by previous nutritional treatments when comparisons are made between animals of similar weights (Black, 1974; Fowler, 1968; Lohman, 1971).

2.2.2.1 Effect of Plane of nutrition

Fat deposition occurs when caloric intake is above the energy demand of the animal. A high plane of nutrition during the early stages of growth will determine the extent of fat deposition occuring in the adult animal, since the high plane of nutrition encourages adipose tissue growth by hyperplasia and thus there are more adipose cells (Haugebak et al., 1974; Knittle and Hirsch, 1968).

However, there are conflicting reports concerning the effect of plane of nutrition on body composition when animals are measured at the same age or the same body weight. Reid (1972) described an experiment with sheep where plane of nutrition, age at slaughter and slaughter weight were controlled. Two planes of nutrition were imposed, the lower of which was sufficient to produce a positive gain in body weight. This author reported that the most important variable which affected body composition was empty body weight. Plane of nutrition affected the time taken to reach a certain body weight, but did not seem to affect carcass composition. Age at slaughter had little influence on body composition independent of weight effects. Searle and Graham (1970) found that there was no difference in the body weight at which the fattening phase began in two groups of lambs fed at different planes of nutrition, although they varied in age.

Several other workers have reported that plane of nutrition had no effect on body composition when comparisons were made using animals of the same body weight (Burton and Reid, 1969; Jesse et al., 1976; Kellaway, 1973; Searle and Hilmi, 1977).

On the other hand, the computer-generated growth curves of Black (1974) predicted that for lambs, increasing the plane of nutrition increased fat deposition at any given body weight, but the magnitude of the effect progressively diminished with increased body weight. In contrast, protein deposition was greatest at the lowest intake. Similarly Pryor and Laws (1972) showed that steers which grew faster on a high level of wheat, had significantly more carcass fat at a similar carcass weight than steers which were on a lower proportion of wheat.

The body weight at which body composition is measured is known to have an effect on this parameter. Waldman et al. (1971) reported that high energy intake did not affect the composition of the gained body weight of Holstein steers fed until they weighed 341kg body weight. However, from 341-455 and 590kg more fat was deposited by those cattle on high energy intake compared to those on restricted energy intake, which deposited more muscle. The same authors reported that the heavier animals on high energy intake, deposited fat at a greater rate than muscle, while those offered medium energy accumulated fat at a rate similar to muscle growth. There is considerable evidence that at any given age, a positive association exists between plane of nutrition and relative body fat content (Guenther et al., 1965; Reid, 1972; Reid et al., 1968; Burton and Reid, 1969; Searle and Graham 1970; Searle and Hilmi, 1977; Jesse et al., 1976; Kellaway, 1973).

The conflicting reports on the effect of plane of nutrition on body composition when measured at the same body weights, could be due to either differences in chemical composition of the diets used by different workers, or the stage of maturity of the experimental animals. Level of nutrition has been shown to produce more effects

on body composition in the fattening stage than during the growth stages (Berg and Butterfield, 1976). Waldman et al. (1971) found that at lower body weights the level of energy intake had no effect on body composition, while there was a significant effect at higher body weights when comparisons were made at the same body weight.

2.2.2.2 Composition of the feed

Feed composition is known to have a considerable effect on body composition especially on body fat content. In monogastric animals, carbohydrate feeding is known to increase fatty acid synthesis and deposition, while feeding of high protein diets has a minor effect on fat deposition, although it might increase the level of protein in the tissues (Hollifield and Parson, 1965). In the case of ruminants the type of feed is an important influence on the level and composition of volatile fatty acids, namely acetic, propionic, butyric and valeric acid. The level of each VFA contributes to the efficiency of fat deposition (Armstrong and Blaxter, 1957; Blaxter, 1965).

(a) Effect of level of protein in the diet

Protein is a major nutrient and a deficiency in protein in the ration might be expected to influence protein levels in the body. Proteins in the body constitute about 20% of wet weight of tissues. They form the important structural units of muscle, tendon and connective tissues. They constitute all of the enzymes, some hormones and a major proportion of the blood solids.

As protein content of the diet increases, the proportion of energy deposited as protein increases to the point where protein intake no longer limits protein synthesis. Thereafter it remains constant (Black, 1974). At a constant energy intake, low protein diets produce lambs containing more fat and less protein; but this

effect diminishes at high protein intakes (Black, 1974). A similar effect of level of dietary protein on body composition was reported by Norton et al. (1970) who observed a considerable increase in the level of fat when very young lambs were fed a diet containing 12% protein, as compared to one containing 28.5% protein. Andrews and Ørskov (1970) working with heavier lambs, showed that more fat was deposited relative to liveweight in the groups on rations containing 10-12.5% protein, than in those with 15% or more protein in the diet. Thus lower levels of protein in the ration seem to result in differentially more fat being deposited in the body than would be expected at the same body weights given higher levels of protein.

The effect of the level of protein in the diet on body composition becomes less pronounced as body weight increases (Black, 1974). Ørskov et al. (1971) observed little difference in body composition attributable to dietary protein concentration in lambs killed at 40kg liveweight, but marked effects in those killed at 27.5kg. These authors concluded that the differences with body weight could be due to a higher protein requirement for growth in the early stages of growth than the low protein diet could supply.

(b) Effect of concentrate vs. hay feeding

Body composition, especially the amount of fat deposited, will depend on the type of nutrient absorbed after digestion of the dietary components. In ruminants the type and proportion of VFA produced in the rumen contribute to the efficiency of fat deposition (Armstrong and Blaxter, 1957; Blaxter, 1965). Most of the fats deposited in ruminant animals are synthesized de novo using acetate as a starting material for the fatty acid moiety (Bouman and Davis, 1975). On the other hand, for triglyceride synthesis, the glycerol moiety is supplied by glucose. Glucose in ruminants is usually synthesized

from propionic acid by the liver (Egan, 1976). Thus a higher proportion of propionic acid will enhance fat deposition because of increased glucose availability. Blaxter (1965) observed that infusion into lambs of a mixture containing 25% acetic acid, 45% propionic acid and 30% butyric acid, led to a greater energy retention than when the infusate contained 75% acetate, 15% propionic and 10% butyric acid.

The use of concentrates in ruminant diets has resulted in the production of ruminant meats with a higher neutral fat content (20%-40% of the carcass weight) than that found in free-ranging ruminants, in which fat was never greater than 5% of the carcass weight (Ledger, 1968). Concentrate feeding is known to increase body fat at the expense of milk fat in lactating cows (Storry and Sutton, 1969; Jorgensen et al., 1965).

The increase in body fat deposition with concentrate feeding could be due either to the high proportion of propionic acid produced (Storry and Sutton, 1969) or to the increased microbial synthesis of long chain fatty acids. Sutton et al. (1970) observed an increase in the total flow of long chain fatty acids leaving the abomasum over and above the amounts eaten in the food when lambs were fed high concentrate diets, as compared to high roughage diets.

In growing animals, Purchas and Davies (1974) and Davies (1977) found that Friesian steers slaughtered at the same fasted liveweight were of different carcass composition if they had been fed on a barley-based diet as contrasted with pasture. The carcass of the group fed barley based diet had more fat than the group on grass. The differences were found to be related to direct effects of the different diets rather than the effect on growth rate. They concluded that an increased availability of glucose leading to an increase in lipogenesis was responsible.

2.2.2.3 Effect of frequency of feeding

According to Black (1974), by reducing meal frequency at a given level of feeding, an animal would effectively be on a higher plane of nutrition immediately following feeding, and a lower plane of nutrition prior to the next feed. Depending on the level of intake and the time interval between feeds, this could result in no effect, a slight decline or an increase in the amount of body fat compared with animals of the same weight fed more frequently. If the level of intake is high and the time interval between feeds small, little effect on body composition would be expected from infrequent meals.

In monogastric animals, rats and man, feeding frequency has been found to increase the body fat without affecting body weight, especially in rats.

Reid et al. (1968) observed an increase in body fat when rats were fed twice daily via stomach tube, as compared to those allowed to nibble the same amount of feed. Similar findings were reported by Cohn and Joseph (1959).

This increase in body fat has been attributed to the fact that increased metabolite load led to an increase in the synthesis of lipogenic enzymes and increase in insulin production (Chakrabarty and Leveille, 1968; Tepperman and Tepperman, 1964; Leveille and Hanson, 1966).

In ruminant animals little effect of feeding frequency on body composition has been reported. Reid et al. (1968) reported that in sheep, eight meals per day resulted in greater storage of energy and higher energetic efficiency of fattening than did one meal per day. On the other hand, Graham (1967) observed no difference between sheep fed once daily or eight times daily, while there was a decrease in

efficiency when animals were fed every fourth day. Faichney (1968) observed an increase in body weight gain when frequency of feeding in sheep was increased. The decrease in overall net energy value of the feed as frequency of feeding decreased resulted from the increased heat production by the animals fed less frequently.

Robards (1970) observed a decrease in the liveweight gain of Merino wethers fed less frequently compared to those fed once daily. The loss in body weight was related to the severity of starvation associated with infrequent feeding. He concluded that the decrease in liveweight with decrease in frequency of feeding was related to the adverse effect of infrequent feeding on energy balance arising from the cost of laying down body fat reserves during the days of above maintenance feeding, and subsequent re-utilization of these reserves for maintenance during days of starvation as reported by Graham (1967).

2.2.2.4 Body weight loss and re-alimentation

(a) Effect of body weight loss on body composition

Weight loss associated with starvation depletes all tissues, but the relative effect on fat is greater than on muscle, while bone resists depletion to a greater extent than muscle and fat. The degree of involvement of muscle and bone depends on the severity and length of time on the regime (Butterfield et al., 1971).

Working with sheep, Reid (1972) reported that at equal body weight, weight loss resulted in similar body chemical composition to continuous growth except that the animals losing weight had a slightly higher level of ash. Butterfield (1966) observed a higher bone weight during weight loss in steers, as compared to that found in normal carcasses of the same weight.

On the other hand, Price (1977) observed a greater percentage of

muscle and bone and a lower percentage of fat in three rib cuts of bulls and steers during weight loss, as compared to those of bulls and steers which were on continuous growth but of the same body weight. The higher proportion of ash, bone and to some extent, muscle, during weight loss was caused by the relative resistance of these tissues to undernutrition, while fat which acts as an energy store, is mobilized first to meet the energy demand of the animal.

(b) Effect of re-alimentation after weight loss on body composition

Animals subjected to a period of undernutrition often exhibit a very high growth rate when later given access to an adequate feed supply (Wilson and Osbourn, 1960; Keenan et al., 1969).

Compensatory growth is very important in countries that depend largely on natural or improved grasslands to feed the animal population under grazing conditions. Lack of winter feed, or the occurrence of summer drought can impose a period of either little growth or weight loss on the animal. A plentiful food supply often follows this deprivation, giving a rapid re-growth.

Reports on the effect of compensatory growth on body composition are conflicting. Some authors have shown that there is an acceleration of protein deposition and water accumulation after re-alimentation when compared with continuous normal growth (Reid et al., 1968; Burton, 1970; Butterfield, 1966). Reid (1972) working with sheep, reported that re-alimentation following weight loss resulted in lower levels of chemical fat and higher levels of water and protein than those maintaining positive growth or those on the down phase of a weight-losing regime, while there were no effects on ash. Similarly Drew and Reid (1975) observed a higher proportion of body water and protein, and less fat and energy than in continuously fed sheep of the same empty body weight when re-alimented at 26kg after losing 25%

empty body weight.

These authors concluded that during early re-growth there is a marked stimulus of lean tissue growth and a depressed fat synthesis. A lowered activity of fatty acid synthesizing enzymes during starvation has been reported in man and rats (Hollifield and Parson, 1965).

On the other hand, some authors have reported different findings. Kellaway (1973) found no differences in body composition during compensatory growth of sheep which were grown to 36kg, starved to 26kg and regrown to 36kg live weight, when compared to those on continuous growth. Meyer and Clawson (1964) working with sheep and rats, found that more fat than normal was laid down during compensatory growth.

The age at which nutritional restriction was applied, its duration and severity as well as the duration of the period of compensatory growth, may account for the variations between experimental findings. According to Berg and Butterfield (1976) re-alimentation following weight loss tends to restore normal carcass composition if the compensation period is long enough. If the weight loss occurs in the early stages of growth before rapid fattening normally takes place, compensation will be complete and normal proportions of fat, muscle and bone will result for a given weight.

2.2.3 Species, breed and sex

Genetic differences in body composition can be observed between species, breeds and between strains within breeds, which may have anatomical, histological, biochemical or physiological bases.

(i) Anatomical differences

A species bearing an organ specialized for fat storage might have a higher proportion of body fat compared to a species without this specialization, especially where the environmental conditions

are not conducive to fat deposition (e.g. when the environment is too hot). Thus the fat-tailed sheep and the fat-rump sheep in the tropics will deposit more fat than the red-haired sheep or goats found in the same region. The hump of the camel and that of Zebu cattle could increase the efficiency of fat deposition. Ledger (1959) reported that the degree of heat tolerance in cattle was associated with their ability to lay down fat in areas other than the subcutaneous site, and that the inability of many Bos taurus cattle to proceed past a store condition in a hot environment was related to the limiting insulation of their own subcutaneous fat, while the Zebu with a different pattern of accumulation continued to fatten.

(ii) Histological differences

Animals with more and larger adipose cells will have a tendency to store more fat when feed is in excess than animals with fewer adipose cell numbers, because adipose tissues, during fattening, grow by an increase in cell size as fat is being deposited and each cell has a certain capacity for fat storage. Hood and Allen (1973) found that adipose tissues from animals of the leaner Holstein breed contained smaller and fewer cells than the respective tissues from the fatter Hereford X Angus animal. The effect of adipocyte size and number on the amount of fat deposited has been reported in other species (in rats, Pitts, 1962; and in obese humans, Anderson et al., 1961; Hirsch and Knittle, 1970). Hirsch and Knittle (1970) working with excessively obese human subjects, found that both adipose cell size and number were greater in the obese subjects compared to non-obese; however, adipocyte number had increased to a greater extent (190%) than adipocyte size (40%). The degree of obesity was found

to be directly and highly correlated with the number of adipose cells, but poorly with adipose cell size.

(iii) Biochemical differences

These depend on the presence and level of factors such as lipogenic or fatty acid synthesizing enzymes and lipolytic or fat mobilizing enzymes. Fatty acids that comprise the body fat stores arise from two sources - those absorbed from the gut, and those synthesized by the animal tissues from other dietary sources. Tissue fat synthesis is known to vary from species to species, between breeds, between tissue sites and with age (Favanger, 1965). A close relationship between acetyl CoA carboxlase activity and lipogenic capacity of fat tissues of fattening lambs was observed by Mellenberger et al. (1973).

(iv) Physiological differences

Factors such as sensitivity to the lipolytic and lipogenic hormones, adrenaline and insulin differ between breeds. Wood et al. (1977) reported that the leaner Piatrain pigs were more sensitive to lipolytic hormones than the fat Large White pigs. Voluntary feed intake and efficiency of utilization of nutrients for fattening is known to differ from species to species and between breeds. Allden (1970) reported that Merino crossbred sheep fed ad libitum consumed more food than pure Merinos and had a higher fat content than Merinos at the same body weight.

Body size

Pitts et al. (1968) reported that mammalian species of small body size have a lower proportion of body fat than those of large mature size. This could be a function of the relatively greater metabolic rate found in smaller animals (Brody, 1945 and Kleiber, 1961).

Effect of species on body composition

Different animal species have different propensities to fatten. Sheep store about 7 times more fat than protein in the highest weight range, while cattle store 4 times and pigs twice as much fat as protein. Thus sheep have the greatest and pigs the least propensity to fatten (Searle and Graham, 1972). Reid et al. (1968) observed a higher proportion of protein in pigs than in sheep and cattle when expressed on a fat-free dry body basis, and showed that the rate of change in fat concentration per unit change in the percentage of water was greater in sheep than in pigs or cattle. Differences in the body composition of several mammalian species have also been reported by Pitts and Bullard (1968). Ledger (1963) found less than 3% in the bodies of antelope in Kenya.

Effect of breed on body composition

Breed difference in body composition is mainly related to the time of onset of the fattening phase. Some begin to fatten at a lower weight than others. Searle and Graham (1972) reported that when Merino and halfbred weaner sheep were fed the same diet ad libitum, the Merino half bred animals ate more and grew faster than pure Merinos which became progressively fatter weight for weight than the half bred sheep. They concluded that animals of small mature size are fatter, weight for weight, than animals of larger mature size. Similar differences in body composition of sheep breeds fed the same diet have been reported (Gnaraybeh et al., 1969; Kellaway, 1973; Reid et al., 1968).

In cattle, Lohman (1971) found that the Angus breed fattened at lighter weights than did Holsteins, while Angus X Holstein and Charolois X Angus were intermediate. Hayman and Gardiner (1972) found that shorthorns were early fatteners and Friesians were later

fatteners while Sahiwal were intermediate.

These findings indicate that genetic differences between breeds are mainly expressed in the time of onset of fattening relative to weight or size of the animal.

Effect of sex

Sex influences carcass and body composition only through its determination of mature body size. In cattle, heifers produce fatter carcasses than bulls of the same body weight. Berg and Butterfield (1976) reported that heifers and steers had more fat than bulls at 225kg live weight and this was due to earlier fattening of heifers and steers. Similarly Kellaway (1973) working with two breeds of sheep, reported that ewes contained more fat than rams, but Reid et al. (1968) failed to find any difference in body composition between males and females of different species and breeds.

2.2.4 Climate

Animals from the cold areas deposit more fat than animals from hot areas. This is genetic adaptation because fat, especially subcutaneous fat, acts as insulation against cold, while insulation in hot environments will be a disadvantage.

2.3 Plasma protein

Plasma protein consists of 4 major classes: albumins, globulins, fibrinogens and lipoproteins. Plasma albumin is involved in the transportation of metabolites such as plasma FFA, hormones, cations and drugs. It regulates the oncotic pressure of the plasma and is a source of nitrogen as a reserve pool (Rothschild et al., 1970).

Albumins are synthesized in the liver (Ganong, 1969) and in the absence of this organ no newly made albumin can be detected (Kukral et al., 1961). It has been reported that the absolute rate of albumin

synthesis appeared to be constant in many species ranging rather closely around 200mg/kg/day (Schultze and Heremans, 1966). The rate of synthesis is affected by nitrogen intake (Waterlow, 1968) and both short term fasting in rabbits' liver (Kirsch et al., 1968; Rothschild et al., 1968) and chronic malnutrition (Coward et al., 1977) are associated with reduced rates of albumin synthesis.

Albumin synthesis is altered by environmental changes; higher albumin levels are seen in cold climates, while hot environments depress albumin synthesis (Oratz et al., 1967).

Plasma albumin levels are relatively constant in healthy and well fed animals, but are reduced in debilitating diseases and trauma.

Plasma globulins usually account for 47% of the proteins in sheep plasma (Koenig et al., 1949), 53.5% in cattle, 58.6% in swine and 56.6% in horses (Downey, 1976). When subjected to electrophoresis, globulins can be split into four major groups, namely α_1, α_2, β and γ globulins, whose proportions to the total plasma protein concentration in different species are as follows:

Sheep	$\alpha_1 + \alpha_2$	= 8.2%	β = 12.8%	γ = 26.2%
Cattle	$\alpha_1 + \alpha_2$	= 21.7%	β = 17.1%	γ = 19.8%
Horses	$\alpha_1 + \alpha_2$	= 16.2%	β = 17.5%	γ = 26.2%

(After Downey, 1976).

The α and β globulins are of hepatic origin while γ globulins (immunoglobulins) originate from plasma cells and lymphocytes. γ - globulins are a group of structurally related proteins. They provide antibody activity against an almost infinite number of antigens to which an individual is normally exposed. The level of globulins can be influenced by exposure of an individual to antigens which induces the synthesis of the immunoglobulins. Age of the animal is also known to play a part in the rate of immunoglobulin synthesis. It is very

low in newborn animals (Waldman et al., 1970).

Fibrinogens are synthesized in the liver and are normally found in low concentrations in the blood, constituting only 17% of the total plasma proteins in sheep (Koening et al., 1949). The main function of fibrinogen is to act as a precursor to fibrin in the blood clotting mechanism.

The plasma lipoproteins comprise a unique group of macromolecules which serve to solubilize and transport cholesterol, glycerides and phospholipids through the plasma from sites of lipid absorption and synthesis to sites of storage and catabolism. Four lipoproteins can be identified on paper electrophoresis: chylomicrons, very low density lipoproteins, low density lipoproteins, and high density lipoproteins.

The different types of lipoproteins are synthesized either in the intestinal mucosa e.g. chylomicrons, in the liver, e.g. very low density lipoproteins, and high density lipoproteins, or in the intestinal mucosa and liver, e.g. low density lipoproteins (Ruderman et al., 1968).

Regulation of synthesis is dependent on the dietary fat ingested and the amount of fat synthesized in the liver.

2.4 Basal metabolic rate

Farm animals are kept by man so that he can reap harvest from their meat, fats, wool, hides, milk, eggs (and blood in the case of the Masai people of East Africa). These products expressed in terms of joules are part of the total energy which animals consume as food. The expenditure of energy in maintaining the structure, integrity and essential functions of the body (basal metabolism) and in muscular activity are considerable. Energy from feed must be sufficient to meet the maintenance requirements and there must be sufficient excess

for foraging and productive purposes.

Because of the importance of basic energy expenditure in the calculation of an animal's energy requirement for growth and for production of useable products, several methods have been developed for its measurement. Basal metabolism is not easily measured. Instead a fasting metabolism or standardized metabolism (which is an approximation of basal metabolism) is measured under controlled conditions. These conditions, according to Blaxter (1967) include measurement during a post-absorptive state, muscular repose, minimal emotional disturbance, a thermoneutral environment and good health with adequate nutrition.

Fasting or standardized metabolic rate may be determined indirectly by measurement of oxygen consumption, carbon dioxide and methane production per unit weight in a specified time.

Apparatus used for these measurements include an open circuit respiratory apparatus where outdoor air is passed through the chamber of the instrument and the changes in its oxygen, methane and carbon dioxide content measured while the air flow rate is also measured. Hence oxygen consumed can be computed from these parameters.

Another approach is to use a closed circuit respiration apparatus where air is circulated continuously through absorbents which remove carbon dioxide and water vapour. The air, free of these gases, returns to the chamber. The amount of carbon dioxide produced is measured by weighing the absorbents before and after the experiment. The amount of oxygen admitted into the system is measured either by weight or by volume and from these values the gas exchange can be computed.

2.5 Factors affecting metabolic rate

Several factors are known to affect the basal metabolism of an

animal. These include (1) body size, (2) species, (3) breed and sex, (4) age, (5) physiological conditions, (6) nutrition, and (7) environment.

2.5.1 Body size

The rate of energy use or heat production in fasting metabolism is a function of body mass but is not directly related to body weight. The fasting metabolic rate of different mammal species decreases as the body weight increases. Brody (1945) found that the basal metabolic rate of mammals large and small was, on average, proportional to 0.731 power of body weight while Kleiber (1947) reported that it should be proportional to 0.75 power of body weight. These findings provide a reference line as a means of comparison of one species with others of widely different sizes. The body weight raised to power 0.73 or 0.75 is termed metabolic body weight. The fasting metabolic rate of a mature mammal was found by Brody (1945) to be on average 70Kcal/kg $^{0.73}$ (294KJ/kg $^{0.73}$). In different ecotypes this varies from 200KJ/kg$^{0.73}$ for camels to 456KJ/kg $^{0.73}$ for reindeer.

The increase in metabolic rate with a decrease in body size in mammals is partly due to the relatively larger surface area per unit body weight in small animals than in larger mammals, and hence more heat loss takes place from these surfaces.

There are also higher concentrations of the carbonic anhydrase enzyme in small mammals which increases carbon dioxide production rate (Kleiber, 1947). Drabkin (1950) found that cytochrome oxidase activity per unit weight of tissue was higher, the smaller the animal and this means greater oxygen consumption. Schmidt-Nielsen (1970) has pointed out that the bacteria, invertebrates and poikilotherms at 20^{o}C all follow this empirically determined exponent, weight 0.75.

Intrinsic cell functions such as sodium pump and protein synthesis rates are probable major components of the process (Macfarlane, 1976).

2.5.2 Species

Apart from size, different species have variable metabolic rates under the same environmental conditions. While metabolic body size ($kg^{0.75}$ or $^{0.73}$) is a useful basis for comparison of basal heat production, individual animals and the mean values of many individuals of a given species may show a substantial deviation from the inter-specific average of $294KJ/kg^{0.75}$. These deviations could arise from the differences in ecological niches where different species evolved. Animals which evolved in areas where food is not readily available have lower metabolic rates than those which evolved in areas where food is plentiful. This mode of adaptation would ensure survival.

Thus cattle which evolved from the jungle and places where food was plentiful have higher fasting metabolic rates than the inter-species average. Values for cattle range from 356 to $420KJ/kg^{0.73}$ compared to $294KJ/kg^{0.73}$ for the interspecies mean (Vercoe, 1970; Blaxter and Wainman, 1966). On the other hand sheep which evolved in drier mountainous areas where food is often scarce have a lower fasting metabolism than that of cattle and lower than the inter-species mean; an average of $231.57KJ/kg^{0.73}$ in adult Merinos (Blaxter, 1962), ranging from 213.18 to $284.24KJ/kg^{0.73}$ (Graham, 1964, 1967).

Apart from the deviation of species from the interspecies mean of $294KJ/kg^{0.73}$, the metabolic rates of some species vary with the weight raised to a power different from either 0.73 or 0.75. Blaxter (1967) reported that the fasting metabolism of adult sheep and cattle varies with weight raised to a power of about 0.9 rather than 0.73. Similar findings were reported by Graham (1972). The

function for small rodents is mass $^{0.65}$. Frisch and Vercoe (1977) found that the regression of log fasting metabolism on log fasted liveweight in cattle was approximately 1 which was significantly different from the accepted 0.75. These differences are probably due to differences of body fat and of adult metabolic processes after growth has ceased.

2.5.3 Breed

Breeds of the same species display variations in their fasting metabolism. These differences may stem from their genetic makeup, resulting from the selection of individuals to fit different ecological systems.

In cattle a significant breed difference in fasting metabolism has been reported. Blaxter and Wainman (1966) found that the fasting metabolic rate of the Ayrshire breed was higher than that of Aberdeen Angus (379.13 and 302.4KJ/kg $^{0.75}$ respectively).

Vercoe (1970) measured fasting metabolism of Brahman, Africander and Hereford X Shorthorn cattle and found that their metabolic rates were 361.15, 428.5 and 407.4 KJ/kg $^{0.75}$/24h respectively and that the differences were significant. Differences in fasting metabolism in sheep breeds have been reported. Graham (1968) observed also a higher fasting metabolic rate in high wool producing rams than in those of low productivity.

2.5.4 Age

During growth and development profound anatomical and metabolic changes occur. As the cells in young animals divide and grow rapidly, the metabolic rate is also high. Basal metabolic rate in young animals is known to increase rapidly from birth to reach a peak which is higher than the adult value, then decline. In man, Kleiber

et al. (1956) reported that the metabolic rate of an infant increases rapidly from birth to reach a peak of up to 480.7 KJ/kg $^{0.75}$/24h at an early physiological age then declines to about 334 KJ/kg $^{0.75}$/24h at puberty when it increases slightly before it declines to reach a mean of about 292.6KJ/kg $^{0.75}$/24h. Hill and Rahimtula (1965) observed a rapid increase in the basal metabolic rate of infants with age. They measured values ranging from 4.76 ml O_2/min/kg at 0-6h of age to 7.0 ml O_2/min/kg at 6-10 days and reported that from 1 week to 18 months of age basal metabolic rate continued to be a proportion of body weight according to the equation: basal metabolic rate (VO_2 ml/min) = 7.2x wt kg. Above 12 kg weight this relation was fitted by a different equation where metabolic rate (ml O_2 consumed/min) = 20x kg $^{0.6}$.

After maturity in man, fasting metabolic rate declines slowly. Keys et al. (1973) measured basal metabolism of young men at an interval of 19 years and noted a decrease of 9% in the fasting metabolism. However there was no significant decrease in fasting metabolism of older men whose fasting metabolic rates were measured initially at 44-56 years of age and then 22 years later. They concluded that the basal metabolic rate diminishes rapidly with age and then when growth is complete the decrease is slower.

In domestic animals metabolic rates have been observed to be higher in young suckling animals than in adults, and this high rate declined at weaning (Blaxter, 1962; Ritzman, 1930; Graham, 1967). Values as high as 418 to 434.7KJ/kg $^{0.73}$/24h were observed by Graham and Searle (1970). Alexander and Williams (1968) reported that the fasting metabolism of lambs declined steadily from about 3.5 l.O_2/kg/h during the first day of life to about 2.01 l.O_2/kg/h at the age of 2 months. Similar findings were reported by Graham et al. (1974)

who observed a higher metabolic rate in milk-fed lambs than weaned lambs of the same weight, and reported that for milk-fed lambs the fasting metabolic rate was described by the equation: FMR = 706 $kg^{0.58}$ while for weaned animals 2 months to 2½ years was described by: FMR = 450 $kg^{0.61}$, where kg= body weight and FMR = fasting metabolic rate in KJ/24h.

Blaxter (1962) reported that the fasting metabolism of sheep expressed per $kg^{0.73}$ falls with age even after the second year. The decrease in basal metabolic rate with age is probably due to the decrease in proportion of lean tissue since basal metabolic rate is related to lean tissue, fat contributing only a small proportion (Graham, 1967).

2.5.5 Physiological condition

When the normal physiological condition of an animal changes, as is the case in pregnancy and lactation, metabolic rate is increased to meet the higher energy requirement for the synthesis of milk or for the conceptus requirements. Basal metabolic rate increases during pregnancy are attributed to the metabolic rate of foetuses. Heat production of foetal lamb just before birth was found to be 125.4KJ/kg/24h (Dawes and Mott, 1959). In lactating animals an increase of up to 50% in basal metabolic rate has been reported (Blaxter, 1967).

2.5.6 Nutrition

It has been reported that the level and type of feed has a remarkable effect on fasting metabolic rate of animals through its effect on body composition and body weight. Flatt and Coppock (1963) fed cows lucerne hay cut at different stages of growth at three levels of feeding. They found that animals which were on a higher plane of nutrition had higher fasting metabolic rates than those on lower planes of nutrition. The group of animals fed late-cut

lucerne hay at half maintenance had the lowest metabolic rate.

Similar increases in fasting metabolic rate in cattle due to a higher plane of nutrition were reported by Frisch and Vercoe (1977). These authors found that Brahman cross and Africander cross breeds increased their fasting metabolic rate by more than 20% and the Hereford cross by 11% when changed from a fixed level of pasture hay to the ad libitum lucerne hay. Graham et al. (1974) measured the metabolic rate of growing lambs fed different levels of diet. They observed that the level of feeding prior to fasting had a marked effect on fasting metabolic rate. Halving the milk intake for 2 days immediately before fasting caused a decrease of 13% in fasting metabolic rate, while doubling intake increased it by 8%. The plane of nutrition increased the fasting metabolic rate through its effect on the growth rate of the animal.

Starvation and undernourishment were found to lower the fasting metabolic rate of mammals (Benedict, 1938).

2.5.7 Environmental factors

Environmental factors such as temperature, rain, wind and solar radiation have an effect on fasting metabolism.

Temperatures above or below thermal neutral temperatures are known to increase the fasting metabolism of an animal. Blaxter and Wainman (1961) reported that fasting heat production in cattle was minimal at environmental temperatures of 15°C and 25°C, while at the temperatures of 5°C and 35°C the metabolic rate was increased.

The increase in heat production in the cold was caused by an increase in fat catabolism to meet the energy required for maintenance of body temperature. Coat density alters the neutral zone however.

Similar findings were reported by Kleiber (1947) who observed

a more rapid onset of death in starving rats at 20°C compared to 30°C. Wind and rain affect the fasting metabolism of animals as they increase the rate of heat loss from the surface of the animal (Alexander, 1958).

Thus depending on the environmental conditions, animals will require more or less food for maintenance and productive purposes.

2.6 Water turnover

Water is the largest component of a living organism and is important as the medium in which the biochemical and physiological reactions of tissues and cells function. In mammals, 60%-75% by weight is water and about 99% by number of the molecules present in ruminant animals is water (Macfarlane and Howard, 1970). Water is a part of the digestion and absorption of nutrients. Transportation of nutrients within the body depends on the circulating plasma which comprises 50ml/kg body weight of a healthy animal and most (91%-92%) of it is water (Macfarlane, 1976; Downey, 1976). Water dissolves the body ions potassium, sodium, chloride and bicarbonate for osmotic and buffering functions. It is important in the excretion of waste and unwanted substances from the body systems, and is also involved in the regulation of body temperature through convective and evaporative cooling.

Water turnover is usually estimated by measuring the rate of dilution of labelled water (TOH) in the body of an animal with time. This indicates the amount of incoming water and that which is excreted. This is done by injecting a volume of TOH of a known radioactive content. After equilibration, the radioactivity in a body fluid is measured, to give an estimation of total body water. The rate of water turnover may be calculated by measuring the rate of disappearance

of tritium from the fluid space. This is an exponential process, from which, by means of linear regression analysis, a decay constant may be calculated. The decay constant λ is related to the biological half life of tritrated water by the equation $\lambda = 0.693/t_{\frac{1}{2}}$. Over short periods the physical half life of tritium may be neglected.

The rate at which an animal uses water in a given environment is partly genetically determined and is under the control of a variety of systems. The limbic cortex and hypothalamus determine water intake; the gut and kidney are the machinery of output regulation. The brain and kidney regulate water turnover through vasopressin, which is secreted by nerve cells in the hypothalamus, to modify the permeability of the kidney tubules.

2.7 Factors affecting water turnover

Among the other factors which affect water turnover are the amount of fluid ingested, lactation, the air temperature, the amount of food eaten and its composition.

Thus water turnover in animals is affected by:

1) species, breeds and sex
2) age of the animal
3) physiological conditions and behaviour
4) nutrition
    (a) quantity of food
    (b) type of feed
        (i) protein content
        (ii) salt content
        (iii) water content
        (iv) roughage content
5) environmental factors.

2.7.1 Species, breed and sex

(a) Species

The rate of water turnover is genetically determined and depends on the ecological regions in which the particular species evolved. Macfarlane et al. (1974) reported that cattle and buffalo which evolved in the humid regions where water is plentiful have a high water turnover, about one third greater than that of donkeys. Sheep and goats which evolved in drier or mountainous regions, were found to turn over water at about half the rate of cattle (Macfarlane, 1964), while the animals adapted by evolution to desert conditions, camel, oryx or musk oxen have even lower rates of water turnover.

These authors concluded that the genetic differences in water turnover derive largely from the rates of fluid reabsorption or secretion achieved by kidneys and gut.

(b) Breeds

Different breeds of the same species display differences in their water turnover rate when grazing the same pasture. Springell (1968) found that Bos indicus breeds have lower water turnover rates than Bos taurus grazing on tropical pasture. Similar observations in cattle breeds grazing together were reported by Macfarlane (1964) who observed a lower water turnover in Zebu cattle, while that of Shorthorns was the highest, with Santa Gertrudis intermediate. Working with 4 types of cattle (Bos taurus, Bos indicus, Bibos banteng and Bos bulbalis) Siebert and Macfarlane (1969) found that the greatest rates of water turnover were among Shorthorn cows (Bos taurus) during summer while Bos indicus types turned over significantly less water on the same pasture. In sheep breeds, Macfarlane et al. (1967) observed higher water turnover in Leicester breeds than Dorset and Merino sheep on the same diet. Similar differences in African sheep breeds

were reported by Macfarlane (1964) who observed a lower water turnover in Dorper breeds than Karakul which had the highest rate and Merinos which were in between.

2.7.2 Age

Water turnover is greatest in the young suckling animals. They have proportionally high metabolic rates and a higher proportion of water in their tissues. The need for water is met by ingestion of milk. Macfarlane and Howard (1970) reported that in a cool climate a suckling lamb turns over 26% of its body water daily, compared with 12% in hoggets at one year on dry pasture and 6% in adults.

2.7.3 Physiological conditions

Lactation and Pregnancy

The greatest metabolic and water strain in mammals occurs during lactation. During synthesis of milk both energy and water consumption rates increase by 40%-60% (Brockway *et al.*, 1963; Macfarlane and Howard, 1972). The lactating animal is sensitive to reduction in water supply because of the large output of water in milk which for sheep is 80% water. Macfarlane and Howard (1972) have shown that lactating camels and Merinos in the arid tropics used 44% more water than non-lactating females grazing with them. Thomas (1971) observed an increase in voluntary water consumption by lactating cows and the increase was affected by milk yield of the animal and the dry matter intake.

In sheep Lynch *et al.* (1972) measured an increase in water turnover in pregnant and lactating ewes compared to non-mated ewes. Similar findings were reported by Davies (1972) who observed an increase in water intake by pregnant ewes and found that the intake was higher for ewes carrying twins. Ewes suckling twin lambs were

found also to consume more water than ewes suckling singles.

The increase in water demand during pregnancy is coupled with an increase in energy intake and an increase in metabolic rate.

2.7.4 Nutrition

There is a good correlation in both cattle and sheep between the food intake of a given type and water turnover (Siebert, 1971; Macfarlane and Howard, 1972). However, some foods are known to alter the amount of water required more than others. Under these circumstances the level of intake and the type of feed (composition) will affect the water turnover.

2.7.4.1 Quantity of food

Feed intake affects water turnover through the water content of the food and the metabolic water formed. The amount of water required for its digestion for nutrient flow in the alimentary tract and for the flow of metabolites in the tissues may also influence turnover. Since food intake is closely correlated with water turnover in sheep (Siebert, 1971; Macfarlane and Howard, 1972) and with water intake (Forbes, 1968; Castle and Thomas, 1975) the increase in the level of feed intake concomitantly increases the water turnover rate.

Low levels of feed intake will reduce the water turnover rate. Similarly deprivation of water reduces the amount of feed taken. In ruminant animals a certain amount of water is necessary to allow a normal passage of dry matter through the digestive tract (Asplund and Pfander, 1972). Kay and Hobson (1963) found that 2 to 4kg of water was consumed for every kg of dry matter eaten.

Thus animals will eat or drink less to maintain this relationship. Bond *et al.* (1976) observed a decrease in water intake when steers were deprived of feed. Macfarlane and Howard (1974) reported

a reduction in water turnover in sheep held at high stocking rate because of the decrease in the available feed.

2.7.4.2 Type of feed and composition

Some feeds are known to alter the amounts of water required more than others. This difference will depend on the chemical composition of the feed and on the bulk or dryness of the feed.

(a) Nitrogen content

High protein content in the feed results in urea formation and this increases the amount of water needed for its elimination. Utley et al. (1970) observed a decrease in ad libitum water consumption by Aberdeen Angus steers when nitrogen intake was reduced by 20g per day. Similar findings were reported by Payne (1964) who observed a decrease in voluntary water intake and a lower urine output when the amount of protein given to ruminant species was reduced. The findings of Livingston et al. (1962) were similar.

(b) Salt content

A high level of salts in the diet will necessitate more water for electrolyte excretion. When potassium concentration is high as in lucerne hay, or sodium as in salt bush (Atriplex spp.) animals will increase water intake for the excretion of electrolytes without increasing osmolality of the urine. Macfarlane et al. (1967) observed an increase in water turnover by both Merino and Border Leicester sheep grazing Atriplex species which had a sodium concentration of 3900 meq/kg of dry matter and a potassium concentration of 980 meq/kg dry matter.

Saline water ingestion has been shown to increase the water turnover in sheep. Jones et al. (1970) observed more than a doubling in water turnover rate by sheep drinking saline water relative to those drinking fresh water. These authors concluded that the increase

in water turnover in animals drinking 1.3% saline could be due to the modification of the fluid transport system. In the observations of Macfarlane et al. (1967) where high food electrolytes were concerned, the increase in water turnover resulted from increased fresh water intake, presumably to dilute the electrolyte consumed in the feed.

(c) Type of forage

Water turnover in animals is affected by intake and by rate of excretion. Intake can be by drinking water or by eating feed which has high water content. Animals grazing on green winter grass have higher water turnover rates than those grazing on dry summer grass. In South Australia, Merinos have a threefold higher water turnover rate in winter when the grass has about 85% more water than in summer. Values as high as 200ml/kg/24h in winter as compared to 80ml/kg/24h in summer have been observed (Macfarlane and Howard, 1970).

Voluntary water intake is greater when animals are fed high roughage feeds than when given concentrate feeds. Bond et al. (1976) observed a decrease in water intake when steers were deprived of a high roughage diet, but not when deprived of a low roughage diet.

2.7.5 Other environmental factors

Variations of solar radiation, air temperature interacting with rainfall and wind during seasonal changes of environment, all affect the flow of water and energy through ruminants. During summer the body water content of cattle, sheep, camels and buffalo increased above the level found in winter (Macfarlane, 1964; Kamal and Seif, 1969). Water turnover is also increased by the need for water in evaporative cooling. Under arid conditions the heat load of summer can double water turnover. Macfarlane et al. (1966) reported that shearing sheep at air temperatures of 40°C in the laboratory reduced their water demand for cooling, while shearing in the open at a

similar air temperature, doubled the water turnover. McDowell et al. (1969) observed an increase in body surface evaporation, a 28% increase in water consumption and a 33% decrease in faecal water when lactating cows were exposed to an ambient temperature of 32.2°C.

2.8 Plasma lipid classes and their long chain fatty acid composition and concentration in ruminants

Introduction

Plasma lipid concentrations, the different lipid classes and their fatty acid composition and concentrations, have been measured as indicators of the physiological state of different animal species. As the plasma lipid is composed of several fractions whose levels may vary independently from each other, the total lipid concentration in the plasma as such makes little contribution to the understanding of lipid metabolism.

Major lipid classes found in the plasma of most mammals and in birds are:

(a) cholesterol esters

(b) triglycerides

(c) mono and diglycerides

(d) free fatty acids (FFA)

(e) free cholesterol

(f) phospholipids.

Due to the physiological and metabolic importance of each individual lipid class and its fatty acid composition, several methods have been developed to facilitate their separation and quantitation.

Methods for the separation of plasma lipids include column chromatography on stationary phases such as (a) silicic acid (Hirsch and Ahrens, 1958; Nelson and Freeman, 1959); (b) lipophilic

sephadex (sephadex LH-20) by several investigators (Dittmer, 1969; Calderon and Bauman, 1970); (c) ion-exchange cellulose mainly for phospholipid separation.

Thin layer chromatography on silica gel is usually employed for analysis of intact lipids. Both one and two dimensional thin layer procedures are useful for the non-polar lipids (Nelson, 1967; Gloster and Fletcher, 1966).

The fatty acid composition of each lipid class may be determined and quantitated by gas liquid chromatography after converting the fatty acids into their methyl esters (Ackman, 1967; Ko and Royer, 1974).

Systems commonly employing celite as the support medium with diethylene glycol succinate or apizon as the stationary liquid phase and high purity nitrogen gas as the mobile phase have been developed. Detection is normally by hydrogen flame ionization.

Quantitation of fatty acids has been attained with either internal standards (Ko and Royer, 1974) or calibration curves.

2.8.1 Nomenclature of long chain fatty acids of plasma lipids

In the literature, several schemes for naming fatty acids have been used by different authors. Unless the types of nomenclature for fatty acids are defined it becomes difficult to understand the information given.

Many fatty acids are known by trivial names such as palmitic, stearic and oleic acid. Many authors prefer this nomenclature because it is more convenient than the systematic names. In systematic nomenclature, the name of an acid is related to the hydrocarbon (saturated or unsaturated) which is formed when the carboxyl group (COOH) is replaced by a methyl group (CH_3). The final 'e' in the name of the appropriate hydrocarbon is changed to 'oic' in the acid.

In comparing structures of some unsaturated fatty acids, the double bond position is defined with respect to the terminal methyl group, as acids derived from one another by chain elongation can then be clearly identified. Thus linoleic acid $CH_3(CH_2)_4CH = CHCH_2CH = CH(CH_2)_7COOH$ can be referred to either as $(\Delta)^{9,12}$ octactecadienoic acid or W-6, 9- octadecadienoic acid.

An abbreviation or shorthand form widely accepted for analytical data obtained by gas chromatography designates a fatty acid by two numbers separated by a colon; the first number is the total number of carbon atoms in the fatty acid and the second is the number of unsaturated centres. Thus palmitic acid is 16:0 or (C16:0). Palmitoleic acid is (C16:1) which refers to a C16 acid with one unsaturated centre. The position of unsaturation can be given by additional numbers or letters. Palmitoleic acid is (C16:1 or 9-16:1 or Δ 9C16:1). Chain branching or substitution is denoted by a prefix thus br-16:0 for a branched chain hexadecanoic acid or HO-16:0 as a hydroxy-palmitic acid (IUPAC-IUB Commission, 1967).

The names of fatty acids likely to be encountered in literature and used in this thesis are summarized in the Table below.

Classification of lipid fatty acids

(A) Saturated fatty acids

Carbon Atoms	Shorthand nomenclature	Systematic name	Trivial name
12	C12:0	n-Dodecanoic	Lauric
14	C14:0	Tetradecanoic	Myristic
15	C15:0	Pentadecanoic	-
16	C16:0	Hexadecanoic	Palmitic
17	C17:0	Heptadecanoic	Margaric
18	C18:0	Octadecanoic	Stearic
19	C19:0	Nonadecanoic	-
20	C20:0	Eucosanoic	Arachidic
22	C22:0	n-Docosanoic	Behenic
24	C24:0	n-tetracosanoic	Lignoceric

(B) mono-unsaturated fatty acids

Carbon Atoms	Shorthand nomenclature	Systematic name	Trivial name
16	C16:1	Cis-9 hexadecenoic	Palmitoleic
18	C18:1	Cis-9-Octadecenoic	Oleic
(C) Diunsaturated fatty acids			
18	C18:2	Cis-Cis -9,12-Octadecadienoic	Linoleic
(D) Tri-unsaturated fatty acids			
18	C18:3	All Cis-9, 12, 15-Octadecatrienoic	α linolenic
(E) Tetra unsaturated fatty acids			
20	C20:4	All Cis-5, 8, 11, 14-Ei cosatetraenoic	Arachidonic

2.9 Factors affecting plasma lipid concentration and their fatty acids composition

The concentrations of total plasma lipids, lipid classes and their fatty acid compositions are affected by the following factors:

(1) Species, breed and sex of an animal

(2) Age of the animal

  (a) plasma lipids in ruminants

  (b) fatty acid composition of plasma lipids

(3) Physiological conditions

  (a) fasting, lactation, pregnancy and egglaying

(4) Nutrition

  (a) level of feeding

  (b) type of feed and composition

    (i) hay vs. concentrate

    (ii) carbohydrate form

    (iii) lipid content in the diet

  (c) frequency of feeding

(5) Other environmental effects

(a) temperature

(b) seasonal variations.

2.9.1 Species, breed and sex of animal

A notable variation in the concentration and composition of plasma lipids is found between ruminants and non-ruminants, although species variation within these groups also occurs. Variation between individuals of the same species and breed is not uncommon.

Due to the differences in the sources and digestion of the feed, lipid metabolism of ruminants has been recognized as differing from that of monogastric herbivores and carnivores. In ruminants, unlike monogastric animals, the fatty acids present in the dietary fat are usually hydrogenated by the micro-organisms in the rumen (Garton, 1961).

Ruminants are notable for the higher plasma stearic acid content, lower triglyceride concentration and greater cholesterol ester concentration than are found in most other species (Emery, 1969; Garton and Duncan, 1964). On the other hand humans have relatively high total blood fat resulting from a high concentration of all lipid classes. Emery (1969) noted that the differences between species were not due to diet since in man the cholesterol ester concentration is twice that of the cat fed a similar ration; the rabbit has 2 to 10 times more triglyceride than the cow, another herbivore.

Within the ruminant group variations exist between species. Garton and Duncan (1964) found that sheep had a relatively low level of plasma lipids compared to the ox whereas the ox had a higher plasma concentration of cholesterol esters than sheep. The plasma concentration of triglycerides and free fatty acids however were similar. Comparable findings were obtained by Leat (1967) who observed that

cows and goats had similar concentrations of plasma lipids which were two to three times higher than those of sheep.

There are some similarities and differences in the fatty acid composition of different lipid classes in ruminants. Garton and Duncan (1964) found that the fatty acid composition of the lipid classes triglycerides, FFA and phospholipids of sheep plasma were similar to ox except for the plasma palmitic acid concentration, which was slightly lower in sheep and oleic acid which was higher in sheep.

In his work with four species, goats, sheep, cows and pigs, Leat (1966) found that sow plasma FFA contained 15% of linoleic acid while in ruminant FFA, it ranged from 1.5% to 3.6%. The fatty acid composition of the plasma triglycerides of the cow, goat and sheep was similar, but there was more saturated fatty acid containing less linoleic acid and more stearic acid than detected in the sow. On the other hand the plasma FFA of the ruminants were less saturated than the triglycerides, whereas in pigs the reverse relationship was obtained. The cow had more linolenic acid (C18:3) in its cholesterol esters than the other ruminant species.

Radloff et al. (1966) reported that the concentration of plasma FFA in fasted goats and sheep was within the same range as fasted non-ruminant species, but under normal non-fasting conditions the concentrations were lower in ruminants than non-ruminants.

In studies with pigs and rats fed the same ration, Thompson and Allen (1969) showed that the oleic/stearic acid ratio of the rat was about twice that of the pig.

Significant differences in the plasma lipids of carnivorous animals have been reported by Altman and Dittmer (1977). These authors found a two-fold higher concentration of plasma phospholipid

and cholesterol in mink (Mustela vison) than in cats and dogs.

Plasma lipid concentrations are known to vary between breeds of the same species and also between strains of animals. Moore and Williams (1964) observed a difference in the plasma cholesterol content in two strains of rabbit. Differences in plasma lipid content between two breeds of cattle maintained under the same environmental conditions was reported by O'Kelly (1973). This author found that the plasma lipid content of Zebu cattle was higher than that of British breed animals grazing together under tropical conditions. Even under conditions of hyperthermia Zebu cattle maintained higher levels of plasma lipids (O'Kelly, 1973b). Under similar environmental conditions, Pietrain pigs had a higher concentration of plasma FFA than the Large White pigs of similar body weight (Wood et al., 1977).

2.9.2 Age of the animal

The amount of lipid present in the whole body and plasma of the newborn mammal varies considerably between species (Widdowson, 1950; Leat, 1966; Masters, 1964a, b; Payne, 1978). In most cases the lipid content of newborn animals is smaller than that of their adult mothers. Within plasma lipids, the concentration of individual lipid classes and their fatty acid composition varies with age. These changes are more marked in growing ruminants than in monogastric animals because of the transition of the young ruminants from monogastric type of digestion to ruminant digestion.

The development of the ruminant animal can be divided into three phases (Wardrop and Coombe, 1961).

(a) Birth to 3 weeks of age - non-ruminant phase.

(b) 3-8 weeks of age - transition phase when the rumen begins to develop.

(c) 8 weeks of age onwards - adult ruminant phase.

At birth all features of the adult ruminant digestive tract are present but in a juvenile state. The fore stomachs are relatively non-functional and under-developed compared with the abomasum which forms 56%-62% of the total stomach (Tamate et al., 1962).

After birth, however, the rumen has the fastest growth rate, followed in order by the reticulum, omasum and abomasum. At about 8 weeks of age the relative proportion of the four parts of the stomach reach adult values (Wardrop and Coombe, 1960) while the absolute volumes increase as the animal grows.

Relatively adult rumen function in lambs is attained at 8-12 weeks post-partum. Tamate (1957) noted that the ruminoreticulum of growing goats increased to about 85% of the total stomach capacity by 70 days of age.

The concentrations of volatile fatty acids (VFA) in the rumen reach adult values at about 8 weeks of age in lambs (Wardrop and Coombe, 1961). Walker and Walker (1961) have shown that the rumen micro-organisms of 3 week old lambs are able to digest as wide a variety of carbohydrates and proteins as those of adults, indicating that from this age lambs could be fed a solid food.

2.9.2.1 Effect of age on plasma lipids in ruminants

Newborn lambs, kids and calves have lower levels of plasma lipids than their mothers (Leat, 1970; Masters, 1964a). Leat (1970) found that the plasma lipid of a lamb at birth was 30%-60% that of an adult. The concentration of plasma phospholipids, free cholesterol, and cholesterol esters in newborn ruminants were only about a third that of the maternal concentration at parturation (Leat, 1967).

The concentrations of plasma lipids are known to change rapidly during the first few hours of neonatal life. At birth the level of FFA in lambs is very low but it increases two-fold within 2 to 5 hours

indicating rapid mobilization of FFA from adipose tissue to supply energy. A concentration as high as 30mg/100ml plasma has been reported in lambs (Noble et al., 1971a). After suckling, plasma FFA decreased to 12mg/100ml and total plasma lipid increased significantly from 84mg/100ml to 230mg/100ml within 24 hours, remaining constant at this level for the following 7 days. This increase resulted from an increase in triglycerides, phospholipids and cholesterol esters.

Leat et al. (1976) reported that the post absorptive hyperlipidemia of suckling lambs arose from an increased concentration of low and high density lipoproteins.

Plasma lipids of suckling ruminants increase with age to a maximum and then decline to achieve adult concentration. Leat (1966) reported that in fasted suckling lambs plasma phospholipid, cholesterol esters and triglyceride increased with age reaching maximum concentration at 3-4 weeks and then declined to adult values at 10-12 weeks. Similar findings were reported by Masters (1964a) in non-fasting lambs in which the concentration of serum lipid increased from 270mg/100ml at birth to 380mg/100ml after 1 to 2 months and then decreased to 280mg/100ml. For individual lipid classes, the level of cholesterol ester reached a maximum at 1 month, declined at weaning and increased again at 3 to 4 months of age.

The maximum lipid concentration in non-fasting calves was found to occur at about 1-2 months (Shannon and Lascelles, 1966). A steady increase in the total plasma cholesterol and its components in calves from birth to 12 weeks of age has been reported (Wood et al., 1971b). These authors also observed an increase in triglycerides and phospholipids from birth to three weeks of age.

The fasting concentration of plasma FFA is also known to change with age. The plasma FFA concentration was high in fasting lambs at

4-10 weeks (Leat, 1967) and in calves (Wood et al., 1971b).

2.9.2.2 Effect of age on fatty acid composition of plasma lipids

The fatty acid composition and concentration in new-born animals differs from that of adult mothers and also between species. Leat (1966) observed a significantly lower concentration of linoleic (C18:2) fatty acid in newborn lambs, kids, calves and piglets, compared to their mothers. The concentration of linoleic acid (C18:2) was 5% of the total fatty acids in piglets, 2% in calves and less than 1% in lambs and kids. The concentration of linoleic acid (C18:2) in piglets was similar to other non-ruminants like rats, rabbits and guinea pigs (Hansen et al., 1964).

The linolenic acid (C18:3) fatty acid was found to be virtually absent from the newborn of all species, although present in the adult mother.

Leat (1966) also observed that trace amounts of C20:3 were present in the lamb and kid while not present in the adult of the species. Newborn animals also had a lower content of stearic acid (C18:0) in plasma phospholipids and higher unsaturated fatty acid in triglycerides compared to their mothers.

Variations in fatty acid composition in the tissues of newborn animals and their mothers have been reported. Payne (1978) found that the level of linoleic acid in muscle phospholipids was lower in calves and in lambs than in their mothers. Similar findings were observed by Garton and Duncan (1969a) who also noted that there were no branched chain fatty acids in the adipose tissue triglycerides of neonatal lambs, whereas their mothers contained these fatty acids. These differences in lipid composition between neonates and their mothers has been attributed to the impermeability of the placenta to these fatty acids and thus the majority of fatty acids present arise

from de novo synthesis (Leat et al., 1978).

During the first three months of life considerable changes occur in the fatty acid composition of the plasma lipids of ruminants. These changes are associated with the transition from monogastric suckling young to adult ruminant with its functional rumen and altered lipid metabolism.

Within 48 hours after birth the plasma linoleic acid (C18:2) content of the suckling lambs increases from very low values to concentrations comparable to those of adult sheep; this results from the consumption of milk which is rich in this fatty acid (Leat, 1964; Leat et al., 1978).

An extensive study of the fatty acid content of the lipid classes in lambs has been carried out by Masters (1964a). He showed that the linoleic acid content of the cholesterol esters and phospholipids in lambs reached a maximum within 20 days and then declined. The stearic acid content in the plasma phospholipids reached and maintained a maximum from 7 days of age whereas that of plasma triglycerides increased slowly to reach a maximum at about 6 months post partum. These findings indicate that triglyceride stearate is affected by the extent of rumen development while that of phospholipid is not.

The concentration of linoleic and linolenic acid in triglycerides was found to have two maxima, the first at 1 month and the second at 3 months.

In the FFA fraction stearic acid fell initially, then rose to a peak at 3½ months, while the oleic acid concentration rose within the first month, declined gradually until 4 months whereupon it rose again. The palmitic acid content in esterified cholesterol increased to peak at 1-2 months and then fell.

In calves Wood et al. (1971b) observed a significant change in

the fatty acid component of plasma lipids with age. At birth the following fatty acids were identified: palmitic, stearic, oleic acids with traces of linoleic and linolenic acids. This composition was similar to that reported by Leat (1966) in calves, lambs and kids. As the animals grew older the authors observed the following changes:

Fatty acid composition % W/W

		Fed once		Fed twice	
FFA	Birth	3 wks.	6 wks.	3 wks.	6 wks.
14:0	5.6	3.3	2.7	4.0	2.4
16:0	33.2	29.8	23.9	29.5	30.2
16:1	-	1.3	1.8	2.0	1.7
18:0	17.5	23.5	24.6	17.0	23.4
18:1	39.8	33.1	30.8	37.1	29.9
18:2	1.7	8.1	12.9	9.9	9.7
18:3	0.3	0.8	1.0	0.6	0.8
Total unsaturated	41.8	43.3	46.6	49.6	42.1
Triglycerides					
14:0	3.5	3.1	7.6	4.4	7.3
16:0	31.6	25.7	39.1	25.8	38.7
16:1	1.7	4.0	3.1	4.0	5.2
18:0	10.4	10.5	20.6	8.6	18.7
18:1	38.0	36.5	26.8	30.8	27.2
18:2	1.7	7.6	2.7	8.6	2.7
20:0	13.2	12.7	-	17.3	-
Total unsaturated	41.4	48.2	32.6	44.2	35.1

Adapted from Wood et al. (1971b).

During the development of ruminant animals changes also occur in the lipid content and fatty acid composition of various organs. Masters (1964b) observed a decline in the percentage triglyceride in adipose tissue during the first 3 months followed by an increase in liver lipids.

The lipids of most tissues, and adipose tissue particularly, show an increase in saturation as development proceeds; the stearic acid content of the triglycerides of internal depots increased from 20% at 1 month to about 35% at 5 months (Garton and Duncan, 1969). Similarly there was an increase in the percentage of trans-unsaturated fatty acids. Leat (1975) reported that the percentage of stearic acid in the subcutaneous fat of Jersey cattle remained constant from 3 months until 1 year of age and then declined from 20% to 5% during the period of 1-2 years. Perinephric fat stearic acid increased from 10%-15% at birth to 40% at 1 year and then declined during the period 1-2 years while that of oleic acid increased.

Increase in stearic acid desaturase has been reported in sheep at 1 year of age and hence this could be the cause of the decline in stearic acid and an increase in oleic acid.

2.9.3 Physiological conditions

2.9.3.1 Lactation and Pregnancy

The hormonal state and physiological condition of an animal have a considerable effect on the plasma lipids. Lipids play a role in the energy economy of the animal. Depending on the energy demand and to what extent this is met by dietary sources, an animal will either synthesize or mobilize fat.

There are specific requirements for different forms of lipids in some physiological states such as lactation and pregnancy. The longer chain fatty acids (of more than 16 carbons) used in milk fat

synthesis are derived from the blood (Tove, 1965). Overall about 25% of fat in milk is derived directly from blood. Thus during lactation the plasma lipids will be increased to meet this demand. Increase in plasma lipids may be achieved by increased fat mobilization, reduced fat deposition and increased synthesis by the liver of some lipid fractions such as phospholipids and cholesterol.

Increase in plasma lipid during lactation of several species such as sheep, goats and cattle, has been reported (Duncan and Garton, 1963; Leat, 1967; Hartman and Lascelles, 1965; Moore et al., 1969; Verman et al., 1968).

The fatty acid composition of plasma lipids is also known to vary during lactation. Leat and Hall (1968) observed a higher proportion of stearic, linoleic, linolenic acid but a lower proportion of oleic, palmitic and palmitoleic acids in the plasma triglyceride and FFA of lactating compared to non-lactating cows.

During pregnancy there is also modification of plasma lipids to meet the energy requirement of the developing foetus. Robinson et al. (1971) observed an increase in the plasma concentration of FFA during the last 55 days of gestation in ewes; the highest concentration was detected in ewes carrying twins indicating that fat was being mobilized to meet the increased energy requirement of twin-bearing ewes. Similar findings were reported by Reid and Hinks (1962) who showed a close relationship between plasma FFA concentration and total foetal weight in ewes on constant feed.

Duncan and Garton (1963) reported that during pregnancy the plasma cholesterol esters contained a greater proportion of linoleic relative to linolenic acid compared to that present at parturition and during lactation.

2.9.3.2 Starvation and fasting

In many parts of the world ruminants are subjected to intermittent periods of low food intake or near fasting due to poor quality pastures at some seasons. The major source of cellular fuel for fasting animals is the triglyceride of adipose tissue. It is generally accepted that triglycerides are hydrolysed to free fatty acids which after passage across the adipose tissue membrane, couple with plasma albumin to form non-esterified fatty acids which are transported to the liver and other tissues (Felts, 1964).

Levels of plasma FFA and their relative proportions change during starvation in mammals (Brumby et al., 1975; Chalmers, 1965; Jurand and Oliver, 1970). In sheep the most striking changes were observed in palmitate, oleate and stearate which doubled in concentration after 4 days starvation, while the concentration of linoleate remained constant (Jackson and Winkler, 1970). In cows, during starvation Brumby et al. (1975) observed a five-fold increase in plasma FFA, and a decrease in the proportion of stearic acid in plasma FFA and triglyceride while that of oleic acid increased. A similar increase in plasma FFA in fasting steers has been reported by O'Kelly (1972, 1973).

Fasting also affects the concentrations of other plasma lipids. Seto et al. (1974) observed a 30% decrease in plasma cholesterol and cholesterol esters, a two-fold increase in triglyceride and 20% increase in phospholipid during a fast of 48 hours in lactating cows.

These increases in fat mobilization during fasting follow the release of fat mobilizing factors such as adrenaline or other lipolytic factors released by pituitary gland (e.g. growth hormone, ACTH). These substances can be recovered in the urine of fasting animals (Chalmer et al., 1960).

2.9.4 Nutritional factors

The nutrition of an animal is the major environmental factor governing the total plasma lipid level, concentration of individual lipid fractions, fatty acid composition and their concentration (Emery, 1969).

In both monogastric and ruminant animals the extent to which nutrition affects the concentration of plasma lipids depends on:

(a) the amount of feed taken

(b) the type and composition of the feed

  (i) concentrate vs. hay

  (ii) lipid content and type

  (iii) milk or milk substitute

(c) feeding frequency.

2.9.4.1 The amount of feed taken

In non-ruminant as well as in ruminant animals, a high feed intake will decrease the concentration of plasma FFA and increase the level of plasma triglycerides and cholesterol esters.

In non-ruminants, regardless of the type of feed, a high level of nutrition increases the level of plasma lipids by either increased absorption of lipids from the alimentary canal, or increased synthesis of lipids by the liver from different dietary sources like carbohydrates and proteins. In humans the concentration of plasma triglycerides is readily increased by diets rich in carbohydrate. The magnitude and duration of this increase is governed by factors such as the amount and type of carbohydrate. Nestel et al. (1970) found that sucrose increased the formation of triglycerides in the plasma more than did starch. They also observed that over-eating increased the concentration of triglycerides while a low level of feed intake decreased the concentration of most lipid classes, but increased the level of plasma FFA.

The intake of feeds rich in polyunsaturated fatty acids by non-ruminants such as man, pigs and rats, caused the composition of fatty acids in the blood lipids to resemble that of the diet (Bragdon and Karmen, 1960).

In ruminants, the type and level of feed affects the levels of plasma lipids and their fatty acid composition to a lesser extent than in non-ruminants, because of the microbial degradation of the feed and the final digestion and absorption of these microbial lipids.

Although the ruminant diet is rich in polyunsaturated fatty acids, only a small amount of polyunsaturated fatty acids appears in plasma lipids of ruminants. The lipids of pasture grasses are very rich in polyunsaturated fatty acids (12.3% C18:2 and 66.8% C18:3) (Garton, 1960). However the lipid fatty acids found in the intestine and lymphatic systems of these animals are highly saturated comprising essentially palmitic, stearic and oleic acids (Leat et al., 1968; Heath et al., 1964).

Hydrolysis and hydrogenation of the dietary fat by the rumen micro-organisms gives rise to the increased degree of saturation.

Ward et al. (1964) found that when linolenic acid (C18:3) was incubated for a short period in an artificial rumen, it was rapidly hydrogenated to dienoic acid of two types initially, subsequently to oleic and other C18:1 fatty acids and finally to stearic acid (C18:0).

The extent of hydrogenation depends on the form in which the substrate is available to the micro-organisms. When maize oil, which is rich in linoleic acid in triglyceride form was infused intra-rumenally, the linoleic acid released by hydrolysis from maize oil was hydrogenated to stearic acid (C18:0), whereas when pure linoleic acid was infused into the rumen, little or no stearic acid was produced and a mixture of C18:1 fatty acids accumulated (Moore et al.,

1969). Moore et al. (1969) also produced similar findings with an artificial rumen and concluded that the concentration of infused fatty acid inhibited some steps in the hydrogenation process. Cramer and Miller (1976) working with radioactive trilinolein reported that 95% of the fatty acids in the rumen were partially hydrogenated and about 60% of the labelled linoleic acid was saturated to stearic acid. The above-mentioned examples indicate that the dietary lipids of ruminants are readily hydrogenated into more saturated forms and at times translocation of unsaturated bonds occurs thus producing branched chain unsaturated fatty acids.

2.9.4.2 Type of feed and composition

Types of feed which affect plasma lipid composition and concentrations include:

(a) Effect of concentrate vs. hay feeding

The predominant diet for ruminants especially the free ranging types, is roughage from natural pasture grasses. However, domesticated ruminants may have access to concentrates or soluble carbohydrates.

The change from roughage diets to concentrate feeding is known to modify the type of VFA produced and the microbial population. The production by micro-organisms in the rumen of long chain fatty acids may also be altered and this affects plasma lipids composition. Davis and Sachan (1966) noted several changes in plasma lipids when lactating cows were fed high concentrate diets. These changes were:

(1) a decrease in the stearic acid of all lipid fractions of plasma lipids except cholesterol esters;

(2) an increase in the C8-C12 fatty acids in the cholesterol esters;

(3) a decrease in the proportion of palmitic acid in all lipid fractions, and an increase in C18 unsaturated fatty acids, especially oleic, linoleic and linolenic acids.

Storry and Sutton (1969) observed an increase in saturated triglyceride fatty acids, and decreased unsaturated fatty acids when cows were changed from high concentrate diet to high roughage diet. On the other hand, Garton (1960) reported that the highest concentrations of plasma lipid (C18:3) linolenic acid, especially in the cholesterol esters, are found in animals having access to pasture which is rich in linolenic acid.

The composition of ruminant adipose tissue fatty acids was found to be affected by the level of roughage in the diet. Ziegler et al. (1967) reported that the addition of roughage to the diet of growing lambs resulted in an increased amount of palmitic, heptadecanoic and stearic acid and decreased amounts of branched (C14:0), palmitoleic acid and linoleic acid in the depot triglycerides. This led to a higher content of total saturated fatty acids in the depot triglycerides of roughage fed lambs compared to concentrate fed lambs. Similar modification of adipose tissue lipids by dietary concentrates was reported by Duncan et al. (1974).

(b) Effect of dietary fat on plasma lipids

Plasma lipids originate from three sources: those absorbed from the alimentary canal which are of dietary, and of microbial origin in the case of ruminants; those originating from adipose tissues through fat mobilization, and those synthesized by liver or small intestine.

Feeding of fat or diets rich in fat will affect the level of plasma lipid, concentration of different lipid fractions and to some

extent the fatty acid composition of these lipid fractions. The extent to which a dietary fat affects the plasma lipid fraction depends on the type of fat and long chain fatty acid composition, since digestibility of dietary fat in ruminants is affected by the proportions of long chain fatty acids (Andrews and Lewis, 1970).

Feeding Safflower oil to cows led to an increase in the proportion of C18:2, C18:3, C19:0, C21:0 in the lymph triglycerides (Wadsworth, 1968).

Macleod et al. (1972) found that the concentration of triglycerides, phospholipids and cholesterol in plasma lipid fractions were higher in cows fed soybean oil compared to tallow, while there was no effect on plasma FFA. The proportion of stearic acid was higher and the proportion of oleic acid was lower in plasma triglyceride, and greater concentrations of linoleic acid in plasma FFA were shown with soybean oil compared to tallow feeding. These effects were due to the different composition of the two fats and to the lower digestibility of tallow compared to soybean oil.

A higher proportion of added animal fat to cattle rations led to an increase in the serum lipid levels, a concomitant increase in the proportion of (C16:1) palmitoleic acid, oleic acid (C18:1) and a decrease in the proportion of linoleic acid (C18:2) in the cholesterol esters and in the phospholipid fractions also occurred. The increase in plasma lipid was a response to the absorption of the added dietary fat (Marchello et al., 1971).

Feeding whole cotton seed increased the serum levels of total, free and esterified cholesterol, triglycerides and phospholipids (O'Kelly and Robinson, 1968).

(e) Effect of feeding protected dietary lipids on the plasma lipid

The protection of lipids from ruminal lipolysis and hydro-

genation has been achieved by coating minute oil droplets with a layer of formaldehyde-treated protein (Scott et al., 1971). The coating is achieved by emulsifying oil seeds (containing both oil and protein) or by emulsifying mixtures of lipid and protein and stabilizing the emulsions by treatment with formaldehyde. The formaldehyde treated protein is resistant to microbial proteolysis in the rumen (Ferguson et al., 1967) and the constituent lipids are resistant to microbial lipolysis and hydrogenation (Scott et al., 1971). Thus, the formaldehyde-treated protein-lipid supplements pass, largely undigested, from the rumen into the abomasum. Following exposure to the acidic conditions of the abomasum the formaldehyde-protein link is weakened, thus permitting the subsequent digestion and absorption of both lipid and protein.

Feeding of this protected lipid is known to affect the lipid levels of blood and the composition of different lipid fractions as shown by an increase in the concentration of linoleic acid in four plasma lipid fractions: cholesterol esters, phospholipids, FFA and triglyceride, after feeding protected safflower oil (Meta-Hernandez et al., 1978). Similar findings were reported by Dryden et al. (1975) and Wrenn et al. (1973). An increase in the concentration of C18:3 in plasma triglycerides of goats fed protected linseed diet was reported by Scott and Cook (1974).

Apart from the increase in the proportion of polyunsaturated fatty acids, the level of individual lipid fractions was also affected by feeding protected fats. Bitman et al. (1973) observed a threefold increase in blood triglycerides and FFA in cows fed protected safflower oil for 50 days. An increase in blood cholesterol was observed by Dinius et al. (1975) and Wrenn et al. (1973). This resulted from increased synthesis by the small intestine since cholesterol is

required for lipid absorption.

2.9.4.3 Effect of feeding frequency on plasma lipids

By reducing meal frequency at a given level of feeding, an animal would effectively be on a higher plane of nutrition immediately following feeding and a lower plane of nutrition prior to the next feed. Depending on the level of feeding and the time interval between feeds, there would be an appreciable effect on plasma lipids.

Eating the whole day's ration in one meal over a prolonged period will lead to an adaptive modification of enzymes and hormones which are involved in fat deposition, fat absorption and synthesis of fatty acids from carbohydrates.

Eating the whole day's ration in a short period in the morning will lead to an increase in plasma lipids on account of the rapid absorption of dietary lipids from the intestine and increased synthesis of fatty acids and triglycerides in the liver from dietary carbohydrates and protein sources. An increased synthesis of phospholipids and cholesterol is also apparent as these compounds are required for the absorption and transportation of the lipids in the plasma (Cohn, 1963).

In man, feeding frequencies have been found to have a considerable effect on the concentration of plasma lipids and lipid classes. Nibbling was found to reduce the serum cholesterol:phospholipid ratio whereas gorging increased it (Hedja and Fabry, 1964). A decrease in fasting serum cholesterol, phospholipids and esterified fatty acids in response to increased feeding frequency has been reported (Gwinup et al., 1963; Hodges and Krehl, 1965; Irwin and Feeley, 1967).

Macdonald et al. (1970) observed a gradual rise in the concentration of fasting serum triglycerides during nibbling, while in gorging the triglyceride concentration rose early in the experimental

period and reached a plateau.

In rats fed eucaloric diets, the meal eating group was found to have lower fasting plasma FFA than those nibbling (Florence and Quarterman, 1972), while the mean daily FFA was higher in meal eating rats than in those nibbling (Fuller and Diller, 1970). Similar observations were reported by Bortz et al. (1969) in man, where higher mean plasma FFA and cholesterol concentrations were observed in lean males eating single meals than those eating three or nine meals a day.

The increased plasma cholesterol results from increased synthesis on account of the fat load at the time of feeding, while higher plasma FFA resulted from fat mobilization before the next feeding time.

In ruminants, little work has been done to compare the effect of feeding frequency on blood lipids, although some work has examined the effect of feeding frequency on body weight gain and fat deposition (Faichney, 1968; Farrel and Watson, 1973; Graham, 1967; Reid et al., 1968).

When fed hay, feeding frequency was found to affect the concentration of plasma FFA more than any other lipid fraction. Changes in the concentration of plasma VFA and insulin levels were shown to produce this response.

Trenkle (1970) observed an increase in plasma insulin and plasma glucose in sheep 4 hours after feeding. A decrease in plasma FFA for 12 hours after feeding occurred, which was followed by an increase to a maximum at 48 hours after feeding.

Basset (1974) noted a change in the pattern of blood metabolites and hormones in sheep when fed once daily or twice daily. When 800g of lucerne oat chaff:oat grain (1:1) was fed once daily, he observed a rapid increase in plasma insulin and rapid decrease in growth hormone 2-4 hours after feeding. At this time there was a maximum

concentration of VFA and a minimum concentration of plasma FFA. An additional 800g 12 hours after the usual feeding resulted in a repetition of changes observed after the first feeding. In animals fed the whole ration in the morning (1600g), the magnitude of increase in insulin was not different from those fed 800g, but the levels remained higher for a longer period than in the group fed 800g. The latter group had lower prefeeding FFA concentration, but this decreased further after feeding. In a group fed ad libitum little diurnal variation in FFA concentration was observed; low concentrations were maintained throughout the day.

In young milk fed calves, fed twice daily, the hourly output of neutral lipid, free fatty acids and phospholipids in lymph changed relatively little with time after feeding. However when fed only once daily the concentrations of neutral lipids in lymph and plasma were lowest 4-5 hours after feeding. These increased sharply to reach their highest level at about 10 hours, decreased between 10 and 12 hours, and then remained relatively constant during 12-24 hours (Shannon and Lascelles, 1969).

Relatively higher concentrations of plasma triglyceride and phospholipid from birth to 3 weeks of age were reported in calves fed milk once daily compared to those fed twice daily (Wood et al., 1971b).

2.9.4.4 Effect of feed on plasma lipids and fatty acid composition in young ruminants

Plasma lipids and fatty acid composition of young ruminants, unlike mature ruminants, can be affected by the type of dietary feed. The extent to which dietary fat affects the concentration of and composition in young ruminants depends on the digestibility and the absorption of the fatty acids. Digestion of lipids in young ruminants is brought about by pregastric esterase and pancreatic lipase.

On feeding milk replacer rich in whey to young calves, Gooden and Lascelles (1973) observed a decreased efficiency in the absorption of lipid to that obtained when whole milk was fed.

Lymph triglycerides of calves fed whole milk was found to contain C18 and other longer chain fatty acids, mainly myristic, palmitic, stearic and oleic acids with small amounts of branched chain and odd carbon number fatty acids. This fatty acid composition closely reflected that of the diet and those in plasma except that plasma had higher proportions of linoleic acid and linolenic acid, while feeding of replacement milk depressed lymph flow to 72% of that during milk feeding and reduced the recovery of dietary long chain fatty acids to 50% long chain fatty acids compared with 83% for whole milk (Wadsworth and Shannon, 1971).

This was probably due to lower efficiency in the digestibility and absorption of milk replacer fats than the whole milk fat.

The decrease in lymph flow when calves were fed skim-milk and the substantial reduction in the concentration of lymph and plasma FFA was considered to result from the lower fat in the alimentary canal (Shannon and Lascelles, 1969).

Feeding of fat rich in polyunsaturated fatty acids to young ruminants increased the concentration of polyunsaturated fatty acids of lymph and plasma (Heath et al., 1964). Thus in young ruminants the digestion and absorption of dietary lipids resembles that of monogastric animals.

2.9.5 Other environmental effects

2.9.5.1 Temperature

Extreme environmental temperatures are known to affect the level and composition of plasma lipids.

Thompson et al. (1975) observed an increase in arterial plasma FFA

in sheep during cold exposure. The order of increase was oleic > stearic > palmitic > other fatty acids. A similar increase in plasma FFA during cold exposure was reported by Olsen and Trenkle (1973) in cows. This increase in fat mobilization during cold exposure resulted from the higher energy requirement for maintaining body temperature.

During hyperthermia in cattle, O'Kelly (1973) observed a decrease in the plasma concentrations of total cholesterol and phospholipid, an increase in the free to total cholesterol ratio, but no effect on FFA concentrations.

2.9.5.2 Seasonal variation

Seasonal changes in the amount of body fat have been reported for mammals and birds. A dicyclic seasonal variation of serum cholesterol concentration was found in rats with maxima occurring in the spring and autumn (Thorp and Waring, 1962; Edgren, 1963). In the migratory Canada goose serum FFA level was lowest during the spring premigratory phase (early March) and highest during moult (early August) (John and George, 1977). Mori and George (1978) found that the serum total cholesterol in these birds was highest in the fall post-migratory phase, while triglycerides were lowest during breeding and moult phase. The highest triglyceride level was seen in females during the spring post-migratory phase prior to egg laying.

In ruminants, small seasonal variations in serum levels were reported for the mature beef cow (Stufflebeam et al., 1964). A significant seasonal difference in plasma cholesterol of sexually mature ewes which were kept in a normal fluctuating seasonal environment during a two year period, was reported by Means and Andrew (1958). Cramer and Marchello (1964) reported that the maximum iodine number of

tissue lipids in growing lambs occurred in summer and the minimum throughout the winter, indicating increased unsaturation of tissue lipids.

O'Kelly (1973) found that plasma cholesterol, phospholipids and total plasma lipid in cattle steers were influenced by season regardless of nutrition. He found higher concentrations of plasma cholesterol and phospholipid in winter than in autumn or summer. Plasma triglyceride levels were higher in autumn and in winter than in any other season, while the plasma FFA was not influenced by season. The same author, O'Kelly (1972), reported similar findings in steers grazing tropical pasture.

2.9.6 Control of fat mobilization in ruminants

The control of lipid mobilization in non-ruminant animals involves the second messenger cyclic AMP system. Initially a hormone interacts with the adipocyte membrane, activating adenyl cyclase which converts ATP to cyclic 3' 5' AMP (Sutherland and Rall, 1960). The cyclic AMP released activates a protein kinase which in turn activates a hormone sensitive lipase (Vaughan, 1964). Hormone sensitive lipase then hydrolyses the adipose tissue triglycerides into FFA and glycerol. Hormone sensitive lipase activity is the rate limiting reaction in triglyceride hydrolysis (Vaughan, 1964). Therefore the cellular levels of cyclic AMP indirectly regulate fat mobilization from adipocytes (Robinson, Butcher and Sutherland, 1971).

Cyclic AMP is inactivated by phosphodiesterase (Rudman, 1965). The level of this enzyme and presence or absence of phosphodiesterase inhibitors affect the extent to which lipolysis occurs in the tissues. The capacity of adipose tissues to inactivate certain lipolytic agents correlated well with the inability of the animals to respond to lipolytic agents by an increase in lipolysis (Rudman and Garcia, 1964).

Fredholm and Hjemdahl (1976) observed a decrease in lipolysis and cyclic AMP accumulation due to acidosis in isolated rat fat cells incubated with adrenaline. They concluded that this was due to an inhibition of the adenyl cyclase activity by the acidity of the medium.

The rate of FFA release from adipose tissue is affected by several hormones that influence either the rate of esterification or the rate of lipolysis. This depends on the nutritional status of the animal. When adipose tissue is metabolizing carbohydrate, principally glucose, as is the case in non-ruminants, the release of FFA is slowed (Bally, 1965; Basset, 1974).

FFA mobilizing hormones can be divided into two groups:

(1) The fast acting hormones, adrenaline, noradrenaline ACTH, TSH and glucagon. These act by stimulating formation of cyclic AMP (Vaughan, 1964).

(2) The delayed type FFA mobilizing hormones glucorticoids, growth hormone.

Adipose tissues from different mammals display different patterns of responsiveness to lipolytic peptides and catecholamines (Prigge and Grande, 1971).

Adrenaline has a marked stimulating effect on lipolysis in rats, dogs and humans, but a minimal effect or no action in pigs, ducks, rabbits and guinea pigs (Prigge and Grande, 1971; Shafrir and Wertheimer, 1965). However, glucagon exhibits a considerable effect in rabbits and avian species, a moderate effect in rats and minimal effect on lipolysis in dogs and humans (Prigge and Grande, 1971; Shafrir and Wertheimer, 1965).

The fast acting lipolytic hormones influence FFA mobilization by increasing simultaneously the uptake of glucose and formation of

glycerolphosphate (Cahill and Flinn, 1960). Lynn et al. (1960) observed an increase in glucose utilization, decrease in tissue glycogen and a sharp increase in medium glycerol and FFA when rat adipose tissues were incubated with adrenaline and corticotrophin.

Apart from species differences in response to lipolytic agents, age and size of adipose tissues play a part (Holm et al., 1975). These authors reported that at a given cell size, the lipolytic effect of glucagon and noradrenaline was increased in young over that of older rats. A resistance to glucagon was found in the old rats, irrespective of fat cell size, while young rats responded. The larger the fat cells the greater the lipolytic effect. Similar resistance to lipolytic agents with age was reported by Gellhorn and Benjamin (1965).

In ruminants relatively few lipolytic agents have been tested. Incubation in vitro of adipose tissues from cows and sheep with adrenaline and noradrenaline gave variable increases from no effect to four-fold increase in medium FFA (Adrouni and Khachaduriani, 1968; Khachaduriani et al., 1966; Young and Baldwin, 1973).

These responses were [illegible] lower than those observed with rat adipose tissue which responded ten to sixty-fold in the presence of adrenaline (Prigge and Grande, 1971).

In vivo studies with different hormones have shown variable responses in different ruminant species. Adrouni and Khachaduriani (1968) and Khachaduriani et al. (1966) observed a small increase in plasma FFA when large doses of adrenaline and noradrenaline were injected into sheep. Basset (1971) obtained a significant increase in plasma FFA when adrenaline was infused into sheep for 30 minutes. A similar increase was observed in lactating cows (Sidhu and Emery, 1971, 1972). In goats, Radloff and Schultz (1966) observed a large response to growth hormone and ACTH while noradrenaline caused an intermediate

increase and glucocorticoid only a slight increase in plasma FFA.

Effect of lipolytic agent on individual fatty acids

Plasma FFA patterns are influenced by hormones. Insulin decreases oleate more than palmitate, whereas adrenaline has the opposite effect (Spitzer and Gold, 1962). These authors observed an increase in the percentage oleic and linoleic acids in plasma FFA when dogs were infused with adrenaline, while the proportional concentration of palmitic and stearic acid decreased. Similar findings were reported by Rothlin et al. (1962) in man and dogs, and by Jurand and Oliver (1970) in humans after injection of human growth hormone and after noradrenaline infusion.

In ruminants comparable findings were reported by Adrouni and Khachaduriani (1968) who observed an increase in the percentage of C18:1 (oleic acid) and decrease in the ratio of stearate to oleate when noradrenaline was injected into fed sheep.

These authors suggested that the increase in the proportion of oleic acid was in response to the mobilization of fatty acids from adipose tissues which are rich in oleic acid and to the fact that oleic acid, rather than other fatty acids, is utilized by tissues such as the heart.

From what is already known in the literature, the present work was designed to study the effect of feeding frequency on growth and body composition and to compare the responses of goats and sheep. Rates of water turnover and oxygen consumption were measured at intervals of 4 weeks to assess general metabolism. Energy and nitrogen balances of the two species were also measured in the course of the experiment.

Because of the available information that goat carcasses are leaner than those of sheep, it was important to investigate the pattern

of fat mobilization with age (in the two species) and also their response to a lipolytic agent (adrenaline) was investigated when the animals were 7 months old.

As the current research in animal production is geared towards the production of animal carcasses with less saturated fatty acids, the fatty acid composition of two plasma lipid classes (FFA and triglyceride) was investigated during growth and also under the influence of adrenaline infusion in the two species.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental animals and management

(A) Animals

3.1.1 Lambs

Pure-bred Merino lambs born in June 1977 were obtained from the sheep flock of Waite Agricultural Research Institute. Four males and five females born during a period of one week were separated from the ewes at 3 weeks of age, weighed, divided into 2 groups and confined indoors in individual pens. Males were not castrated during the experimental period.

All lambs were shorn at 4 months and 8 months of age. On weaning at 7 weeks the animals were divided into 3 groups, 3 animals in each group on a weight basis, so that the differences between group mean weight was minimal. One group was returned to the paddock while the other 2 groups remained indoors.

3.1.2 Goats

Three male and 3 female feral goat kids were obtained from Gepps Cross abbatoirs at an approximate age of 1 to 3 days. They were confined indoors in 2 groups of 3 for the first 2 weeks then transferred to individual pens.

All males remained entire during the experimental period. They were weaned at the age of 8 weeks.

3.2 Diet and feeding

3.2.1 Lambs

For the first 3 weeks after parturition the lambs were allowed to suck their mothers. They were then fed on freshly reconstituted milk substitute (Denkavit) for a further 4 weeks as summarized in Table 1.

Table 1

Feeding scheme for lambs

Feeding pattern	Milk reconstitution ratio solid:water	Total volume given/day	Milk solid given/day	Feeding times
Fed once daily	1:4	1050 ml	250 g	0700 - 0900 h
Fed twice daily	1:5	1200 ml	250 g	0700 - 0900 h and 1700 - 1800 h

Water was offered ad libitum except on the day when TOH space was being estimated.

Milk given and refusals were measured at each feeding time. All lambs had access to lucerne chaff from the time they were separated from their mothers. The amount consumed was weighed each day.

After weaning at the age of 7 weeks, the lambs were re-divided into 3 groups as described previously. One indoor group was fed once and the other group twice each day, except on the day before body weight was to be measured when all animals were fed only once. The diet was a mixture of lucerne chaff and crushed oats 80:20% W/W. Chemical composition of the various dietary components is shown in Table 2. The third group was returned to the paddock.

Feeding was semi-ad lib, that is, the lambs were given the amount of feed they could finish each day. This was determined by a 7-day feed trial in which the animals were given a known quantity of feed which was either increased or decreased the following day, depending on whether the animals finished the feed offered or not.

After the 7 day trial period, each lamb was given 450g/day in individual feeding pens. This quantity was increased weekly to a new

level which at least 75% of the animals could finish. Feeding time was the same as that used during the pre-weaning period. Any refusals were collected each morning, dried in the oven at 100°C for 24 hours and weighed. Drinking water was freely available except during estimation of tritiated water space.

3.2.2 Goats

For the first 21 days feeding of the goats was as summarised in Table 3. After 21 days the animals were divided into two groups on a body weight basis so as to minimise the differences between their group mean weights. One group was fed once daily, while the other group was fed twice daily except on the day before body weight measurement, when all animals were fed only once, in order to standardize weighing conditions. Milk reconstitution, feeding times and volume of milk given were the same as for lambs.

The goats were introduced to solids at the age of 6 weeks. They were weaned at 8 weeks of age. The diet and feeding pattern used thereafter were similar to those used for the lambs, except that the quantity eaten at any time was lower for goats than for lambs.

3.3 Blood sampling

All blood samples were taken from the jugular vein using a 10 ml disposable syringe and an 18 gauge needle. Blood was collected in heparinized 10 ml disposable tubes immersed in ice. Plasma was separated within 45 minutes, after centrifugation of the samples at 4°C and 1100g for 15min in an MSE refrigerated centrifuge. Plasma was stored frozen in 5ml plastic tubes until analyzed.

For TOH space estimation the remaining plasma and the packed blood cells were stored at 4°C for 1 week prior to sublimation of the samples to obtain TOH in water with low quenching rate for scintillation counting.

Table 2

Chemical composition of the diet

Feed sample	% DM	Crude Protein	Gross energy KJ/g	Ether extract %	Long chain fatty acids % W/W							
					C14	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	C20:0
Lucerne												
1-12 August	92.4	20.79	19.64	4.280		36.60	3.64	6.80	4.17	20.00	28.80	
13.8 - 10.10.77	91.8	22.85	20.30									
11.10 - 6.1.78	93.0	19.20	19.83									
7.1 - 15.2.78	91.0	21.50	18.50	4.007		46.30	2.41	7.84	3.60	20.30	19.54	
Paddock pasture												
19.9.77	24.8	22.11	20.29	7.207	-	15.03	2.86	3.01	3.01	14.50	61.56	
19.10 - 26.10	38.2	14.23	18.35									
21 - 28.11.77	93.0	12.92	17.73	1.640	6.49	37.03		8.44	9.74	22.08	16.23	
Oats	89.0	12.04	21.37	7.788	-	16.42			41.53	24.10	-	
Denkavit		27.36	21.55	17.000	10.27	41.15	4.11	17.22	20.66	2.10		

Table 3

Feeding scheme for goats

Age	Feeding pattern	Milk reconstitution ratio solid/water	Amount given ml/day	Feeding Time
0-3 days	as frequently as possible	1:5	-	-
4-14 days	3 times daily	1:5	900 ml	0700 - 0900 h
				1200 - 1300 h
				1700 - 1800 h
15-21 days	twice daily	1:5	1000 ml	0700 - 0900 h
				1700 - 1800 h

3.4 Growth and bioenergetic measurements

3.4.1 Body weight

Body weight was measured at one-week intervals after 18 hours starvation for milk fed animals and 24 hours for weaned animals. Prior to the estimation of TOH space the animals were also deprived of water for the same period. In all results with the exception of those presented with total body water estimates, body weight includes wool weight. Wool free body weight (live body weight minus estimated wool weight) was used in conjunction with TOH space for the calculation of body protein and fat content.

Average wool growth per month was obtained by shearing the lambs at 4 month intervals.

3.4.2 Estimation of TOH spaces and water turnover rate

Prior to determination of TOH spaces, the following procedures were adopted (Table 4).

Table 4

Treatment before TOH spaces estimation

Animal species	Age	TOH dose	Pre-treatment regime	Equilibration period
Lambs	1 month	3ml (100μCi/ml) isotonic saline	18h without food and water	3h
Lambs	2 to 6 months	3ml (100μCi/ml)	24h without food or water	6h
Goats	9 days to 1 month	2ml (100μCi/ml)	18h without food and water	3h
Goats	2 months	2ml (100μCi/ml)	24h without food and water	6h
Goats	3 to 6 months	3ml (100μCi/ml)	24h without food and water	6h

The tritiated water in isotonic saline was injected into the thigh muscle using a calibrated syringe with an 18 gauge needle (Macfarlane et al., 1974). After the equilibration period a blood sample was obtained, the animals were weighed and food and water replaced. One week later a further blood sample was removed and the animals were weighed. This procedure was repeated at monthly intervals. Before TOH was injected, blood samples were taken for the estimation of any residual TOH activity from previous estimations.

3.4.3 Sublimation of plasma samples and preparation for scintillation counting

3.4.3.1 Assay of tritium

Water was extracted using the method of Vaughan and Boling (1961) by sublimation from blood cells. Approximately 2 ml of cells and any remaining plasma was poured into a 20 ml Thunberg tube which

was then connected by a 45° bend to a 15 cm, 40 ml capacity receiving tube.

A thin, frozen film of the sample was obtained by rotating the Thunberg tube in liquid nitrogen. The system was then evacuated to approximately 0.2 Torr, the side arm closed and the receiving tube immersed in liquid nitrogen in a vacuum flask. This allowed water to be sublimed from the sample to the colder collecting tube. If the samples did not dry completely overnight, they were re-processed to ensure that no differential distillation of ^3HHO from H_2O took place. Sublimed water was stored in small glass vials until counted.

3.4.3.2 Scintillation counting

An aliquot of the water collected (0.5 ml) was pipetted into a scintillation vial and scintillation fluid (10 ml) was added.

The scintillation fluid consisted of

5 g PPO (2, 5, diphenylaxazohol)

80 g napthalene

250 ml redistilled ethanol

375 ml toluene

375 ml dioxan

Duplicate standards containing 0.5 ml of water were made up. They comprised either 0.02 μCi/ml or 0.04 μCi/ml of TOH in water. To each standard was added 10 ml of scintillation fluid. Blanks were identical except for the omission of the TOH. Each vial was counted for 10 minutes in a Packard-TriCarb liquid scintillation counter.

3.4.3.3 Calculation of TOH space, water turnover rate, body protein and body fat

Total body water was estimated by comparing the sample counts with the standard counts.

$$\text{TOH space (ml)} = \frac{\text{Tritium dose } (\mu Ci)}{\text{Tritium concentration in body water } (\mu Ci/ml)}$$

water turnover rate k

was calculated from the formula:

$$C_t = C_o\, e^{-kt}$$

$$\text{so that } k = \frac{\ln \left(\frac{\text{counts at equilibrium}}{\text{counts at 7 days}}\right)}{7}$$

Water turnover rate was expressed as $ml/kg^{0.82}/day$. Body weight used in the estimation of water turnover rate was the average of the two measurements made at time 0 and after 7 days.

Body protein and body fat were computed using the estimated TOH space and body weight by means of regression equations reported by Searle (1970a).

Fat = 0.01 - 1.05X + 0.90Y X = TOH space (kg)

Protein = 0.007 + 0.139X + 0.050Y Y = body weight (kg)

3.4.4 Determination of energy and nitrogen balance

Estimation of energy and nitrogen balance was made when the animals were 6 months old and could be accomodated in the metabolism crates.

The animals were removed from their pens and placed in individual metabolism crates and allowed time to adapt to the new environment before any collection was made.

3.4.4.1 Collection of urine and faeces

After an adaptation period of 3 weeks, total collection of urine and faeces was made for 5 consecutive days. Urine was collected in polyethylene bottles containing 18N-HCl (5 ml). The 24 hour volume was measured, and a 2% aliquot taken each day and stored at $4^{\circ}C$. The 5-day combined collection was then frozen until analysed.

Faeces were collected in plastic bags which were removed each morning at 0800 h. After weighing, a sample comprising 5% of the daily faeces from each animal was set aside and stored at 4°C. A composite 5-day sample was prepared from each animal and stored frozen until analysed.

During this period any refusals of feed were collected, dried and weighed daily.

3.4.4.2 Determination of dry matter in urine, faeces and feed

(a) Urine

After thawing, 100 ml was evaporated to a small volume in a rotary evaporator. This was then transferred to a tared 100 ml glass beaker and dried, first on a steam bath and finally in a 64°C oven. The dry matter content of the urine was obtained by difference.

(b) Faeces

The frozen faeces samples were thawed and a weighed sample was dried to constant weight in an oven at 64°C and the percentage dry matter calculated.

(c) Feed

A sample of known weight from each batch of feed was dried to constant weight (24h) in an oven at 90°C and the percentage dry matter calculated. Samples from the paddocks were treated in a similar manner.

3.4.4.3 Milling of samples

The dried samples were milled through a 1 mm sieve and stored in airtight containers until analysed.

3.4.4.4 Determination of nitrogen in urine, faeces and feed

Total nitrogen was determined by the micro-Kjeldahl method.

For faeces and feed, duplicate samples (0.3 g) were weighed on

rice paper. The paper and its contents were placed in a labelled long necked flask with a Kjeldahl catalyst tablet and 4.5 ml concentrated sulphuric acid (A.R.) added. After digestion for 1 hour the flasks were cooled and water was added to 75 ml. For urine, the digestion flasks were weighed and 2 g of urine added. Blank samples, consisting of rice paper, catalyst and sulphuric acid (4.5 ml) were estimated for each digestion.

(b) Distillation and calculation

An aliquot of 5 ml of digested material was pipetted in a Markham still and 5 ml of 40% sodium hydroxide solution added. The ammonia was distilled off over a period of 3 minutes and collected in a flask containing 1% boric acid / indicator solution (5 ml). The distillate was titrated against 0.01N-potassium periodate, the end point of the reaction being determined by the change in colour of the indicator from green to pink.

Calculation

The percentage nitrogen in the sample was calculated from the following formula.

$$\% N = (\text{sample titration} - \text{blank titration}) \times 0.1401 \times 10^{-3} \times \frac{75}{5} \times \frac{100}{0.3}$$

where 0.1401 = mg N equivalent for each 1 ml of 0.01N-$KH(103)_2$

75 = volume after dilution

5 = sample volume distilled

0.3 = weight of sample digested. (2.0 for urine)

3.4.4.5 Measurement of gross energy

Gross energy was determined on triplicate samples of feed (0.5 g) of urine (1.0 g) and of faeces (1.0 g) in a Ballistic bomb calorimeter (Gallenkamp, England).

After grinding to a uniform powder, samples of feed (0.5 g) were pressed into a compact level layer in a crucible. The crucible

was placed on the support pillar and cotton wick fitted. The sample was then sealed into the heavy metal bomb casing and a thermocouple attached.

Oxygen was admitted into the bomb to a pressure of 25 atmospheres, the galvanometer was brought to zero and the sample fired. The maximum deflection was read on the galvanometer. A blank reading determined by burning cotton wick of standard length was subtracted from sample or standard deflections.

The machine was standardized by burning benzoic acid tablets of known caloric value in the same manner as the samples.

Calculation

Energy content (joules) of the samples was calculated by comparing the deflection of the samples with that of the standard of known energy content.

3.4.5 Measurement of fasting metabolic rate

Fasting metabolic rates of lambs and goats were measured at monthly intervals in an open circuit type metabolimeter.

Animals between 1 week and 4 weeks of age were fasted for 24 hours. Older animals were fasted for 36 to 60 hours before measurement.

Fasting body weight was taken and the animal placed in the measuring chamber maintained at 25°C for 4 hours. Readings were taken at 2 hours and 4 hours without disturbing the animal. The lower of these two values was used for calculation.

Oxygen content of the air in the chamber was measured by comparing the partial pressure of O_2 (Po_2) in the chamber with the Po_2 of normal air on a Servomex paramagnetic oxygen analyser type OA 1841 (normal air contained 20.93% O_2). From the percentage change of O_2 content in the chamber air, relative to normal air, and the

volume of air passing through the chamber in a given time, the volume of O_2 consumed in that time by the animal was calculated. This volume was corrected to STP using the following equation.

$$VO_2 \text{ (STP)} = \frac{VO_2^1 \times PB^1 \times 273}{(273+T) \times 760} \quad \text{ml}$$

where:

VO_2 (STP) = volume of O_2 consumed at STP (ml O_2)

VO_2^1 = volume of O_2 consumed as directly measured from Servomex reading

PB^1 = barometric pressure **Torr** - Pressure of H_2O at T

T = temperature in the volume meter

Ml O_2 consumed were converted to Kcal by multiplying by 4.82 (1 litre of oxygen consumed is equivalent to 4.82 Kcal)(Blaxter, 1967).

The metabolimeter was standardized by measuring the O_2 consumption of burning ethanol, and comparing this value with the theoretically obtained value based on the equation

$$2C_2H_5OH + 6O_2 \quad 6H_2O + 4CO_2$$

3.5 Plasma lipids analyses

3.5.1 Materials

The materials used for the determination of plasma lipids were:

(1) Silica Gel G (Merk. A.G.) for the thin layer plates

(2) Rhodamine 6G (Hopkin and Williams Ltd. Chadwell Heath, Essex, England) for staining fats

(3) Fatty acids standards, trilinolein and boron trifluoride/ methanol (Applied Science Laboratories Inc.)

(5) Adrenaline tartrate (Koch - Siglot Ltd)

(6) Anhydrous sodium sulphate (Ajax Chemicals, division of Searle Australia Pty. Ltd.)

(8) Methanol and petroleum spirit (below 40°C B.P.) were redistilled before use.

3.5.2 Methods

3.5.2.1 Preparation of fat-free filter paper

Filter papers were extracted twice with chloroform and dried in a warm draught from a hair dryer.

3.5.2.2 Washing of glassware

All glassware and thin layer plates were rinsed twice in warm chloroform after normal washing to ensure that no lipid remained.

3.5.2.3 Preparation of Thin Layer plates

Preparative TLC Plates

A silica gel G slurry (silica gel and distilled water, 1:2) was applied to the plates by means of a Desaga applicator set to a thickness of 0.7 mm. The adsorbent was allowed to solidify and dry in air.

Prior to use, the plates were activated at 110°C for 1 hour to remove water. They were then cooled for 2 minutes and placed in a desiccator.

3.5.2.4 Plasma lipid extraction

(a) Plasma samples

Plasma assayed included:

i) Samples collected at monthly intervals after different periods of fasting from goats and lambs as tabulated below (Table 5).

Table 5

Duration of fasting prior to blood sampling in lambs and kids of different ages

Fasting Period	Age in months Animal species Lambs	Goat kids
21h	1	9 days, 1 month
24h	2	2
30h	3, 4, 5 and 6	3, 4 and 5

ii) Samples collected from goats over a 24-hour period at 3 hourly intervals, after morning feeding during milk feeding. Samples collected during saline and adrenaline infusion in both goats and sheep.

(b) Extraction

Plasma lipids were extracted according to the method of Folch et al. (1957).

To 1 ml plasma 20 ml of chloroform:methanol (2:1) was added and stirred occasionally for 2 hours. The extract was then filtered through a fat-free filter paper into a 50 ml tube to which 0.4 volumes of 0.2M monobasic potassium phosphate was added. The tubes were shaken vigorously and left to stand overnight for separation of the phases.

The water phase was removed leaving the chloroform layer containing lipids. The lipids were again washed with pure chloroform and any water phase formed was removed.

The chloroform layer was dried by the addition of 1 g of anhydrous sodium sulphate (using a calibrated scoop); the tubes were shaken and left to stand until the chloroform was clear. This was then filtered through a fat-free filter paper (Whatman No.I) into

a tared, labelled, 16 x 150 mm screw-capped tube. Chloroform was evaporated in a stream of dry nitrogen and the tubes were capped, dried and re-weighed for estimation of total lipids.

3.5.2.5 Separation of FFA and triglycerides from other lipids

This was carried out by thin layer chromatography.

Procedure

The activated silica gel-coated chromatography plates were pre-run in ether and dried in a stream of warm air. Nitrogen-dried plasma lipids were re-dissolved in 0.4 ml of chloroform and applied to labelled plates 1 cm from the margin as a narrow streak, with a finely drawn Pasteur pipette.

The chromatography developing tank was lined with two pieces of fat-free filter paper (19 cm x 19 cm), on each large face to facilitate saturation of the atmosphere with solvent. Carrier solvent (n-hexane: diethyl ether:glacial acetic acid) (80:20:1, V/V, 30 ml) was poured into the tank, and some on to each liner. The tank lid was then replaced. After 2 minutes the prepared chromatography plates were placed in the tank and solvent was allowed to run up to 15 cm at room temperature.

The plates were removed and the solvent front was immediately marked before drying the plates under a stream of unheated air.

Lipid classes were identified by spraying the dry plates with 0.005% Rhodamine 6G in water, and viewing under ultraviolet light. The lipid classes were visible as dark yellow bands, each of which was marked. The exact positions of triglycerides and FFA were identified by using trilinolein as a triglyceride standard, a mixture of C18:0, C16:0 and C14:0 as FFA standard, and cholesterin as a standard for free cholesterol.

The triglyceride and FFA bands were scraped into labelled test

tubes with a thin spatula. After extraction with 5 ml diethyl ether, the tubes were shaken on a vortex mixer, allowed to stand for 15 minutes and filtered through fat-free filter paper into labelled 16 x 150 mm screw-capped tubes.

The tubes were dried under a stream of dry nitrogen, tightly stoppered, and stored at 4°C ready for methylation.

3.5.2.6 Preparation of methyl esters

Methyl esters were prepared according to the method of Metcaffe et al. (1966).

To each tube of either triglyceride or FFA, 100 µl of 100 µg/ml C15:0 in chloroform was added as an internal standard for long-chain fatty acids. The tubes were then mixed on a vortex mixer and dried under a stream of nitrogen. This fatty acid was chosen as the standard because of its low concentration in animal tissues.

To each tube 1 ml of 0.5N-methanolic NaOH was added; after capping, the tubes were shaken on a vortex mixer and heated in a boiling water bath (2 minutes for FFA and 20 minutes for TG).

After cooling, 1 ml of boron trifluoride/methanol was added under nitrogen to each tube which was then tightly stoppered, mixed on a vortex mixer and heated on a boiling water bath (2 minutes for FFA and 45 minutes for TG).

The tubes were removed from the water bath, and after cooling, esters were extracted by adding 2 volumes of redistilled petroleum spirit (30-40° BP) and 1 volume of water. The tubes were shaken by hand and centrifuged for 5 minutes at 550 g in a MSE Mistral centrifuge at 4°C. The top organic phase was removed by means of a Pasteur pipette, passed through a fluted fat-free filter paper containing anhydrous sodium sulphate and finally collected into a labelled 13 x 100 mm screw-cap tube.

The tubes were dried under nitrogen, tightly stoppered and stored in the cold room ready for GLC analysis.

3.5.2.7 GLC analyses of fatty acids methyl esters

All sample methyl esters and the standards were analysed in a Packard gas liquid chromatograph model 7621.

Column - all glass coiled column 2 m x 4 mm

Supporting material - chromosorb W

Liquid phase - 20% diethylene glycol succinate (DEGS)

Carrier gas - high purity nitrogen

Detectors - hydrogen flame ionisation detector HVS 500V

Electrometer range - 3×10^{-10} amps

Temperatures - inlet $235^{o}C$

column $175^{o}C$

outlet $240^{o}C$

detector $220^{o}C$

Chart speed - 4 min /inch (1.6 min/cm)

Air flow rates - hydrogen 30 ml/min/detector

air 300 ml/min/detector

carrier gas inlet pressure 20 psi.

A small volume of methyl esters in redistilled petroleum spirit ($< 40^{o}C$) was injected into the column with a 10 µl Hamilton microsyringe.

3.5.2.8 Identification and calculations

The fatty acid methyl esters in the sample were identified by comparing their retention time with that of C12:0, C14:0, C15:0, C16:0, C16:1, C17:0, C18:0, C18:1, C18:2, C18:3 methyl ester standards, analysed separately and as a mixture under conditions identical to those used for the samples. Under these conditions, only 10 fatty acids could be identified, and any other peaks were characterized as

unidentified fatty acids.

The quantity of each fatty acid present in the sample was calculated by the following procedure:-

Known weight ratios of 16:0:C15:0 were prepared in 18 ratios and chromotographed together. Their peak areas (mm^2) were calculated by multiplying peak height x peak width at half heights. Peak height and width were measured using a ruler graduated in mm.

From the peak areas peak area ratios were calculated.

$$\text{i.e.} \quad \frac{\text{Peak area of C16:0}}{\text{Peak area of C15:0}}$$

The peak area ratios were plotted against weight ratios to form a standard curve.

From the chromatography data in which 10 µg of C15:0 was added to the samples before methylation, a peak area ratio of each fatty acid to that of C15:0 was calculated. Their weight ratios were computed by multiplying the area ratios by the slope of the standard curve. The weight of each fatty acid was obtained by multiplying the weight ratios by 10 µg (the weight of internal std.) The sum of all fatty acids in a sample gave the total FFA or total triglyceride.

3.6 Fat mobilization (Adrenaline infusion)

3.6.1 Preparation of animals

An indwelling G14 plastic cannula was secured in each jugular vein of experimental lambs and goats 12 hours before adrenaline infusion. Infusions were routinely begun at 0900 hours after a fast of 24 hours. The cannulae were kept patent overnight using 1 ml heparin (1000 i.u./ml) in sterile saline.

3.6.2 Infusion and blood sampling

After weighing the animals adrenaline tartrate (10 µg/ml in 0.9% sterile saline) was infused by means of a one-channel LKB 1200 peristaltic pump at a rate such that the final concentration of 10 µg/kg body weight was attained in 30 minutes. Immediately prior

to each adrenaline infusion, a baseline concentration of FFA was obtained under the conditions of 0.9% sterile saline infusion for 30 minutes at the same rate as that of the adrenaline infusion.

One cannula was used for infusion while the other was used for blood collection. Blood samples were collected into heparinized tubes immersed in ice at 0, 15, 30, 45 and 60 minutes for both saline and adrenaline infusions. The 60-minute blood sample for saline infusion was used as the zero sample for the subsequent adrenaline infusion.

The cannula patency between successive blood samplings was maintained by means of 1 ml 150i.u/ml heparin in sterile saline.

Lipid analysis was performed as described previously.

Statistical analysis

Two-way split plot analysis of variance by a standard computer programme was performed on all variates using 'F' and LSD as tests for significance.

A multiple regression analysis was chosen for analyses of body composition together with analysis of variance.

Pearson correlation coefficients were computed between the following variates: body weight, body fat, body protein, body water, metabolic rate, water turnover, total FFA, total plasma triglyceride. The t-test was used as a test for significance.

During analysis of variance, the computation was performed on the ln transformation of the original data for some variates. Thus the results presented in some tables contain the original means enclosed in brackets and their ln values. The standard errors of difference and the LSD values are for the ln transformed values where transformation is applied.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 GROWTH AND BIOENERGETICS

4.1.1 RESULTS

4.1.1.1 Growth rate and food intake in goats and lambs

The growth curves for lambs and goats are shown in Fig.1 and Fig.2 respectively.

Fig.1 Growth curve of lambs

There were no significant differences in body weight between the three groups of lambs for the first 15 weeks of life. From the 15th to the 22nd week the body weight of the paddock group was significantly higher than that of the other two groups kept indoors ($P < 0.05$). Thereafter, body weight of the two indoor groups was significantly higher ($P < 0.05$) than that of the paddock group.

There was no significant difference between the once fed and twice fed groups.

The growth rate of the three groups of lambs is shown in Table 6.

Table 6

Growth rate - lambs

	Growth rate g/day		
	Feeding regimen		
Age	Fed once daily	Fed twice daily	Grazing in paddock
First 77 days after weaning	69.09	69.35	112.99
From weaning to end of experiment	100.97	109.54	59.25

The results in Table 6 show that the paddock group gained more weight during the first 77 days than the pen fed groups. The availability of green pasture in the paddock during late winter and early spring probably led to an increased food intake for those animals. The higher overall gain in the pen fed groups than in the paddock group was the result of weight loss in the grazing lambs during summer.

Table 7

Feed intake of lambs

Age (months)	Feed intake kg solids/month (mean) Feeding regimen Fed once daily	Fed twice daily	
1-2	7.93	7.78	weaned
2-3	12.93	12.67	
3-4	16.6	15.86	
4-5	21.3	21.17	
5-6	24.76	24.42	
6-7	25.34	27.13	
7-8	29.56	28.95	
Total	138.42	137.16	
Mean	19.77	19.59	

The results in Table 7 show that feed intake increased with age. The group fed once daily had a higher feed intake on almost all occasions.

The increase in body weight with age in goats is shown in Fig.2.

There was no significant difference in body weight between the two feeding groups at any age.

Table 8

Growth rate - goats

Period in experiment	Growth rate g/day Feeding regimen Fed once daily	Fed twice daily
Milk feeding 0-8 weeks	156.12	162.96
Weaning to end of experiment	110.2	114.48
Mean	133.16	138.72

Table 8 shows that growth rates during milk feeding were higher than after weaning, and the twice daily feeding regimen resulted in

FIGURE 1 shows the growth curves for lambs on 3 feeding patterns. Each point represents a mean for 3 animals.

Body weight was measured at weekly intervals after food deprivation.

FIGURE 1

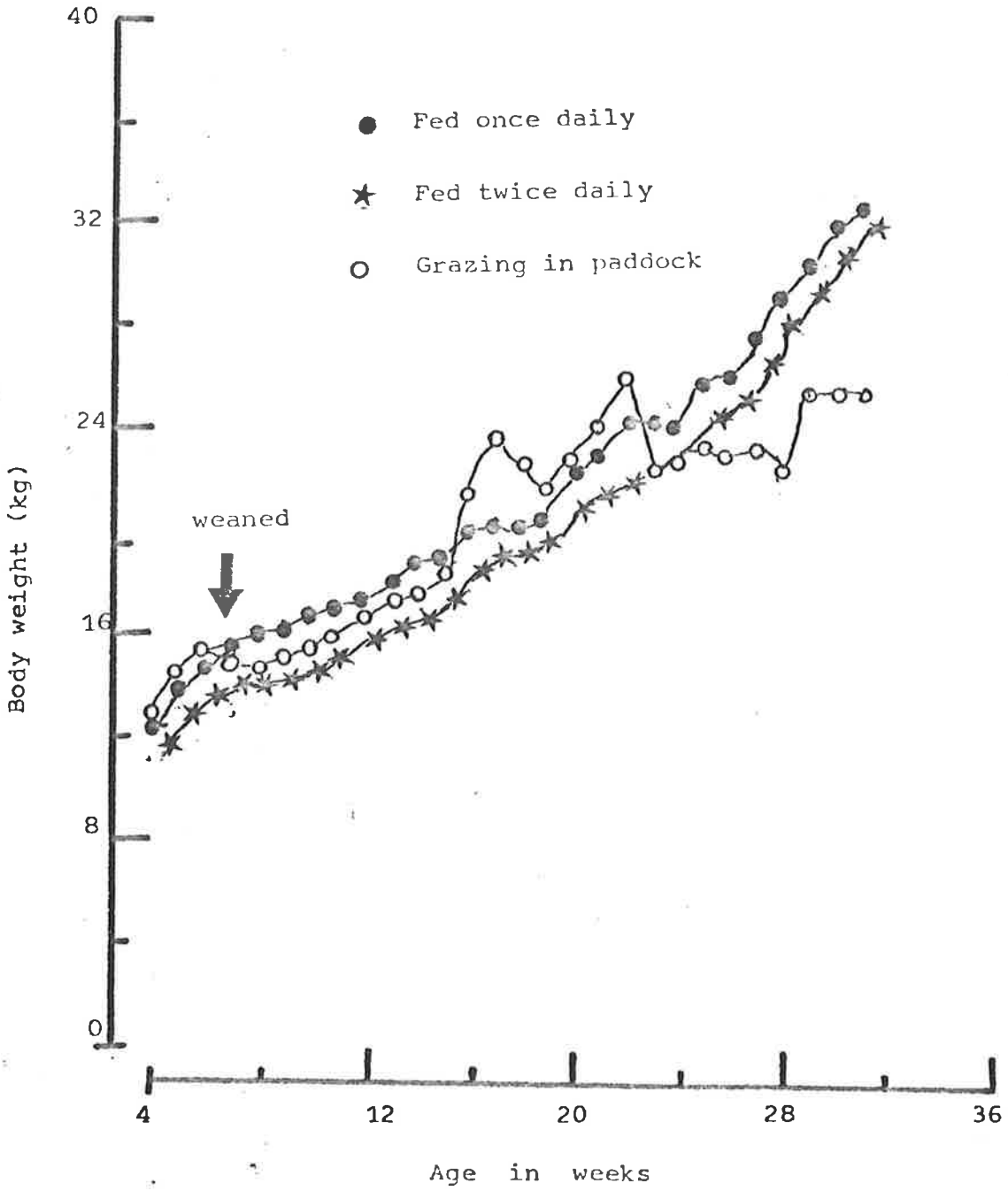
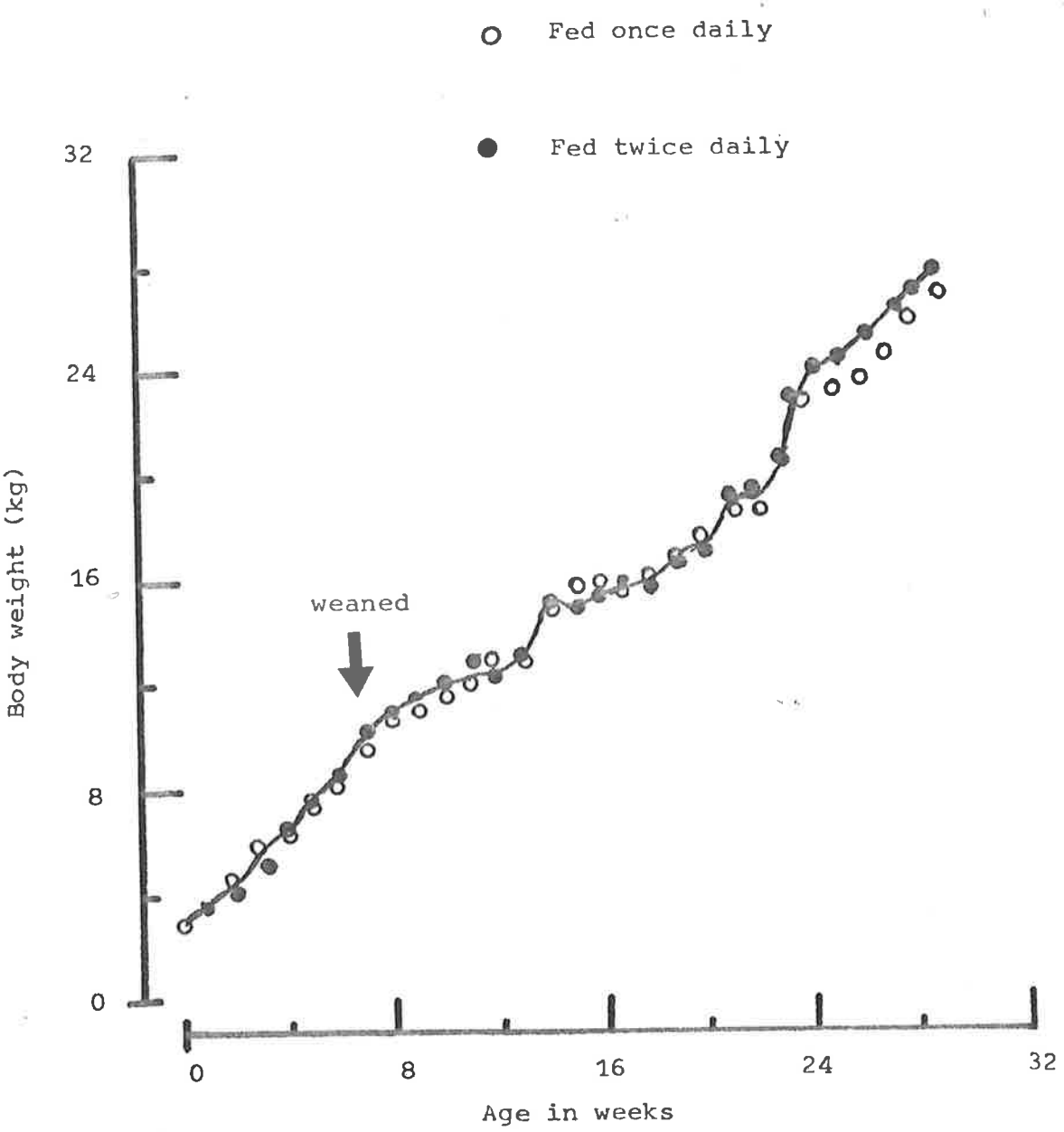

40
32
24
16
8
0
Body weight (kg)
Fed once daily
Fed twice daily
Grazing in paddock
weaned
4
12
20
28
36
Age in weeks

FIGURE 2 shows the growth curves for goats on 2 feeding regimen. Each point represents a mean for 3 animals.

Body weight was measured at weekly intervals after food deprivation.

FIGURE 2


Fed once daily
Fed twice daily
32
24
16
8
0
Body weight (kg)
weaned
0
8
16
24
32
Age in weeks

slightly higher gains than those achieved by the group fed once daily.

Table 9

Feed intake of goats

Age (months)	Feed intake kg solids/month Feeding regimen Fed once daily	Fed twice daily	
0-1	6.11	6.17	
1-2	6.64	6.46	weaning
2-3	10.99	10.27	
3-4	13.92	13.44	
4-5	16.13	15.98	
5-6	20.68	19.77	
6-7	21.76	21.8	
Total	96.23	93.89	
Mean	13.74	13.41	

Table 9 shows that although the animals in the two groups were offered the same amount of feed, the group fed once daily consumed significantly more feed ($P < 0.05$) than the other group after weaning.

4.1.1.2 Nitrogen and energy balance in goats and lambs

Nitrogen balance measured over a 5 day period at the age of 6 months is shown in Table 10 and energy balance in Table 11.

Goats fed once daily had a lower intake of D.M and N than those fed twice daily, but there was no effect of feeding frequency on intake in lambs (Table 10).

Nitrogen digestibility was similar in the two species with slightly higher values for the once daily feeding regime in both sheep and goats.

While the daily intake of DM and Nitrogen was over 40% higher for lambs than for goats, daily retention (g) was similar so that a significantly greater proportion of the dietary N intake was retained by the goats than by the lambs.

Dry matter intake and gross energy intake were significantly higher ($P < 0.01$) for lambs than for goats (Table 11). There was no significant difference in intake within species, although the goats fed twice daily had a higher intake than those fed once each day. The digestibility of energy was of the same magnitude within species and there was no significant difference between lambs and goats. The group fed one meal each day had a slightly higher digestibility in both species. Metabolizable energy as a proportion of gross energy intake was not different between feed groups nor between species. The group of lambs fed one meal each day utilized its energy more efficiently than any other group.

Table 10

Nitrogen balance in goats and lambs

Species feeding regime	D.M intake (mean g)	Nitrogen intake (g)	N lost in faeces g	N lost in urine g	Digestibility of N %	Nitrogen retained (mean g)	Nitrogen retained % total intake
Goats fed once daily	667.60	22.37	4.20	11.107	82.17	7.19 ± 1.5	34.8 ± 4.4 a b
fed twice daily	680.19	23.38	4.60	10.654	80.37	8.68 ± 1.5	36.94 ± 4.94 a b
Lambs fed once daily	999.90	31.58	5.61	16.330	82.14	9.34 ± 0.65	29.58 ± 2.13
fed twice daily	987.80	31.20	5.80	17.410	81.29	7.61 ± 0.80	24.4 ± 2.42

(a) % N retained significantly higher for goats than for lambs fed once daily ($P < 0.05$)

(b) % N retained significantly higher for goats than for lambs fed twice daily ($P < 0.01$)

Table 11

Energy balance in goats and lambs

Species and feeding regime	D.M intake (mean g)	Gross energy intake (MJ)	Energy lost in faeces (MJ)	Energy lost in urine (MJ)	Digestibility of energy	Metabolizable energy mean MJ	ME % of gross
Goats							
fed once daily	667.6	11.52	3.7927	0.3198	68.5	7.9 ± 0.58	65.63±0.67
fed twice daily	680.19	12.24	3.9974	0.3456	67.34	7.9 ± 0.47	64.51±0.18
Lambs							
fed once daily	999.9 a	19.78 b	5.7597	0.578	72.86	13.99±0.06	69.96±0.50
fed twice daily	987.8 a	19.75 b	6.433	0.510	67.51	12.81±0.222	64.92±2.27

(a) Dry matter intake significantly higher for lambs than for goats ($P < 0.01$).

(b) Gross energy intake significantly higher for lambs than for goats ($P < 0.01$).

4.1.1.3 Body Composition in goats and lambs

Fasted body weights at time of estimation of body composition

Table 12

Goats

Age (months)	Body weight (mean kg) Feeding regimen: Fed once daily	Fed twice daily
0	3.64	3.54
1	8.13	8.45
2	11.27	11.27
3	13.43	13.10
4	15.77	15.60
5	19.27	18.77

Table 13

Lambs

Age (months)	Body weight (mean kg) Feeding regimen: Fed once daily	Fed twice daily	Grazing
1	13.84	12.29	13.74
2	16.18	14.28	14.67
3	18.18	15.57	17.8
4	20.60	18.77	21.9
5	23.77	21.84	22.26
6	26.88	25.75	22.33

(a) Body fat

The body fat content in goats as affected by age and feeding regimen is presented in Table 14. Body fat increased significantly as the animals grew older. However, there was a slight decrease in body fat at 2 months compared to that at 1 month of age. This happened immediately after weaning and could be that the animals were mobilizing fat to meet their energy demand.

The proportion of fat to body weight increased significantly

Table 14

Effect of age and feeding on the body fat content of goats (mean kg) and its proportion to body wt (%) W/W

Age (months)	Fat content kg and its proportion to body wt (%) Feeding regimen: Fed once daily	Fed twice daily	Effect of age
0	0.136 (3.74%)	0.176 (5%)	0.156 (3.65%)
1	0.978 (12.01%)	1.198 (14.22%)	1.088 a (13.115%)
2	0.848 (7.53%)	0.958 (8.4%)	0.903 a (7.455%)
3	1.157 (8.72%)	1.293 (9.88%)	1.225 b (9.265%)
4	1.235 (7.83%)	1.46 (9.32%)	1.347 (8.575%)
5	2.753 (14.28%)	2.580 (13.75%)	2.667 c (14.01%)
Effect of feed	1.185 (9.9%)	1.278 (10.09%)	1.231 (9.99%)

		5%	1%	0.1%
SED Feed means	0.1359	LSD 0.2881	0.3970	0.5456
SED age means	0.2420	0.5130	0.7069	0.9716
SED age x feed interaction	0.3407			
SED within feed means	0.3422			

(a) Fat content 1-2 months significantly higher than at 9 days ($P < 0.01$).

(b) Fat content at 3 months significantly higher than at 9 days ($P < 0.001$).

(c) Fat content at 5 months significantly higher than at any other age ($P < 0.001$).

Table 15

Effect of feeding patterns and age on the level of body fat in lambs (mean kg) and its proportion to body wt (%) W/W

Age (months)	Body fat kg (and its proportion to body wt (%) Feeding regimen: Fed once daily	Fed twice daily	Grazing	Effect of age
1	0.58 (4.19%)	0.33 (2.69%)	0.65 (4.73%)	0.52 (5.72%)
2	1.46 (9.02%)	1.38 (9.66%)	0.57 (3.88%)	1.14 (6.35%)
3	2.30 (12.65%)	2.82 (17.8%)	2.45 (13.53%)	2.53 a (14.66%)
4	2.54 (12.4%)	2.57 (13.64%)	2.55 (11.62%)	2.55 a (12.55%)
5	3.01 (12.74%)	3.16 (14.41%)	2.54 (11.13%)	2.90 a (12.76%)
6	4.72 (17.59%)	4.79 (18.73%)	2.10 c (8.99%)	3.82 b (15.10%)
Effect of feed	2.44 (11.54%)	2.51 (13.05%)	1.81 (8.98%)	2.25 (11.19%)

			5%	1%	0.1%
SED Feed means	0.375	LSD	0.795		
SED Age means	0.392		0.8310	1.1450	1.5739
SED Age x feed means	0.724		1.5349		
SED Within feed means	0.679		1.4395		

(a) Body fat at 3, 4 and 5 months of age significantly higher than at 1 and 2 months ($P < 0.001$).

(b) Body fat at 6 months significantly higher than at 3, 4 and 5 months of age ($P < 0.01$).

(c) Body fat at 6 months of age significantly lower for the grazing group than for the other two ($P < 0.001$).

($P < 0.01$) at 1 month of age, declined during the following month, then showed a significant increase between 4 and 5 months of age ($P < 0.001$).

Feeding regimen had no significant effect on the body fat, although the group fed once daily had slightly lower body fat throughout.

In lambs (Table 15) the total body fat and its proportion to body weight increased significantly with age from 1 to 3 months. Thereafter the proportion of body fat remained relatively constant until the age of 6 months, when there was a significant increase in the two indoor groups and a decrease in the grazing group. The body fat for the grazing group was half that of other groups at the age of 6 months. During the same period, however, the actual fat content (kg) was increasing. Body fat in the two species was described by the following multiple regression equations.

Goats Body fat = -0.16475 + 0.3387 Age + 0.01775 Bwt. (1)

Lambs Body fat = -2.2934 + 0.08468 Age + 0.22475 Bwt. (2)

(b) Total body water

Total body water in goats (Table 16) increased significantly as the animals grew older. The magnitude of increase decreased with age.

The proportion of water to body weight declined by 10% between 9 days and one month of age, and increased by 5% at 2 months with no further change until it declined by 6% at 5 months of age.

In lambs (Table 17) the total body water also increased significantly as the animals grew older. The proportion of water to body weight decreased considerably between 1 month to 3 months of age. Thereafter it remained relatively constant.

The grazing lambs had a slightly higher proportion of body water than the other two groups.

Table 16

Effect of age and feeding on the total body water content in goats (mean kg) and its proportion to body wt (%) W/W

Age (months)	Total body water (kg) and its proportion to body wt (%) Feeding regimen: Fed once daily	Fed twice daily	Effect of age
0 (9 days)	3.08 (85.3%)	2.88 (81.9%)	2.98 (83.6%)
1	6.05 (74.68%)	6.09 (72.2%)	6.07 a (73.44%)
2	8.86 (78.6%)	8.75 (77.42%)	8.81 b (78.01%)
3	10.42 (77.2%)	10.02 (76.21%)	10.27 c (76.72%)
4	12.65 (80.11%)	11.98 (76.58%)	12.32 d (78.35%)
5	13.90 (71.82%)	13.64 (72.32%)	13.77 e (72.07%)
Effect of feed	9.16 (77.95%)	8.89 (76.11%)	9.03 (77%)

			5%	1%	0.1%
SED Effect of age means	0.574	LSD	1.2169	1.6767	2.3046
SED Effect of feed means	1.355				
SED Feed x age	1.545				

There was a significant increase in water content with each month of age.

(a) 9 days to 1 month $P < 0.001$

(b) 1 to 2 months $P < 0.001$

(c) 2 to 3 months $P < 0.05$

(d) 3 to 4 months $P < 0.01$

(e) 4 to 5 months $P < 0.05$

Table 17

Effect of feeding patterns on the total body water in lambs (mean kg) and its proportion to body wt (%) W/W

Total body water kg

Age (months)	Feeding regimen: Fed once daily	Fed twice daily	Grazing	Effect of age
1	11.49 (82.93%)	10.13 (81.47%)	11.17 (81.41%)	10.93 (81.94%)
2	12.48 (72.14%)	10.93 (76.87%)	12.04 (82.09%)	11.82 (78.7%)
3	13.81 (76.1%)	10.67 (68.74%)	12.93 (72.15%)	12.47 a (72.33%)
4	15.25 (73.95%)	13.65 (72.77%)	16.35 (74.7%)	15.08 b (73.81%)
5	17.52 (73.62%)	15.53 (71.23%)	16.67 (75.41%)	16.57 c (73.42%)
6	18.55 (68.99%)	17.52 (67.92%)	17.15 (77.2%)	17.74 d (71.37%)
Effect of feed	14.85 (75.49%)	13.07 (73.17%)	14.38 (77.16%)	14.10 (75.27%)

			5%	1%	0.1%
SED Feed means	0.833	LSD	1.7659		
SED Age means	0.508		1.0769	1.4839	2.0396
SED Feed x age	1.157				
SED Within feed means	0.881				

There was a significant increase in water content with each month from 3 months old.

(a) 1 to 3 months $P < 0.001$

(b) 3 to 4 months $P < 0.01$

(c) 4 to 5 months $P < 0.01$

(d) 5 to 6 months $P < 0.05$

Goats were found to have a higher proportion of body water than lambs: statistical comparison was not made. However total body water in the two species was described by the following multiple regression equations.

Goats Total body water = 0.18466 - 0.29586 Age + 0.83364 Bwt. (3)

Lambs Total body water = 2.2704 - 0.101067 Age + 0.64398 Bwt. (4)

(c) Body protein

Body protein content in goats (Table 18) increased significantly as the animals grew older. The highest increase was observed during the first two months.

The proportion of protein to body weight was highest at 9 days, declined slightly at 1 month, then was unchanged until a further fall between 4 and 5 months of age.

Feeding patterns had no significant effect on the protein content. However, the group fed once daily had slightly higher protein content than the other group.

Protein content in lambs is shown in Table 19. Body protein increased steadily and significantly with age. The proportion of protein to body weight declined by 1% between the ages of 1 and 3 months, then remained relatively constant with a slight decline between 5 and 6 months of age.

Feeding patterns had no significant effect on the proportion of body protein, although it was slightly lower for the group fed twice daily than for the other two groups.

Body protein in the two species was described by the following multiple regression equations.

Goats Body protein = 0.03372 - 0.04126 Age + 0.16578 Bwt. (5)

Lambs Body protein = 0.031947 - 0.01445 Age + 0.13975 Bwt. (6)

Table 18

Effect of age and feeding on the body protein content in goats (mean kg) and its proportion to body wt (%) W/W

Age (months)	Body protein kg and proportion to body wt (%) Feeding regimen: Fed once daily	Fed twice daily	Effect of age
0	0.617 (17.09%)	0.583 (16.38%)	0.600 (16.74%)
1	1.256 (15.43%)	1.278 (15.07%)	1.267 a (15.25%)
2	1.802 (15.99%)	1.787 (15.86%)	1.795 b (15.93%)
3	2.126 (15.83%)	2.053 (15.67%)	2.090 c (15.75%)
4	2.552 (16.19%)	2.453 (15.73%)	2.503 d (15.96%)
5	2.900 (15.05%)	2.840 (15.14%)	2.870 c (15.09%)
Effect of feeding	1.847 (15.93%)	1.776 (15.64%)	1.811 (15.78%)

			5%	1%	0.1%
SED Feed means	0.2668	LSD	0.5656		
SED Effect of age means	0.1037		0.2198	0.3029	0.4164
SED Effect of feeding x age	0.2985				
SED Within feed means	0.1467				

There was a significant increase in protein content with each month of age.

(a) 9 days to 1 month $P < 0.001$

(b) 1 to 2 months $P < 0.001$

(c) 2 to 3 months $P < 0.05$

(d) 3 to 4 months $P < 0.01$

(e) 4 to 5 months $P < 0.01$

Table 19

Effect of feeding patterns and age on total body protein in lambs (mean kg) and its proportion to body wt (%) W/W

Body protein (kg)

Age (months)	Feeding regimen: Fed once daily	Fed twice daily	Grazing	Effect of age
1	2.296 (16.57%)	2.021 (16.38%)	2.246 (15.57%)	2.188 (16.17%)
2	2.551 (15.77%)	2.240 (15.74%)	2.414 (15.98%)	2.402 a (15.83%)
3	2.836 (15.61%)	2.268 (14.6%)	2.693 (15.17%)	2.599 b (15.13%)
4	3.156 (15.31%)	2.842 (15.15%)	3.375 (15.41%)	3.124 c (15.29%)
5	3.630 (15.26%)	3.260 (14.93%)	3.436 (15.48%)	3.442 d (15.22%)
6	3.932 (14.61%)	3.731 (14.47%)	3.505 (15.76%)	3.723 e (14.95%)
Effect of feed	3.067 (15.52%)	2.727 (15.21%)	2.945 (15.56%)	2.913 (15.43%)

			5%	1%	0.1%
SED Feed means	0.1831	LSD	0.3882		
SED Age means	0.0820		0.1738	0.2395	0.3292
SED Age x Feed means	0.2243				
SED Within feed means	0.1420				

There was a significant increase in water content with each month of age.

(a) 1 to 2 months $P < 0.05$

(b) 2 to 3 months $P < 0.05$

(c) 3 to 4 months $P < 0.001$

(d) 4 to 5 months $P < 0.01$

(e) 5 to 6 months $P < 0.01$

(d) Plasma proteins

Plasma protein concentration in goats (Table 20) increased significantly as the animals grew older. There were significant increases in concentration between 9 days and 1 month of age ($P < 0.001$), 1 month and 2 months ($P < 0.01$) and between 2 and 3 months of age ($P < 0.01$) but no change between 3 and 4 months. It could be that the adult concentration of plasma protein had been reached by the age of 3 months.

Feeding regimen and its interaction with age had no significant effect on the concentration of plasma protein.

The plasma protein concentration in lambs is shown in Table 21. Age and its interaction with feeding had significant effects on the concentration of plasma protein while feeding alone had no effect.

The concentration of plasma protein increased with age and was significantly higher at 5 months than at any other age ($P < 0.05$).

At the age of 4 months the concentration for the grazing group was significantly higher than for the other two groups ($P < 0.01$). The concentration for the twice fed group was significantly lower than the concentration for the other two groups ($P < 0.01$) at 5 months of age.

Table 20

Effect of feed and age on the concentration of plasma protein in goats (mean g/100ml plasma)

Age (months)	Plasma protein concentration (g/100ml plasma) Fed once daily	Fed twice daily	Effect of age
0	(4.00) 1.6079	(3.867) 1.5811	(3.933) 1.5945
1	(5.533) 1.8762	(5.133) 1.8133	(5.333) a 1.8447
2	(6.00) 1.9456	(5.933) 1.9360	(5.967) b 1.9408
3	(6.733) 2.0455	(6.867) 2.0621	(6.800) c 2.0538
4	(6.800) 2.0539	(6.733) 2.0455	(6.767) 2.0497
Effect of feed	(5.813) 1.9058	(5.707) 1.8876	(5.760) 1.8967

			5%	1%	0.1%
SED Feed means	0.01788	LSD	0.0379		
SED Age means	0.02219		0.0470	0.0648	0.1148
SED Feed x Age means	0.03328				
SED Within feed	0.03138				

(a) Concentration of plasma protein significantly higher at 1 month than at 9 days ($P < 0.001$)

(b) Concentration of plasma protein at 2 months significantly higher than at 1 month ($P < 0.01$)

(c) Concentration of plasma protein at 3 months significantly higher than at 2 months of age ($P < 0.01$)

All statistical analyses were performed on ln transformation of the original data. The original means are enclosed in brackets.

Table 21

Effect of feeding patterns and age on the concentration of plasma protein in lambs (mean g/100ml)

	Concentration plasma protein g/100ml			
	Feeding regimen			
Age (months)	Fed once daily	Fed twice daily	Grazing	Effect of age
1	6.167	6.00	5.667	5.944
2	5.967	6.033	6.067	6.022
3	5.800	5.967	5.933	5.900
4	5.600	5.800	6.667 b	6.022
5	6.733	6.00 c	6.933	6.556 a
Effect of feed	6.053	5.96	6.253	6.089

			5%	1%	0.1%
SED Age means	0.2512	LSD	0.5325	0.7337	1.0086
SED Feed means	0.1544		0.3273	0.4510	
SED Feed x Age means	0.3469		0.7354	1.0133	1.3928
SED Within feed means	0.2675		0.5671	0.7814	

(a) Plasma protein at 5 months significantly higher than at any other age ($P < 0.05$).

(b) Plasma protein at 4 months significantly higher for the grazing group than for the other two ($P < 0.05$).

(c) Plasma protein at 5 months significantly lower for the group fed twice daily than for the other two ($P < 0.01$).

4.1.1.4 Fasting metabolic rate

The fasting metabolic rate of goats (Table 22) decreased with age. A significant decrease was observed between 9 days and 1 month of age ($P < 0.05$). Thereafter the metabolic rate did not decrease significantly up to 5 months of age.

Feeding regimen had no significant effect on the metabolic rate of goats. However the metabolic rate for the group fed once each day was slightly higher than that of the group fed twice daily.

In lambs (Table 23), the fasting metabolic rate was not affected significantly by either age or feeding patterns. The fasting metabolic rate at 1 month was slightly higher, and at 2 months (immediately after weaning) was lower than any other age in the two groups, while the grazing group had lower fasting metabolic rates at 1 month and higher at 4 months.

The grazing group had overall a lower metabolic rate than the other two groups.

4.1.1.5 Water turnover rate

Water turnover rate in goats is shown in Table 24. Water turnover rate changed with age; at 9 days the turnover rate was significantly higher than the water turnover at 1 month ($P < 0.05$) and at 2 months ($P < 0.001$). Water turnover at the age of 2 months was significantly lower than that at 1 month ($P < 0.05$) or 4 months ($P < 0.01$).

Age x feed interaction had a significant effect on the water turnover rate in lambs (Table 25), while age or feed individually had a slight effect on the water turnover rate.

Water turnover rate for the grazing group was significantly higher than for the other two groups at 2, 3 and 4 months of age.

Table 22

Effect of age and feeding regimen on the fasting metabolic rate of goats (mean KJ/kg $^{0.75}$/24h)

Age (months)	Metabolic rate KJ/kg $^{0.75}$/24h Feeding regimen Fed once daily	Fed twice daily	Effect of age mean
0	606.10	504.94	555.52
1	320.61	407.55	364.00 a
2	365.33	364.91	364.90 a
3	304.30	301.38	302.63 b
4	410.60	187.68	298.87 b
5	420.93	299.71	360.32 a
Effect of feed mean	404.62	344.43	374.53

			5%	1%
SED Effect of feed means	46.06	LSD	97.654	
SED Effect of age means	67.13		142.32	196.089
SED Effect of age x feed means	98.15			
SED Within feed means	94.93			

(a) Metabolic rate at 1, 2 and 5 months significantly lower than that at 9 days ($P < 0.05$).

(b) Metabolic rate at 3 and 4 months significantly lower than at 9 days of age ($P < 0.01$).

Table 23

Effect of feeding patterns and age on the fasting metabolic rate of lambs (mean KJ/kg $^{0.75}$/24h)

Age (months)	Metabolic rate KJ/kg $^{0.75}$/24h Feeding regimen Fed once daily	Fed twice daily	Grazing	Effect of age
1	534.2	723.14	321.02	526.26
2	302.2	273.37	397.94	324.37
4	390.41	669.64	446.84	502.02
5	425.5	551.34	409.22	462.31
7	468.99	487.39	408.39	454.78
Effect of feeding	423.02	539.22	396.68	453.95

SED Effect of feed	56.59
SED Effect of age	68.89
SED Effect of feed x age	120.80
SED Effect of within feed	119.29

Table 24

Effect of age and feeding patterns on water turnover rates in goats (mean ml/kg $^{0.82}$/24h)

Age (months)	Water turnover rate ml/kg $^{0.82}$/24h Feeding regimen Fed once daily	Fed twice daily	Effect of age
0	(280.7) 5.634	(282.1) 5.643	(281.4) 5.639
1	(186.3) 5.226	(195.1) 5.277	(190.7) a 5.251
2	(132.9) 4.892	(141.9) 4.929	(137.4) b 4.929
3	(169.3) 5.135	(272.6) 5.463	(221.0) 5.463
4	(212.4) 5.324	(239.4) 5.455	(225.9) c 5.455
5	(192.7) 5.263	(202.7) 5.316	(197.7) 5.316
Effect of feed	(195.7) 5.246	(222.3) 5.347	(209.0) 5.296

			5%	1%	0.1%
SED Effect of feed means	0.1519	LSD			
SED Effect of age means	0.1229		0.2605	0.3590	0.4934
SED Effect of feed x age means	0.2197				
SED Within feed means	0.1739				

(a) Water turnover at 1 month significantly lower than at the age of 9 days ($P < 0.05$).

(b) Water turnover at 2 months significantly lower than at the age of 1 month ($P < 0.05$).

(c) Water turnover at 4 months significantly higher than at 2 months ($P < 0.01$).

(a) Water turnover at 2 months of age significantly higher for grazing group than that for twice fed group ($P < 0.01$) and for once daily group ($P < 0.001$).

(b) Water turnover at 3 months significantly higher for grazing group than that for twice and once fed groups ($P < 0.001$).

(c) Water turnover at 4 months significantly higher for grazing group than that for the other two groups ($P < 0.01$).

(d) Water turnover at 1 month for the grazing group significantly lower than that at the age of 2, 3 and 4 months ($P < 0.01$).

(e) Water turnover for twice fed group significantly higher at 1 and 6 months than that at 2, 3 and 4 months ($P < 0.01$).

(f) Water turnover for once fed group significantly higher at 5 and 6 months than at all other ages ($P < 0.01$).

Table 25

Effect of feeding patterns and age on water turnover in lambs ($ml/kg^{0.82}/24h$)

Water turnover $ml/kg^{0.82}/24h$

Feeding regimen

Age (months)	Fed once daily	Fed twice daily	Grazing in Paddock	Effect of age
1	(204.1) 5.320	(260.8) e 5.572	(219.3) d 5.391	(228.1) 5.428
2	(177.3) 5.176	(208.4) 5.315	(318.5) a 5.764	(234.7) 5.418
3	(201.0) 5.288	(204.0) 5.315	(384.9) b 5.946	(263.3) 5.516
4	(204.5) 5.314	(208.4) 5.328	(316.5) c 5.755	(243.1) 5.466
5	(278.7) f 5.624	(242.0) 5.476	(220.4) 5.399	(247.0) 5.500
6	(270.8) f 5.567	(258.7) 5.554	(255.6) 5.546	(261.7) 5.556
Effect of feed	(222.7) 5.382	(230.4) 5.427	(285.9) 5.634	(246.3) 5.481

			5%	1%	0.1%
SED Effect of feed means	0.1269	LSD	0.2690		
SED Effect of age means	0.0516		0.1094	0.1507	
SED Age x feed means	0.1509		0.3199	0.4408	0.6059
SED Within feed means	0.0894		0.1895	0.2611	0.3589

For the grazing group, water turnover at 1 month was significantly lower than at 2, 3 and 4 months of age ($P < 0.01$). Water turnover rate for the group fed one meal each day was significantly higher at 5 and 6 months than at any other age ($P < 0.01$) while in the group fed twice each day, water turnover was higher at 1 and 6 months of age than at any other age ($P < 0.01$).

4.1.2 Discussion

4.1.2.1 Growth rate and food intake in goats and lambs

From the results on growth curve, daily gain and total feed consumption throughout the experimental period, it was clear that there were slight differences in the two feeding regimen. Although there was a slightly higher growth rate by goats fed twice daily than for those fed once daily, both during milk feeding (difference of 6.84 g/day) and after weaning (4.28 g/day), the gain was not sufficient to warrant either the effort or the cost of extra labour.

The higher gain for the group fed twice daily, especially during milk feeding, indicates that this regimen led to greater efficiency in conversion of nutrients to body tissues, although the apparently lower efficiency in the once fed group was probably due to slight scouring observed in one animal.

There are contradictory reports on the effect of once versus twice a day milk feeding on the performance of young animals. Petresch *et al.* (1976) reported that feeding calves once daily from the age of 3 weeks led to a higher weight gain for the first two months than feeding twice daily for 5 weeks then changing to once daily. White and Radcliffe (1970) observed a higher body weight in calves fed milk once daily than in those fed twice daily, and noted that the incidence of scouring was lower in the once fed group. On the other hand, Wood *et al.* (1971a) reported that there was no

significant effect of twice versus once daily feeding on rate of gain or digestibility of protein and energy in calves. Similarly Willet et al. (1969) found no significant differences in average weight, heart girth and wither height gains in calves fed milk replacer twice or once daily.

Contrary findings have also been reported. Ackerman et al. (1969) showed that calves fed once daily gained 0.188 kg less than calves fed twice daily at the age of five weeks, while calves fed once daily gained faster than calves fed twice daily at seven weeks of age, indicating that at younger ages once daily feeding has a detrimental effect because animals are not equipped to digest and absorb all the nutrients at once. This is possible when the animals are older. Wooden et al. (1968) observed a higher incidence of scouring in calves fed milk once daily compared to those fed milk twice daily.

The cause of the health problems reported by Wooden et al. was suggested by White and Radcliffe (1970) to be associated with over-feeding when animals fed once daily are given the same volume of milk as those fed twice daily. This problem could be overcome by raising the milk replacer concentration for the animals fed once daily.

The rate of gain in goats during milk feeding (162g and 156g per day) (Table 8) was slightly lower than gains reported in the literature. Fehr et al. (1976) observed a gain of 200g/day by goat kids fed milk replacer. Searle and Griffiths (1975) observed a maximum growth rate of 330g/day for male lambs fed milk replacer ad lib while the group restricted to half that intake grew at 230g/day.

The higher levels observed by Searle and Griffiths (1975) compared to the present work was due to the higher feed intake by lambs which were taking up to 500g/day dry matter, while goats in the

present work were getting a maximum of 250g solids/day. Other causes for the lower growth rate observed in the present work could be fasting for metabolic rate measurements and repeated blood sampling. Wood et al. (1971a) suggested that the cause for low growth rate in calves in which blood was sampled at weekly intervals was due to the stress imposed to those animals by blood sampling, as the animals had to synthesize new blood cells.

Growth rate in lambs during milk feeding was not measured in this work because they were bottle fed at the age when they could eat hay so it was not possible to partition the effect of milk from that of hay; also lambs in the field were allowed to suckle their mothers.

Between weaning (at 2 months) and 7 months of age, a linear relationship existed between food consumption and age, the rate of increase in the indoor groups fed once daily being 15% greater ($P < 0.05$) for lambs (210g/week) than for goats (183g/wk). Average monthly intakes for the same period (Tables 7 and 9) also show that the lambs had a higher intake than the goats at any age ($P < 0.01$, paired 't' test).

Food intake and age were related by the following regression equations.

Lambs $FI = 1.201 + 0.210A$ FI = food intake - kg/week

Goats $FI = 0.660 + 0.183A$ A = age (weeks) (a)

This is also the period (2-7 months), between weaning and puberty, when body weight increases exponentially with age. The goats were smaller than the lambs at any age, but grew (3.87% increase in weight/week) 21% faster ($P < 0.001$) than the lambs (3.19%/week).

The growth curve for lambs and goats were described by the following regression equations.

Lambs $Bwt = 11.87e^{0.0319t}$ Bwt = body weight (kg)

Goats $Bwt = 8.18e^{0.0387t}$ t = age (in weeks) (b)

Combining these equations (a and b) shows food intake to be linearly related to ln body weight over this range.

Lambs FI = 6.471 ln Bwt - 14.646

Goats FI = 4.671 ln Bwt - 9.037

Bwt = average body weight (kg) for week

FI = food intake (kg) during that week

The rate of increase in food intake with increasing body weight was 38% greater ($P < 0.001$) for the lambs than for the goats. Initially, intake was higher for goats at any given body weight, but the difference steadily diminished until the lines intersected, almost at the end of the experimental points for the goats, at 22.6 kg body weight.

The alternative expression relating body weight at the end of each week to food consumption during that week shows a significantly greater response ($P < 0.001$) by the goats than by the lambs.

Lambs $Bwt = 10.14e^{0.147FI}$

Goats $Bwt = 7.36e^{0.204FI}$

Bwt = body weight (kg) at end of week

FI = food intake (kg) during that week

An increase in weekly food intake of 1 kg was associated with a 20% increase in body weight in goats compared with only a 15% increase in lambs.

Thus, while food intake increased both with age and with body weight at a faster rate in lambs than in goats, lambs consumed more at any age, but goats more in terms of body weight over this experimental range.

Goats were smaller than lambs at any age, but grew faster, and over this weight range, not only ate relatively more, but showed a relatively greater weight response to a given increment in food intake, as this increased with age.

Two of the factors contributing to this superior efficiency in

goats have been presented in sections 4.1.1.2 and 4.1.1.4.

A nitrogen balance study undertaken when these animals were 6 months old, showed that lambs had greater urinary losses of nitrogen than goats and they retained only 27% of ingested dietary protein compared with a 35.8% retention by the goats.

In addition, resting oxygen consumption was usually lower for the goats than for the lambs (Tables 22 and 23). Both of these functional differences result in less energy wastage and would therefore lead to greater efficiency in the utilization of dietary nutrients by goats than by lambs.

4.1.2.2 Nitrogen and energy balance in goats and lambs

(a) Nitrogen balance

The results presented in Table 10 show that feeding lucerne chaff twice or once daily resulted in a similar efficiency in the utilization of dietary protein. This finding agrees with those reported by Wood et al. (1971a) in milk fed calves where the two groups had similar efficiency.

Of the two ruminant species studied, goats were found to have higher efficiency in utilizing dietary nitrogen. The higher proportion of N retained by goats than by lambs was not due to any difference in digestibility, but rather to the amount of nitrogen lost in the urine. This loss represented 53.74% of the total nitrogen intake in lambs, while in goats it was 47.57%. This difference could have been brought about by differences in urine volume since the water turnover rates were higher in the lambs than in the goats. Urine flow rate is known to be positively correlated with urinary urea nitrogen output in sheep (Cocimano and Leng, 1967).

Differences in the amount of nitrogen retained between sheep and goats fed the same diet under the same environmental conditions have

been reported. El Hag (1976) working with desert goats and sheep in Sudan observed a higher nitrogen retention by goats than sheep. He also recorded a lower level of rumen ammonia in goats than in sheep and a lower level of blood urea concentration in goats. Similar observations have been reported by Devendra (1977) who recorded a significantly higher nitrogen balance in goats than in sheep fed Guinea grass.

If the greater water turnover in the lambs (Tables 24 and 25) resulted in a greater urine volume for the lambs than for the goats, this may have influenced the relative nitrogen retention. Water intake is known to affect the amount of nitrogen retained. Utley et al. (1970) observed an increase in nitrogen retention by Aberdeen Angus steers when water was restricted. Similar findings have been reported in sheep (Goodall and Kay, 1968). On the other hand, Thornton and Yates (1969) and Johnson et al. (1965) reported a decrease in nitrogen retention when water was restricted in cattle.

(b) Energy balance

Energy digestibility was similar for lambs and goats (Table 11) so that the two species showed an apparently similar efficiency in utilizing energy present in the feed as metabolizable energy.

This finding agrees with those reported in the literature. Gibad (1976) reported that, with the exception of crude fibre, goats and sheep exhibited similar patterns in their ability to digest the various nutrients in hay composed of Hyparrhenia spp. El Hag (1976) reported that the efficiency of utilization of dietary energy in sheep and goats was similar when the feed was of good quality, while it was higher for goats on poor quality roughage diets. These differences follow from the higher crude fibre digestibility for goats than sheep. Similar findings were reported by Devendra (1977). Wilson (1977)

observed a higher crude fibre digestibility for goats than sheep fed tree leaves.

Goats and lambs in the present work were fed good quality lucerne chaff:oats so that similar efficiencies would be expected.

4.1.2.3 Body composition of goats and sheep

The change in body composition with age, that is the increase in the amount of protein, water and fat observed in the present work, supports the accepted concept that growth of an animal is the sum of the increase in size of its organs and tissues which occur by cell hyperplasia during early stages of growth, cell hypertrophy during the later stage of growth and addition of intracellular and extracellular material into the organs and tissues. Growth is under the influence of hormones, genetics and environment which includes nutrition, temperature and diseases.

(a) Body fat

Fat is the most variable carcass and body tissue, both in amount and in distribution. Therefore it has the greatest influence on the amount of each of the other tissues in the body at any particular weight (Berg and Butterfield, 1976).

Fat is important in the biology of the animal as an energy store, providing survival buffer against periodic low food availability such as in drought and in winter. Subcutaneous fat could be useful as an insulating layer against cold as shown for cattle by Young and Dietz (1971). Lipids combined with structural protein form the membranes essential to life in all cells.

In the past, during the nineteenth and early twentieth centuries, fat was a highly desirable part of a beef carcass. The demand for fat on beef in most western-European countries has fallen under the influence of lower caloric requirements brought about by more sedentary

occupations, and the health problems caused by consumption of excessive amounts of fat by humans. However, in other countries fat is still preferred in meat and cuts with more fat bring higher prices in the market.

Because of these factors, emphasis has changed from breeding animals which fatten at a lighter weight to animals which grow faster and have much less fat on their carcasses. The understanding of patterns of fat deposition in different species, and factors which affect this deposition is important in making decisions related to production of meat animals.

The results observed in the present study indicate that fat forms a relatively low proportion of body weight in young animals, and that the proportion increases slowly with age (Tables 14 and 15). Most animals at birth have a low proportion of body fat (Widdowson, 1950). Alexander (1962) reported that the body fat of newly born lambs was 3% of body weight, while Jagusch et al. (1970) reported a value of 2% body weight. In the present study, the proportion of fat in goats at the age of 9 days (Table 14) was 3.65%, which indicates that the goats at this age had accumulated fat obtained from milk. As the animals grew older and increased in body weight, the actual and proportion of body fat increased. The higher proportion of body fat observed at the age of 1 month indicates that during milk feeding and especially in the first month of life, animals deposit fat at a high rate. This is probably due to high energy intake and high efficiency of utilization of dietary nutrients for body tissue development. At this stage the adipose tissue cells are known to increase in number by hyperplasia and the rate is affected by the level of nutrition (Haugeback et al., 1974). Searle et al. (1972) reported that during the first 3 weeks of life, when animals depend wholly on milk, they gain around 0.16kg -

0.17kg fat and 0.15 - 0.16 kg protein per kg body weight gain. In the present study the gain for the first month was 0.175kg - 0.2kg fat and 0.12kg - 0.14kg protein per kg body weight gain in goats, indicating that goats deposit more fat at this period than lambs.

At the age of two months, which was immediately after weaning, the total body fat and its proportion to the body weight in goats decreased. This indicates that animals were losing body fat due to the change of diet from milk to lucerne hay. Development of a functional rumen at this stage could decrease the efficiency of nutrient utilization due to the formation of methane gas in the rumen. Other reasons for fat mobilization could be that the animals were not taking enough energy or that absorption of volatile fatty acids in the rumen was low. An accumulation of VFA in the rumen of lambs at the age of 8 weeks has been reported by Boda et al. (1962) indicating low efficiency in VFA absorption. Similar changes in body fat in lambs at weaning have been reported. Searle et al. (1972) found that at weaning no fat was accumulated in sheep fed ad libitum, while animals on a restricted intake lost body fat. Kellaway (1973) observed a decrease in body fat at weaning, while there was no change in the body protein. The utilization, or the failure to accumulate body fat at weaning, was found to be associated with a decrease in energy intake (Graham and Searle, 1972; Black, 1974). Fennessy et al. (1972) found a rise in plasma FFA in lambs weaned from ewes at the age of 3.5 and 5.5 weeks indicating mobilization of body fat. In the present study plasma FFA was at its highest level at this time (Table 26). Thus the decrease in body fat at weaning was due to a decrease in energy intake and an increase in fat mobilization.

In lambs, the body fat content at the age of one month (Table 15) was relatively lower than that found in goats. The plasma FFA was

also higher (Table 27) at the age of one month, indicating fat mobilization. The lower fat content could be due to the effect of change in diet and low feed intake. The lambs were separated from ewes at the age of 3 weeks and their body fat measured one week later. These lambs did not readily accept the milk replacer and thus they drank very little and ate more hay. After weaning, total body fat increased in the groups maintained indoors while the grazing group lost body fat. However, the proportion of body fat to body weight decreased in all groups except the indoor group fed twice daily. This decline in the proportion of body fat would have occurred for the same reasons as discussed earlier for goats.

From 3 months of age the proportion of fat to body weight in goats remained relatively constant until at the age of 5 months it increased from 8.6% to 14%, while in lambs the proportion of fat increased from 6.4% to 14.7% between 2 and 3 months of age. This level declined to 12.8% by 4 months and remained relatively constant until it increased to 15% at 6 months of age.

This relatively constant proportion of fat to body weight with age indicates that during growth, before the fattening phase begins, fat increases slowly with age. Searle et al. (1972) reported that below a certain body weight in sheep the proportion of fat in the body increases slowly.

The observed increase in proportion of body fat at the age of 6 months in the sheep suggested that the fattening phase might have begun. At this period the animals weighed 25 kg. Searle et al. (1972) and Searle and Griffiths (1975) reported that rapid accretion of fat in lambs occurs when their body weight was above 25 kg. In this fattening phase, the adipose cells are known to increase by both hyperplasia and hypertrophy while during the growth period adipose cell

growth is mainly by cell hyperplasia (Haugeback et al., 1974).

An increase in the proportion of body fat with age has been reported by several workers (Guenther, 1965; Jagusch et al., 1970; Rouse et al., 1970; Searle et al., 1972; Kellaway, 1973; Searle and Griffiths, 1975). This increase in the proportion of body fat was found to be more related to the body weight than to age per se. Thus age affects body fat only by its effect on body weight. In the present work, fat was significantly correlated to body weight in both species (0.6 and 0.71 in goats and lambs respectively). Multiple regression analysis (equations 1 and 2) indicated that body weight had a greater influence than age on body fat content in lambs, while in goats the opposite was true, suggesting that the two species differ in their fat deposition characteristics.

When comparison is made on an age basis between the two species receiving the same diet, the actual and proportion of body fat to body weight was higher in lambs than in goats at all ages, except at one month, when it was higher for goats.

Comparisons on a body weight basis were difficult because of insufficient overlap in range of body weight after weaning for the two species. It would appear, however, that below 18 kg body weight these goats contained more fat at a given weight than the lambs, but that the rate of increase was significantly less ($P < 0.001$) for goats (218g/kg weight increase) than for lambs (270g/kg).

Body fat in goats and lambs were described by the following linear regression equation.

Goats after weaning Body fat = 0.218 Bwt - 1.6986

In lambs Body fat = 0.270 Bwt - 2.6645

Bwt = body weight (kg)

This study covered only the first 3 of the 4 phases of ruminant growth as proposed by Searle et al. (1972), namely, milk feeding, rumen development and the pre-fattening ruminant phases. The rate of accumulation of fat by the lambs in this study is the same as that reported by Searle et al. (1972) in the pre-fattening phase for lambs fed ad libitum.

The higher rate of fat accumulation by lambs than goats indicates that lambs were genetically equipped to lay down more fat than goats. This would provide the sheep with some biological advantage in cold country where fat is both insulation and a food reserve. The goats would have less survival potential if they were without food in the cold than lambs. On the other hand, they would be better off in the heat.

Investigation in the fattening phase would have given useful information because it is in this phase that most differences in body composition occur. Rouse et al. (1970) reported that only one third of fat development in sheep occurred before lambs weighed 32 kg. Differences in fattening between sheep, pigs and cattle were observed at the highest stage of fattening (Graham and Searle, 1972).

Differences in body composition between goats and sheep have been reported. Fehr et al. (1976) observed a lower proportion of fat in carcasses of goats than in lambs, especially the subcutaneous fat. This was due to the poor development of subcutaneous adipose tissue in goats which does not permit optimum storage of fat. Eggen et al. (1973) observed a very low proportion of trimmed and chemical fat in goats, values ranging from 4 - 23% fat, while lamb carcasses can have from 11.8 - 36% fat (Searle and Graham, 1972). Goat meat is known to be leaner than sheep meat because of the patterns of fat deposition in the two species. Sheep deposit most of their fat in the subcutaneous and intermuscular adipose tissues (Murray and Slezacek,

1976), while goats deposit more fat in the omental and mesenteric depots (Devendra, 1977).

Although feeding pattern had no effect on the proportion of body fat in goats, in lambs the group fed twice daily had a slightly higher proportion of body fat than either of the other groups. These differences indicate that lambs fed twice daily were more efficient in converting feed into body fat than the group fed once daily, which probably mobilized more fat between meals than they deposited. Increase in fat deposition due to meal frequencies have been reported in several species.

In rats, meal eating is known to result in greater fat deposition than nibbling (Reid et al., 1968, Cohn and Joseph, 1959). This was attributed to an increase in the activity of lipogenic enzymes (Leveille and Hanson, 1966; Chakrabarty and Leveille, 1968). Walker (1970) obtained a higher backfat thickness in pigs fed four times a day compared with those fed twice or eight times daily. In ruminant animals, Reid et al. (1968) observed a higher proportion of fat in lambs fed eight times a day than in those fed once daily. The increase in efficiency of nutrient utilization in sheep with increased frequency of feeding was found to be due to a decrease in the heat increment after a meal (Graham, 1967; Faichney, 1968; Farrell, 1973).

Hunter (1967) reported that frequent meals depress plasma growth hormone and thus reduce the rate of release of FFA from adipose tissue and this leads to a net gain of body fat.

The lower level of body fat observed in the paddock group as compared to the stall fed groups at 5 and 6 months of age was mainly caused by the lower availability of pasture in summer. These animals were losing body weight as well. However, the proportion of body protein did not change, indicating preferential utilization of body

fat for energy while protein was spared.

(b) Total body water

The content of body water in the two species (Tables 16 and 17) increased as animals grew older, while its proportion to body weight decreased slightly with age, mostly between birth and 4 weeks of age in goats. The increase in volume of total body water indicates that as animals grow older the water spaces mainly extracellular, intracellular and trancellular increase due to increase in cell mass and size, while the decline in the proportion of water to body weight indicates that cells of younger animals are more hydrated, and as the animal grows older, they are replaced by less hydrated cells and tissues, mainly fat, collagen and fibrous tissues (Kamal and Seif, 1969).

The proportion of body water in goats was highest at 9 days of age and lower at the age of 1 and 5 months. This lower proportion of body water corresponded with higher proportions of body fat, indicating a negative relationship.

The decrease in the proportion of body water during growth has been reported (Searle, 1970a, b; Searle and Graham, 1972; Searle et al., 1972; Searle and Griffiths, 1975).

The subsequent increase in the proportion of body water after the initial decline, was mainly due to the decrease in body fat after weaning and probably an increase in the gut volume due to rumen development. An increase in the proportion of body water immediately after weaning has been observed. Kellaway (1973) reported a change in the relationship between the proportion of body water and body fat. Searle et al. (1972) observed a decrease in the proportion of body fat and an increase in body water at weaning.

Another factor which could account for the increase in body water

after weaning was the change in environmental temperature (from 17°C - 23°C). Increase in air temperature is known to increase body water and water turnover rate (Kamal and Seif, 1969; Macfarlane and Howard, 1974). This is mainly due to an increase in extracellular water.

In lambs the proportion of body water to body weight was highest at 1 to 2 months of age (Table 17) then declined to a relatively constant proportion of body weight. The higher values at the age of 1 and 2 months corresponded with low proportion of body fat at this age. The decline was also accompanied by an increase in the proportion of body fat.

Body water was significantly correlated to body weight, 0.991 and 0.934, and to body protein, 0.999 and 0.992 for goats and lambs respectively.

Goats had relatively higher proportions of body water than lambs. These differences are mainly due to higher proportions of protein and lower proportions of fat in goats as reported earlier for fat.

(c) Total body protein

Total body protein in the two species (Tables 18 and 19) increased significantly as animals grew older. It was significantly correlated to body weight in both species (0.972 and 0.996 for lambs and goats respectively). There was also a significant linear multiple regression between body protein, body weight and age. The proportion of protein to body weight was highest at younger ages, but later the proportion remained constant for most of the time. It declined slightly at the age of 6 months in lambs (Table 19) and 5 months in goats (Table 18). This finding indicates that increase in body weight of an animal is accompanied by an increase in body protein which bears a fairly constant proportion to the body weight up to a certain body

weight where it declines.

Protein is a major constituent of muscle (where it forms 21% (Branang, 1966)) and other organs and tissues such as liver, spleen and blood, and is found in most enzymes and some hormones.

Similar findings have been reported in different animals. Waldman et al. (1971) reported that carcass protein percent did not vary widely from birth to 590 kg live weight in Holstein steers, while Jesse et al. (1976) observed a decrease in empty body protein from 19.42% to 15% when steers increased in body weight from 227 kg to 545 kg. Guenther et al. (1965) reported that lean deposition reached its maximum rate during the early part of growth and diminished as the animal approached maturity. Rouse et al. (1970) reported that as lambs increased in liveweight from 32 kg to 50 kg, body lean decreased by 3.8%, while fat increased by 9.9%.

A decrease in the proportion of protein with age was observed at the stage where fattening starts (Searle et al., 1972; Searle and Griffiths, 1975). In the present work, probably the fattening phase was just starting at 6 months of age when the ratio of fat to protein was highest in lambs.

Goats had a slightly higher proportion of body protein than lambs at the same age. This indicates that goats utilized the dietary protein for tissue protein accretion more efficiently than lambs. This was reflected in the higher proportion of dietary protein retained by goats than lambs in a nitrogen balance trial (section 4.1.1.2). Goats were found to retain 35.8% of nitrogen intake, while lambs retained 27%. The differences were mainly due to loss of more nitrogen in the urine by lambs than by goats, since the animals had similar digestibilities of dietary nitrogen.

(d) Plasma proteins in goats and lambs

From the results in Tables 20 and 21 for goats and lambs respectively, it was clear that plasma proteins increased as animals grew older until near adult values were attained.

Goats in the present work had relatively low plasma protein concentrations at the age of 9 days, but these increased significantly to levels near adult concentrations at the age of 3 months. Similarly the plasma protein for lambs increased to near adult values of 6.5g/100 ml plasma at the age of 5 months.

This increase in plasma protein as animals grow older is in agreement with published findings. Plasma proteins of goats, kids, lambs and calves were found to contain only a small percentage of β globulin (6%), but higher percentages of α globulin (37%) and albumin (57%). After suckling there was a rapid increase in the γ globulin level due to the ingestion of colostrum which is rich in γ globulins with compensating decreases in albumin and α globulins (Jameson et al., 1942; McCarthy et al., 1953; Holliday, 1970). At the age of 5 or 6 weeks McCarthy et al. (1953) observed a decrease in the proportion of globulin in plasma protein, while that of albumin increased.

Heyns (1971) reported that the albumin fractions of the serum protein in cattle did not change significantly with age, while the globulin changed with age and that older animals had higher levels of globulin than young animals. In the present study, individual protein fractions were not analysed so it is hard to know which portion of plasma proteins contributed most to the increase in plasma protein with age. A significant positive correlation between age and serum protein level in the bovine was reported by Larson and Touchberry (1959). These authors observed that the increase in serum protein with age was mainly due to the increase in the β2, γ1, and γ2 immunoglobulins. A similar increase in plasma globulins with age in

reindeer calves was reported by Hyvarinen et al. (1975).

Although dietary treatment had no effect on plasma protein in goats, in lambs the grazing group had slightly higher plasma protein than the other two groups. It could be that the grazing animals were exposed to more antigens than the group indoors, thus they increased the synthesis of immunoglobulins. Similar findings were reported by Keightley (1971) who observed a higher level of plasma protein in lambs maintained in the field as compared to those maintained indoors.

4.1.2.4 Effect of age and feeding patterns on the fasting metabolic rate in goats and lambs

The higher fasting metabolic rate found during the milk stage in both lambs and kids (Tables 22 and 23) indicates that the animals expended more energy at younger ages than when older, due probably to rapid cell division and protein synthesis, differentiation and growth. The significant negative correlation observed between body protein and body fat with metabolic rate in goats (- 0.54 and -0.596 respectively) indicates that the metabolic rate is higher when these body components are lower, thus metabolic rate will decrease as animals grow older and accumulate these components. Graham and Searle (1972) observed higher maintenance requirements by lambs, as with the higher energy expenditure by the very young animals observed in this work.

High fasting metabolic rates in young suckling lambs have been reported by Graham and Searle (1970) who observed values as high as $434KJ/kg^{0.73}/24h$. Ritzman and Benedict (1930) obtained values as high as $551.76KJ/kg^{0.73}/24h$ in lambs at the age of 1 week. In the present work the fasting metabolic rate of month old lambs was $426KJ/kg^{0.75}/24h$ and that of goats at 9 days was $555.5KJ/kg^{0.75}/24h$. These values are slightly higher than those observed by Graham and Searle (1970), but similar to those of Ritzman and Benedict (1930). These differences

could be associated with the type and accuracy of the metabolimeter used, and with the lack of previous training of the animals. Graham and Searle (1970) used a closed circuit apparatus which is known to be more efficient, while in the present study an open circuit system was used. Graham (1967) suggested that lambs should be placed in the apparatus in pairs to avoid any upset due to isolation.

At 1 month the fasting metabolic rate of goats declined by 30% from 9 days of age and there was a slight decline at subsequent ages. This decrease in fasting metabolic rate agrees with the findings of Graham and Searle (1970) who observed a rapid decline in metabolic rate of young growing lambs. At the age of 2 months the fasting metabolic rate reported by these authors was one third of the value obtained at birth.

Alexander (1961) observed a rapid decline in fasting metabolic rate at the age of 2 months in lambs; 2.0 l.O_2/kg/h consumed when 2 months old compared to 3.5 l.O_2/kg during the first day of life. The decline in fasting metabolic rate with age could be accounted for by the decline in growth rate with age and accumulation of protein and fat which were negatively correlated with fasting metabolic rate in the present study. Graham et al. (1974) observed a higher fasting metabolic rate in lambs which had higher growth rates than those with lower growth rates.

The fasting metabolic rate in lambs after 2 months increased initially and declined subsequently. The increase in fasting metabolism at 4 months could be due to the effect of shearing as animals were shorn 2 weeks before the metabolic rate measurement. Shearing is known to increase the metabolism because of heat loss and extra maintenance requirements. The cause of the higher metabolic rate could be the extra energy requirement for heating the body and for wool growth.

Farrell and Corbett (1970) also observed an increase in fasting metabolic rate of lambs after shearing. They reported that the return to pre-shearing values was not observed until after 135 days. Whether shearing could be the cause of the increase in metabolic rate in the present finding is questionable, because Farrell and Corbett's sheep were grazing in the field where they were exposed to weather variations, while sheep in the present work were kept indoors save for the 3 animals in the paddocks.

Feed

Although feeding pattern had no significant effect on fasting metabolic rate, this was consistently lower for the grazing group than for the animals indoors. This lower metabolic rate could be due to the type and amount of nutrient which was available to the animals in paddocks. The level of feed intake is known to affect fasting metabolism (Frisch and Vercoe, 1977; Graham and Searle, 1974).

The paddock group were eating less than those kept indoors especially during the months of October to December when pasture available to the animals was low in nutrient content. In the wet season pasture was plentiful and the animals had a slightly higher metabolic rate than the other groups at the age of 2 months.

When comparison is made between the two species on an age for age basis, the lambs had consistently higher metabolic rates than goats and there was more variability between individuals in lambs than for goats. The higher metabolic rate for lambs than for goats indicates species variation which suggests that these goats were more adapted to areas where food is scarce. This is the reason why they can survive in the regions where other ruminants cannot.

Species differences in fasting metabolic rate have been reported (Brody, 1945; Blaxter and Wainman, 1966; Graham and Searle, 1972).

The variability in fasting metabolic rate observed in lambs could be that the animals were restless in the chamber due to isolation, while goats were more calm since they were introduced to the chamber at a very young age and grew to accept that procedure.

4.1.2.5 Effect of age and feeding patterns on the water turnover rate in lambs and goats

The water turnover rate in goats (Table 24) was highest when they were 9 days old. The rate declined steadily to a minimum level at 2 months of age, immediately after weaning. The higher rate of water turnover at 9 days is likely to be due to the intake of milk, which was 75% - 80% water. The animals drank more than 900 ml of milk daily. Extra water was also produced from oxidation of the hydrogen in milk solids. High water turnover rates in suckling animals have been reported (Siebert, 1971; Keightley, 1971; Macfarlane et al., 1974). These authors found that the water turnover rate was related to the milk intake by these animals. The higher proportion of water (83% or more) in the tissues of young animals is associated with a higher rate of water turnover. The rate of water turnover is known to be closely related to energy metabolism (Macfarlane et al., 1974) and the rates observed in these goats at the time when water turnover was high, agrees with these authors' reports. The higher metabolic rate helps to determine the demand for water.

After 30 days the rate of water use in the goats had declined by 32% and metabolic rate (Table 22) by 33%. This decrease in water turnover rate was accompanied by a decrease in the proportion of total body water (Table 16), 72% of body weight indicating that the tissues were becoming less hydrated thus reducing water turnover. Keightley (1971) observed a 50% decrease in water turnover of lambs at 30 days

of age when compared to that at 4 days, supporting the results reported here.

After weaning, the decline in water turnover of the animals kept indoors (but not in the grazing group) was partly due to change in the diet from liquid feeds to dry lucerne hay. Another factor was the low energy intake of the animals as was shown by the higher level of plasma FFA (Table 26) at this period as they adapted to change of feed. Water turnover or intake has been shown to be related to the amount of feed intake (Siebert, 1971; Macfarlane et al., 1974).

After the initial decrease at weaning, water turnover of the animals kept indoors increased steadily with age to levels as high as those observed during milk drinking stage in lambs (Table 25), but it was slightly lower in goats. This increase in water turnover as animals grew older was contrary to what was expected. Water turnover is known to decrease as animals grow older, due to the reduction of metabolic rate, and to the increase in the mass of less hydrated tissues such as fat. Macfarlane and Howard (1970) reported a higher water turnover in young lambs than in hoggets and adult sheep. However the increase in water turnover of the goats and sheep with age could be accounted for partly by the increase of food intake as they adapted to hay and partly to the rise in environmental temperature as indicated (in Appendix Table Y). The environmental temperatures increased from October, 1977 to December, remaining high through February, 1978. The higher water turnover rates were observed during the months where temperatures were highest.

Increase in water turnover and water intake in animals due to increase in ambient temperature have been reported (Macfarlane et al., 1966; McDowel et al., 1969). This increase in water turnover was mainly due to the amount of water required for evaporative cooling (Macfarlane et al., 1966).

Effect of feeding patterns on water turnover

The major effects of feeding patterns on the turnover of water were observed in the group of lambs grazing in the paddock. These animals had water turnover rates significantly higher than the groups kept indoors. This greater use of water (observed in the months of August, September and October) was due to the consumption of winter pasture which comprised more than 85% water (Table 2). There was also extra water on the surface of the grass from the rainfall which was slightly higher during this period than in summer (Appendix Table Y). As the dry matter content of the feed was low, the animals had to eat more to meet their energy needs, hence increasing their water turnover rates.

A higher water turnover of sheep grazing winter pasture has also been reported by Macfarlane and Howard (1970) and Keightley (1971).

During late spring and summer (November, December and January) the water turnover of the paddock group was slightly lower than that for the indoor groups. This difference could be accounted for by the scarcity of feed and the dry quality of feed which was available to the grazing animals as pasture became desiccated in summer.

There were no significant differences in water turnover rates between the two feeding regimens for the groups kept indoors. However the twice daily fed group of goats had consistently higher water turnover rates than the group fed once daily. The greater turnover of water in goats fed twice each day during the milk feeding stage can be accounted for by the amount of water taken in their milk, since the milk had 80% water. For those fed once daily the water content was 75% to reduce the volume of intake without affecting dry matter intake.

Thus although there was free water available during the milk stage of feeding, it seems that the animals obtained their water from milk

only.

During hay feeding, possible causes for the increase in water turnover in the group fed twice each day would be an increase in water intake to compensate for the lower level of feed available to them during daytime. Drinking due to boredom was also possible.

While the twice daily fed groups of goats had slightly higher rates of water turnover, the opposite was observed in lambs where those fed once a day had slightly higher water turnover rates during the summer months (November and December). This could be due to an increase in heat production when the animals ate their whole ration in a short period and thus they would need more water for cooling.

The sex distribution in the two groups could have been a cause of difference, however, since there were more males (2 males, 1 female) in the once daily fed group of lambs and more males (2 males, 1 female) in the twice daily fed goats. Males are known to have slightly higher water turnover rates than females, at least in sheep (Macfarlane and Howard, 1970).

It is difficult to draw an age to age comparison between goats and lambs because of differing environmental conditions. For example, the goats did not become available until the lambs were 2 months old, and thus most of the measurements with goats which could correspond in age with those of lambs, were made during a different warmer season. During the same season, however, the lambs had higher water turnover rates than goats, especially during the hot summer months.

The lower turnover rate generally in goats when compared to lambs suggests that the goats would be better adapted to drier regions. This would be consistent with their evolution in drier areas.

Higher water turnover rates in sheep than in goats grazing in the same environment in tropical Africa have been reported (Macfarlane,

1964). The lower water turnover in goats would be associated with reduction in urine volume and reduction in water loss through faeces. Smaller volumes of urine and slightly drier faeces were observed in goats than lambs. Dry matter content of goats' faeces ranged from 39% - 42%, while in lambs it ranged from 32% - 40%. Average volume of urine passed daily was 1867.5 ml for lambs and 1045.3 ml for goats.

4.1.3 Summary

(a) Growth rate, food intake and nitrogen and energy balance in goats and lambs

1) During milk feeding goats gained relatively more body weight/day than after weaning, indicating greater efficiency during milk feeding.

2) The goats fed twice daily had slightly higher growth rate, both before and after weaning, than those fed once daily, indicating a greater efficiency in the conversion of nutrients to body tissues by this group.

3) Between 2 and 7 months of age, a linear relationship existed between food consumption and age and lambs consumed 15% more than goats fed the same diet at the same age.

4) Although goats were smaller than lambs between 2 and 7 months they grew 21% faster than lambs, ate relatively more feed/kg Bwt and had higher feed conversion efficiency than lambs.

5) Goats and lambs had similar efficiency in the digestibility of nitrogen and energy, and utilization of dietary energy as metabolizable energy, but goats retained more of the dietary protein than lambs (35.8% and 27% respectively).

(b) Body composition

The increase in body weight as animals grew older was accompanied by an increase in the three major body components, fat, protein and

water, which agreed with the accepted concept, that growth is the sum total of increase in all tissues and organs by the addition of intracellular and extracellular material.

1) The low proportion of body fat observed in the goats at 9 days of age agrees with reports by Widdowson, (1950), Alexander, (1962), and Jagusch et al., (1970) in young animals.

2) The increase in proportion of body fat in goats at one month of age resulted from the deposition of fat obtained from milk which had 17% crude fat. This was in agreement with the findings of Searle et al. (1972).

3) After weaning the decrease in body fat was attributed to change in diet, decrease in efficiency of nutrient utilization caused by development of the rumen, reduced feed intake and increased fat mobilization. Similar decreases in body fat after weaning were reported by Searle et al. (1972), Graham and Searle (1972), and Black (1974). On the whole the proportion of fat after weaning increased after the initial decline to a level which remained relatively constant and increased towards the end of the experiment, suggesting commencement of the fattening phase.

4) The lambs were found to be slightly fatter than goats at the same age and body fat in lambs was influenced mostly by body weight, age having little effect. In goats, however, body fat was influenced more by age than by body weight. Lambs fed twice daily deposited more fat than the other two groups, but this difference was not observed in goats.

5) The increase in body water content as animals grew older was accounted for by the increase in water spaces (extracellular, intracellular and trancellular) as cell mass and size increased, while the decrease in its proportion to body weight was brought

about by the increase in less hydrated tissue, mainly fat, collagen and fibrous tissues (Kamal and Seif, 1969). Decrease in proportion of water as animals grow older is well documented (Searle, 1970a, b; Searle and Graham, 1972; Searle et al., 1972).

The increase in the proportion of body water immediately after weaning was caused by the decrease in body fat, and probably by the increase in gut volume resulting from development of the rumen. Goats had a slightly higher proportion of water than lambs.

6) Body protein increased with age and was significantly correlated to body weight in both species. The proportion of body protein to body weight was relatively constant with age and showed a slight decline at the age of 6 months in lambs and 5 months in goats. As protein is an important component of all tissues, forming 21% of muscle, its proportion is maintained relatively constant. The slight decrease at later ages indicates that during the fattening phase, the proportion of body protein declines.

Goats were found to have a slightly higher proportion of body protein than lambs and this was mainly due to the ability of goats to retain relatively more of the dietary protein than lambs.

7) Plasma protein in both species increased significantly with age to near adult values at 3 and 4 months. This agreed with other published observations. The increase is mostly contributed by the increase in globulins (Heyns, 1971). The lambs grazing in the paddocks had higher plasma protein than the indoor fed groups indicating an increase in the synthesis of immunoglobulins resulting from the exposure to more antigens.

(c) Fasting metabolic rate

Higher fasting metabolic rates were observed during milk feeding in both species, indicating that animals were expending more energy during rapid cell division, protein synthesis and growth. This high metabolic rate supports the findings of Graham and Searle (1970).

At 1 month of age there was a significant decrease in fasting metabolic rate in goats which resulted from an increased accumulation of protein and body fat, both of which were negatively correlated to metabolic rate. This agrees with the findings of Alexander (1961) and those of Graham and Searle (1970).

At weaning the fasting metabolic rate of lambs decreased while that of goats did not change further.

Shearing was followed by an increase in fasting metabolism in lambs at 4 months of age, and this resulted from extra energy requirements for wool growth and for protection against weather.

Feeding patterns had no significant effect on fasting metabolic rate, although the grazing group had a slightly lower metabolic rate overall.

Goats generally had lower fasting metabolic rates than lambs.

(d) Water turnover

1) The high water turnover rate observed in 9 day old goats resulted from ingestion of milk which was 75% - 80% water, and the higher proportion of water in their tissues. Similar high rates of water turnover in young animals were reported by Keightley (1971), Siebert (1971) and Macfarlane *et al*. (1974).

2) The decrease in water turnover at the age of 1 month was associated with the decrease in total body water and the increase in proportion of body fat. Similar observations were reported by Keightley (1971).

3) After weaning the decrease in water turnover rate in the group kept indoors resulted from both change in diet from liquid to dry feed and to low energy intake.

4) The increase in water turnover rate after the initial decrease was associated with an increase in food intake and a rise in environmental temperature (17°C - 23°C); increase in water turnover rate with increase in environmental temperature has been reported (Macfarlane et al., 1966; McDowel, 1969).

5) The higher water turnover rate observed in the grazing group of lambs after weaning was caused by the consumption of winter pasture which contained more than 85% water and rain water on the surface of the grass, as previously reported by Macfarlane and Howard (1970) and Keightley (1971). The decrease observed in this group from November onwards was due to low feed intake as pasture became desiccated in summer.

6) The slightly higher water turnover observed in goats fed twice daily during milk stage resulted from the water content of the milk fed to them while after weaning the higher rate was probably produced by drinking to fill the empty stomach, boredom or by a difference in sex ratio between the two groups. The higher rate for lambs fed once daily was mostly due to sex ratio.

The lower water turnover in goats than in lambs indicated a species difference and this was accompanied by higher feed intake by lambs and higher urine flow rate.

4.2 PLASMA LIPIDS, AGE AND FEEDING PATTERN

4.2.1 RESULTS

4.2.1.1 Plasma FFA in goats and lambs

Total plasma FFA in goats (Table 26 and Fig. 3) changed significantly with age. The concentration increased significantly ($P < 0.001$) for the first 2 months of age over the concentration at 9 days of age, then declined. At 3 and 4 months of age, concentrations were significantly lower ($P < 0.01$) than at 2 months, but significantly higher ($P < 0.01$) than at 9 days of age.

Feeding pattern together with age had a slight but not significant effect on the concentration of fasting plasma FFA. The concentration for the group fed once daily was lower than that of the group fed twice daily at 9 days and 4 months, but higher at 1, 2 and 3 months of age.

The highest concentration for both groups was obtained when the animals were 2 months old, which was immediately after weaning. Hence animals were more sensitive to fasting at this age.

In lambs (Table 27 and Fig. 4) the concentration of plasma FFA decreased significantly with age. The concentrations at 1 and 2 months of age were significantly higher than those at 3 months ($P < 0.05$), 4 months ($P < 0.01$) or 5 months ($P < 0.001$).

Feeding patterns had no significant effect on the fasting concentration of plasma FFA nor did the interaction between feed and age. However, there were slight differences in the pattern of concentration change with age. The group of animals fed once daily had the highest concentration at the age of 2 months, while the highest concentration for the other two groups was at the age of 1 month. At 4 months, the grazing group had a higher concentration of plasma FFA than the indoor groups.

FIGURE 3 shows the effect of age and feeding patterns on the fasting concentration of plasma FFA in goats (mean µg/ml plasma) Each point represents a mean for 3 animals.

FIGURE 3

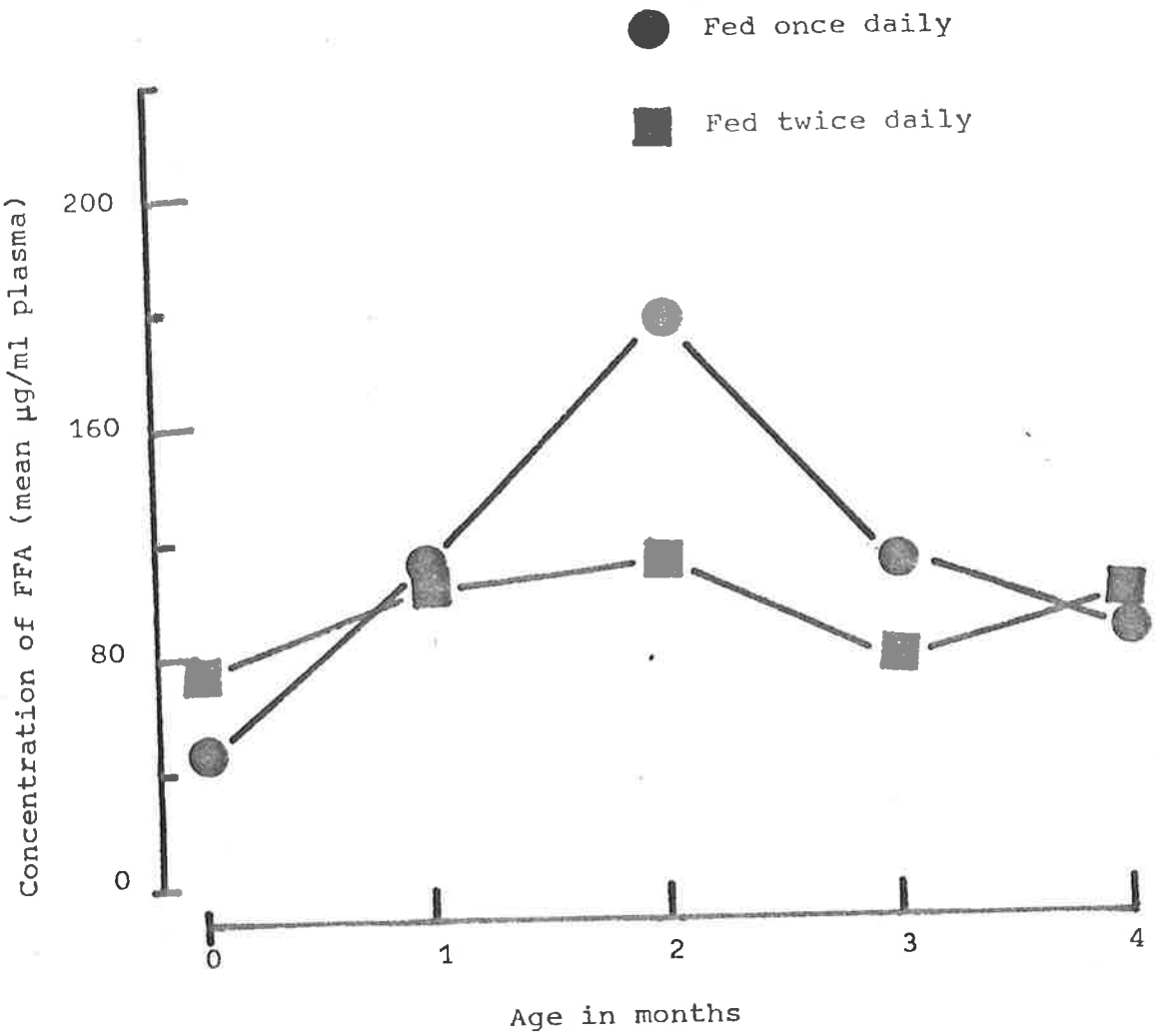
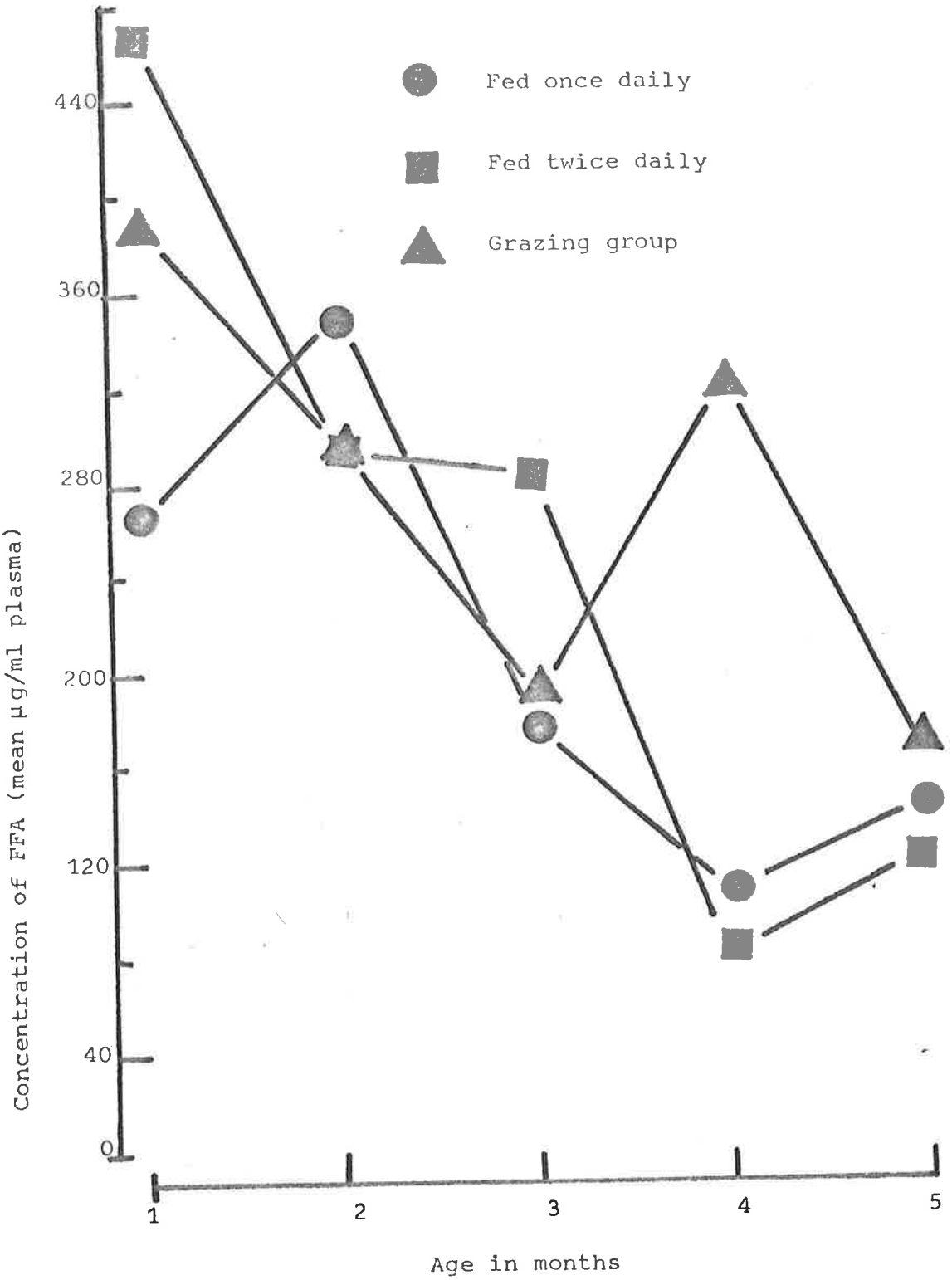

Fed once daily
Fed twice daily
Concentration of FFA (mean µg/ml plasma)
200
160
80
0
0
1
2
3
4
Age in months

FIGURE 4 shows the effect of age and feeding patterns on the fasting concentration of plasma FFA in lambs (mean µg/ml plasma). Each point is a mean for 3 animals.

FIGURE 4


Fed once daily
Fed twice daily
Grazing group
440
360
280
200
120
40
0
Concentration of FFA (mean µg/ml plasma)
1
2
3
4
5
Age in months

4.2.1.2 Total saturated and unsaturated fatty acids

(a) Saturated fatty acids

The concentration of free saturated fatty acids in goats (Table 28 and Fig. 5) increased significantly ($P < 0.001$) at 1 month of age compared to the concentration at 9 days of age. The concentration increased slightly at 2 months then decreased at 3 months of age. There was no significant difference between the concentrations of saturated fatty acids from 1 month to 4 months.

Neither feeding regimen nor their interaction with age had a significant effect on the concentration of saturated fatty acids. The once daily feeding group had slightly higher concentrations at 1, 2 and 3 months and slightly lower concentrations at 9 days and 4 months of age, than the group fed twice daily.

Saturated free fatty acids concentrations in lambs (Table 29 and Fig. 6) decreased as animals grew older. The concentrations at 4 and 5 months of age were significantly lower than those at 1 month ($P < 0.001$), and lower, but not significantly, than the concentrations at 2 and 3 months.

Feeding patterns or their interaction with age had no significant effect on the concentration. The once daily fed group, however, had slightly lower concentrations than the other two groups. At 4 months of age, the grazing group had a slightly higher concentration of saturated free fatty acids than the other two groups.

(b) Unsaturated fatty acids

Table 30 and Fig. 5 show that age had a significant effect on the concentration of unsaturated free fatty acids in goats. There was a significant increase for the first 2 months, followed by a significant decline. The concentration at 1 month was significantly higher ($P < 0.001$) than the concentration at 9 days and significantly

lower ($P < 0.01$) than the concentration at 2 months. After 2 months of age, the concentration of unsaturated fatty acids declined to a level significantly lower ($P < 0.001$) at 3 and 4 months than the concentration at the age of 2 months, but significantly higher ($P < 0.05$) than the concentration at 9 days of age.

In lambs, the concentration of unsaturated free fatty acids (Table 31 and Fig. 6) decreased significantly with age. The concentrations at 1 and 2 months were significantly higher ($P < 0.05$) than at the age of 3 months or 4 months ($P < 0.01$) and 5 months ($P < 0.001$).

There was no significant effect due to feeding patterns or their interaction with age. The group fed once daily had a slightly lower concentration of unsaturated fatty acids than the other groups. At 3 months of age, the group fed twice daily had slightly higher concentrations of unsaturated fatty acids than the other groups, while the grazing group had slightly higher concentrations than the other two groups at the age of 4 months.

(c) Ratios saturated/unsaturated fatty acids

The ratios of saturated/unsaturated fatty acids in goats as affected by age and feeding patterns are presented in Table 32. Both age and feeding patterns had a significant effect on the ratios. The ratios decreased significantly ($P < 0.05$) up to the age of 2 months. Thereafter they increased significantly ($P < 0.001$) at 3 and 4 months when compared to the ratios at 1 and 2 months. This shows that the concentration of unsaturated free fatty acids increased with age above that of saturated fatty acids up to 2 months, then it declined faster than that of saturated fatty acids in the later ages.

The ratio for the once daily fed group was significantly lower than for the group fed twice daily ($P < 0.05$). The differences were

FIGURE 5 shows the effect of age on the concentration of plasma saturated and unsaturated free fatty acids in goats (mean µg/ml plasma). Each point is a mean for 6 animals.

FIGURE 5

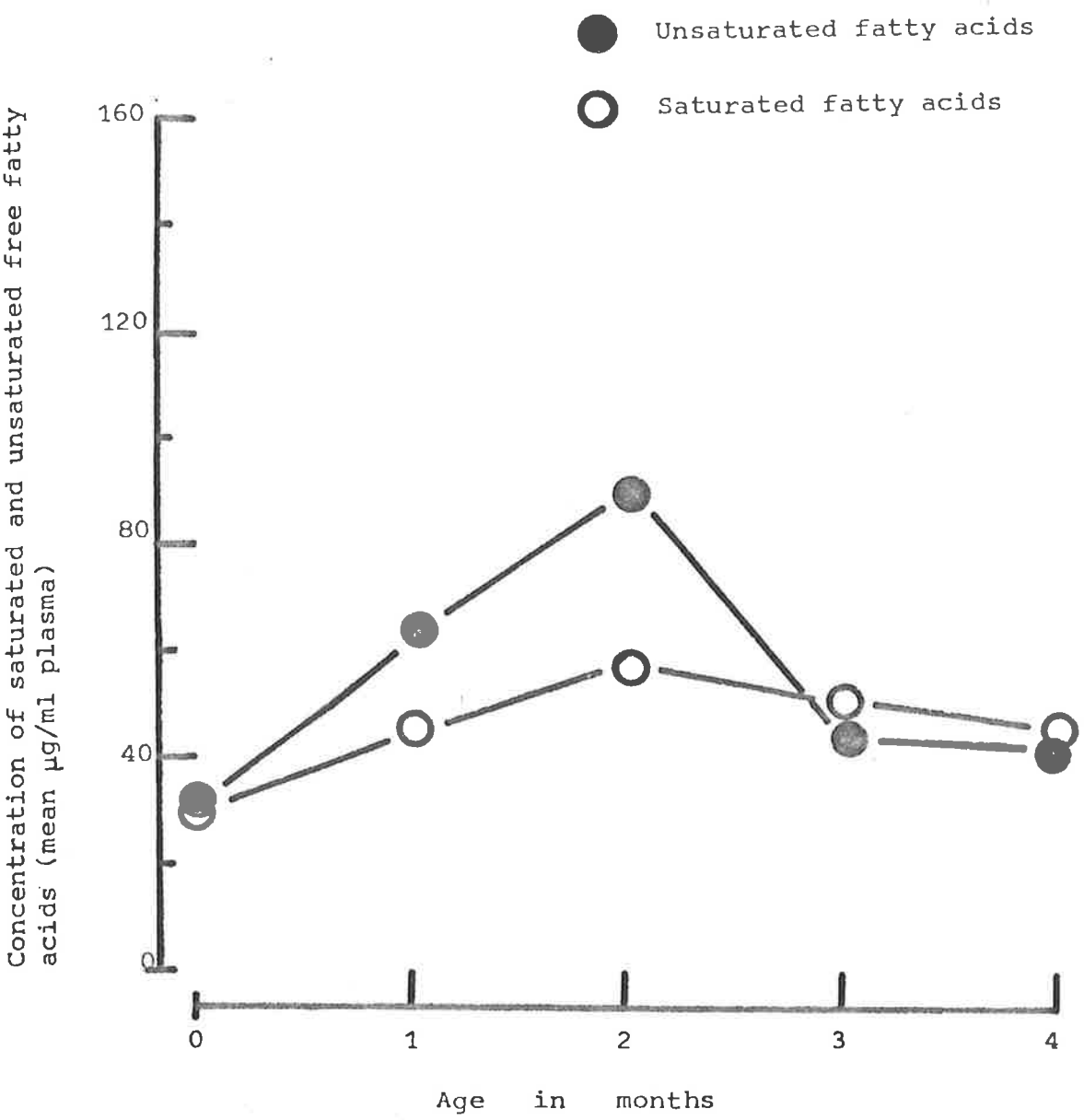

Unsaturated fatty acids
Saturated fatty acids
Concentration of saturated and unsaturated free fatty acids (mean µg/ml plasma)
160
120
80
40
0
0
1
2
3
4
Age in months

FIGURE 6 shows the effect of age on the concentrations of plasma saturated and unsaturated free fatty acids in lambs (mean μg/ml plasma) Each point is a mean for 9 animals.

FIGURE 6

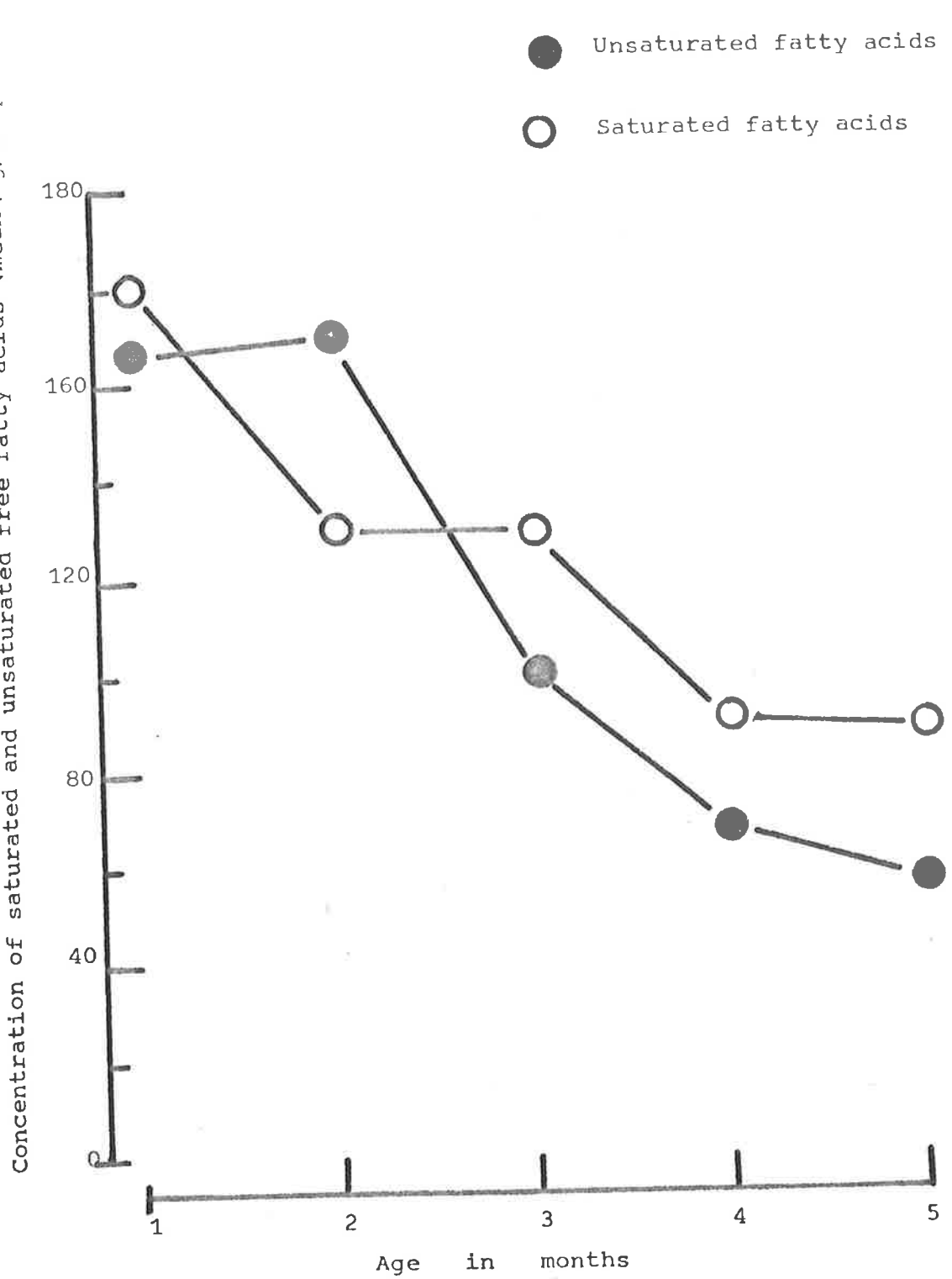

Unsaturated fatty acids
Saturated fatty acids
Concentration of saturated and unsaturated free fatty acids (mean µg/ml plasma)
180
160
120
80
40
0
1
2
3
4
5
Age in months

Table 26

Effect of age and feeding on fasting plasma FFA concentration in goats (mean µg/ml plasma)

Age (in months)	Total FFA concentration (µg/ml plasma) Feeding regimen: Fed once daily	Fed twice daily	Effect of age means
0 (9 days)	(46.7) 3.866	(74.4) 4.25	(60.6) 4.058
1	(111.3) 4.701	(105.2) 4.653	(108.2) a 4.677
2	(198.3) 5.220	(113.6) 4.731	(155.9) b 4.975
3	(112.3) 4.701	(76.1) 4.343	(94.2) c 4.522
4	(88.4) 4.482	(98.8) 4.581	(93.6) c 4.532
Feed mean	(111.4) 4.594	(93.6) 4.512	(102.5) 4.553

		LSD 5%	1%	0.1%
SED effect of feed means	0.1267			
SED effect of age means	0.1432	0.3036	0.4183	0.5749
SED effect of feed x age means	0.221	0.4685	0.6455	0.8873
SED effect of within feed means	0.2025			

n = 6

(a) Concentration at 1 month significantly higher than at 9 days ($P < 0.001$).

(b) Concentration at 2 months significantly higher than at 1 month ($P < 0.05$).

(c) Concentration at 3 and 4 months significantly lower than at 2 months ($P < 0.01$) and significantly higher than at 9 days ($P < 0.01$).

N.B. All statistical analyses (in Tables 26-31, 34-37, 40-51, 54-57, 60-67) were performed on the ln transformation of the original data. The original means are enclosed in brackets.

Table 27

Effect of feeding frequency and age on fasting plasma FFA concentration in lambs (mean µg/ml plasma)

Plasma FFA concentration µg/ml

Feeding regimen

Age (months)	Fed once daily	Fed twice daily	Grazing Paddocks	Effect of age
1	(267) 5.567	(468) 6.173	(389) 5.922	(374) 5.887
2	(350) 5.681	(293) 5.677	(294) 5.657	(312) 5.672
3	(175) 5.113	(284) 5.522	(191) 5.249	(216) a 5.295
4	(108) 4.548	(85) 4.284	(321) 5.68	(171) b 4.931
5	(145) 4.971	(121) 4.711	(170) 5.110	(145) c 4.837
Effect of feed	(209) 5.176	(250) 5.273	(273) 5.523	(244) 5.324

			5%	1%	0.1%
SED effect of age means	0.2356	LSD	0.4994	0.6882	0.9459
SED effect of feed means	0.1575				
SED effect of feed x age means	0.3975				
SED within feed means	0.4080				

n = 9

(a) Concentration at 3 months significantly lower than at 1 month ($P < 0.05$).

(b) Concentration at 4 months significantly lower than at 1 month ($P < 0.01$).

(c) Concentration at 5 months significantly lower than at 1 month ($P < 0.001$).

Table 28

Effect of age and feeding on the concentration of plasma free saturated fatty acids in goats (mean µg/ml plasma)

Saturated fatty acids concentration µg/ml

Age (months)	Feeding regimen: Fed once daily	Fed twice daily	Effect of age means
0 (9 days)	(22.5) 3.149	(37.7) 3.586	(30.1) 3.368
1	(46.4) 3.85	(43.7) 3.782	(44.8) a 3.816
2	(67.2) 4.167	(47.5) 3.87	(57.4) a 4.018
3	(56.3) 4.041	(43.8) 3.8	(50.1) a 3.92
4	(45.7) 3.832	(54.8) 3.98	(50.2) a 3.906
Effect of feed	(47.6) 3.808	(45.4) 3.804	(46.5) 3.806

			5%	1%	0.1%
SED Effect of feed means	0.1085	LSD			
SED Effect of age means	0.1403		0.2974	0.4098	0.5633
SED Effect of age x feed means	0.2080				
SED Within feed means	0.1985				

(a) Concentrations at 1, 2, 3 and 4 months significantly higher than at 9 days of age ($P < 0.001$).

Table 29

Effect of feeding frequency and age on fasting concentration of plasma free saturated fatty acids in lambs (mean μ g/ml plasma)

Concentration of saturated free fatty acids (μg/ml plasma)

Age (months)	Feeding regimen: Fed once daily	Fed twice daily	Grazing Paddocks	Effect of age means
1	(138.8) 4.922	(228.6) 5.474	(177.8) 5.134	(181.8) 5.177
2	(125.6) 4.765	(131.3) 4.869	(132.2) 4.831	(129.7) 4.822
3	(92.9) 4.504	(160.4) 4.979	(96.3) 4.549	(116.6) 4.677
4	(59.6) 4.031	(59.9) 3.956	(151.4) 4.936	(90.3) a 4.308
5	(86.9) 4.462	(75.1) 4.243	(103.3) 4.620	(88.4) a 4.442
Effect of feeding	(100.8) 4.537	(131.6) 4.704	(132.2) 4.814	(121.35) 4.685

			5%	1%	0.1%
SED Effect of feed means	0.1401	LSD			
SED Effect of age means	0.2007		0.4255	0.5862	0.8058
SED Effect of age x feed means	0.3410				
SED Within feed means	0.3476				

(a) Concentrations at 4 and 5 months significantly lower than at 1 month ($P < 0.001$).

Table 30

Effect of feeding patterns and age on the concentration of plasma free unsaturated fatty acids in goats (mean µg/ml plasma)

Age (months)	Concentration of unsaturated fatty acids µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Effect of age means
0 (9 days)	(24.3) 3.227	(36.7) 3.551	(30.5) 3.389
1	(64.9) 4.157	(62.1) 4.126	(63.5) a 4.141
2	(114.2) 4.706	(66.1) 4.196	(90.1) b 4.451
3	(55.9) 3.979	(32.3) 3.498	(44.1) cd 3.739
4	(42.7) 3.765	(44.0) 3.797	(43.4) cd 3.781
Effect of feeding	(60.4) 3.967	(48.2) 3.834	(54.3) 3.900

			5%	1%	0.1%
SED Effect of feed means	0.1244	LSD			
SED Effect of age means	0.1537		0.3258	0.449	0.6171
SED Age x feed means	0.2308				
SED Within feed means	0.2174				

(a) Concentration at 1 month significantly higher than at 9 days ($P < 0.001$).

(b) Concentration at 2 months significantly higher than at 1 month ($P < 0.01$).

(c) Concentrations at 3 and 4 months significantly lower than at 2 months ($P < 0.01$).

(d) Concentrations at 3 and 4 months significantly higher than at 9 days ($P < 0.05$).

Table 31

Effect of feeding patterns and age on the fasting concentrations of plasma free unsaturated fatty acids in lambs (mean µg/ml plasma)

Age (months)	Concentration of free unsaturated fatty acids µg/ml Feeding regimen Fed once daily	Fed twice daily	Grazing Paddocks	Effect of age means
1	(127.7) 4.830	(185.1) 5.288	(191.0) 5.23	(167.9) 5.116
2	(190.1) 5.2475	(161.0) 5.077	(161.6) 5.078	(170.9) 5.141
3	(82.1) 4.336	(123.2) 4.655	(94.3) 4.556	(99.9) a 4.516
4	(35.3) 3.463	(25.2) 3.064	(144.8) 4.887	(68.5) b 4.2268
5	(63.4) 4.121	(45.5) 3.73	(66.3) 4.169	(58.4) c 4.0673
Effect of feed	(99.7) 4.36	(108.0) 4.6821	(131.6) 4.8751	(113.1) 4.502

			5%	1%	0.1%
SED Feed means	0.1606	LSD			
SED Effect of age means	0.2483		0.5264	0.7253	0.9969
SED Effect of feed x age means	0.4169				
SED Within feed means	0.4301				

(a) Concentration at 3 months significantly lower than at 1 and 2 months ($P < 0.05$).

(b) Concentration at 4 months significantly lower than at 1 and 2 months ($P < 0.01$).

(c) Concentration at 5 months significantly lower than at 1 and 2 months ($P < 0.001$).

Table 32

Effect of age and feeding patterns on the ratios of saturated to unsaturated plasma free fatty acids in goats (mean)

Age (months)	Ratios saturated/unsaturated Feeding regimen Fed once daily	Fed twice daily	Age mean
0 (9 days)	0.939	1.049	0.994
1	0.740	0.708	0.724 a
2	0.582	0.718	0.650
3	1.096	1.377	1.237 b
4	1.076	1.232	1.154 b
Effect of feed	0.887 c	1.017	0.952

			5%	1%	0.1%
SED Effect of feed means	0.0511	LSD	0.1083	0.1493	0.2052
SED Effect of age means	0.1202		0.2548	0.3511	0.4826
SED Effect of feed x age	0.1604				
SED Within feed means	0.1700				

(a) The ratio at 1 month significantly lower than at 9 days ($P < 0.05$).

(b) The ratios at 3 and 4 months significantly higher than at 1 and 2 months ($P < 0.001$).

(c) Ratios for once-daily fed animals significantly lower than for twice-daily fed animals ($P < 0.05$).

Table 33

Effect of feeding patterns and age on the ratios of plasma saturated to unsaturated free fatty acids in lambs (mean)

Ratios saturated/unsaturated fatty acids

Age (months)	Feeding regimen: Fed once daily	Fed twice daily	Grazing Paddocks	Effect of age
1	(1.100) 0.741	(1.194) 0.787	(0.912) 0.647	(1.069) 0.725 a
2	(0.784) 0.571	(0.836) 0.602	(0.797) 0.582	(0.805) 0.585
3	(1.202) 0.786	(1.406) 0.874	(1.022) 0.697	(1.210) 0.785 b
4	(1.825) 1.032	(2.548) 1.263	(1.061) 0.721	(1.811) 1.005 c
5	(1.432) 0.884	(1.758) 0.998	(1.600) 0.950	(1.597) 0.944
Effect of feed	(1.268) 0.803 d	(1.548) 0.905	(1.078) 0.719 e	(1.298) 0.809

			5%	1%	0.1%
SED Effect of feed means	0.0397	LDS	0.0842	0.1159	0.1594
SED Effect of age means	0.0600		0.1272	0.1753	0.2409
SED Age x feed means	0.1011				
SED Within feed means	0.1039				

(a) Ratio at 1 month significantly higher than at 2 months ($P < 0.05$).

(b) Ratio at 3 months significantly higher than 2 months ($P < 0.01$).

(c) Ratio at 4 months significantly higher than at 3 months ($P < 0.01$).

(d) Ratios for the twice daily fed group significantly higher than the ratios for the once daily fed group ($P < 0.05$).

(e) Ratios for the twice daily fed group significantly higher than the ratios for the grazing group ($P < 0.001$).

considerable at all ages except at 1 month of age, when they were almost the same.

In lambs, the ratios of saturated to unsaturated fatty acids (Table 33) were affected significantly by both age and feeding patterns. The ratio at 1 month was significantly higher than that at the age of 2 months ($P < 0.05$), but not significantly different from the ratio at 3 months. The ratio at 3 months was significantly higher than at 2 months ($P < 0.01$), but significantly lower than the ratios at 4 and 5 months of age ($P < 0.01$).

The ratios for the group fed twice daily were significantly higher ($P < 0.05$) than for those fed once daily or for the grazing group ($P < 0.001$).

The interactions between feed and age had no significant effect on the ratios. The ratios for sheep fed twice each day were always higher than those for the other two groups.

4.2.1.3 Individual free fatty acids

(a) Stearic acid

From the results given in Table 34 and from the analyses of variance, it appears that age had a significant effect on the concentration of plasma free stearic acid in goats. The concentration at 1 month of age was significantly higher ($P < 0.01$) than the concentration at 9 days, but significantly lower ($P < 0.01$) than the concentration at 2 months. The concentration at 2 months was not significantly different from those at 3 and 4 months of age. There was a slight feed x age interaction on the concentration of free stearic acid in plasma. The group of animals fed once daily showed an increase for the first 3 months with a peak at the age of 2 months followed by a slight decline at the age of 3 and a significant decline at the age of 4 months. While the group fed twice daily displayed a

steady increase of this fatty acid, the highest concentration was observed at the age of 4 months.

In lambs (Table 35 and Fig. 8) there was no significant effect due to age or feeding patterns on the concentration of plasma free stearic acid. However, the highest concentrations were observed at 1 month and the lowest at 4 months when taking the overall age effect. In individual feeding groups the concentration at 4 months was the lowest for the two indoor groups, while it was the highest in the grazing group.

(b) Oleic acid

From Table 36 and from analyses of variance, it was observed that age and age x feeding regimen had a significant effect on the concentration of fasting free oleic acid in goats. The concentration increased significantly for the first 2 months and then declined. The concentration at 1 and 2 months was significantly higher than the concentration observed at the age of 9 days ($P < 0.001$). Furthermore the concentration at 2 months was significantly higher ($P < 0.05$) than the concentration at the age of 1 month.

The concentration after 2 months of age declined to a level significantly lower at 3 and 4 months than the concentration at 2 months ($P < 0.001$) and 1 month ($P < 0.01$), but was significantly higher than the concentration at 9 days of age ($P < 0.01$).

There were significant feed x age interactions. The group fed once daily had significantly lower oleic acid concentration than the group fed twice daily at 9 days ($P < 0.05$) and significantly higher concentrations at 3 months than the twice-daily fed group. On all other occasions the concentration of oleic acid in the once-daily feeding goats was slightly higher or similar to that of the twice daily feeding goats.

FIGURE 7 shows the effect of age on the fasting concentration of individual plasma free fatty acids in goats (mean µg/ml plasma). Each point represents a mean for 6 animals.

FIGURE 7

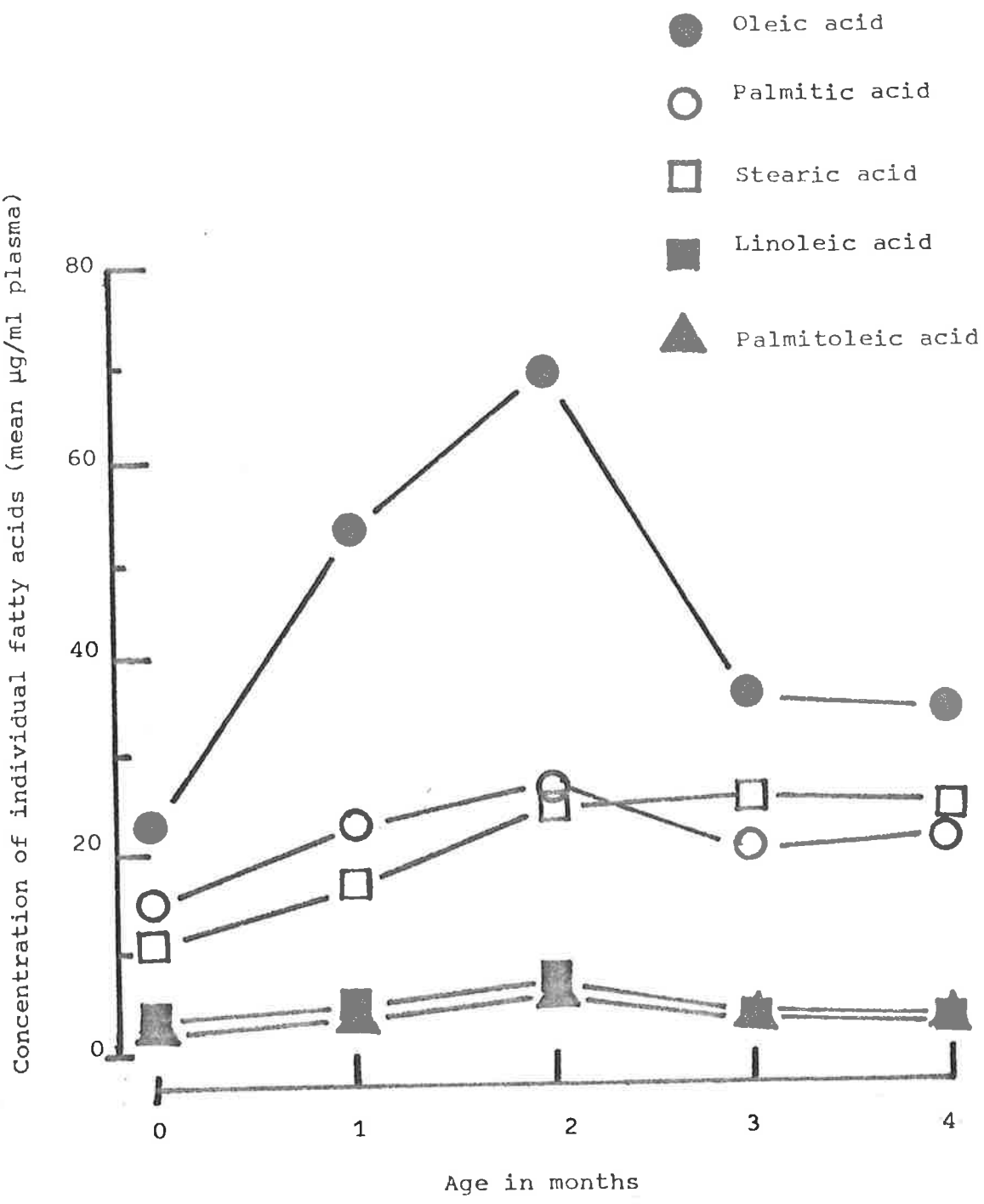
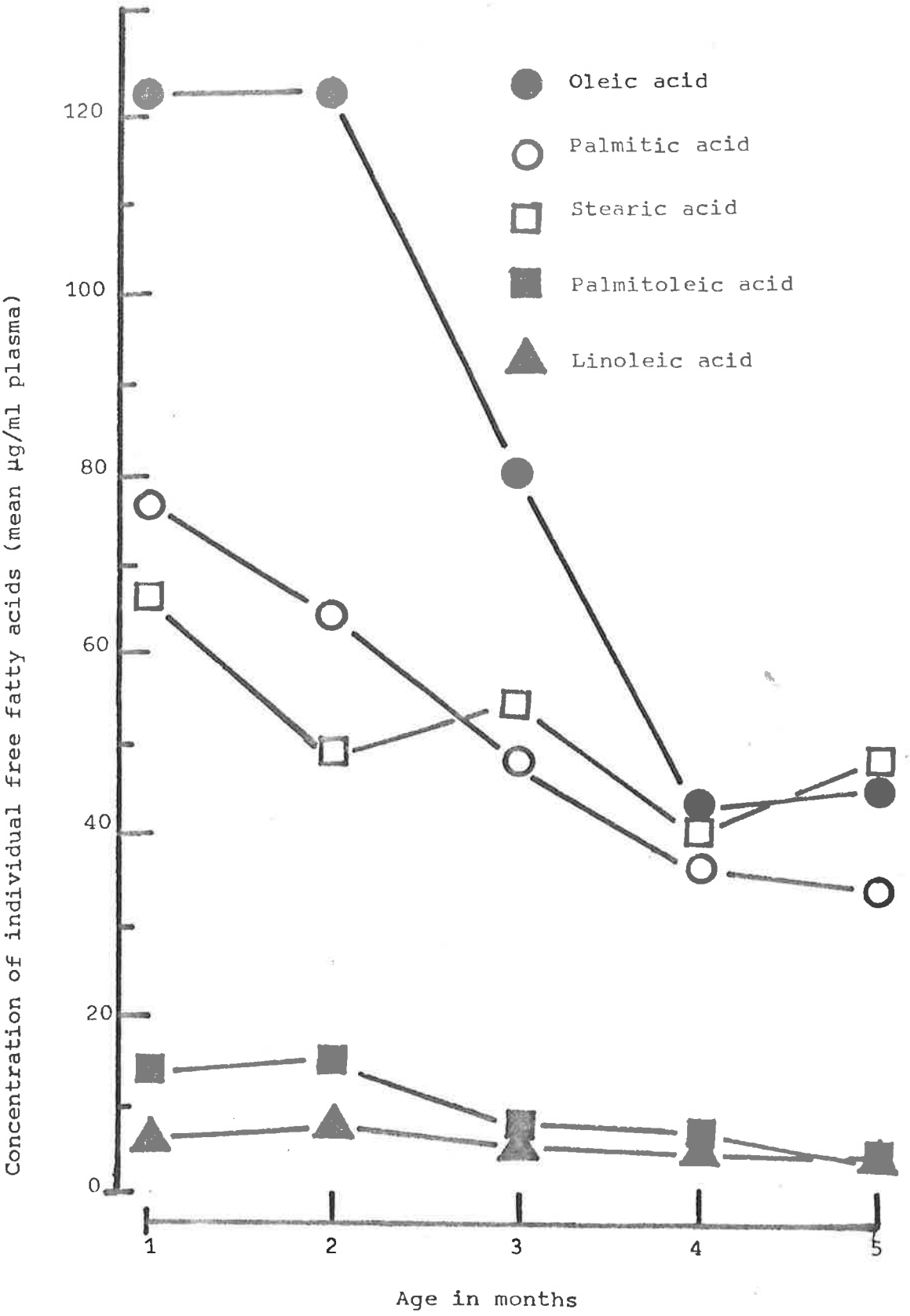

Oleic acid
Palmitic acid
Stearic acid
Linoleic acid
Palmitoleic acid
Concentration of individual fatty acids (mean µg/ml plasma)
80
60
40
20
0
0
1
2
3
4
Age in months

FIGURE 8 shows the effect of age on the concentration of individual plasma free fatty acids in lambs (mean μg/ml plasma). Each point represents a mean for 9 animals.

FIGURE 8


Oleic acid
Palmitic acid
Stearic acid
Palmitoleic acid
Linoleic acid
120
100
80
60
40
20
0
1
2
3
4
5
Concentration of individual free fatty acids (mean µg/ml plasma)
Age in months

The effect of feeding pattern and age on the concentration of free oleic acid in lambs is shown in Table 37; feeding patterns, age and the interaction between age and feeding had a significant effect on the concentration of plasma free oleic acid in lambs. There was a significant decrease in the concentration from the age of 3 months to 5 months when compared to the concentrations in lambs 1 and 2 months old. The concentrations at 1 and 2 months were significantly higher than that at 3 months ($P < 0.05$), or 4 and 5 months ($P < 0.001$).

The concentration of free oleic acid in the grazing group was significantly higher than the concentration found in the other two groups ($P < 0.05$). This was due to a higher concentration in this group at 4 months of age. Each feeding group had a different pattern of change with age. For the group fed once daily the highest concentration of this fatty acid was at 2 months, while for the other two groups the highest concentration was at 1 month. The grazing group had a significantly higher concentration of oleic acid at 4 months than the other two groups of lambs ($P < 0.001$).

(c) Ratios stearic/oleic acid

The results in Table 38 show that age and feeding patterns had a significant effect on the ratios of plasma free stearic acid to free oleic acid in goats. The ratios were small from 9 days up to 2 months. At 3 and 4 months of age, the ratios increased significantly over those at 9 days to 2 months ($P < 0.001$). This sudden change indicates that the concentration of stearic acid increased at this age over that of oleic acid.

The group fed once daily had significantly lower ratios than the group fed twice each day ($P < 0.01$). These differences were observed at ages 3 and 4 months.

The results in Table 39 show that both feeding pattern and age had a significant effect on the ratios of free stearic acid to free oleic acid in lambs. The ratios at 1 and 2 months were significantly lower than those at 3 months ($P < 0.01$) or 4 and 5 months of age ($P < 0.001$). The ratios for the twice daily fed group were significantly higher than those of the grazing group ($P < 0.001$) or the group fed once a day ($P < 0.05$).

(d) Linoleic acid

Table 40 shows that age had a significant effect on the concentration of linoleic acid in goats. The concentration at 2 months of age was significantly higher than the concentrations at 9 days and 1 month ($P < 0.001$). There was no difference between the concentration at the age of 9 days and 1 month. The concentrations declined after 2 months of age to a level significantly lower at 3 and 4 months compared to that at the age of 2 months ($P < 0.001$). This concentration was not significantly different from those at 9 days or 1 month of age, although they were slightly lower.

Neither feeding regimen nor its interaction with age had a significant effect on the concentration of linoleic acid. Once daily fed group had a slightly higher concentration at the age of 2 months than the group fed twice daily.

Table 41 shows that neither feeding pattern, age, nor the interactions between age and feeding had a significant effect on the concentration of free linoleic acid in lambs. There was however, a slight decrease in concentration from 7.98 at 2 months of age to 4.26 µg/ml at 5 months. In individual groups, some differences were observed. The concentration for the group fed once a day was slightly lower than for the other groups at 1 month and at 4 months of age, but slightly higher at the age of 2 months.

(e) Palmitic acid

The results in Table 42 show that the fasting concentration of free palmitic acid increased as the goats grew older. The concentrations at 1 and 2 months of age were significantly higher than the concentration at 9 days ($P < 0.01$). The concentration then declined to a level significantly lower at 3 and 4 months than the concentration at 2 months ($P < 0.05$), but significantly higher than the concentration at 9 days of age ($P < 0.05$).

Neither feeding regimen nor the interaction of feed and age had a significant effect on the concentration of palmitic acid, although the group fed once daily had a slightly lower concentration at 9 days and a higher concentration at the age of 2 months than the group fed twice each day.

In lambs (Table 43) age had a significant effect on the concentration of free palmitic acid. The concentration decreased significantly with age from 3 months. The concentrations at 1 and 2 months were significantly higher than the concentration at 3 months of age ($P < 0.05$) or at 4 and 5 months ($P < 0.01$). This pattern of decrease was observed in all feed regimen. There was no significant effect due to feed or its interaction with age on the concentration of palmitic acid, although the concentration for the once daily fed group was slightly lower than for the other two groups.

(f) Palmitoleic acid

From analyses of variance and from the results in Table 44, it was observed that concentration of fasting free palmitoleic acid in goats was affected significantly by both age and by the interaction between age and feeding regimen. The concentration increased for the first 2 months to a level significantly higher at 1 and 2 months than the concentration observed at the age of 9 days ($P < 0.01$). There-

after the concentration declined to a value significantly lower at 3 and 4 months than the concentration at the age of 2 months ($P < 0.001$). This concentration was not significantly different from the concentration observed at 9 days of age.

The effect of feed x age interaction was significant when the animals were 2 months old, where the concentration for the group fed once each day was significantly higher than for the other group ($P < 0.01$). On all other occasions the differences were small, although values were higher in the group fed once daily except at the age of 9 days.

The effect of age and feeding pattern on the concentration of free palmitoleic acid in lambs is shown in Table 45. Age had a significant effect on the concentration of this fatty acid. The concentration decreased significantly from the age of 3 months. The concentration of palmitoleic acid at the age of 5 months was significantly lower than that in lambs 1 and 2 months old ($P < 0.001$) or at 3 and 4 months ($P < 0.005$).

Neither feeding patterns nor their interaction with age had a significant effect on the concentration of this fatty acid. However the concentrations for the once-daily fed group were slightly lower than the concentrations for the other two groups.

Table 34

Effect of age and feeding patterns on the fasting concentration of plasma free stearic acid in goats (mean µg/ml plasma)

Age (months)	Concentration of stearic acid (µg/ml plasma) Feeding regimen: Fed once daily	Fed twice daily	Effect of age mean
0 (9 days)	(7.5) 2.133	(15.2) 2.671	(11.3) 2.402
1	(18.1) 2.941	(15.2) 2.779	(16.7) a 2.860
2	(29.5) 3.371	(20.4) 3.060	(24.9) b 3.215
3	(27.8) 3.359	(23.0) 3.171	(25.4) 3.265
4	(21.0) 3.069	(28.6) 3.352	(24.8) 3.211
Effect of feed mean	(20.8) 3.082	(20.5) 3.068	(20.6) 3.073

			5%	1%	0.1%
SED Effect of feed means	0.1148	LSD			
SED Effect of age means	0.1512		0.3205	0.4417	0.6071
SED Effect of feed x age means	0.2231				
SED Effect of Within feed means	0.2139				

(a) Concentration at 1 month significantly higher than at 9 days ($P < 0.01$).

(b) Concentration at 2 months significantly higher than at 1 month ($P < 0.01$).

Table 35

Effect of feeding patterns and age on the fasting concentration of plasma free stearic acid in lambs (mean µg/ml plasma)

Concentration of free stearic acid (µg/ml plasma)

Age (months)	Feeding regimen: Fed once daily	Fed twice daily	Grazing Paddock	Effect of age
1	(46.4) 3.820	(69.9) 4.183	(65.5) 4.100	(60.6) 4.034
2	(46.9) 3.786	(57.7) 4.034	(42.8) 3.763	(49.1) 3.857
3	(40.8) 3.69	(84.6) 4.361	(38.2) 3.65	(54.5) 3.901
4	(26.5) 3.261	(23.2) 3.054	(86.3) 4.349	(45.3) 3.555
5	(43.8) 3.795	(43.6) 3.727	(59.4) 4.082	(48.9) 3.868
Effect of feed	(40.9) 3.67	(55.8) 3.872	(58.5) 3.986	(51.7) 3.843

SED Effect of age means	0.2199
SED Effect of feed means	0.1590
SED Effect of feed x age means	0.3760
SED Within feed means	0.3809

(a) Concentration at 1 month significantly higher than at 9 days ($P < 0.001$).

(b) Concentration at 2 months significantly higher than at 1 month ($P < 0.05$).

(c) Concentrations at 3 and 4 months significantly lower than at 2 months ($P < 0.001$).

(d) Concentrations at 3 and 4 months significantly higher than at 9 days ($P < 0.01$).

(e) At 9 days the group fed once daily had a significantly lower concentration than the group fed twice daily ($P < 0.05$).

(f) At 3 months the group fed once daily had a significantly higher concentration than the group fed twice daily ($P < 0.05$).

Table 36

Effect of age and feeding on the fasting concentration of plasma free oleic acid in goats (mean µg/ml plasma)

Age (months)	Concentration of oleic acid (µg/ml plasma) Feeding regimen: Fed once daily	Fed twice daily	Effect of age mean
0 (9 days)	(18.0) 2.94 e	(28.4) 3.306 e	(23.2) 3.123
1	(54.4) 3.987	(51.4) 3.938	(52.9) a 3.963
2	(84.6) 4.442	(54.5) 4.01	(69.6) b 4.226
3	(46.3) f 3.796	(26.5) 3.31	(36.4) cd 3.553
4	(34.3) 3.55	(35.4) 3.578	(34.9) cd 3.564
Effect of feed means	(47.6) 3.743	(39.3) 3.628	(43.4) 3.686

			5%	1%	0.1%
SED Effect of feed means	0.1214	LSD			
SED Effect of age means	0.1442		0.3057	0.4212	0.5790
SED Effect of age x feed means	0.2191		0.4645	0.6400	0.8797
SED Effect of within feed means	0.2040		0.4325	0.5959	0.8191

(a) Concentration at 3 months significantly lower than at 1 and 2 months ($P < 0.05$).

(b) Concentration at 4 months significantly lower than at 3 months ($P < 0.001$).

(c) Concentration at 5 months significantly lower than at 3 months ($P < 0.05$).

(d) Concentrations for the grazing group were significantly higher than for the other groups ($P < 0.05$).

(e) Concentration for grazing group at 4 months significantly higher than the concentration for the other two groups ($P < 0.001$).

Table 37

Effect of feeding patterns and age on the fasting concentration of plasma free oleic acid in lambs (mean µg/ml plasma)

Concentration of free oleic acid mean (µg/ml plasma)

Age (months)	Feeding regimen: Fed once daily	Fed twice daily	Grazing Paddock	Effect of age
1	(108.7) 4.675	(138.3) 5.006	(138.0) 4.896	(128.3) 4.859
2	(137.1) 4.773	(119.7) 4.788	(126.5) 4.828	(127.8) 4.796
3	(64.8) 4.100	(97.8) 4.468	(78.5) 4.372	(80.4) a 4.314
4	(17.8) 2.921	(14.3) 2.587	(95.9) e 4.455	(42.7) b 3.321
5	(48.0) 3.878	(35.7) 3.485	(53) 3.963	(45.8) c 3.775
Effect of feed	(75.3) 4.067	(81.2) 4.069	(98.5) d 4.503	(85.0) 4.213

			5%	1%	0.1%
SED Effect of age means	0.2156	LSD	0.4571	0.6298	0.8656
SED Effect of feed means	0.1541		0.3269	0.4501	0.6187
SED Effect of feed x age means	0.3678		0.7797	1.0743	1.4767
SED Within feed means	0.3734		0.7916	1.0907	1.4992

Table 38

Effect of age and feeding patterns on the ratios of plasma free stearic to free oleic acid in goats (means)

Age (months)	Ratios stearic acid/oleic acid Feeding regimen Fed once daily	Fed twice daily	Effect of age means
0 (9 days)	0.420	0.518	0.469
1	0.343	0.301	0.322
2	0.340	0.375	0.358
3	0.663	0.876	0.769 a
4	0.610	0.810	0.710 a
Effect of feed means	0.475 b	0.576	0.526

			5%	1%	0.1%
SED Feed means	0.0334	LSD	0.0708	0.0976	0.1341
SED Age means	0.0735		0.1558	0.2147	0.2951
SED Age x feed means	0.0989				
SED Within feed means	0.1040				

(a) The ratios at 3 and 4 months significantly higher than at 0, 1 and 2 months ($P < 0.001$).

(b) The ratios for the once daily fed group were significantly lower than those for twice daily fed animals ($P < 0.01$).

Table 39

Effect of feeding patterns and age on the ratios of plasma free stearic acid to free oleic acid in lambs (means)

Ratios stearic acid/oleic acid

Age (months)	Feeding regimen: Fed once daily	Fed twice daily	Grazing Paddocks	Effect of age means	
1	(0.422) 0.352	(0.441) 0.368	(0.454) 0.373	(0.439) 0.364	
2	(0.386) 0.323	(0.473) 0.386	(0.337) 0.290	(0.398) 0.333	
3	(0.671) 0.511	(0.907) 0.643	(0.487) 0.395	(0.688) 0.516	a
4	(1.451) 0.890	(1.657) 0.976	(0.902) 0.642	(1.337) 0.836	b
5	(0.922) 0.653	(1.439) 0.852	(1.168) 0.765	(1.176) 0.756	
Effect of feed	(0.771) 0.546	(0.983) c 0.645 d	(0.669) 0.493	(0.808) 0.561	

			5%	1%	0.1%
SED Effect of age means	0.0611	LSD	0.1295	0.1785	0.2453
SED Effect of feed means	0.0346		0.0733	0.1011	0.1389
SED Effect of feed x age means	0.1007				
SED Within feed means	0.1059				

(a) Ratio at 3 months significantly higher than at 1 and 2 months ($P < 0.01$).

(b) Ratios at 4 and 5 months significantly higher than at 3 months ($P < 0.001$).

(c) Ratios for twice daily fed group significantly higher than for grazing group ($P < 0.001$).

(d) Ratios for twice daily fed group significantly higher than for those fed once each day ($P < 0.05$).

Table 40

Effect of age and feeding patterns on the fasting concentration of plasma free linoleic acid in goats (mean µg/ml plasma)

Age (months)	Concentration of linoleic acid (µg/ml plasma) Feeding regimen: Fed once daily	Fed twice daily	Effect of age means
0 (9 days)	(3.20) 1.402	(3.51) 1.494	(3.36) 1.448
1	(3.62) 1.502	(3.13) 1.408	(3.37) 1.455
2	(8.95) 2.152	(4.64) 1.706	(6.80) a 1.929
3	(3.33) 1.454	(2.44) 1.215	(2.89) b 1.334
4	(2.79) 1.308	(2.85) 1.344	(2.82) b 1.326
Effect of feed	(4.38) 1.564	(3.31) 1.433	(3.85) 1.498

			5%	1%	0.1%
SED Feed means	0.1156	LSD			
SED Age means	0.1744		0.3697	0.5094	0.7002
SED Age x feed means	0.2491				
SED Within feed means	0.2467				

(a) Concentration at 2 months significantly higher than at 9 days and 1 month of age ($P < 0.001$).

(b) Concentrations at 3 and 4 months significantly lower than at 2 months ($P < 0.001$).

Table 41

Effect of feeding patterns and age on the fasting concentration of plasma free linoleic acid in lambs (mean µg/ml plasma)

Concentration of free linoleic acid (µg/ml plasma)

Age (months)	Feeding regimen: Fed once daily	Fed twice daily	Grazing Paddocks	Effect of age
1	(3.39) 1.120	(8.09) 2.090	(8.56) 2.195	(6.68) 1.749
2	(12.51) 2.480	(5.27) 1.802	(6.17) 1.934	(7.98) 2.072
3	(4.29) 1.604	(8.49) 2.138	(3.60) 1.521	(5.46) 1.739
4	(1.79) 0.851	(4.40) 1.586	(7.46) 2.000	(4.55) 1.500
5	(3.78) 1.564	(3.81) 1.459	(5.17) 1.811	(4.26) 1.611
Effect of feed means	(5.15) 1.524	(6.01) 1.774	(6.19) 1.904	(5.79) 1.734

SED Effect of feed means	0.2762
SED Effect of age means	0.2164
SED Effect of feed x age means	0.4795
SED Within feed means	0.4784

Table 42

Effect of age and feeding on the concentration of plasma free palmitic acid in goats (mean µg/ml plasma)

Age (months)	Palmitic acid concentration (µg/ml plasma) Feeding regimen: Fed once daily	Fed twice daily	Effect of age mean
0 (9 days)	(11.9) 2.548	(18.2) 2.907	(15.0) 2.728
1	(23.1) 3.176	(22.8) 3.162	(22.9) a 3.169
2	(31.7) 3.432	(22.4) 3.162	(27.1) a 3.286
3	(23.6) 3.183	(17.3) 2.905	(20.5) b c 3.044
4	(21.0) 3.085	(22.1) 3.090	(21.5) b c 3.088
Effect of feed means	(22.3) 3.085	(20.5) 3.041	(21.4) 3.063

			5%	1%	0.1%
SED Feed means	0.1121	LSD			
SED Age means	0.1340		0.2841	0.3914	0.538
SED Effect of age x feed means	0.2032				
SED Within feed means	0.1896				

(a) Concentration at 1 and 2 months significantly higher than at 9 days ($P < 0.01$).

(b) Concentration at 3 and 4 months significantly lower than at 2 months ($P < 0.05$).

(c) Concentration at 3 and 4 months significantly higher than at 9 days ($P < 0.05$).

Table 43

Effect of feeding patterns and age on the fasting concentration of plasma free palmitic acid in lambs (mean µg/ml plasma)

Age (months)	Concentration of palmitic acid (µg/ml plasma) Feeding regimen: Fed once daily	Fed twice daily	Grazing Paddocks	Effect of age
1	(71.4) 4.264	(93.7) 4.623	(66.3) 4.037	(77.1) 4.308
2	(59.6) 4.022	(61.2) 4.119	(72.9) 4.252	(64.6) 4.131
3	(42.0) 3.709	(61.9) 4.061	(40.8) 3.711	(48.2) a 3.827
4	(26.6) 3.242	(28.3) 3.24	(53.1) 3.945	(36.0) b 3.475
5	(35.8) 3.585	(27.4) 3.217	(37.3) 3.59	(33.5) b 3.464
Effect of feed	(47.1) 3.765	(54.5) 3.852	(54.1) 3.907	(51.9) 3.841

			5%	1%	0.1%
SED Effect of age means	0.2121	LSD	0.4496	0.6195	0.8515
SED Effect of feed means	0.1836				
SED Effect of feed x age means	0.3764				
SED Within feed means	0.3674				

(a) Concentration at 3 months significantly lower than at 1 month ($P < 0.05$).

(b) Concentrations at 4 and 5 months were significantly lower than at 1 month ($P < 0.01$).

Table 44

Effect of age and feeding patterns on the concentration of plasma free palmitoleic acid in goats (mean µg/ml plasma)

Age (months)	Palmitoleic acid concentration (µg/ml plasma) Feeding regimen: Fed once daily	Fed twice daily	Effect of age
0 (9 days)	(1.99) 1.072	(2.45) 1.225	(2.22) 1.148
1	(4.11) 1.614	(4.15) 1.614	(4.13) a 1.614
2	(8.5) c 2.126	(2.61) 1.179	(5.55) a 1.652
3	(3.32) 1.432	(2.34) 1.201	(2.83) 1.316 b
4	(2.44) 1.232	(2.22) 1.166	(2.33) 1.199 b
Effect of feed means	(4.07) 1.495	(2.75) 1.277	(3.41) 1.386

			5%	1%	0.1%
SED Feed means	0.1484	LSD			
SED Age means	0.1752		0.3714	0.5118	0.7034
SED Age x feed means	0.2668		0.5656	0.7793	1.0712
SED Within feed means	0.2478		0.5253	0.7238	0.9949

(a) Concentration at 1 and 2 months significantly higher than at 9 days ($P < 0.01$).

(b) Concentration at 3 and 4 months significantly lower than at 1 and 2 months ($P < 0.01$).

(c) Concentration for once daily feeding higher at the age of 2 months than for the twice daily fed group ($P < 0.01$).

Table 45

Effect of feeding patterns and age on the fasting concentration of plasma free palmitoleic acid in lambs (mean µg/ml plasma)

Concentration of palmitoleic acid (µg/ml plasma)

Age (months)	Feeding regimen: Fed once daily	Fed twice daily	Grazing Paddocks	Effect of age means
1	(9.7) 2.33	(18.2) 3.02	(12.2) 2.43	(13.4) 2.59
2	(6.7) 2.01	(25.6) 3.28	(13.9) 2.66	(15.4) 2.734
3	(7.2) 2.03	(8.0) 2.197	(7.0) 2.08	(7.4) 2.128
4	(4.5) 1.54	(4.7) 1.54	(13.6) 2.46	(7.6) 2.152
5	(4.0) 1.53	(2.7) 1.29	(3.2) 1.42	(3.3) a b 1.41
Effect of feed	(6.4) 1.89	(11.8) 2.55	(10.0) 2.398	(9.4) 2.342

			5%	1%	0.1%
SED Effect of age means	0.3270	LSD	0.6932	0.9552	1.3129
SED Effect of feed means	0.2610				
SED Feed x age means	0.5700				
SED Within feed means	0.5670				

(a) Concentration at 5 months significantly lower than at 1 and 2 months ($P < 0.001$).

(b) Concentration at 5 months significantly lower than at 3 and 4 months ($P < 0.05$).

4.2.1.4 Plasma triglyceride in goats and lambs

The concentration of plasma triglyceride in goats is shown in Table 46. Neither age nor feeding regimen had a significant effect on plasma triglyceride concentration in goats. However, the concentration was highest at the age of 9 days when the concentration of plasma FFA was low. This was followed by month to month fluctuations which were not statistically significant.

In lambs (Table 47) age and its interactions with feeding had a significant effect on the concentration of plasma triglyceride. Feeding pattern alone had no significant effect on the concentration of plasma triglycerides in lambs. Concentrations at 1 and 2 months were significantly higher than the concentrations at the age of 3 and 4 months ($P < 0.05$) or 5 months ($P < 0.001$).

At the age of 1 month the group fed twice daily had a significantly higher concentration of plasma triglyceride than the once fed group ($P < 0.05$). It was also higher than the concentrations at 2, 3, 4 and 5 months ($P < 0.01$). The concentration for the group fed once daily was significantly higher at the age of 2 months than at other ages ($P < 0.01$) and significantly higher than that for the twice fed group ($P < 0.05$). At the age of 4 months, the concentration for the grazing group was significantly lower than the concentrations at ages 1, 2 and 3 months and significantly lower than that for the once fed ($P < 0.01$), and for the twice fed ($P < 0.05$) groups.

4.2.1.5 Saturated and unsaturated triglyceride fatty acids

(a) Saturated fatty acids

In goats (Table 48) the concentrations of saturated fatty acids in plasma triglyceride were not significantly affected by age or feeding regimen. The concentration was highest at 9 days for all groups. The concentrations fluctuated about 10% around the mean.

Age and its interaction with feed had a significant effect on the concentration of triglyceride saturated fatty acids in lambs (Table 49) while feed alone had only a slight effect. The concentration at 5 months was significantly lower than at 1, 2 and 4 months of age ($P < 0.001$). The concentration for the group fed twice daily was significantly higher ($P < 0.05$) than the group fed once daily at 1 month of age, but slightly higher than for the grazing group. The concentrations at 4 months of age were significantly lower for the grazing group than for the once fed group ($P < 0.001$) and than for the group fed twice daily ($P < 0.05$).

(b) Triglyceride unsaturated fatty acids

The results in Table 50 show that neither age nor feeding regimen had a significant effect on the concentration of triglyceride unsaturated fatty acids in goats. The concentration at 9 days was slightly higher than the concentration at other ages. The variations between months were not statistically significant.

In lambs (Table 51) age had a significant effect on the concentration of triglyceride unsaturated fatty acids. The concentrations at the age of 4 and 5 months were significantly lower than the concentrations at 1 and 2 months of age. Feeding pattern had no significant effect on the concentration of unsaturated fatty acids. However the concentration for the grazing group was slightly lower than the concentration for the other two groups. At the age of 1 month the twice fed group had a slightly higher concentration than the other two groups, while that for the group fed once daily was slightly higher at the age of 2 months.

(c) Ratios : Triglyceride saturated to unsaturated fatty acids

The results in Table 52 show that there was no significant effect due to age or feeding patterns on the ratios of saturated to

Table 46

Effect of age and feeding on the concentration of plasma triglycerides in goats (mean µg/ml plasma)

Age (months)	Concentration of plasma triglyceride (µg/ml plasma) Feeding regimen: Fed once daily	Fed twice daily	Effect of age
0 (9 days)	(68.6) 4.119	(92.6) 4.453	(80.6) 4.286
1	(52.7) 3.927	(47.0) 3.815	(49.9) 3.871
2	(74.0) 4.282	(58.9) 4.043	(66.4) 4.162
3	(50.4) 3.931	(39.6) 3.698	(45.0) 3.815
4	(63.1) 4.13	(73.9) 4.305	(68.5) 4.218
Effect of feed	(61.8) 4.078	(62.4) 4.063	(62.1) 4.070

SED Effect of feed means	0.1424
SED Effect of age means	0.2141
SED Effect of feed x age means	0.3060
SED Within feed means	0.3028

(a) Concentrations at 3 and 4 months significantly lower than at 1 and 2 months ($P < 0.05$).

(b) Concentration at 5 months significantly lower than at 1 and 2 months ($P < 0.001$).

(c) Concentration for twice fed group significantly higher than that for once fed group at 1 month ($P < 0.05$).

(d) Concentration for once daily fed group significantly higher at 2 months than for the group fed twice each day.

(e) Concentration for the grazing group significantly lower at 4 months than the concentration for once daily feeding ($P < 0.01$) or for twice daily feeding ($P < 0.05$).

Table 47

Effect of feeding patterns and age on the concentration of plasma triglycerides in lambs (mean µg/ml plasma)

Triglyceride concentration (µg/ml plasma)

Age (months)	Feeding regimen: Fed once daily	Fed twice daily	Grazing Paddocks	Effect of age
1	(85.6) 4.417	(168.0) c 5.104	(94.5) 4.534	(116.0) 4.685
2	(206.1) d 5.120	(84.3) 4.436	(108.4) 4.695	(133.0) 4.750
3	(67.0) 4.201	(86.7) 4.382	(92.0) 4.475	(81.9) a 4.353
4	(130.5) 4.856	(96.0) 4.570	(49.5) e 3.858	(92.0) a 4.428
5	(64.6) 4.141	(61.5) 4.098	(52.2) 3.962	(59.4) b 4.067
Effect of feed	(110.8) 4.547	(99.3) 4.518	(79.3) 4.305	(96.5) 4.457

			5%	1%	0.1%
SED Feed means	0.1556	LSD	0.3299		
SED Age means	0.1694		0.3591	0.4948	0.6801
SED Feed x age means	0.3051		0.6468	0.8912	1.2249
SED Within feed means	0.2935		0.6222	0.8573	1.1784

Table 48

Effect of age and feeding on the concentration of plasma triglyceride saturated fatty acids in goats (mean µg/ml plasma)

Age (months)	Concentration of saturated triglyceride fatty acids (µg/ml plasma) Feeding regimen: Fed once daily	Fed twice daily	Effect of age
0 (9 days)	(35.3) 3.478	(37.1) 3.605	(36.2) 3.542
1	(22.5) 3.117	(21.2) 3.068	(21.8) 3.093
2	(33.6) 3.506	(27.4) 3.313	(30.5) 3.409
3	(26.4) 3.306	(20.8) 3.069	(23.6) 3.188
4	(33.0) 3.482	(33.2) 3.519	(33.1) 3.500
Effect of feed	(30.1) 3.378	(27.9) 3.315	(29.0) 3.346

SED Effect of feed means	0.1175
SED Effect of age means	0.1942
SED Effect of feed x age means	0.2723
SED Within feed means	0.2746

(a) Concentration at 5 months significantly lower than at 1, 2 and 4 months of age ($P < 0.001$).

(b) Concentration for twice fed group at age of 1 month significantly higher than for once fed group ($P < 0.05$).

(c) Concentration for the grazing group at 4 months significantly lower than for once fed group ($P < 0.001$).

(d) Concentration for the grazing group at 4 months significantly lower than for twice fed group ($P < 0.05$).

Table 49

Effect of feeding patterns and age on the concentration of plasma triglyceride saturated fatty acids in lambs (mean µg/ml plasma)

Concentration of triglyceride saturated fatty acids (µg/ml plasma)

Age (months)	Feeding regimen: Fed once daily	Fed twice daily	Grazing Paddocks	Effect of age
1	(38.6) 3.651	(68.0) b 4.254 ::	(45.3) 3.831	(50.6) 3.912
2	(64.3) 4.016	(49.5) 3.917	(48.2) 3.892	(54.0) 3.947
3	(37.3) 3.628	(38.5) 3.612	(42.7) 3.736	(39.5) 3.659
4	(90.3) 4.473	(64.7) 4.185	(25.8) c 3.24 d	(60.3) 3.966
5	(37.3) 3.600	(33.6) 3.498	(25.5) 3.268	(32.1) a 3.455
Effect of feed	(53.6) 3.874	(50.9) 3.893	(37.5) 3.593	(47.3) 3.787

			5%	1%	0.1%
SED Feed means	0.1205	LSD	0.2555		
SED Age means	0.1551		0.3288	0.4530	0.6227
SED Age x feed means	0.2688		0.5697	0.7852	1.0792
SED Within feed means	0.2686		0.5694	0.7846	1.0784

Table 50

Effect of age and feeding patterns on the concentration of plasma triglyceride unsaturated fatty acids in goats (mean µg/ml plasma)

Concentration of unsaturated triglyceride fatty acids (µg/ml plasma)

Age (months)	Feeding regimen: Fed once daily	Fed twice daily	Effect of age
0 (9 days)	(33.3) 3.407	(45.7) 3.764	(39.5) 3.585
1	(30.3) 3.366	(25.9) 3.210	(28.1) 3.288
2	(40.4) 3.692	(31.4) 3.417	(35.9) 3.555
3	(24.0) 3.203	(18.9) 2.978	(21.4) 3.091
4	(28.5) 3.377	(38.6) 3.668	(33.6) 3.523
Effect of feed	(31.3) 3.409	(32.1) 3.408	(31.7) 3.408

SED Effect of feed means	0.1599
SED Effect of age means	0.2175
SED Effect of age x feed means	0.3183
SED Within feed means	0.3076

Table 51

Effect of feeding patterns and age on the concentration of plasma triglyceride unsaturated fatty acids in lambs (µg/ml plasma)

Concentration of triglyceride unsaturated fatty acids (µg/ml plasma)

Age (months)	Feeding regimen: Fed once daily	Fed twice daily	Grazing Paddocks	Effect of age
1	(47.0) 3.799	(76.6) 4.293	(41.6) 3.708	(55.1) 3.933
2	(102.3) 4.482	(33.7) 3.518	(49.9) 3.926	(62.0) 3.975
3	(29.7) 3.401	(48.2) 3.767	(48.3) 3.833	(42.0) 3.667
4	(37.6) 3.624	(28.7) 3.374	(23.7) 3.129	(30.0) a 3.376
5	(26.4) 3.281	(26.7) 3.297	(26.7) 3.307	(26.6) a 3.295
Effect of age	(48.6) 3.717	(42.8) 3.650	(38.0) 3.581	(43.1) 3.649

			5%	1%	0.1%
SED Feed means	0.1711	LSD			
SED Age means	0.1786		0.3786	0.5217	0.7171
SED Interaction means	0.3254				
SED Within feed means	0.3094				

(a) Concentration at 4 and 5 months significantly lower than at 1 and 2 months ($P < 0.01$).

Table 52

Effect of age and feeding patterns on the ratio of triglyceride saturated to unsaturated fatty acids in goats (mean)

Age (months)	Ratios saturated/unsaturated Feeding regimen Fed once daily	Fed twice daily	Effect of age
0 (9 days)	1.081	0.859	0.970
1	0.790	0.879	0.834
2	0.826	0.903	0.865
3	1.120	1.128	1.124
4	1.132	0.858	0.995
Effect of feed	0.990	0.925	0.958

SED Effect of feed means	0.0693
SED Effect of age means	0.1027
SED Effect of age x feed means	0.1473
SED Within feed means	0.1453

Table 53

Effect of feeding patterns and age on the ratios of plasma triglyceride saturated to unsaturated fatty acids in lambs (means)

Ratios TG saturated/unsaturated fatty acids

Age (months)	Feeding regimen: Fed once daily	Fed twice daily	Grazing Paddocks	Effect of age
1	(0.890) 0.630	(1.013) 0.684	(1.170) 0.766	(1.024) 0.693
2	(0.646) 0.493	(1.557) b 0.926	(0.967) 0.676	(1.057) 0.699
3	(1.278) 0.820	(0.889) 0.628	(0.908) 0.646	(1.025) 0.698
4	(2.557) 1.234	(2.326) 1.195	(1.128) 0.754	(2.003) 1.061 a
5	(1.392) 0.872	(1.245) 0.805	(0.961) 0.673	(1.200) 0.783
Effect of feed	(1.352) 0.810	(1.406) 0.848	(1.027) 0.703	(1.262) 0.787

			5%	1%	0.1%
SED Age means	0.0627	LSD	0.1329	0.1831	0.2517
SED Feed means	0.0651		0.1380		
SED Feed x age means	0.1169		0.2478	0.3415	0.4693
SED Within feed means	0.1085		0.2300		

(a) Ratio at 4 months significantly higher than at any other age ($P < 0.001$).

(b) Ratios higher for twice fed group than for once daily fed or grazing groups at 2 months of age ($P < 0.01$).

unsaturated triglyceride fatty acids in goats.

The ratios of saturated to unsaturated triglyceride fatty acids in lambs (Table 53) were affected by age and its interaction with feeding significantly. The ratios at the age of 4 months were significantly higher than the ratios for the other months ($P < 0.001$). The ratio for the group fed twice daily was significantly higher than for the group fed once daily ($P < 0.01$) and for the grazing group ($P < 0.05$) at the age of 2 months.

4.2.1.6 Individual triglyceride fatty acids

(a) Triglyceride stearate

From Table 54 and from analysis of variance, it was observed that age had a significant effect on the concentration of stearic acid in plasma triglyceride of goats. Highest concentration was observed at 9 days of age which was then followed by a significant decrease at the age of 1 month ($P < 0.01$). This was followed by a subsequent rise in the concentration of this fatty acid in the following months to levels which were slightly lower than, but not statistically different from the concentration at 9 days.

Neither feeding regimen nor its interaction with age had a significant effect on the concentration of triglyceride stearate. The once daily fed group had slightly higher concentrations at 2 and 3 months and lower concentrations at 9 days and 4 months of age than the group fed twice daily.

Table 55 showed that feed and age had significant effects on the concentration of plasma triglyceride stearate in lambs. The concentration at 4 months was significantly higher than the concentrations at other ages except for the concentration at the age of 2 months ($P < 0.01$).

The grazing group had significantly lower concentrations of

stearate than the other two groups ($P < 0.01$). The concentration for the grazing group was also lower at the age of 4 months than for the other two groups. Once fed group had slightly higher concentrations of triglyceride stearate than the other two groups at the age of 2 months.

(b) Triglyceride oleate

The concentration of triglyceride oleate in goats (Table 56) was not affected significantly by either age or feeding regimen. The highest concentration was in 9 day old goats for both groups and the lowest at the age of 3 months. However, there was a non-significant fluctuation between months.

In lambs (Table 57) the concentration of triglyceride oleate was not affected significantly by age or feeding regimen. However, there was a slight decrease with age, with the highest concentration at 1 month and the lowest at 5 months. The group fed once daily had a slightly higher concentration than the grazing group. The interaction between feed and age had a slight effect on the concentration of triglyceride oleate.

The twice fed group at 1 month had a slightly higher concentration than at other ages and than the other two groups. The highest concentration for the once fed and grazing groups was at the age of 2 months.

(c) Ratios, triglyceride stearate to oleate

Table 58 shows that age had a significant effect on the ratios of plasma triglyceride stearate to oleate in goats. The ratio at 1 month was significantly lower than that at 9 days ($P < 0.01$) and significantly lower than those at 2, 3 and 4 months of age ($P < 0.05$). There was no significant effect due to feeding pattern.

The ratio of stearate to oleate in lambs (Table 59) increased with age. The only significant increase was observed at the age of 4 months where it was significantly higher than the ratio at 1 month ($P < 0.01$). Neither feed nor its interaction with age had a significant effect on the ratios. However, the ratio for the group fed twice daily was slightly higher than the other two groups.

(d) Triglyceride linoleate

In goats (Table 60) neither age, feed nor their interactions had a significant effect on the concentration of linoleic acid in plasma triglyceride. The concentration was slightly higher at 4 months and lowest at 3 months. The group fed once daily had the lowest concentration at 9 days of age and the highest concentration at 2 and 4 months of age, while those fed twice daily had their highest concentrations at 9 days and lowest at 3 months of age. Month to month variations were not statistically significant.

The effect of feeding pattern and age on the concentration of plasma triglyceride linoleate in lambs is shown in Table 61. Age had a significant effect. The concentrations decreased significantly with age being significantly higher at 1 and 2 months than at 3 and 5 months ($P < 0.05$) and at 4 months of age ($P < 0.01$).

Feeding pattern and its interaction with age had no significant effect on the concentration of triglyceride linoleate. However, the group fed once daily had a slightly higher concentration than the other two groups. The concentration in this group was also higher at the age of 2 months than in the other groups.

(e) Triglyceride palmitate

In goats (Table 62) there was no significant difference between the concentrations of triglyceride palmitate at different ages. The highest concentration was observed at 9 days of age. There were small

fluctuations in the monthly values.

In lambs the results in Table 63 show that age and its interaction with feeding patterns had a significant effect on the concentration of plasma palmitate while feeding alone had no effect. The concentrations decreased significantly with age. The concentration at 1 month was significantly higher than the concentrations at 3 and 4 months ($P < 0.01$) and at 5 months of age ($P < 0.001$).

At the age of 1 month the concentration for the twice fed group was significantly higher than the concentration for the group fed once daily and for the grazing group at the same age ($P < 0.05$). For the group fed once daily the concentration of palmitate was significantly higher than for the grazing group at the age of 4 months ($P < 0.001$) and slightly higher than for the group fed twice daily.

(f) Triglyceride palmitoleate

The concentration of palmitoleate in goats (Table 64) was not affected significantly by either age, feed or the interactions. However, the concentrations at 9 days and at 2 months of age were slightly higher than the concentrations at 1, 3 and 4 months in both groups.

In lambs (Table 65) the concentration of palmitoleate decreased significantly with age. The concentrations at the ages of 4 and 5 months were significantly lower than the concentrations at 2 and 3 months ($P < 0.01$) and at one month of age ($P < 0.05$).

Feeding pattern had no significant effect on the concentration of palmitoleate nor was its interaction with age significant. However, the concentration at the age of 3 months was slightly higher for the twice fed group than for the other two groups.

Table 54

Effect of age and feeding patterns on the concentration of plasma triglyceride stearate in goats (mean μg/ml plasma)

Concentration of triglyceride stearate (μg/ml plasma)

Age (months)	Feeding regimen: Fed once daily	Fed twice daily	Effect of age
0 (9 days)	(11.51) 2.382	(14.08) 2.608	(12.79) 2.495
1	(4.99) 1.757	(4.48) 1.691	(4.74) a b 1.724
2	(11.69) 2.505	(8.43) 2.222	(10.06) 2.364
3	(8.99) 2.282	(6.98) 2.063	(7.98) b 2.172
4	(11.63) 2.523	(12.17) 2.555	(11.90) 2.539
Effect of feed	(9.76) 2.290	(9.23) 2.259	(9.49) 2.259

			5%	1%	0.1%
SED Effect of feed means	0.1171	LSD			
SED Effect of age means	0.2097		0.4446	0.6125	0.8419
SED Effect of feed x age means	0.2899				
SED Within feed means	0.2965				

(a) Concentration at 1 month significantly lower than at 9 days, 2 months and 4 months ($P < 0.01$).

(b) Concentration at 1 month significantly lower than at 3 months ($P < 0.05$).

Table 55

Effect of feeding patterns and age on the concentration of plasma triglyceride stearate in lambs (mean μg/ml plasma)

Age (months)	Concentration of triglyceride stearate μg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Grazing Paddocks	Effect of age
1	(10.1) 2.364	(18.5) 2.997	(10.1) 2.364	(12.9) 2.588
2	(31.5) 3.038	(16.8) 2.876	(15.8) 2.798	(21.4) 2.904
3	(12.7) 2.601	(13.9) 2.634	(13.9) 2.648	(13.5) 2.627
4	(46.8) 3.79	(36.6) 3.610	(9.5) 2.335	(31.0) a 3.245
5	(13.7) 2.641	(12.7) 2.546	(8.6) 2.240	(11.7) 2.476
Effect of feed	(23.0) 2.887 b	(19.7) 2.932 b	(11.6) 2.485	(18.1) 2.768

			5%	1%	0.1%
SED Feed means	0.1284	LSD	0.2722	0.3751	0.5155
SED Age means	0.2155		0.4569	0.6294	0.8652
SED Age x feed means	0.3576				
SED Within feed means	0.3732				

(a) Concentration at 4 months significantly higher than at 5, 3 and 1 month of age ($P < 0.01$).

(b) Concentration for once and twice fed groups significantly higher than for the grazing group ($P < 0.01$).

Table 56

Effect of age and feeding on the fasting concentration of plasma triglyceride oleate in goats (mean µg/ml plasma)

Age (months)	Concentration of triglyceride oleate µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Effect of age
0 (9 days)	(27.8) 3.231	(28.9) 3.391	(28.3) 3.311
1	(22.8) 3.090	(20.8) 3.006	(21.8) 3.048
2	(30.3) 3.411	(22.3) 3.105	(26.3) 3.258
3	(18.5) 2.957	(13.2) 2.64	(15.9) 2.799
4	(24.2) 3.204	(26.0) 3.263	(25.1) 3.234
Effect of feed	(24.7) 3.179	(22.2) 3.081	(23.5) 3.130

SED Effect of feed means	0.1622
SED Effect of age means	0.2021
SED Age x feed means	0.3028
SED Within feed means	0.2858

Table 57

Effect of feeding patterns and age on the fasting concentration of plasma triglyceride oleate in lambs (mean µg/ml plasma)

Age (months)	Concentration of triglyceride oleate µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Grazing Paddocks	Effect of age
1	(19.7) 2.995	(43.5) 3.807	(26.1) 3.267	(29.8) 3.356
2	(31.4) 3.305	(14.7) 2.462	(28.3) 3.349	(24.8) 3.039
3	(20.6) 3.039	(23.0) 3.132	(18.2) 2.814	(20.6) 2.995
4	(29.4) 3.383	(19.2) 2.965	(16.4) 2.776	(21.7) 3.04
5	(24.5) 3.183	(17.8) 2.910	(16.6) 2.858	(19.6) 2.984
Effect of feed	(25.1) 3.181	(23.6) 3.055	(21.1) 3.013	(23.3) 3.083

SED for feed means	0.0872
SED for age means	0.2554
SED for age x feed means	0.4052
SED Within feed means	0.4424

Table 58

Effect of age and feeding patterns on the ratios of plasma triglyceride stearate to oleate in goats (means)

Age (months)	Ratios stearate/oleate Feeding regimen Fed once daily	Fed twice daily	Effect of age
0 (9 days)	0.402	0.468	0.435
1	0.230	0.239	0.235 a
2	0.383	0.388	0.386 b
3	0.482	0.531	0.506 b
4	0.494	0.488	0.491 b
Effect of feed	0.398	0.423	0.411

			5%	1%	0.1%
SED Effect of feed means	0.045	LSD			
SED Effect of age means	0.0595		0.1261	0.1738	0.2389
SED Effect of age x feed means	0.0877				
SED Within feed means	0.0841				

(a) Ratio at 1 month significantly lower than at 9 days ($P < 0.001$).

(b) Ratios at 2, 3 and 4 months significantly higher than at 1 month ($P < 0.05$).

Table 59

Effect of feeding patterns on the ratios of plasma triglyceride stearate to oleate in lambs (mean)

Ratios stearate/oleate

Age (months)	Feeding regimen: Fed once daily	Fed twice daily	Grazing Paddocks	Effect of age
1	(0.51) 0.410	(0.27) 0.335	(0.40) 0.338	(0.39) 0.361
2	(0.81) 0.577	(2.8) 1.085	(0.56) 0.445	(1.39) 0.702
3	(0.63) 0.489	(0.59) 0.463	(1.40) 0.726	(0.87) 0.559
4	(1.65) 0.946	(1.99) 1.089	(0.63) 0.488	(1.43) 0.841 a
5	(0.57) 0.448	(0.71) 0.527	(0.51) 0.414	(0.60) 0.463
Effect of feed	(0.83) 0.574	(1.27) 0.700	(0.70) 0.482	(0.94) 0.585

			5%	1%	0.1%
SED Feed means	0.0861	LSD			
SED Age means	0.1497		0.3174	0.4373	0.6010
SED Age x feed means	0.2473				
SED Within feed means	0.2592				

(a) Ratio at 4 months significantly higher than at 1 month ($P < 0.01$).

Table 60

Effect of age and feeding patterns on the concentration of plasma triglyceride linoleate in goats (mean µg/ml plasma)

Age (months)	Concentration of linoleate µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Effect of age
0 (9 days)	(2.07) 1.067	(6.47) 1.774	(4.27) 2.421
1	(2.59) 1.241	(2.17) 1.118	(2.38) 1.179
2	(4.08) 1.595	(3.49) 1.484	(3.79) 1.539
3	(2.26) 1.141	(1.79) 1.022	(2.03) 1.082
4	(4.03) 1.579	(5.62) 1.849	(4.83) 1.714
Effect of feed	(3.01) 1.325	(3.91) 1.449	(3.46) 1.387

SED Effect of feed means	0.1638
SED Effect of age means	0.2195
SED Effect of age x feed means	0.3224
SED Within feed means	0.3104

Table 61

Effect of feeding patterns and age on the fasting concentration of plasma triglyceride linoleate in lambs (mean µ.g/ml plasma)

Concentration of triglyceride linoleate µg/ml plasma

Age (months)	Feeding regimen: Fed once daily	Fed twice daily	Grazing Paddocks	Effect of age
1	(8.7) 2.266	(10.0) 2.431	(7.8) 2.135	(8.8) 2.277
2	(22.4) 2.221	(4.5) 1.700	(5.1) 1.696	(10.7) 2.3702
3	(4.2) 1.585	(5.0) 1.705	(3.8) 1.552	(4.3) b 1.614
4	(2.0) 0.900	(2.8) 1.306	(2.5) 1.228	(2.4) a 1.145
5	(3.6) 1.459	(6.8) 1.911	(4.8) 1.706	(5.1) b 1.692
Effect of feed	(8.2) 1.686	(5.8) 1.811	(4.8) 1.663	(6.3) 1.72

			5%	1%	0.1%
SED Feed means	0.1889	LSD			
SED Age means	0.3026		0.6415	0.8839	1.2149
SED Age x feed means	0.5054				
SED Within feed means	0.5241				

(a) Concentration at 4 months significantly lower than at 1 and 2 months ($P < 0.01$).

(b) Concentrations at 3 and 5 months significantly lower than at 1 and 2 months ($P < 0.05$).

Table 62

Effect of age and feeding patterns on the concentration of plasma triglyceride palmitate in goats (mean µg/ml plasma)

Age (months)	Concentration of triglyceride palmitate µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Effect of age
0 (9 days)	(19.4) 2.923	(18.92) 2.982	(19.16) 2.952
1	(14.49) 2.694	(14.13) 2.673	(14.31) 2.683
2	(19.4) 2.973	(16.54) 2.822	(17.97) 2.898
3	(15.32) 2.792	(12.30) 2.578	(13.81) 2.685
4	(15.96) 2.798	(18.81) 2.974	(17.38) 2.886
Effect of feed	(16.91) 2.836	(16.14) 2.806	(16.53) 2.821

SED Effect of feed means	0.1357
SED Effect of age means	0.1770
SED Effect of age x feed means	0.2619
SED Within feed means	0.2504

Table 63

Effect of feeding patterns and age on the concentration of plasma triglyceride palmitate in lambs (mean µg/ml plasma)

Age (months)	Concentration of palmitate in plasma µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Grazing Paddocks	Effect of age
1	(22.60) c 3.137	(41.00) 3.77	(29.41) 3.412	(31.01) 3.440
2	(23.86) 3.198	(27.35) 3.337	(27.42) 3.346	(26.21) 3.294
3	(19.86) 3.007	(23.10) 3.136	(24.21) 3.194	(22.39) a 3.112
4	(35.36) d 3.580	(23.71) 3.172	(14.07) 2.660	(24.38) a 3.137
5	(19.71) 3.003	(18.24) 2.931	(14.76) 2.755	(17.57) b 2.896
Effect of feed	(24.28) 3.185	(26.68) 3.269	(21.98) 3.073	(24.31) 3.176

			5%	1%	0.1%
SED Feed means	0.1338	LSD			
SED Age means	0.1104		0.2340	0.3225	0.4433
SED Age x feed means	0.2172		0.4605	0.6344	0.8721
SED Within feed means	0.1913		0.4055	0.5588	0.7681

(a) Concentrations at 3 and 4 months significantly lower than at 1 month ($P < 0.01$).

(b) Concentration at 5 months significantly lower than at 1 month ($P < 0.001$).

(c) Concentration for twice fed group at 1 month significantly higher than for once fed group ($P < 0.05$) and higher than at other ages ($P < 0.05$).

(d) Concentration for once fed group at 4 months significantly higher than for grazing group ($P < 0.001$).

Table 64

Effect of age and feeding on the concentration of plasma triglyceride palmitoleic acid in goats (mean µg/ml plasma)

Age (months)	Concentration of palmitoleate µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Effect of age
0 (9 days)	(3.19) 1.368	(3.94) 1.551	(3.56) 1.460
1	(2.92) 1.293	(2.29) 1.125	(2.6) 1.209
2	(3.84) 1.562	(3.88) 1.442	(3.86) 1.502
3	(2.93) 1.362	(1.6) 0.953	(2.26) 1.157
4	(2.15) 1.136	(3.22) 1.435	(2.68) 1.286
Effect of feed	(3.00) 1.344	(2.98) 1.301	(2.99) 1.323

SED Effect of feed means	0.1085
SED Effect of age means	0.2188
SED Effect of age x feed means	0.2973
SED Within feed means	0.3094

Table 65

Effect of feeding patterns and age on the concentration of plasma triglyceride palmitoleate in lambs (mean µg/ml plasma)

Age (months)	Concentration of triglyceride palmitoleate µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Grazing Paddocks	Effect of age
1	(4.5) 1.644	(6.2) 2.042	(5.3) 1.816	(5.3) 1.834
2	(13.5) 2.337	(3.4) 1.430	(7.5) 2.123	(8.1) 2.091
3	(2.8) 1.328	(17.5) 2.208	(5.2) 1.763	(8.5) 2.140
4	(3.1) 1.410	(3.0) 1.363	(2.6) 1.209	(2.9) 1.327 a
5	(2.2) 1.126	(3.1) 1.399	(2.1) 1.090	(2.5) a 1.205
Effect of feed	(5.2) 1.569	(6.6) 1.689	(4.5) 1.600	(5.5) 1.619

			5%	1%	0.1%
SED Feed means	0.2247	LSD			
SED Age means	0.2487		0.5272	0.7264	0.9985
SED Age x feed means	0.4460				
SED Within feed means	0.4307				

(a) Concentrations at 4 and 5 months significantly lower than at 2 and 3 months ($P < 0.01$) and at 1 month ($P < 0.05$).

Table 66

Effect of age and feeding patterns on the concentration of plasma lipid in goats (mean µg/ml plasma)

Age (months)	Concentration of plasma lipid µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Effect of age
0 (9 days)	(8.07) 2.203	(8.63) 2.265	(8.35) 2.234
1	(5.75) 1.909	(6.5) 2.003	(6.12) 1.956
2	(4.85) 1.752	(6.85) 1.980	(5.85) 1.866
3	(5.25) 1.598	(6.97) 1.989	(6.11) 1.793
4	(2.97) 1.22	(6.83) 1.918	(4.9) 1.57
Effect of feed	(5.38) 1.737	(7.16) 2.031	(6.27) 1.884

SED Feed means	0.2067
SED Age means	0.2584
SED Age x feed means	0.3867
SED Within feed means	0.3654

Table 67

Effect of feeding patterns and age on the concentration of total plasma lipids in lambs (mean µg/ml plasma)

Concentration of plasma lipid µg/ml

Age (months)	Feeding regimen: Fed once daily	Fed twice daily	Grazing Paddocks	Effect of age
1	(34.5) 3.569	(33.6) 3.533	(36.78) 3.628	(34.96) 3.577 a
2	(3.98) 1.606	(3.50) 1.504	(4.30) 1.667	(3.93) 1.592
3	(5.08) 1.805	(5.0) 1.791	(5.58) 1.883	(5.22) 1.826
4	(0.66) 0.499	(1.32) 0.724	(1.42) 0.879	(1.13) b 0.701
5	(1.03) 0.706	(1.0) 0.688	(1.27) 0.808	(1.10) b 0.734
Effect of feed	(9.05) 1.637	(8.88) 1.648	(9.87) 1.773	(9.27) 1.686

			5%	1%	0.1%
SED Feed means	0.0726	LSD			
SED Age means	0.0848		0.1798	0.2477	0.3405
SED Age x feed means	0.1500				
SED Within feed means	0.1468				

(a) Concentration at 1 month significantly higher than at any other age ($P < 0.001$).

(b) Concentration at 4 and 5 months significantly lower than at 2 and 3 months ($P < 0.001$).

Table V

Concentration and Composition of Plasma FFA in Goats and Sheep and their % Proportion (w/w)

(µg/ml)

Component	Animal Species	AGE IN MONTHS: 9 days		1 month		2 months		3 months		4 months		5 months	
		Feeding Patterns: Once Daily	Twice Daily	Once Daily	Twice Daily	Once Daily	Twice Daily	Once Daily	Twice Daily	Once Daily	Twice Daily	Once Daily	Twice Daily
FFA	Goats	46.7	74.4	111.3	105.2	198.3	113.6	112.3	76.1	88.4	98.8		
	Sheep			267	468	350	293	175	284	108	85	145	121
C18:0	Goats	7.5	15.2	18.1	15.2	29.5	20.4	27.8	23	21.0	28.6		
	%	(16)	(20)	(16.3)	(14.4)	(14.9)	(17.9)	(24.7)	(30.2)	(23.8)	(28.9)		
	Sheep			46.4	69.9	46.9	57.7	40.8	84.6	26.5	23.2	43.6	43.8
	%			(17.4)	(14.9)	(13.4)	(19.7)	(23.3)	(29.8)	(24.5)	(27.3)	(30.1)	(36.2)
C18:1	Goats	18.0	28.4	54.4	51.4	84.6	54.5	46.3	26.5	34.3	35.4		
	%	(38.5)	(38.1)	(48.9)	(48.9)	(42.7)	(47.9)	(41.2)	(34.8)	(38.8)	(35.8)		
	Sheep			108.7	138.3	137.1	119.7	64.8	97.8	17.8	14.3	48.0	35.7
	%			(40.7)	(29.6)	(39.2)	(40.8)	(37.0)	(34.4)	(16.5)	(16.8)	(33.1)	(29.5)
C18:2	Goats	3.2	3.5	3.62	3.13	8.95	4.64	3.33	2.44	2.79	2.85		
	%	(6.8)	(4.7)	(3.2)	(3.0)	(4.5)	(4.1)	(2.9)	(3.2)	(3.2)	(2.9)		
	Sheep			3.39	8.09	12.51	5.27	4.29	8.49	1.79	4.40	3.78	3.81
	%			(1.3)	(1.7)	(3.6)	(1.8)	(2.5)	(2.98)	(1.6)	(5.2)	(2.6)	(3.2)
C16:0	Goats	11.9	18.2	23.1	22.8	31.2	22.4	23.6	17.3	21.0	22.1		
	%	(35.5)	(24.5)	(20.8)	(21.7)	(16.0)	(19.7)	(21.0)	(22.7)	(23.8)	(22.4)		
	Sheep			71.4	93.7	59.6	61.2	42.0	61.9	26.6	28.3	35.8	27.4
	%			(26.7)	(20.0)	(17.0)	(20.9)	(24.0)	(21.8)	(24.6)	(33.3)	(24.7)	(22.6)
C16:1	Goats	1.99	2.45	4.11	4.15	8.5	2.61	3.32	2.34	2.44	2.22		
	%	(4.3)	(3.3)	(3.7)	(3.9)	(4.3)	(2.3)	(2.9)	(3.1)	(2.8)	(2.2)		
	Sheep			9.7	18.2	6.7	25.6	7.2	8.0	4.5	4.7	4.0	2.7
	%			(3.6)	(3.9)	(1.9)	(8.7)	(4.1)	(2.8)	(4.2)	(5.5)	(2.8)	(2.23)
C14:0	Goats	2.84	3.09	3.52	3.08	2.96	2.34	2.47	1.75	1.66	2.01		
	%	(6.1)	(4.2)	(3.1)	(2.9)	(1.5)	(2.1)	(2.2)	(2.3)	(1.9)	(2.0)		
	Sheep			16.78	17.6	11.75	8.36	6.14	9.07	4.68	6.05	4.32	2.4
	%			(6.28)	(3.76)	(3.36)	(2.85)	(3.51)	(3.19)	(4.33)	(7.1)	(2.98)	(1.98)
C18:3	Goats	0.73	1.4	1.35	1.73	8.26	1.96	1.72	0.52	2.13	2.65		
	%	(1.6)	(1.9)	(1.2)	(1.64)	(4.2)	(1.7)	(1.5)	(0.7)	(2.4)	(3.1)		
	Sheep			2.38	20.5	19.75	6.73	3.54	5.7	6.22	1.32	1.72	1.72
	%			(0.9)	(4.4)	(5.6)	(2.3)	(2.02)	(2.01)	(5.76)	(1.55)	(1.18)	(1.42)
Others	Goats	1.24	2.15	2.99	3.204	28.05	4.59	3.64	2.29	2.859	3.077		
	%	(2.66)	(2.89)	(2.69)	(3.04)	(14.15)	(4.04)	(3.24)	(3.01)	(3.23)	(3.11)		
	Sheep			7.78	69.86	51.68	8.08	6.75	7.22	19.52	2.88	3.67	3.27
	%			(2.9)	(14.92)	(14.76)	(2.76)	(3.86)	(2.54)	(18.07)	(3.4)	(2.53)	(2.7)
Total saturated	Goats	22.5	37.7	46.4	43.7	67.2	47.5	56.3	43.8	45.7	54.8		
	%	(48.18)	(50.67)	(41.69)	(41.5)	(33.89)	(41.8)	(49.87)	(57.56)	(51.7)	(55.46)		
	Sheep			138.8	228.6	125.6	131.3	92.9	160.4	59.6	59.9	86.9	75.1
	%			(51.98)	(48.85)	(35.9)	(44.8)	(53.1)	(56.48)	(55.19)	(70.5)	(59.93)	(62.1)
Total unsaturated	Goats	24.3	36.7	64.9	62.1	114.2	66.1	55.9	32.3	42.7	44.0		
	%	(52.0)	(49)	(58.31)	(59.03)	(57.59)	(58.19)	(49.78)	(42.44)	(48.3)	(44.5)		
	Sheep			127.7	185.1	190.1	161.1	82.1	123.2	35.3	25.2	63.4	45.5
	%			(47.83)	(39.55)	(54.31)	(54.98)	(46.9)	(43.38)	(32.68)	(29.65)	(43.72)	(37.61)
Ratio Sat/ Unsat	Goats	0.939	1.049	0.74	0.708	0.582	0.718	1.096	1.377	1.076	1.232		
	Sheep			1.100	1.94	0.784	0.836	1.202	1.406	1.825	2.548	1.432	1.758
Ratio 18:0/ 18:1	Goats	0.420	0.518	0.343	0.301	0.340	0.375	0.663	0.876	0.610	0.810		
	Sheep			0.422	0.441	0.386	0.473	0.671	0.907	1.451	1.657	0.922	1.439

4.2.1.7 Total plasma lipids

From the results in Table 66 and from the analysis of variance ratio, it was clear that neither age, feed nor their interactions had a significant effect on the concentration of total plasma lipids in goats. The highest concentration was observed at the age of 9 days. There were non-significant month to month fluctuations. The concentration for the group fed once daily was slightly lower than that for the group fed twice daily.

Table 67 shows that there was a significant effect on plasma lipids concentration due to age in lambs. The concentration decreased significantly with age. The concentration at 1 month was significantly higher than at all other ages ($P < 0.001$). The concentrations at 4 and 5 months were significantly lower than the concentrations at 2 and 3 months of age ($P < 0.001$). Neither feeding nor its interaction with age had a significant effect on the concentration of plasma lipids.

4.2.2 Discussion

4.2.2.1 Plasma free fatty acids (FFA) and age

From the data in Table 26 and Figure 3 for goats and Table 27 and Figure 4 for lambs as summarized in Table V for both lambs and goats, it is clear that age had a significant effect on the fasting concentration of plasma FFA in the two species while feeding patterns had a slight effect.

The fasting plasma FFA in goats regardless of feeding pattern increased to a maximum level at the age of 2 months which coincided with weaning. The concentration then declined with age despite the longer fasting period imposed.

The large increase from 60.6 μg/ml at 9 days of age to 108.2 μg/ml

at 1 month may indicate that in 9-day old goats, 21h fasting was not sufficient to cause full mobilization of fat. It could be that at this age the goats had enough glycogen reserve in the liver and other tissues with which to meet the energy demand during fasting. Glycogen reserve is known to be higher in young ruminants with a maximum at 2 weeks of age (Boda et al., 1962) because the dietary carbohydrate is absorbed as glucose, unlike in older ruminants where VFA is the major source of energy (Edwards, 1970). Another possible cause for the lower fat mobilization in younger goats is that there was still some absorption of metabolites from the alimentary tract, especially the milk fat. Shannon and Lascelles (1967) observed a continuous absorption of lipids from the intestine for 24 hours when calves were fed milk once daily. The higher level of triglyceride compared to that of plasma FFA could well support this reasoning.

When 1 month old animals were fasted for the same length of time (21 hours) as 9-day old goats the mobilization of FFA was higher in the older animals. The fasting concentration of FFA in lambs at 1 month of age was also higher than the FFA level found in goats of the same age.

A similar increase in fasting concentration of plasma FFA has been reported by Leat (1967). This author observed an increase in fasting plasma FFA in lambs from 20 days to a peak at 45 days. Wood et al. (1971b) also found an increase in fasting plasma FFA with age in calves.

This increase in fasting plasma FFA indicates that the animals were more sensitive to fasting at 1 month of age, and mobilize fat from their adipose tissues to meet part of their energy demand during fasting. In lambs 1 month old, Masters (1964b) observed a decrease in the percentage of triglyceride in the adipose tissue which indicated

an active mobilization of tissue triglyceride into plasma FFA.

It has been observed that from the age of 4 weeks, the importance of glucose to young ruminants decreases; at the same time the level of plasma VFA is not high enough to meet their energy demand. Thus a short fast is enough to deplete the liver glycogen and to stimulate fat mobilization (Reid, 1953; Boda et al., 1962). Boda et al. (1962) reported a drastic fall of liver glycogen at 4 weeks in lambs from 50 µg/gm wet weight at 2 weeks to 6 µg/gm after a 16 hour fast, which indicated a near complete depletion of liver glycogen and a decrease in muscle glycogen. The higher concentration of plasma FFA in sheep than in goats could arise if lambs had lower reserves of glycogen or more triglyceride in their adipose tissue than goats.

At 2 months of age (2 weeks after weaning) a 24 hour fast in goats led to a greater mobilization of fat than at 1 month, while in sheep the concentrations were virtually unchanged. Higher mobilization of fat at this time could be associated with inability of the goats to obtain enough energy from the lucerne hay. Although some of the goats were eating about 400g/day, 2 goats were eating only 100g/day. According to Boda et al. (1962) and Reid (1953), the absorption of VFA from the rumen is relatively low at the age of 8 weeks and this could contribute to the low energy available to those animals. Low energy intakes associated with weaning have been reported (Searle et al., 1972). Large changes have been noticed in the body composition of lambs following weaning (Searle et al., 1972; Kellaway, 1973). These changes are associated with either a loss or little change in body fat but with an increase in body lean. A decrease in body fat was observed in this study at weaning (Table 14) and this could explain the higher level of fasting plasma FFA at that time, indicating that at this age the goats were meeting part of their

energy demand by mobilizing fat reserves.

In lambs (Table 27) the concentration of plasma FFA at the age of 2 months was not significantly different from that at 1 month of age, although slightly lower. The sample was taken 3 weeks after weaning. This level was twice as high as the value obtained for goats, indicating higher mobilization of fat by this species. Unlike goats, the actual concentration of body fat of lambs did not change significantly, but its proportion to body weight declined in the group held indoors, while both the concentration and proportion of body fat decreased in the grazing group (Table 16).

Although the lambs and goats were fasted for a longer period (30 hours) after the age of 3 months the fasting plasma FFA decreased with age. Thus the plasma FFA at 3 months was significantly lower than the plasma FFA in 2-month old lambs and goats. This indicates that a 30 hour fast was not long enough to deplete metabolites already in the blood and rumen and the glycogen reserve. Decreases in fasting plasma FFA with age have been reported in ruminants and non-ruminant species. Boda et al. (1962) observed almost total depletion of liver glycogen and a reduction of skeletal muscle glycogen reserve when lambs 4 to 7 weeks of age were fasted for 16 hours. Yet a similar fast had relatively little effect on liver glycogen or skeletal muscle reserves of lambs older than 7 weeks. A non-significant decline in fasting plasma FFA with age in calves was reported by Wood et al. (1971b) while Webb et al. (1969) failed to detect any significant change in fasting plasma FFA with age in calves fasted for 16 hours. On the other hand, Leat (1967) observed a decrease in fasting plasma FFA with age in lambs from 45 days old. A decrease in fasting plasma FFA with age has also been observed in rats (Florence and Quaterman, 1972). These authors found a decrease in fasting plasma FFA in rats

at about 33 days of age.

4.2.2.2 Effect of feeding pattern on fasting plasma FFA

Apart from the higher plasma FFA concentration observed in grazing lambs at the age of 4 months, there was no regular pattern evident in animals of different groups.

The higher level of plasma FFA in the grazing group at 4 months of age was due to the small quantity and low nutritive value of pasture available towards the end of October. At this time two of the animals in this group were losing body fat. The lower FFA level at 5 months compared with that at 4 months, was due to the animals being provided with extra lucerne hay.

The lack of significant effect of feeding patterns on fasting plasma FFA indicates that the animals in different feeding groups were utilizing the feed given to them with similar efficiency. It has been shown that the amount of feed eaten before fasting has a marked effect on the fasting plasma FFA (Florence and Quarterman, 1972). This could account for some of the variability observed in this study. The goats fed once daily had a slightly higher plasma FFA over 4 months, while in lambs the group fed once each day had a relatively lower plasma FFA than the group fed twice daily. The relatively lower fasting plasma FFA observed in the group fed once daily agrees with the report of Florence and Quarterman (1972) on rats trained to eat all their feed at once as compared to nibblers.

The mode of fasting imposed was favourable to the animals eating their food rapidly because animals had access to food for 3 hours after which it was removed. Under these circumstances the lambs fed once a day were at an advantage. They ate faster and consumed their ration within 3 hours, while the other group ate only half of this ration in the same period.

In the group of goats fed once a day, two ate their ration throughout the day, so when they were allowed only 3 hours they had consumed only half of their daily ration before fasting.

4.2.2.3 Individual free fatty acids and age

The major fatty acid components of plasma FFA in goats are presented in Tables 34, 36, 40, 42 and 44 and in Tables 35, 37, 41, 43 and 45 for lambs. They are summarized in Figure 7 for goats, Figure 8 for lambs, and in Table V for both goats and lambs.

The major fatty acids were shown to be stearic, oleic, palmitic, palmitoleic, myristic and linolenic acids with others as minor contributers.

Oleic acid

Of the C18 fatty acids (stearic, oleic and linoleic) in goats the concentration of oleic acid (Table 36) followed the pattern observed for total FFA, increasing to a maximum at 2 months then declining to a minimum at 4 months. In lambs the concentration of oleic acid (Table 37) was highest at 1 and 2 months, declined to a minimum at 4 months and then increased slightly at 5 months. As a proportion of total FFA, oleic acid was highest at the age of 1 month then decreased to a minimum value at the age of 4 months in both species. Oleic acid, however, formed the highest proportion of the plasma FFA at all ages except at the age of 4 months in lambs.

This pattern of change in oleic acid concentration agrees with the report of Masters (1964a) in lambs. This author observed an increase in the proportion of oleic acid in plasma FFA which reached a maximum after a month and then declined steadily until 4 months of age where it rose again.

The higher proportion of oleic acid indicates that young ruminants, whilst consuming milk, deposit oleic acid in adipose

tissues which is then mobilized actively into plasma FFA as a source of energy or for the synthesis of other lipids such as cholesterol and phospholipids. An increase in the proportion of oleic acid in the triglycerides of various tissues and in FFA for the first 2 months in lambs has been reported by Masters (1964b). Garton and Duncan (1969) found that the tissues of milk-fed calves, before rumen development, had a higher proportion of oleic acid than later. Stokes and Walker (1970) observed a close relationship between the fatty acid composition of the diet and that of the carcass of milk-fed lambs.

The higher proportion of oleic acid in fasting plasma FFA found in the present experiments supports the findings of Horgan and Masters (1963) who observed a preferential mobilization and utilization of oleic acid by ovine tissues.

The decline in the actual concentration and in the proportion of oleic acid in plasma FFA from 2 months could be due to the change of diet from milk to grass and also to the development of a functional rumen with micro-organisms which hydrogenate the polyunsaturated fatty acids. Pasture grasses are rich in polyunsaturated fatty acids. Garton (1960) presented value of 60% of total fatty acids for linoleic acid which compares favourably with 61% for pasture grass and 20% linoleic acid, 29% linolenic acid for lucerne hay in the present study (Table 2).

However, only small amounts of these polyunsaturated fatty acids are absorbed by the animal because they are hydrogenated to saturated fatty acids, mainly stearic acid (Ward, et al., 1964; Moore et al., 1969; Cramer and Miller, 1976).

A decline in percentage of oleic acid with age has been demonstrated in the plasma and tissues of ruminants (Masters, 1964a, 1964b,

Garton and Duncan, 1969; Duncan et al., 1971; Leat et al., 1973; Leat, 1975). Since the major source of plasma FFA is adipose tissue (Emery, 1969) the decline in the proportion of oleic acid in the tissues will be reflected in the plasma FFA.

Stearic acid

The stearic acid (Tables 34 and 35) in plasma for both species varied with age although differently from that of oleic acid. In goats the concentration of stearic acid (Table 34) in plasma increased to a maximum at 3 and 4 months. The proportion in the total plasma FFA declined initially from 18% at 9 days to 16% at 1 and 2 months (Table V) and then increased to 27% at 3 and 4 months in an inverse relationship with the proportion of oleic acid.

In lambs 2 months old, the measured concentration of stearic acid (Table 35) decreased slightly and remained constant for the rest of the experimental period. Its proportion to total FFA decreased slightly from 16.2% to 15.7% then increased in a manner similar to that observed in goats. Similar observations have been reported by Masters (1964a) in lambs.

The increase in the proportion of stearic acid to total FFA after weaning indicates that at this stage the tissues from which it was mobilized were relatively rich in this fatty acid. This change could be due also to hydrogenation of dietary lipids by the rumen micro-organisms. Increasesin the proportion of stearic acid in blood and in tissues during rumen development have been reported (Ward et al., 1964; Duncan et al., 1971; Leat et al., 1973; Leat, 1975).

Stearic acid in adipose tissues originates from two sources; from hydrogenation of dietary fat in the rumen and from de novo synthesis. Endogenous synthesis is known to account for 16%-17% of perinephric stearic acid (Leat et al., 1973; Leat et al., 1977).

A lower proportion of stearic acid in perinephric triglycerides was observed in lambs raised on a lipid-free diet compared to those on a diet of grass cubes which contained C18 unsaturated acids available for hydrogenation (Duncan et al., 1971).

Garton and Duncan (1969) observed a higher proportion of stearic acid in the tissues of a year-old lamb than in neonatal lambs. Similar observations in calves were reported by Leat (1975). When rumen development was arrested by continuous milk feeding the proportion of stearic acid in adipose tissue was found to be lower than in the calves introduced to solid feeds (Garton and Duncan, 1969).

The significant increase in the ratio of stearic to oleic acid with age is an indication of rumen development and hydrogenation of polyunsaturated fatty acids in the rumen.

Linoleic acid (Tables 40 and 41)

The concentration of linoleic acid in lambs (Table 41) did not change significantly with age while in the goat (Table 40) concentration of this fatty acid was significantly higher at 2 months than at earlier or later ages. The proportion of this fatty acid to total free fatty acid decreased initially in 1 month old goats, then increased at 2 months and subsequently declined, while in lambs there was little difference with age.

The increase in the proportion of linoleic acid at the age of 2 months in goats could be due to ready availability of this acid from the feed (lucerne hay) which was rich in C18:2 and C18:3 fatty acids. At this age hydrogenation of polyunsaturated fatty acid was probably low due to the smaller population of micro-organisms involved in hydrogenation compared to the numbers found in adult ruminants. The full adult micro-organism population in the rumen is not acquired until lambs are at least 3 months old (Reid, 1951;

Barnet and Reid, 1961). A decrease in the proportion of linoleic acid at 1 month agrees with the results of Masters (1964a). Probably this was due to the increase in the proportion of oleic acid in plasma FFA at the expense of linoleic acid.

The proportion of linoleic acid to the total fatty acid was the lowest of C18 fatty acid (Table V) and this agrees with the reports of Leat et al. (1966), Noble et al. (1971) and Noble (1973) who showed that the proportion of linoleic acid in neonatal ruminants is very low but increases slightly for the first 30 days after suckling, then remains constant.

Palmitic acid (Tables 42 and 43)

Palmitic acid (Table 42) concentration in plasma increased with age in goats to a maximum at 2 months, then declined during the third and fourth months, while the proportion of this fatty acid to the total fatty acids was highest at 9 days of age and declined to a minimum at the age of 2 months and then increased. In lambs (Table 43) the lowest proportion was also at 2 months, after which there was an increase.

Masters (1964a) observed that the proportion of palmitic acid in total plasma FFA was maximal at 1-2 months, after which it declined, and concluded that the higher proportion of palmitic acid present in plasma during suckling was due to the high content of palmitic acid in ovine milk. The milk substitute used in the experiments reported in this thesis had a high proportion of palmitic acid (40%) which could account for the high proportion of this acid in 9 day old goats and 1 month old lambs. At weaning this source of palmitic acid was lost. This may account for the initial decline in the proportion of this fatty acid in the plasma FFA.

The increase in the proportion of palmitic acid with age is due to the decline in the proportion of oleic acid and probably also to the formation of palmitic acid from the rumen digesta resulting in an increased proportion of palmitic acid in the adipose tissue. Moore et al. (1969) observed a high proportion of palmitic acid in the adult sheep rumen. Ziegler et al. (1967) found that the addition of roughage to growing lambs resulted in increased amounts of palmitic and stearic acid in the adipose tissue triglycerides. The depot triglyceride of an adult ruminant consists of 31% palmitic acid (Cramer and Miller, 1976).

Palmitoleic acid

The plasma concentration of palmitoleic acid C16:1 (Tables 44 and 45) increased with age in both species up to the age of 2 months then declined. The proportion of this fatty acid showed a slight change with age but displayed no definite pattern. In goats the proportion of palmitoleic acid (Table 44) decreased slightly from between 3 months and 4 months of age, while in lambs there was no definite pattern.

The variations observed may be related to the dynamic nature of plasma FFA. The higher proportion in the plasma of goats during the milk stage probably arises from the milk which contained 4% palmitoleic acid. After weaning the proportion of this fatty acid in feed was relatively low. Another factor which could account for the higher fraction of palmitoleic acid is the low proportion of linoleic acid. Noble et al. (1971a) have shown that when the proportion of linoleic acid in plasma is low the animal synthesizes palmitoleic acid which is utilized in place of linoleic acid, for example in forming phospholipids.

Ziegler et al. (1967) observed a decrease in the proportion of palmitoleic acid in adipose tissues when roughage was added to the diets of growing and fattening lambs. Since adipose tissue is the main source of plasma FFA, the decrease in proportion of certain fatty acids in the adipose tissue will be reflected in the plasma FFA. Masters (1964a) observed a slight change in the proportion of palmitoleic acid with age in the plasma of lambs.

Myristic acid C14:0 Table V

The concentration and the proportion of myristic acid in the plasma declined with age. Only a small amount of this fatty acid was present in the hay fed to the animals after weaning, while the milk diet contained 10%. This could account for its higher proportion during the milk stage than after weaning.

The increase in the ratio of saturated fatty acids (Tables 32 and 33) with age is in agreement with the findings of Masters (1964) in lambs. Development of the rumen changes the fatty acid patterns from those found in monogastric animals to a highly saturated state characteristic of the adult ruminant (Garton, 1960).

4.2.2.4 Effect of feeding pattern on fatty acid composition of plasma FFA

Feeding pattern was shown to have significant effects on the concentration of oleic acid and the ratios of stearic acid to oleic acid and saturated to unsaturated fatty acids in lambs and goats.

The significantly higher concentration of oleic acid observed in the grazing group than among the pen fed groups could be due to the availability of feed richer in polyunsaturated fatty acids. Paddock grass contained 62% C18:3 which may have escaped hydrogenation in the rumen (Table 2). Animals grazing on green pasture

have higher proportions of oleic acid and linoleic acid, especially in phospholipids and cholesterol esters (Garton, 1960; Qureshi et al., 1972). Another reason could be due to higher concentrations of plasma FFA at 4 months of age in the grazing group.

The ratios for stearic to oleic acid and saturated to unsaturated fatty acids were significantly higher among the groups fed twice daily than for the grazing group and for the lambs and goat groups fed once a day.

The reason for this difference could be that the polyunsaturated fatty acids in the group fed twice a day were hydrogenated to a greater extent than in those fed once daily during rumen development since the differences were observed from 2 months to 5 months of age in lambs and to the age of 4 months in goats.

The extent to which a dietary fatty acid is hydrogenated in the rumen depends on several factors.

(a) The population of the micro-organisms involved in the hydrogenation.

(b) Relative concentration of substrate to number of micro-organisms.

(c) The length of time the substrate is exposed to the micro-organisms.

The hydrogenation of linolenic acid (C18:3), which is a major pasture fatty acid, involves three steps: firstly to a dienoic acid (C18:2), secondly to a monoenoic acid, and thirdly into stearic acid (Ward et al., 1964).

It has been shown by Moore et al. (1969) that if the concentration of linolenic acid is high relative to the micro-organism population, some of the fatty acids would escape hydrogenation at step 3, resulting in a build-up of monoenoic acid.

These authors observed an accumulation of C18:1 in the rumen of sheep when linoleic acid was infused into the rumen. Infusion of maize oil resulted in a lower concentration of linoleic acid at a given time, as this fatty acid was hydrogenated rapidly to stearic acid. They concluded that higher concentrations of linoleic acid inhibited some steps in the hydrogenation mechanism. The basis for this was that when the ruminants ate the whole day's ration within 3 hours, the hydrolysis of the dietary lipids (rich in oleic, linoleic and linolenic acids) resulted in a high concentration of these polyunsaturated fatty acids which inhibited the full process of hydrogenation to stearic acid. In the group fed twice daily, most of the polyunsaturated fatty acids were probably hydrogenated to stearic acid since a relatively lower concentration of polyunsaturated fatty acids would be produced in a given time.

Another reason for the lower proportion of saturated and stearic acid in the once-daily fed group may be the short time the substrate was exposed to the micro-organisms. It is known that increasing food intake by ruminants, increases the content of the reticulo-rumen and this results in a decrease in retention time (Schellenberger and Kesler, 1961; Balch and Campling, 1965), which means that the substrate would be exposed to the rumen micro-organisms for a shorter period and hence some of the fatty acids would escape hydrogenation.

On the whole, goats plasma was found to have a lower proportion of saturated fatty acid as shown by a low saturated/unsaturated fatty acid ratio and also a low stearic/oleic acid ratio. These differences could arise if goats had micro-organisms in their rumen different from those of lambs. Leat (1966) reported a higher proportion of oleic acid in the plasma of goats and a lower proportion of stearic acid than in sheep.

4.2.2.5 Plasma triglyceride and age

From the results presented in Table 46 for goats and Table 47 for lambs, it appears that age did not have a significant effect on total triglycerides in goats, whereas there was a significant change in lambs.

The concentration in lambs increased for the first 2 months, then declined slightly while in goats the level decreased slightly from a maximum at 9 days to a lower value at 1 month, but showed no further change thereafter. Similar findings have been reported by Leat (1966, 1967) who observed in sheep a rapid increase in fasting plasma triglyceride to a peak at 20 days of age, which then remained constant until weaning. Masters (1964a) found an increase in the proportion of plasma triglyceride which reached a peak at 1-2 months in lambs and then declined with age. Wood et al. (1971b) reported an increase in plasma triglyceride in dairy calves with age up to 3 weeks which was then followed by a subsequent decline.

The increase in plasma triglyceride during the first month of life arose from the ingestion of milk, which is rich in fat. The milk substitute used in the present experiment contained 17% crude fat. As the animals' dependence on milk declines, the plasma triglyceride level declines to the adult values.

The higher concentration of plasma triglycerides also corresponded with the relatively high plasma FFA concentrations. It could be that the increase in plasma FFA led to the concomitant increase in plasma triglyceride, since FFA is known to be a source for plasma triglyceride (Nestel, 1964; Grande and Pringe, 1970).

4.2.2.6 Effect of feeding pattern on fasting plasma triglyceride

Feeding pattern had no significant effect on plasma triglyceride

concentration in goats, while in lambs the group fed twice daily had significantly higher concentrations at 1 month than the once-daily fed group, while the group fed once daily had higher concentration at 2 months of age.

The reason for these differences is not clear. The overall effect in lambs was that feeding once daily led to a slightly higher concentration of plasma triglycerides, which corresponded with a slightly lower level of plasma FFA (Table 27). The values for the grazing group were lower than for the pen fed animals. This lower concentration of plasma triglyceride (which corresponds with slightly higher levels of plasma FFA) could be due to the type of feed as these animals were on pasture grass diet compared to the lucerne/oat diet in the pen fed group.

Grain in the diet of ruminants is known to increase the proportion of propionic acid in the rumen and blood (Storry et al., 1969). Propionic acid is a gluconeogenic precursor (Annison et al., 1967). Increase in glucose synthesis would lead to an increase in fatty acid synthesis in the liver and hence increase plasma triglycerides. Diets rich in carbohydrates have been shown to increase the plasma triglycerides concentration in monogastric animals (Nestel et. al., 1970).

4.2.2.7 Individual triglyceride fatty acids and age

The composition of triglyceride fatty acids in both goats and lambs shows a close similarity to the fatty acid composition of plasma FFA.

Stearic acid

The concentration of stearic acid (Table 54) in plasma triglycerides of goats decreased initially (at 1 month) and then increased subsequently, while that of lambs (Table 55) increased significantly at the age of 4 months. As a proportion of total

triglyceride fatty acids it decreased in 1 month old goats then increased thereafter to the highest proportion at 4 months of age. A similar course was followed in lambs.

This increase in the proportion of stearic acid is similar to that observed for plasma FFA (Tables 26 and 27) and coincides with development of a functional rumen and hence hydrogenation of polyunsaturated fatty acids. However, these findings contradict those of Masters (1964a) who observed an increase in the proportion of stearic acid to a peak at 2 months in lambs which was followed by a subsequent decline. However, it agrees with those of Wood et al. (1971b) who observed an increase in the proportion of stearic acid with age in calves.

Oleic acid

The concentration of oleic acid in plasma did not change with age in either species. However, the proportion of oleic acid to total triglyceride fatty acids showed a slight change with age. The proportion of this acid in goats increased to its highest value at 1 month, then declined to its lowest values at 3 and 4 months of age. In lambs the change in proportion of oleic acid displayed no regular pattern. There was a slight decrease at the age of 2 months, followed by an increase and then a decrease.

The decrease in the proportion of triglyceride oleic acid in goats corresponds with the increase in the proportion of stearic acid and also the decrease of this fatty acid in the plasma FFA.

This suggests hydrogenation of dietary polyunsaturated fatty acids. Masters (1964a) observed a decline in the proportion of oleic acid in plasma triglycerides in lambs 1-1½ months old, which was followed by a subsequent rise and then a fall at 3-3½ months. The level then increased at 4½ months. In the present work, the proportion

of oleic acid in lambs followed the same pattern.

Linoleate

The concentration and proportion of triglyceride linoleate in goats did not change significantly with age, while in lambs there was a significant decrease in the concentration of this fatty acid with age. The proportion of this fatty acid was lowest at 4 months, while remaining constant at all other ages. These differences between lambs and goats represent species differences in the pattern of hydrogenation of the dietary C18 polyunsaturated fatty acids. Masters (1964a) observed a higher concentration of linoleic acid in plasma triglycerides in lambs 1-1½ months and at 3½ months of age.

Palmitic acid

The actual and proportional concentrations of triglyceride palmitic acid did not change significantly with age in goats, while in lambs there was a significant decrease with age. The proportion of this fatty acid to total triglyceride fatty acids was lowest at 2 months and highest at 5 months. The higher concentration of palmitate in lambs 1 month old could be due to the higher availability of this fatty acid in the milk substitute (40% of total fatty acids) (Table 2). Masters (1964a) observed a similar pattern in lambs.

Palmitoleic acid

The concentration of triglyceride palmitoleic acid in goats did not change with age, neither did its proportion to the total triglyceride fatty acid, while in lambs it declined significantly with age to a minimum value at 5 months. The proportion of this fatty acid was minimal at 4 months. The decline in the concentration and proportion of triglyceride palmitoleic acid in lambs indicates a decrease in the synthesis of this fatty acid, probably due to the availability of other unsaturated fatty acids. A decrease in the concentration of

palmitoleic acid with age has been reported previously in lambs (Noble et al., 1971).

4.2.3 Summary

1) The fasting plasma FFA in goats increased to a peak at 2 months of age which was immediately after weaning, and decreased subsequently. The increased FFA mobilization in 1 and 2 month old goats was attributed to the decrease in glycogen reserves as observed by Boda et al. (1962) in lambs, and to the intrinsic transfer of lipids from adipose tissues to the liver as reported by Masters (1964b). The decrease in the importance of glucose as a source of energy and low VFA availability was another possible cause for the increase in plasma FFA.

After weaning the increased fatty acid mobilization as indicated by higher plasma FFA in both lambs and goats resulted from the change in diet, low feed intake and low efficiency in the absorption of VFA from the rumen. This was supported by the decrease in body fat observed in these animals.

From 3 months onwards, the fasting plasma FFA for the two species decreased significantly despite the longer fasting period. This indicated that 30 hour fasting was not long enough to deplete all the metabolites in the blood and rumen, and glycogen reserves as reported by Boda et al. (1962) in lambs. These observations agreed with the findings of Leat (1967) in lambs, Wood et al. (1971b) in calves and those of Florence and Quarterman (1972) in rats.

2) Feeding once or twice daily had no significant effect on the fasting FFA. However the lambs in the paddock had a higher concentration of plasma FFA at the age of 4 months probably

because of low food intake due to lack of pasture in late October.

3) The lambs were found to mobilize more fat than the goats on all occasions.

4) The individual FFA displayed different patterns of change with age. Of the C18 fatty acids, oleic acid (C18:1) was found to follow the pattern observed for total FFA, with a peak at 2 months of age followed by a subsequent decline. The proportion of this fatty acid in both species declined with age, while that of stearic acid increased. This inverse relationship resulted from the development of a functional rumen which hydrogenates the dietary polyunsaturated fatty acids. A similar relationship has been reported for lambs (Masters, 1964a, b; Garton and Duncan, 1971; Leat et al., 1973; Leat, 1975).

5) Linoleic acid did not change significantly with age in lambs, while in goats, it was significantly higher at 2 months than at any other age. This resulted presumably from the limited hydrogenation capacity of the micro-organisms in the rumen. Adult micro-organism population is not acquired until animals are 3 months old (Reid, 1951).

6) Palmitic acid concentration was highest during milk feeding, decreased immediately after weaning, and then increased in both species. These changes arose from the high intake of this fatty acid in the milk diet (which contained 40% palmitic acid). Immediately after weaning this source was removed. In older animals the increase in this fatty acid arose from microbial sources and from de novo synthesis by adipose tissues.

7) Palmitoleic acid was slightly higher in goats and lambs at 1 and 2 months and then declined in both species. The higher level in young animals was caused by the low proportion of linoleic acid in the milk diet and in the plasma lipids which led to the increased synthesis of palmitoleic acid. Palmitoleic acid can be used in places of linoleic acid for example in forming phospholipids as reported by Noble et al. (1971a).

The decline in myristic acid in plasma FFA with age was caused by the low level of this fatty acid in the hay while it was present in milk.

8) Goats had lower saturated/unsaturated fatty acid ratios and lower stearic/oleic acid ratios than lambs. This indicates that goats plasma FFA was less saturated than that of lambs and this could have arisen from differences in the hydrogenation of dietary polyunsaturated fatty acids in the rumen. This could mean that the type and population of micro-organism in the two species are different.

9) Feeding once daily was found to increase the proportion of unsaturated fatty acids in plasma as indicated by significantly lower saturated/unsaturated fatty acids in the two species.

This may have resulted from the increased ingesta flow rate when animals ate their day's meal in a short period and thus some of the fatty acids escaped hydrogenation, or from the increased concentration of polyunsaturated fatty acids in the rumen immediately after feeding, thus permitting some fatty acids to escape hydrogenation. The concentration of poly-unsaturated fatty acid in the rumen is known to affect the process of hydrogenation (Moore et al., 1969).

10) Fasting plasma triglyceride changed little with age in goats, while in lambs the concentration was significantly higher at 1 and 2 months of age and then decreased. This is in agreement with the findings of Leat (1966, 1967) and Wood *et al.* (1971b). The higher concentration in younger animals was caused by the ingestion of milk which was rich in fat (17%).

11) The individual triglyceride fatty acids in both species showed a close similarity to the fatty acid composition of plasma FFA. Thus the increase in the proportion of stearate and the decrease in the proportion of oleate was brought about by the development of a functional rumen.

The change in triglyceride linoleate and palmitate with age was different in the two species. While there was no significant change in goats, in lambs there was a significant decrease with age and this may be due to a species difference in hydrogenation pattern.

4.3 DIURNAL VARIATION IN PLASMA LIPIDS IN GOATS

4.3.1 RESULTS

4.3.1.1 Plasma FFA

The concentration of plasma FFA (Table 68) decreased significantly with time in the group fed once daily. The pre-feeding concentration was the highest. This was followed by a significant decrease 2 hours after feeding and remained relatively constant for 6 hours. A slight increase occurred at 1900 and remained constant for the rest of the day.

For the group fed twice daily the concentration declined slightly immediately after feeding which was then followed by an increase to a maximum concentration at 1600h which was immediately before the evening feed. This was followed by a significant decline ($P < 0.05$) after the evening meal and did not change much with time except for a slight increase at 0400h.

4.3.1.2 Saturated and unsaturated FFA

(a) Saturated fatty acids

Significant effect due to time after feeding on the concentration of saturated FFA (Table 69) was observed in the group fed milk twice daily. The concentration at 1600h was significantly higher than the concentrations at 1000, 2200 and 0100h ($P < 0.05$) and slightly higher than at other times. The concentration for the group fed once daily was highest at 0800h just before feeding. This declined considerably 2 hours after feeding. Thereafter there was only slight variation between times. The mean for the two groups did not show any particular pattern of variation.

(b) Unsaturated fatty acids

There was a significant effect due to time after feeding on the

FIGURE 9 shows the diurnal variation in the concentration of plasma FFA in 3 goats fed milk once per day (μg/ml plasma). Each point represents one animal.

FIGURE 9

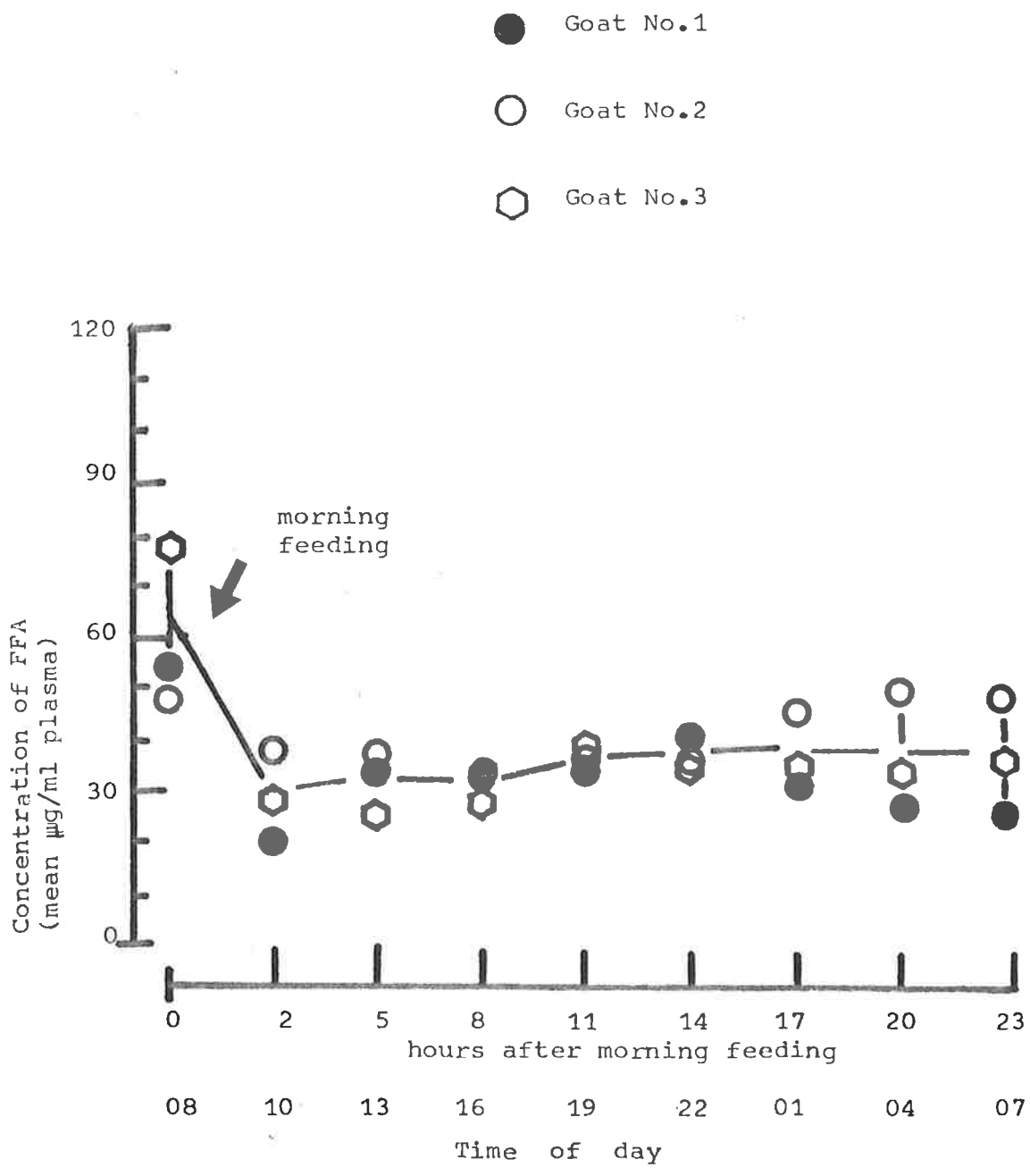
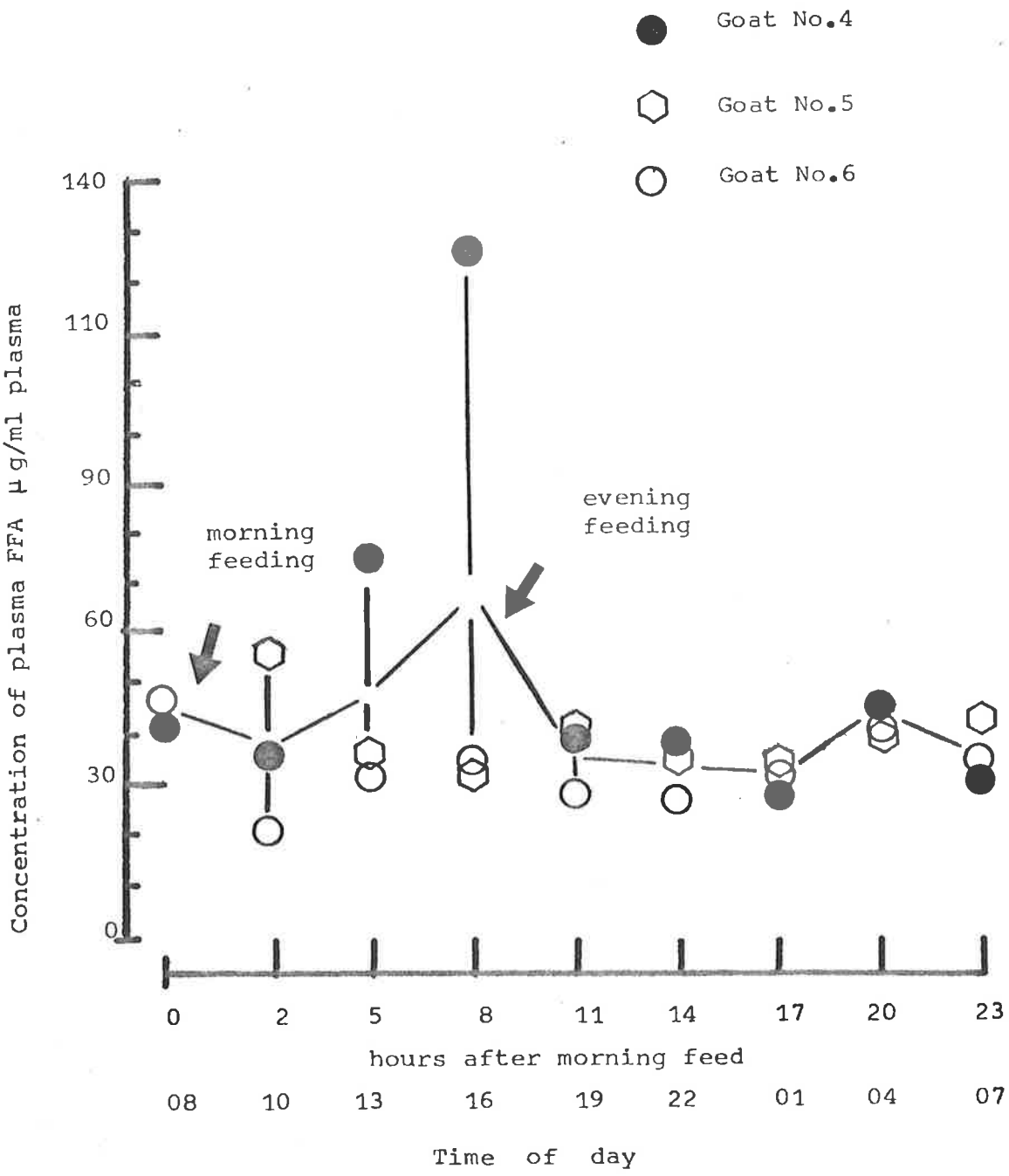

Goat No.1
Goat No.2
Goat No.3
120
90
60
30
0
morning feeding
Concentration of FFA (mean µg/ml plasma)
0
2
5
8
11
14
17
20
23
hours after morning feeding
08
10
13
16
19
22
01
04
07
Time of day

FIGURE 10 shows the diurnal variations in the concentration of plasma FFA in 3 goats fed milk twice daily (μg/ml plasma). Each point represents one animal.

FIGURE 10


Goat No.4
Goat No.5
Goat No.6
140
110
90
60
30
0
Concentration of plasma FFA µg/ml plasma
morning feeding
evening feeding
0
2
5
8
11
14
17
20
23
hours after morning feed
08
10
13
16
19
22
01
04
07
Time of day

concentration of unsaturated fatty acids (Table 70). Feeding pattern had no significant effect.

The concentration in the group fed once daily was significantly higher before feeding and decreased significantly ($P < 0.01$) 2 hours after feeding. Thereafter the concentration increased slightly to a level significantly lower than the concentration before feeding ($P < 0.05$) for the rest of the day, but not significantly higher than the concentration observed 2 hours after feeding. In the group fed twice daily, the concentration at 1600h was the highest. It was significantly higher than the concentrations observed at 1000, 1900, 2200, 0100 and 0700h ($P < 0.05$), but only slightly higher than the concentrations at 0800, 1300 and 0400h.

The overall mean for the two groups showed two peaks. One peak at 0800h was significantly higher ($P < 0.05$) than the concentrations at 1000, 1900 and 0100h, while it was slightly higher than the concentrations at 1300, 1600, 0400 and 0700h.

The second peak which was at 1600h was only slightly higher than the concentrations at other times and slightly lower than the concentration at 0800h.

The group which was fed milk twice daily had slightly higher concentrations of unsaturated free fatty acids than the group fed milk once daily.

4.3.1.3 Individual plasma FFA

(a) Stearic acid

Table 71 shows that concentration of free stearic acid in plasma changed significantly with time in the group fed twice daily, while there was no significant change in the group fed once daily, although there was a slight decrease. The concentrations for the

group fed twice daily were significantly lower at 1000, 1900 and 0700h than the concentration at 1600h ($P < 0.05$), while the concentration at 1600h was significantly higher than the concentrations at 2200 and 0100h ($P < 0.01$). The overall mean for the two groups did not show any consistent change with time, although the concentrations at 0800 and 1600h were slightly higher than the concentrations observed at other times.

Feeding patterns did not have a significant effect on the concentration of free stearic acid, but a slightly higher concentration was observed in the group fed milk twice per day.

(b) Oleic acid

The effect of feeding patterns on diurnal variations in the concentration of free oleic acid is shown in Table 72. The concentration for the group fed once daily was significantly higher before feeding than at any other time of day ($P < 0.01$), while in the group fed twice per day the concentration at 1600h was significantly higher than the concentration at 1900, 2200 and 0100h ($P < 0.05$).

The overall means for the two groups showed that the concentration at 0800h was significantly higher than at other times ($P < 0.05$), except that at 1600 and 0400h it was slightly higher. There was no difference between the two feed groups.

(c) Ratios stearic to oleic acid

The ratios of stearic to oleic acid (Table 73) increased significantly after feeding. The ratios at 1000, 1300, and 1600h were significantly higher ($P < 0.01$) than the before feeding values.

For the group fed once daily the ratios were significantly higher ($P < 0.05$) at 1000, 1300 and 1600h and thereafter declined to values not significantly different from the pre-feeding values. For the group fed twice daily the ratios increased slightly at 1000, 1300,

1600 and 1900h and then declined. There was no significant difference between feeding patterns although the twice fed group had slightly higher ratios.

(d) Palmitic acid

Table 74 shows that time had a significant effect on the concentration of free palmitic acid in the group of goats fed milk twice daily.

Concentrations at 2200 and 0100h were significantly lower than the concentration at 1600h ($P < 0.05$) while the levels at other times were slightly lower. For the group fed milk once per day, the concentration before feeding was slightly higher than the concentrations at any other time. There was a very little fluctuation with time in this group. The overall mean for the two groups did not show any regular pattern of variation.

Table 68

Effect of feeding frequency on diurnal variation in concentration of plasma FFA measured at 3 hourly intervals after feeding

		Plasma FFA concentration µ g/ml plasma		
		Feeding regimen		
Hours after morning feeding	Time of day	Fed once daily	Fed twice daily	Effect of time mean
0h	0800	64.2 c	44.4	54.3 a
2h	1000	29.9	38.3	34.1
5h	1300	32.8	47.8	40.3
8h	1600	32.1	68.1 b	50.1
11h	1900	37.0	35.7	36.4
14h	2200	37.7	34.3	36.0
17h	0100	38.5	32.1	35.3
20h	0400	38.3	43.5	40.9
23h	0700	38.4	35.8	37.1
Feed mean		38.8	42.2	40.5

			5%	1%
SED Effect of time means	9.84	LSD	20.069	27.009
SED Effect of feed means	5.89		12.013	
SED Feed x age means	14.39		29.35	
SED Within feed means	13.92		28.391	38.208

Effect of time mean

(a) The concentration at 0800h significantly higher than at 1000h ($P < 0.05$).

Fed twice daily

(b) The concentration at 1600h significantly higher than at 1000h, 2200h, 0100h and 0700h ($P < 0.05$).

Fed once daily

(c) Concentration of plasma FFA significantly higher at 0800h than at 1000, 1300 and 1600h ($P < 0.05$).

Table 69

Effect of feeding frequency on the diurnal variation in the concentration of saturated free fatty acid in goats

Concentration of saturated free fatty acids μg/ml plasma

Hours after morning feeding	Time of day	Feeding regimen: Fed once daily	Fed twice daily	Effect of time mean
0	0800	27.5	21.9	24.7
2h	1000	17.1	18.6 a	17.9
5h	1300	16.7	24.5	20.6
8h	1600	15.6	31.5	23.6
11h	1900	17.7	19.5	18.6
14h	2200	19.2	15.3 a	17.3
17h	0100	18.6	17.0 a	17.8
20h	0400	18.8	21.1	20.0
23h	0700	19.2	18.6	18.9
Feed means		18.9	20.9	19.9

			5%	1%
SED Effect of time means	4.37	LSD	8.913	11.995
SED Effect of feed means	2.29		4.671	
SED Feed x time means	6.26		12.768	
SED Within feed means	6.17		12.584	16.935

Group fed twice daily

(a) Concentrations at 1000, 2200 and 0100h significantly lower than the concentrations at 1600h ($P < 0.05$).

Overall Mean - Effect of time

(a) Concentrations at 1000, 1900 and 0100h significantly lower than the concentration at 0800h ($P < 0.05$).

Fed twice daily

(b) The concentrations at 1000, 1900, 2200, 0100 and 0700h significantly lower than at 1600h ($P < 0.05$).

Fed once daily

(c) Concentration at 0800h significantly higher than the concentrations from 1300h to 0700h ($P < 0.05$).

(d) Concentration at 0800h significantly higher than at 1000h ($P < 0.01$).

Table 70

Diurnal variations in the concentration of unsaturated free fatty acids in 3 goats fed milk once daily and in 3 goats fed milk twice daily (mean μg/ml plasma)

		Concentration of unsaturated free fatty acids μg/ml plasma		
		Feeding regimen		
Hours after feeding	Time of day	Fed once daily	Fed twice daily	Effect of time mean
0	0800	36.6 dc	22.6	29.6
2h	1000	12.8	19.6 b	16.2 a
5h	1300	16.1	23.3	19.7
8h	1600	16.5	36.6	26.6
11h	1900	19.3	16.2 b	17.8 a
14h	2200	18.4	19.0 b	18.7
17h	0100	19.9	15.1 b	17.5 a
20h	0400	19.5	22.4	21.0
23h	0700	19.2	17.2 b	18.2
Feed means		19.8	21.3	20.6

			5%	1%
SED Effect of time means	5.80	LSD	11.83	
SED Effect of feed means	3.65		7.44	
SED Effect of feed x time means	8.55		17.438	
SED Within feed means	8.20		16.725	22.507

Table 71

Diurnal variations in the concentration of free stearic acid in 3 goats fed milk once daily and 3 goats fed milk twice daily (mean µg/ml plasma)

Hours after morning feed	Time of day	Concentration of free stearic acid µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Effect of time mean
0h	0800	10.96	8.22	9.59
2h	1000	6.16	6.60 a	6.38
5h	1300	5.62	9.44	7.53
8h	1600	5.25	13.51	9.38
11h	1900	6.92	6.09 a	6.50
14h	2200	6.92	5.11 b	6.02
17h	0100	6.60	5.18 b	5.89
20h	0400	6.66	8.32	7.49
23h	0700	6.42	6.44 a	6.43
Feed means		6.83	7.66	7.25

			5%	1%
SED Time means	2.025	LSD	4.13	5.558
SED Feed means	1.082		2.207	
SED Feed x time means	2.909		5.933	
SED Within feed means	2.864		5.841	7.861

Fed twice daily

(a) Concentrations at 1000, 1900 and 0700h significantly lower than at 1600h ($P < 0.05$).

(b) Concentrations at 2200 and 0100h significantly lower than at 1600h ($P < 0.01$).

Overall mean - Effect of time

(a) Concentrations of free oleic acid at 1000, 1900, 2200 and 0100h significantly lower than at 0800h ($P < 0.01$).

(b) Concentrations at 1300 and 0700h significantly lower than at 0800h ($P < 0.05$).

Fed twice daily

(c) Concentrations at 1900, 2200 and 0100h significantly lower than at 1600h ($P < 0.05$).

Fed once daily

(d) The concentration at 0800h significantly higher than at 1000, 1300, 1600, 1900 and 2200h ($P < 0.01$).

(e) Concentration at 0800h significantly higher than at 0100, 0400 and 0700h ($P < 0.05$).

Table 72

Diurnal variations in the concentration of free oleic acid in the plasma of 3 goats fed milk once daily and in 3 goats fed milk twice daily (mean µg/ml plasma)

Hours after morning feed	Time of day	Concentration of free oleic acid µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Effect of time mean
0h	0800	27.05 de	15.85	21.45
2h	1000	8.47	13.31	10.89 a
5h	1300	9.24	13.72	11.48 b
8h	1600	8.68	21.36	15.02
11h	1900	11.74	9.87 c	10.81 a
14h	2200	12.35	9.61 c	10.98 a
17h	0100	13.20	10.97 c	12.08 a
20h	0400	14.77	15.45	15.11
23h	0700	14.44	11.47	12.96 b
Feed mean		13.33	13.51	13.42

			5%	1%
SED Time means	3.607	LSD	7.357	9.900
SED Feed means	1.918		3.912	
SED Feed x time means	5.178		10.56	
SED Within feed means	5.102		10.406	14.004

Table 73

Effect of feeding frequency on the diurnal variations in the ratio of C18:0 to C18:1 in goats

Ratios C18:0/C18:1 in goats plasma

Hours after morning feeding	Time of day	Feeding regimen: Fed once daily	Fed twice daily	Effect of time mean
0h	0800	0.417 bc	0.523	0.470
2h	1000	0.737	0.603	0.670 a
5h	1300	0.618	0.681	0.650 a
8h	1600	0.600	0.613	0.606 a
11h	1900	0.588	0.630	0.609 a
14h	2200	0.569	0.569	0.569
17h	0100	0.494	0.468	0.481
20h	0400	0.466	0.543	0.505
23h	0700	0.445	0.575	0.510
Feed means		0.548	0.578	0.563

			5%	1%
SED Time means	0.0615	LSD	0.1255	0.1863
SED Feed means	0.0290		0.0592	0.0879
SED Feed x time means	0.0870		0.1776	0.2636
SED Within feed means	0.0835		0.1705	0.2530

(a) Ratios at 1000, 1300, 1600 and 1900h significantly higher than ratios at 0800h ($P < 0.01$).

Fed once daily

(b) Ratios at 0800h significantly lower than ratios at 1000h ($P \ll 0.01$).

(c) Ratios at 0800h significantly lower than ratios at 1300h and 1600h ($P < 0.05$).

Table 74

Effect of feeding frequency on the diurnal variations in the concentration of free palmitic acid in goats (mean µg/ml plasma)

Hours after morning feeding	Time of day	Concentration of free palmitic acid µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Effect of time means
0h	0800	13.67	11.11	12.39
2h	1000	8.59	10.09	9.34
5h	1300	8.89	12.16	10.52
8h	1600	7.48	14.70	11.09
11h	1900	8.08	10.59	9.33
14h	2200	9.34	8.00 a	8.67
17h	0100	9.80	8.55 a	9.18
20h	0400	10.29	11.28	10.78
23h	0700	10.90	8.63	9.76
Feed means		9.67	10.57	10.12

			5%	1%
SED Time means	2.114	LSD	4.3117	5.802
SED Feed means	1.060		2.1619	
SED Feed x time means	3.011		6.1412	
SED Within feed means	2.989		6.096	8.2042

(a) For the group fed twice daily concentration at 1600h significantly higher than the concentrations at 2200 and 0100h ($P < 0.05$).

4.3.1.4 Plasma triglyceride

There was a significant increase in the concentration of plasma triglyceride with time after feeding in the two groups (Table 75 and Figs. 11 and 12). However, the pattern of increase was different between the two groups.

The concentration of plasma triglyceride in the group fed once daily increased steadily to a peak 14 hours after morning feeding (2200h). This concentration was significantly higher than the concentration before feeding ($P < 0.01$) and than the concentration 2 hours after feeding ($P < 0.05$). The concentration obtained 11 hours after feeding was also significantly higher than the concentration before feeding. The concentration of plasma triglyceride decreased at 0100h and then rose again to form a second peak before declining at 0700h to a value significantly lower than the concentration at 2200h ($P < 0.05$), but slightly higher than the concentration observed before feeding.

For the group fed twice daily the concentration of plasma triglyceride increased to a peak at 1300h (5 hours after feeding), followed by a decline to a value lower than the pre-feeding value at 1900h. Thereafter an increase to a peak at 0100h was observed. This value was significantly higher than the concentrations at 0800 and 1900h ($P < 0.05$).

The overall mean for the two feed groups showed that the concentration of plasma triglyceride increased steadily to a peak at 2200h which was significantly higher ($P < 0.05$) than the pre-feeding values and higher ($P < 0.05$) than the concentration observed 2 hours after feeding. The concentration then declined to a level significantly lower at 0700h than the concentration at 2200h ($P < 0.05$). The concentration at 0100h was significantly higher than the concen-

tration before feeding ($P < 0.05$).

4.3.1.5 Saturated and unsaturated triglyceride fatty acids

a) Saturated triglyceride fatty acids

The concentration of triglyceride saturated fatty acids (Table 76) increased significantly with time. The overall mean for the two groups showed a significant increase over the pre-feeding concentrations at 1300h, 1600h, 0100h and at 0400h ($P < 0.05$), while the concentration at 2200h was significantly higher than the concentration before feeding ($P < 0.01$) and higher than the concentration at 1000h ($P < 0.05$). At 0700h the concentration was significantly lower than the concentration at 2200h ($P < 0.05$).

For the group fed once daily the concentration increased steadily after feeding to a peak at 1900h and 2200h. The concentrations at 0800h and 1000h were significantly lower than the concentrations at 1900h, 2200h and 0400h ($P < 0.05$). The concentration observed at 0700h was lower than the concentrations at other times, except at 0800h and 1000h, but it was not significantly lower. For the group fed twice daily, there was an increase after feeding to a maximum at 1300h (5 hours after morning feed) followed by a decline to a value lower than the pre-feeding level. The concentration then increased to a peak at 2200h followed by a decline. However, these variations were not significantly different.

Feeding patterns did not have a significant effect on the concentration of triglyceride saturated fatty acids. However the group fed once daily had slightly higher concentrations of these fatty acids.

b) Unsaturated triglyceride fatty acids

The concentration of triglyceride unsaturated fatty acids (Table 77) increased steadily with time after feeding. Significant

FIGURE 11 shows the diurnal variation in the concentration of plasma triglyceride in 3 goats fed milk once per day (µg/ml plasma). Each point represents one animal.

FIGURE 11

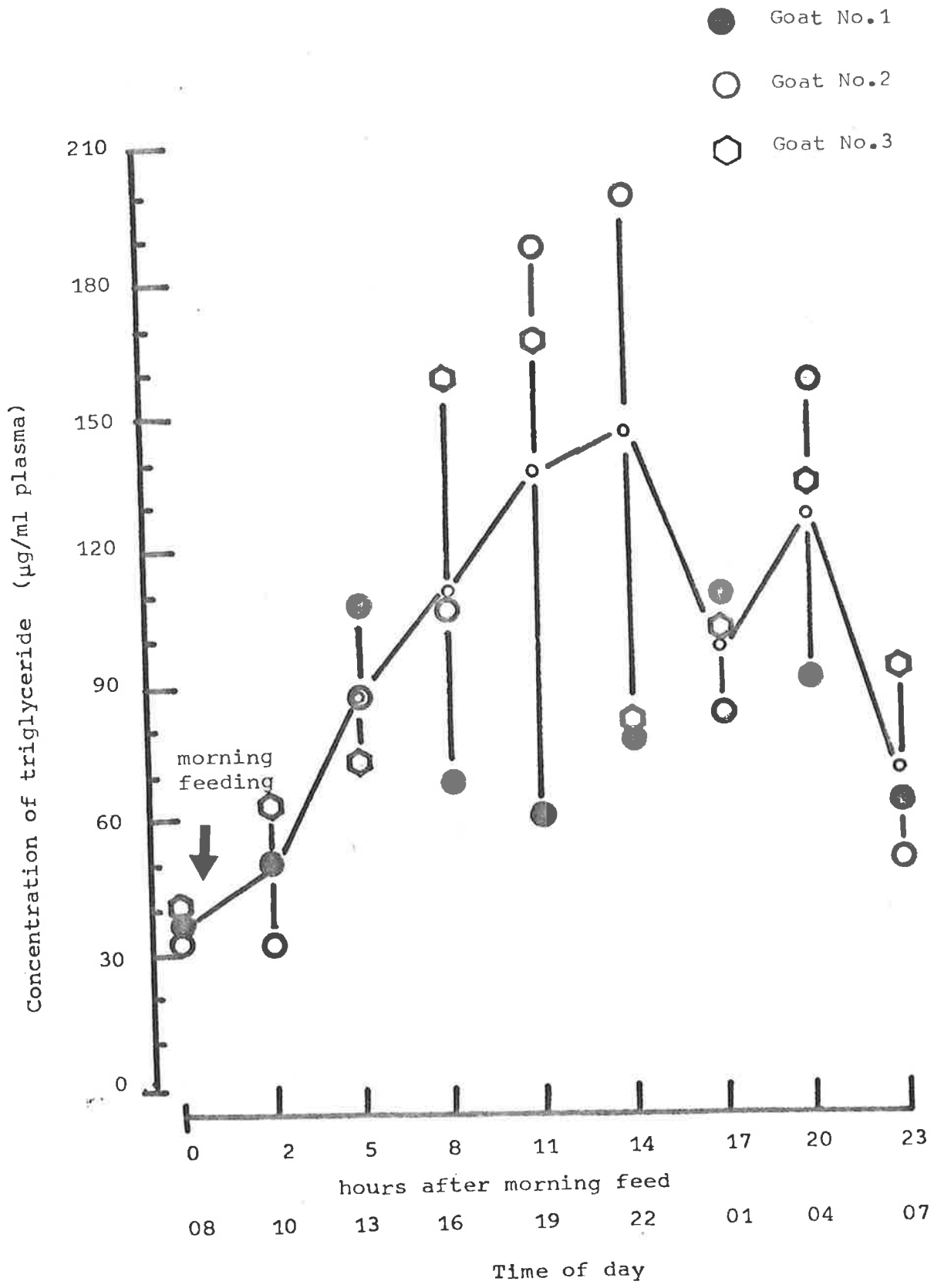
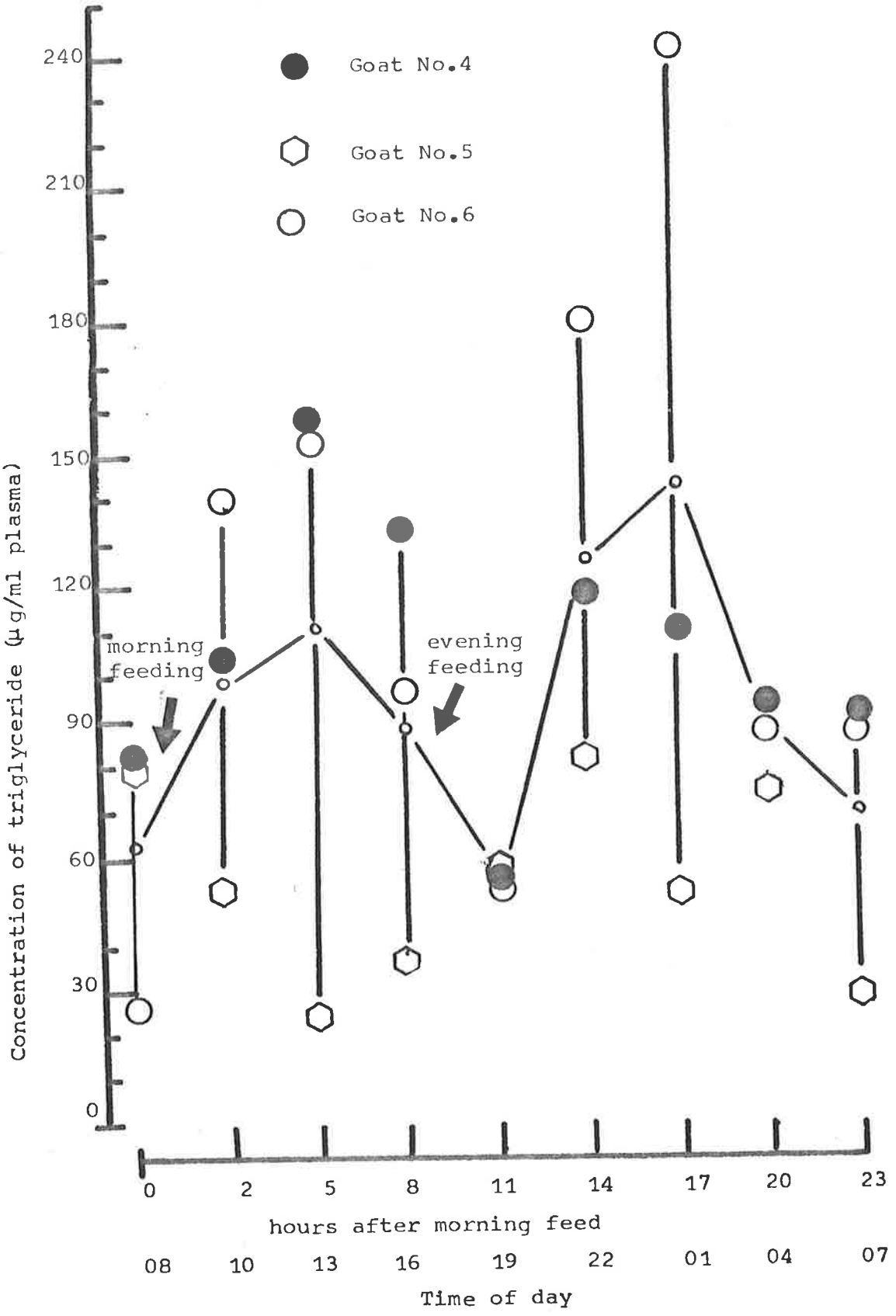

Goat No.1
Goat No.2
Goat No.3
210
180
150
120
90
60
30
0
Concentration of triglyceride (µg/ml plasma)
morning feeding
0
2
5
8
11
14
17
20
23
hours after morning feed
08
10
13
16
19
22
01
04
07
Time of day

FIGURE 12 shows the diurnal variation in the concentration of plasma triglyceride in 3 goats fed milk twice daily (µg/ml plasma). Each point represents one animal.

FIGURE 12


Goat No.4
Goat No.5
Goat No.6
240
210
180
150
120
90
60
30
0
Concentration of triglyceride (µg/ml plasma)
morning feeding
evening feeding
0
2
5
8
11
14
17
20
23
hours after morning feed
08
10
13
16
19
22
01
04
07
Time of day

increase ($P < 0.01$) over the pre-feeding value was observed at 2200h and at 0100h in the overall mean. This was followed by a decrease to a value significantly lower at 0700h than the concentration at 2200h ($P < 0.05$).

The group fed once daily had steadily increasing concentrations of triglyceride unsaturated fatty acids with time to a peak at 2200h. The concentration at 0800h and 1000h were significantly lower than the concentrations at 2200h ($P < 0.05$). The concentrations declined after 2200h to a low level at 0700h. However, this concentration was not significantly lower than other concentrations.

For the group fed twice daily, the concentration of this fatty acid increased for the first 5 hours then declined to a level slightly lower than the pre-feeding level at 1900h. This was followed by an increase to a peak at 0100h. The concentration at the peak was significantly higher than the concentrations at 1900h and 0800h ($P < 0.05$). The concentrations then declined with time to a value significantly lower at 0700h than the concentration at 2200h ($P < 0.05$).

4.3.1.6 Individual triglyceride fatty acids

a) Triglyceride stearate

There was a significant increase in the concentration of plasma stearate with time (Table 78). However, the two feeding groups displayed different patterns of increase.

For the group fed once daily the concentration of triglyceride stearate increased steadily with time after feeding. The concentrations at 1900h, 2200h and 0400h were significantly higher than the pre-feeding concentration ($P < 0.05$). After attaining a peak at 1900h the concentration declined at 0100h and then increased to a second peak before declining finally at 0700h. The concentration at 0700h was slightly higher than the pre-feeding concentration.

For the group fed milk twice daily, the concentration of triglyceride stearate increased steadily to a peak 5 hours after morning feeding, then declined to a level which was lower than the pre-feeding level at 1900h. Thereafter the concentration increased to a second peak at 0100h which was significantly higher ($P < 0.05$) than the concentrations at 0800h and 1900h. Thereafter the concentrations declined to a level which was significantly lower ($P < 0.05$) at 0700h than the concentration at 0100h. This level was almost the same as the pre-feeding value.

The mean for the two groups showed two peaks, one at 1300h which was significantly higher ($P < 0.05$) than the pre-feeding value, followed by a slight decline, and then a second peak from 2200h to 0100h which was significantly higher than the before-feeding concentration. This was followed by a decline to a value at 0700h which was significantly lower than the concentration at 2200h ($P < 0.05$).

The 24 hour mean concentrations for the once and twice fed groups were the same.

b) Triglyceride oleate

There was an increase in the concentration of triglyceride oleate with time after morning feeding (Table 79). The two feeding groups displayed different patterns of change.

For the group fed once daily the concentration of triglyceride oleate increased steadily with time after feeding. However, the significant increase over the pre-feeding concentration was observed at 1900h (11 hours after feeding) ($P < 0.05$) and a maximum at 2200h (14 hours after feeding), which was significantly higher ($P < 0.01$) than the pre-feeding concentration and the concentration 2 hours after feeding. From 2200h the concentration declined steadily to a level which was significantly lower at 0700h than the concentration at

2200h ($P < 0.05$), but slightly higher than the pre-feeding value.

The group fed twice per day had two peaks, the first peak at 1300h which was not significantly higher than the pre-feeding level. This peak was followed by a decline to a level as low as the pre-feeding level 11 hours after morning feeding which was followed by an increase to a peak at 0100h. The concentration at 0100h was significantly higher than the pre-feeding level and than the concentration at 1900h ($P < 0.05$).

The overall mean for the two groups showed a steady increase over 20 hours with a peak at 2200h followed by a steady decline to a value significantly lower at 0700h than the concentration at 2200h ($P < 0.05$). The concentration at 0800h was significantly lower than the concentrations at 2200h ($P < 0.01$) and at 0100h and 0400h ($P < 0.05$). Feeding patterns had no effect on the triglyceride oleate concentration.

c) Ratios stearate/oleate

There was no significant variation with time in the ratio of triglyceride stearate to oleate.

d) Triglyceride palmitate

The results presented in Table 81 show that the concentration of triglyceride palmitate increased with time. A significant increase was observed in the overall mean and in the group fed once daily, while the concentrations in the group fed twice per day did not increase significantly, although there was a marked increase.

For the group fed one meal daily the concentrations at 0800h (before feeding) and at 1000h (2 hours after feeding) were significantly lower ($P < 0.05$) than the concentrations at both 1900h and 2200h ($P < 0.01$).

The concentration for this group was at its peak at 2200h which

Overall mean - Effect of time

(a) Concentration at 0800h significantly lower than at 2200h ($P < 0.01$).

(b) Concentration at 0800h significantly lower than at 0100 and 0400h ($P < 0.05$).

(c) Concentration at 1000h significantly lower than at 2200h ($P < 0.05$).

(d) Concentration at 0700h significantly lower than at 2200h ($P < 0.05$).

Fed twice daily

(e) Concentrations at 0800h and 1900h significantly higher than at 0100h ($P < 0.05$).

Fed once daily

(f) Concentration at 0800h significantly lower than at 1900 and 0400h ($P < 0.05$).

(g) Concentration at 1000h significantly lower than the concentrations at 1900h and 2200h ($P < 0.05$).

(h) Concentration at 0700h significantly lower than at 2200h ($P < 0.05$).

Table 75

Effect of feeding frequency on the diurnal variations in the concentration of plasma triglyceride in goats (mean µg/ml plasma)

Concentration of plasma triglycerides µg/ml plasma

Hours after morning feed	Time of day	Feeding regimen: Fed once daily	Fed twice daily	Effect of time mean
0h	0800	37.1 f	63.5 e	50.3 ba
2h	1000	48.0 g	99.0	73.5 c
5h	1300	89.3	112.0	100.7
8h	1600	110.7	89.1	99.9
11h	1900	138.6	55.5 e	97.1
14h	2200	146.7	127.1	136.9
17h	0100	97.9	143.6	120.8
20h	0400	127.1	86.9	107.0
23h	0700	67.9 h	70.0	68.9 d
Effect of feed means		95.9	94.1	95.0

			5%	1%
SED Effect of time means	26.93	LSD	54.926	73.3899
SED Effect of feed means	23.62		48.196	
SED Effect of feed x time means	42.98		89.161	
SED Within feed means	38.09		77.69	

Overall mean - Effect of time

(a) Concentrations at 1300, 1600, 0100 and 0400h significantly higher than the concentration at 0800h ($P < 0.05$).

(b) Concentration at 2200h significantly higher than at 0800h ($P < 0.01$).

(c) Concentration at 2200h significantly higher than at 1000h ($P < 0.05$).

(d) Concentration at 0700h significantly lower than at 2200h ($P < 0.05$).

Fed once daily

(e) Concentrations at 1900, 2200 and 0400h significantly higher than at 0800 and 1000h ($P < 0.05$).

Table 76

Effect of feeding frequency on the diurnal variations in the concentration of triglyceride saturated fatty acids in goats (mean µg/ml plasma)

Hours after morning feed	Time of day	Concentration of triglyceride saturated fatty acids mean µg/ml Feeding regimen Fed once daily	Fed twice daily	Effect of time mean
0h	0800	20.0	33.6	26.8
2h	1000	27.4	54.6	41.0
5h	1300	47.9	61.6	54.8 a
8h	1600	59.0	45.6	52.3 a
11h	1900	73.6 e	27.3	50.4
14h	2200	73.2 e	63.3	68.3 bc
17h	0100	53.0	58.3	55.7 a
20h	0400	68.3 e	40.9	54.6 a
23h	0700	34.9	37.5	36.2 d
Effect of feed means		50.8	47.0	48.9

			5%	1%
SED Effect of feed means	11.81	LSD	24.09	
SED Effect of time means	12.23		24.94	33.56
SED Effect of feed x time means	20.13		41.00	
SED Within feed means	20.04		40.87	54.98

Overall mean - Effect of time

(a) Concentration at 2200h significantly higher than at 0800h ($P < 0.01$).

(b) Concentration at 0100h significantly higher than at 0800h ($P < 0.05$).

(c) Concentration at 2200h significantly higher than at 1000h ($P < 0.05$).

(d) Concentration at 0700h significantly lower than at 2200h ($P < 0.05$).

Fed twice daily

(e) Concentrations at 0800, 1900 and 0700h significantly higher than at 0100h ($P < 0.05$).

Fed once daily

(f) Concentrations at 0800 and 1000h significantly lower than at 2200h ($P < 0.05$).

Table 77

Effect of feeding frequency on the diurnal variations in the concentration of triglyceride unsaturated fatty acids in goats (mean µg/ml plasma)

Hours after morning feeding	Time of day	Concentration of triglyceride unsaturated fatty acids µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Effect of time means
0h	0800	17.1 f	30.0 e	23.5
2h	1000	20.6 f	44.4	32.5
5h	1300	41.4	50.4	45.9
8h	1600	51.7	43.6	47.6
11h	1900	65.0	28.2 e	46.6
14h	2200	73.5	63.8	68.6 a c
17h	0100	44.9	85.3	65.1 b
20h	0400	58.8	46.0	52.4
23h	0700	32.9	32.5 e	32.7 d
Effect of feed means		45.1	47.1	46.1

			5%	1%
SED Feed means	12.69	LSD	25.88	
SED Effect of time means	16.08		32.79	44.14
SED Effect of time x feed means	24.91		50.80	
SED Within feed means	24.82		50.62	

For overall mean

(a) Concentrations at 1300, 2200 and 0100h significantly higher than the concentration at 0800h ($P < 0.05$).

(b) Concentration at 0700 significantly lower than at 2200h ($P < 0.05$).

Fed twice daily

(c) Concentration at 0100h significantly higher than at 0800h ($P < 0.05$).

(d) Concentration at 1900h significantly lower than at 0100h ($P < 0.05$).

(e) Concentration at 0700h significantly lower than at 0100h ($P < 0.05$).

Fed once daily

(f) Concentrations at 1900 and 2200h significantly higher than at 0800h ($P < 0.05$).

(g) Concentration at 0400h significantly higher than at 0800h ($P < 0.05$).

Table 78

Effect of feeding frequency on the diurnal variations in the concentration of triglyceride stearate in goats (µg/ml plasma)

Hours after morning feeding	Time of day	Concentration of triglyceride stearate in plasma (mean µg/ml plasma) Feeding regimen: Fed once daily	Fed twice daily	Effect of time mean
0h	0800	5.9	11.0	8.4
2h	1000	9.2	16.7	12.9
5h	1300	16.5	21.0	18.8 a
8h	1600	19.7	16.5	18.1
11h	1900	24.0 f	8.0 d	16.0
14h	2200	22.6 f	21.8	22.2 a
17h	0100	16.0	26.1 c	21.0 a
20h	0400	21.6 g	13.8	17.7
23h	0700	11.3	11.5 e	11.4 b
Effect of feed means		16.3	16.3	16.3

			5%
SED Effect of time means	4.99	LSD	10.178
SED Effect of feed means	4.17		8.494
SED Effect of feed x time means	7.85		16.011
SED Within feed means	7.06		14.399

Overall Mean - Effect of time

(a) Concentration at 0800h significantly lower than at 2200h ($P < 0.01$).

(b) Concentration at 0800h significantly lower than at 0100 and 0400h ($P < 0.05$).

(c) Concentration at 0700h significantly lower than at 2200h ($P < 0.05$).

Fed twice daily

(d) Concentrations at 0800 and 1900 significantly lower than at 0100h ($P < 0.05$).

Fed once daily

(e) Concentration at 0800h significantly lower than at 1900h ($P < 0.05$).

(f) Concentration at 0700h significantly lower than at 2200h ($P < 0.05$).

(g) Concentration at 0800h and 1000h significantly lower than at 2200h ($P < 0.01$).

Table 79

Diurnal variation in the concentration of triglyceride oleate in 2 groups of 3 goats fed milk once or twice daily (mean µg/ml plasma)

Hours after morning feeding	Time of day	Concentration of triglyceride oleate mean µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Effect of time means
0h	0800	12.8 g e	20.9 d	16.8 a b
2h	1000	15.5 g	34.9	25.2
5h	1300	34.8	43.2	39.0
8h	1600	42.9	36.1	39.5
11h	1900	53.5	19.4 d	36.4
14h	2200	61.3	50.4	55.8
17h	0100	37.6	57.7	47.6
20h	0400	49.6	34.9	42.3
23h	0700	26.3 f	26.5	26.4 c
Effect of feed mean		37.2	36.0	36.6

			5%	1%
SED Feed means	9.77	LSD	19.927	26.817
SED Time means	11.59		23.639	31.812
SED Time x feed means	18.28		37.284	50.175
SED Within feed means	16.39		33.429	44.987

Table 80

Effect of feeding frequency on the diurnal variations in the stearate/oleate ratio on plasma triglyceride in goats

Hours after morning feeding	Time of day	Ratios stearate:oleate Feeding regimen Fed once daily	Fed twice daily	Effect of time means
0h	0800	0.456	0.531	0.494
2h	1000	0.573	0.469	0.521
5h	1300	0.465	0.475	0.470
8h	1600	0.461	0.456	0.459
11h	1900	0.430	0.414	0.422
14h	2200	0.395	0.432	0.414
17h	0100	0.474	0.456	0.465
20h	0400	0.431	0.399	0.415
23h	0700	0.440	0.428	0.434
Effect of feed means		0.458	0.451	0.455

SED Effect of time means	0.0465
SED Effect of feed means	0.0179
SED Effect of feed x time means	0.0645
SED Within feed means	0.0619

Overall mean

(a) Concentration at 0800h significantly lower than the concentration at 1300, 0100 and 0400h ($P < 0.05$).

(b) Concentration at 2200h significantly higher than at 0800h ($P < 0.05$).

(c) Concentration at 1000h significantly lower than at 2200h ($P < 0.05$).

(d) Concentration at 0700h significantly lower than at 2200h ($P < 0.05$).

(e) Concentration at 0700h significantly lower than at 0100h ($P < 0.05$).

Fed once daily

(f) Concentrations at 0800 and 1000h significantly lower than at 1900h ($P < 0.05$).

(g) Concentrations at 0800 and 1000h significantly lower than the concentration at 2200h ($P < 0.01$).

Table 81

Effect of feeding frequency on the diurnal variation in the concentration of triglyceride palmitate in goats fed milk

(mean µ g/ml plasma)

Hours after morning feeding	Time of day	Mean concentration of triglyceride palmitate µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Effect of time mean
0h	0800	12.1 fg	19.3	15.7 a
2h	1000	15.8 fg	32.6	24.2 c
5h	1300	26.8	34.7	30.8
8h	1600	33.4	25.0	29.2
11h	1900	42.0	16.6	29.3
14h	2200	43.2	37.4	40.3 b
17h	0100	31.2	40.4	35.8
20h	0400	39.9	27.8	33.9
23h	0700	20.1	22.5	21.3 ed
Effect of feed means		29.4	28.5	28.9

			5%	1%
SED Feed means	6.94	LSD	14.155	20.366
SED Effect of time means	7.42		15.134	
SED Feed x time means	12.08		24.640	
SED Within feed means	11.99		24.455	32.901

Table 82

Effect of feeding frequency on the diurnal variation in the concentration of plasma protein in goats mean g/100ml plasma

Hours after morning feeding	Time of day	Concentration of plasma protein g/100ml Feeding regimen: Fed once daily	Fed twice daily	Effect of time mean
0h	0800	4.800	5.133	4.967
2h	1000	4.867	4.733	4.800
5h	1300	4.867	4.800	4.833
8h	1600	4.800	4.467	4.633
11h	1900	5.000	4.667	4.833
14h	2200	5.000	4.400	4.700
17h	0100	5.000	4.767	4.883
20h	0400	5.200	5.067	5.133
23h	0700	4.867	4.267	4.567
Effect of feed means		4.933	4.700	4.817

SED Effect of feed means	0.1004
SED Effect of time means	0.2578
SED Effect of time x feed means	0.3582

was followed by a decline to a lower level at 0700h. However, this level was slightly higher than the pre-feeding concentration.

For the group fed twice daily, the concentration of palmitate increased for 5 hours after morning feeding, then declined by 1900h to a value lower than the before-feeding value. Thereafter it increased to a peak at 0100h followed by a decline to a level slightly higher than the pre-feeding value at 0700h. These changes were not statistically significant.

The overall mean for the two groups showed an increase to a level significantly higher ($P < 0.05$) at 2200h than the concentrations before and at 2 hours after feeding. Thereafter the concentration declined significantly at 0700h ($P < 0.05$).

4.3.1.7 Plasma protein

Neither feeding frequency nor time of the day or after feeding had a significant effect on the concentration of plasma protein (Table 82). However, for the group fed once daily, a slight increase was observed at 1900h which remained constant until 0400h where it increased slightly before declining at 0700h. While in the twice fed group there was a steady decrease after feeding, an increase was observed at 0400h.

The group fed once daily had slightly higher levels of plasma protein than the other group.

4.3.2 Discussion

Diurnal variations in the concentration of plasma FFA in goats on two feeding regimens

4.3.2.1 Plasma FFA

The concentration of plasma FFA in the two groups as shown in Table 68 and Figs. 9 and 10, and the concentration of individual

free fatty acids (Tables 71, 72 and 74) display different patterns of variation within a 24 hour period. When considering the overall means it can be seen in Table 68 that the concentration of FFA at 0800h was significantly higher than at 0100h (i.e. 2 hours after feeding). No other differences were significant.

The concentrations for the group fed milk once daily decreased significantly 2 hours after the morning feed and remained significantly lower for 6 hours before rising to a constant level which was not significantly different from the pre-feeding level. With the group fed twice daily there was a slight decline 2 hours after the morning feed followed by an increase to a peak 6 hours later in the sample taken immediately before the evening meal. This concentration was significantly higher than that observed 2 hours after the morning feed. The concentration of plasma FFA in this group decreased significantly 2 hours after the evening meal, remained low for 9 hours before rising slightly at 0400h and thereafter declined to pre-feeding levels. The observed mean increase at 1600h in the group fed twice daily is attributed to a large increase in one animal, whereas the other two animals (Fig. 10) showed a steady decline.

This change in the concentration of plasma FFA with time indicates the pattern of absorption of nutrients of the ingested milk from the small intestine and the utilization of these nutrients by the animal. The decrease in the concentration of plasma FFA 2 hours after feeding in both groups indicates that at this time the animals had absorbed sufficient hexose from the small intestine with other metabolites which could be utilized as a source of energy. At the same time the concentration of plasma triglyceride rose (Table 75 and Figs. 11 and 12) and this presumably inhibited fat mobilization from the adipose tissues. Increase in blood glucose

2 hours after feeding milk to calves has been reported (Shannon and Lascelles, 1966; Preston and Ndumbe, 1961).

Thus the decrease in plasma FFA was probably the result of an increased concentration of plasma glucose. Trenkle and Kuhlemeir (1966) observed a decline in plasma FFA and an increase in blood glucose 1 and 2 hours after glucose injection in adult sheep, indicating that decrease in plasma FFA is associated with the increase in blood glucose.

The significant increase in the concentration of plasma FFA from 5 to 8 hours after a meal in the group fed twice daily was the result of the large response of one animal (Fig. 10). It may be that over this interval of time it utilized most of the absorbed glucose and was using FFA as a source of energy. Another possible cause might have been the greater sensitivity of this animal to sampling procedures, thus releasing fat mobilizing factors like adrenaline which led to the increased FFA concentration. The concentration of triglyceride in this group was also decreasing at this time and this was contributed by two animals in this group.

The lack of variation in plasma FFA after the initial decline in the group fed once daily agrees with the findings of Shannon and Lascelles (1966) who reported that there was no consistent pattern of variation in the total FFA, esterified fatty acids, phospholipids or protein in calf plasma collected at intervals for 24 hours. This is probably due to the continuous absorption of esterified lipids from the alimentary canal for 24 hours as observed by Shannon and Lascelles (1967) in calves. The second decrease in plasma FFA in the group fed twice each day was brought about by the absorption of nutrients from the intestine after the evening meal.

The slightly higher overall concentration of plasma FFA in the

group fed twice each day than for the group fed once daily, indicates greater mobilization and utilization of FFA as a source of energy. This is contrary to the finding for monogastric animals. Bortz et al. (1969) observed a higher mean plasma FFA in men eating their daily food intake in a short period in the evening compared to those eating more frequent meals.

The concentration of the 3 major plasma FFA had similar patterns of change to that of plasma FFA. The palmitic and stearic acid in the group fed once a day declined considerably after the morning meal and remained relatively constant for the rest of the day, while in the group fed twice daily there was a decline 2 hours after the morning feed, followed by a rise to a peak 8 hours after the morning feed and this declined after evening feeding.

Oleic acid concentration was highest and stearic acid concentration lowest in both groups.

The ratios of stearic to oleic acid in the group fed once daily was significantly higher at 2, 5 and 8 hours after the morning feed, indicating that the proportion of oleic acid decreased faster than that of stearic acid. When the concentration of plasma FFA increased the concentration of oleic acid was greater than that of stearic acid. Thus when FFA is meeting part of the energy requirement of the animal, the proportion contributed by oleic acid is higher.

4.3.2.2 Plasma triglyceride

The concentration of plasma triglyceride in the two groups (Table 75 and Figs. 11 and 12) and the concentration of individual triglyceride fatty acids (Tables 78, 79 and 80) show that the concentration of plasma triglyceride increased steadily with time in the group fed once daily to a level which was significantly higher than

the pre-feeding concentration and then declined. This peak was attained 14 hours after the morning feed. Although the mean concentration for the 3 animals in this group showed a steady increase, individual animals showed different patterns of change (Fig. 11). The concentration for individual animals tended to increase after feeding to a peak which was different in time in the three animals. Whereas animal No.1 attained its peak at 1300h (5 hours after the morning feed) No.2 attained a peak at 1900h and No.3 at 2200h. Thus there is a variation between individual animals in the pattern of digestion absorption and utilization of dietary triglycerides.

The mean increase in the concentration of plasma triglyceride in this group with time after feeding bears some similarity to the observations of Shannon and Lascelles (1967) who reported that the concentration of neutral lipids in the lymph of milk-fed calves reached its peak 10 hours after feeding and then declined. The difference in the time taken for the triglycerides to reach a maximum in blood plasma in this study compared to the finding of Shannon and Lascelles indicates that a considerable time lapses before metabolites in the lymphatic system mix completely with plasma. On the other hand species differences in lymph flow could also account for the differences. Shannon and Lascelles (1968) compared their findings in calves with those of Heath and Morris (1962) in suckling lambs 2-3 weeks old and concluded that lambs had a slower lymph flow rate than calves. The present observed variation between individuals could result from differences in lymph flow or differences in the clearance rate of the absorbed triglycerides by different tissues. Shannon and Lascelles (1966) reported that there were no consistent patterns of variation in the plasma esterified fatty acids in calves when

collected at intervals for 24 hours. Thus the observed variation agrees with their finding.

For the group fed milk twice daily, there were two peaks which were contributed by 2 of the 3 animals in the group. The first peak was observed 5 hours after morning feeding, followed by a sharp decline (Fig. 12). However, one animal in the group showed a negative peak where the concentration of triglyceride decreased to a minimum level 5 hours after the morning feed and then increased after the evening feed. The pattern followed by this individual is similar to that reported by Shannon and Lascelles (1967) in calves where the concentration of neutral lipids in the lymph was minimal 4-5 hours after feeding. Thus probably there was a delay in the absorption of triglycerides by this animal or the clearance rate was higher than the absorption rate.

For the other two animals in this group, the finding agrees with those of Heath and Morris (1962) who observed a maximum output of lipids in lymph 2-4 hours after feeding 200-250 ml of diluted cow's milk to lambs.

Thus the amount of milk and probably the concentration of fat have an effect on the rate of absorption and transportation of the lipids. However, the second peak after the evening meal was observed 9 hours after feeding in two animals. This variation could be associated with lymph flow in the night.

The decline in the concentration of plasma triglyceride for 3 hours after the evening meal agrees with the findings of Shannon and Lascelles (1967) in calves where the concentration of neutral lipids in the lymph was minimal 4-5 hours after feeding. They concluded that the decline in the concentration of lipids at this time was due to the incorporation of the lipids already in the stomach

into a new casein fat curd which delays digestion and absorption of the fat.

The concentration of individual triglyceride fatty acids followed the pattern observed for the total triglyceride in both groups.

The concentration of oleic acid was the highest followed by palmitic and then stearic acid.

This composition was slightly different from that found in the actual milk substitute fed to these animals which had higher proportions of palmitic acid followed by oleic and then stearic acid (Table 1).

The higher proportion of oleic acid in plasma triglyceride than that found in the feed indicates that some of this fatty acid was of endogenous origin. Wadsworth and Shannon (1971) observed a higher proportion of linoleic and linolenic acids in plasma triglycerides than in the milk fed to the calves. They concluded that some of these fatty acids were of endogenous origin.

The lack of significant difference between the two groups indicates that regardless of pattern of feeding, the level of nutrient output is likely to be the same in a 24 hour period.

4.3.3 Summary

i) Very little diurnal variation in plasma FFA was observed in the two groups of goats. The slight variation observed in the group which was fed milk twice daily was attributed to a large increase in one animal in the group. The decline 2 hours after feeding arose from the absorption of milk hexose and other metabolites. Feeding twice daily resulted in two peaks of plasma FFA.

ii) There was no diurnal variation in the individual plasma FFA concentrations. Oleic acid formed the higher proportion.

iii) The triglyceride concentration in the group of goats fed milk once daily increased steadily to a peak 14 hours after feeding. Individual variation in the pattern of increase was considerable, indicating differences in digestion, absorption and utilization of dietary triglycerides by individual animals.

iv) Feeding milk twice daily resulted in the formation of two triglyceride concentration peaks resulting from the absorption of morning and evening feeds. There was also individual variation in this group.

v) A longer time lapsed between feeding and the appearance of the triglyceride peak after evening feeding indicating diurnal variation in lymph flow.

vi) There was no variation in the concentration of individual triglyceride fatty acids. Oleic acid formed the highest proportion. This composition differed slightly from the composition of fatty acids in the milk diet.

4.4 EFFECT OF SALINE AND ADRENALINE INFUSION ON PLASMA LIPIDS

Saline and adrenaline infusion in goats and lambs was performed when the animals were 7 months old. Nine lambs and four goats were used.

4.4.1 RESULTS

4.4.1.1 Plasma FFA in goats and lambs

During 30 min. saline infusion there was no significant change in the concentration of plasma FFA in goats (Table 83 and Fig. 13). However, by the end of saline recovery a significant increase was evident over the control time value and that after 15 min. infusion ($P < 0.001$). Adrenaline infusion increased the concentration of plasma FFA significantly at 30 min. ($P < 0.001$) in the two groups.

During adrenaline recovery, the concentration of plasma FFA decreased to a level significantly lower ($P < 0.001$) after 30 min. than at 30 min. adrenaline infusion and also lower than the concentrations at 15 min. and 30 min. saline recovery ($P < 0.05$).

Feeding regimen had no significant effect on the concentration of plasma FFA. However, the group fed once daily had a higher concentration of plasma FFA on all occasions.

In lambs (Table 84 and Fig. 14) saline infusion caused a slight increase in the concentration of plasma FFA in all feed regimens and at all sampling occasions. At no time during saline infusion did the increases observed reach significance level.

Adrenaline infusion on the other hand, caused a threefold increase in the concentration of plasma FFA which was significant ($P < 0.001$) in all three feed regimen . Maximum concentration of FFA was attained after 30 min. infusion period (with the exception of the group fed twice each day, which reached a maximum after 15 min.) During the recovery period, the concentration of plasma FFA declined

FIGURE 13 shows the effect of saline and adrenaline infusion on the concentration of plasma FFA in goats on two feeding patterns (mean µg/ml plasma). Each point represents a mean for 2 goats.

FIGURE 13

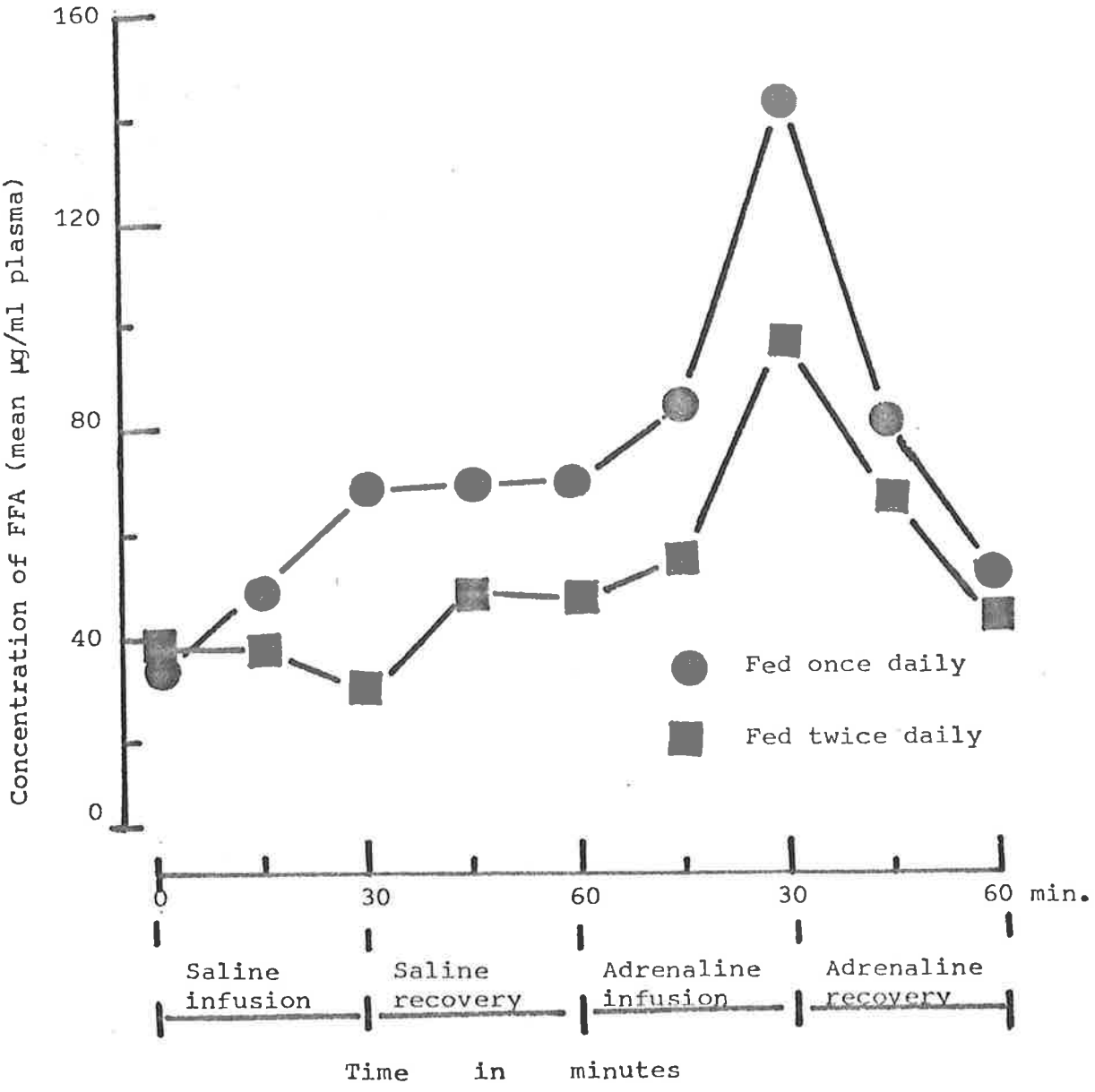
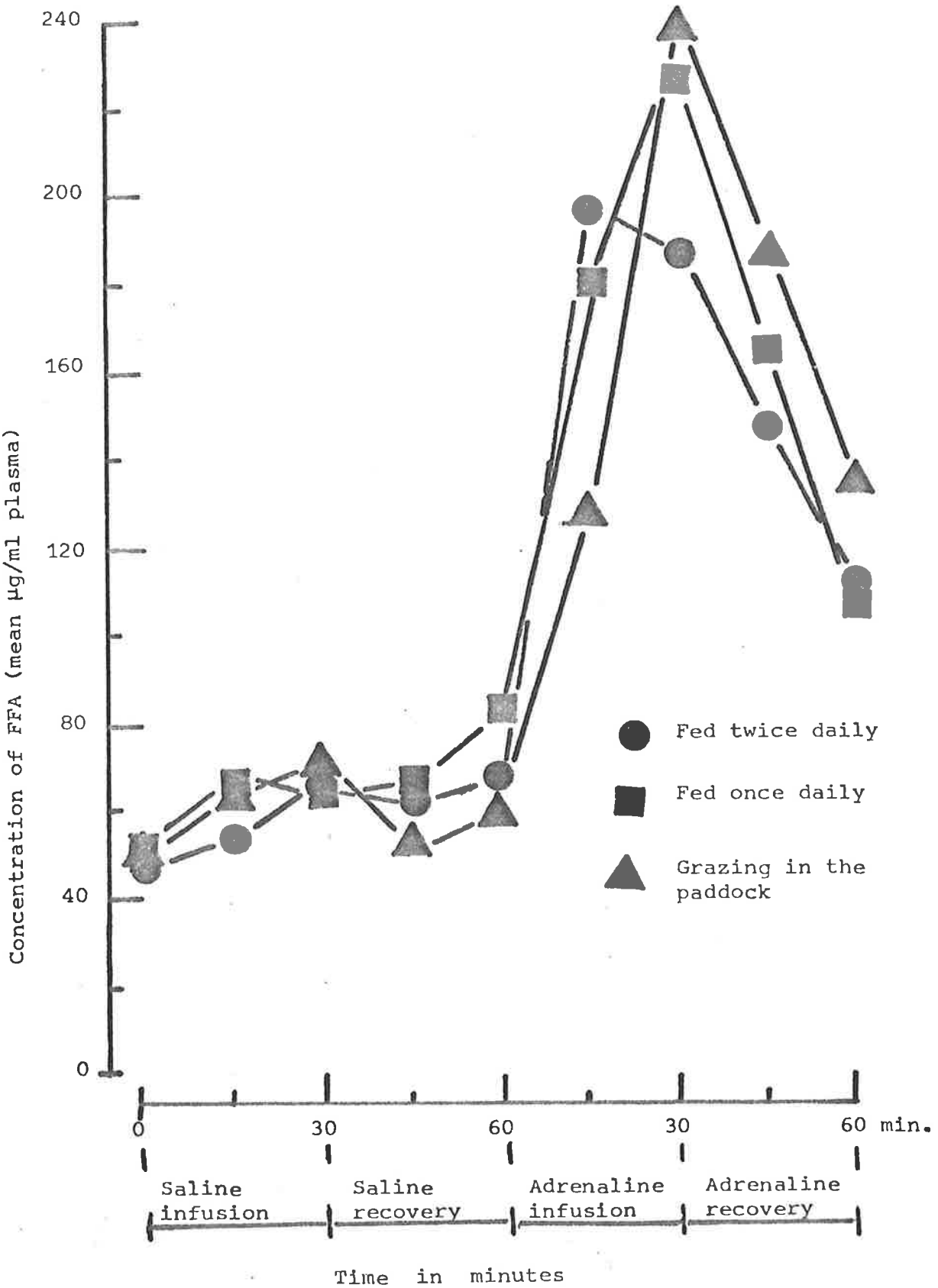

160
120
80
40
0
Concentration of FFA (mean µg/ml plasma)
Fed once daily
Fed twice daily
0
30
60
30
60 min.
Saline infusion
Saline recovery
Adrenaline infusion
Adrenaline recovery
Time in minutes

FIGURE 14 shows the effect of saline and adrenaline infusion on the concentration of plasma free fatty acids in lambs on 3 feeding patterns (mean µg/ml plasma). Each point represents a mean for 3 animals.

FIGURE 14


240
200
160
120
80
40
0
Concentration of FFA (mean µg/ml plasma)
Fed twice daily
Fed once daily
Grazing in the paddock
0
30
60
30
60 min.
Saline infusion
Saline recovery
Adrenaline infusion
Adrenaline recovery
Time in minutes

to a value significantly lower (after 30 min.) than the concentration at 30 min. infusion period ($P < 0.001$), but it was not significantly different from the concentration at 15 min. infusion period although it was slightly lower.

Although the concentration of plasma FFA fell rapidly on termination of the adrenaline infusion after 30 min. it was still significantly higher ($P < 0.05$) than the concentration attained 30 min. after the cessation of the saline infusion (i.e. at the time of commencement of adrenaline infusion).

4.4.1.2 Saturated and unsaturated fatty acids in goats and lambs

(a) Saturated fatty acids

Table 85 shows that adrenaline infusion significantly increased ($P < 0.001$) the concentration of plasma free saturated fatty acids in goats after 30 min. compared to the concentration during saline infusion. The concentration at 15 min. adrenaline infusion period was not significantly different from the concentration at 30 min. saline recovery period. The increase due to adrenaline infusion was observed in both feeding groups.

During 30 min. adrenaline recovery period, the concentration of saturated fatty acids decreased to a value significantly lower than at 30 min. adrenaline infusion period ($P < 0.001$), but not significantly different from the concentration obtained during the 30 min. saline recovery period.

Saline infusion increased the concentration of free saturated fatty acids when compared to the concentration before infusion ($P < 0.05$). The concentration during the saline recovery period was significantly higher ($P < 0.05$) than that observed during the saline infusion period.

Feeding regimen had no significant effect on the concentration

of free saturated fatty acids. However, the concentration was slightly higher in the group fed once daily on all occasions.

In lambs the concentration of plasma saturated free fatty acids (Table 86) did not increase significantly during saline infusion. However 30 min. after termination of saline infusion the concentration rose and was significantly higher than the concentration before infusion ($P < 0.05$).

Adrenaline infusion increased the concentration of saturated free fatty acids significantly ($P < 0.001$) in all feeding regimen , the highest concentration being attained after 30 minutes infusion. Feeding regimen had no effect on the concentration of saturated free fatty acids.

During the adrenaline recovery period the concentration of saturated fatty acids declined to a level significantly lower at 30 min. than the concentration after 30 min. of adrenaline infusion ($P < 0.001$), but was significantly higher than the concentration obtained at 30 min. saline recovery ($P < 0.001$), indicating that more time was required for full recovery.

(b) Unsaturated fatty acids

In goats (Table 87), adrenaline infusion significantly ($P < 0.001$) increased the concentration of unsaturated free fatty acids in plasma at 30 min. compared to that obtained at 30 min. saline recovery period. The concentration attained at the 30 min. adrenaline infusion period was significantly higher ($P < 0.05$) than at 30 min. saline recovery. The concentration of unsaturated free fatty acids did not increase significantly during saline infusion period, but was significantly higher ($P < 0.001$) during the saline recovery period.

During the 30 min. adrenaline recovery period, the concentration of unsaturated fatty acids decreased rapidly to a value which was

significantly lower ($P < 0.001$) than the concentration at the 30 min. adrenaline infusion period and significantly lower ($P < 0.01$) than the concentration at the 30 min. saline recovery period.

Feeding regimen had no significant effect on the concentration of unsaturated fatty acid; the group fed once daily had a slightly higher concentration of unsaturated free fatty acids than the group fed twice daily on all occasions.

Saline infusion had no significant effect on the concentration of unsaturated free fatty acids in lambs (Table 88), although there was a slight increase during saline recovery. Adrenaline infusion caused more than a threefold increase in the concentration of plasma unsaturated free fatty acids which was highly significant ($P < 0.001$). The highest concentration was attained at 30 min. infusion period.

During adrenaline recovery period the concentration of unsaturated free fatty acids declined to a value significantly lower at 30 min. than the concentration obtained at 30 min. of adrenaline infusion ($P < 0.001$). However, it was significantly higher than at 30 min. saline recovery ($P < 0.05$) indicating that a longer period was required for full recovery.

Feeding regimen had no significant effect on the concentration of unsaturated free fatty acids, although the paddock group had a slightly higher concentration than the other two groups during adrenaline infusion.

(c) Ratios saturated/unsaturated fatty acids

Table 89 shows that adrenaline infusion decreased the ratios of saturated to unsaturated free fatty acids significantly ($P < 0.001$) at 15 min. and 30 min. in the two groups of goats.

Saline infusion and feeding regimen had no significant effect on the ratios.

FIGURE 15 shows the effect of saline and adrenaline infusion on the concentration of plasma saturated and unsaturated fatty acids in goats (mean µg/ml plasma). Each point is a mean for 4 animals.

FIGURE 15

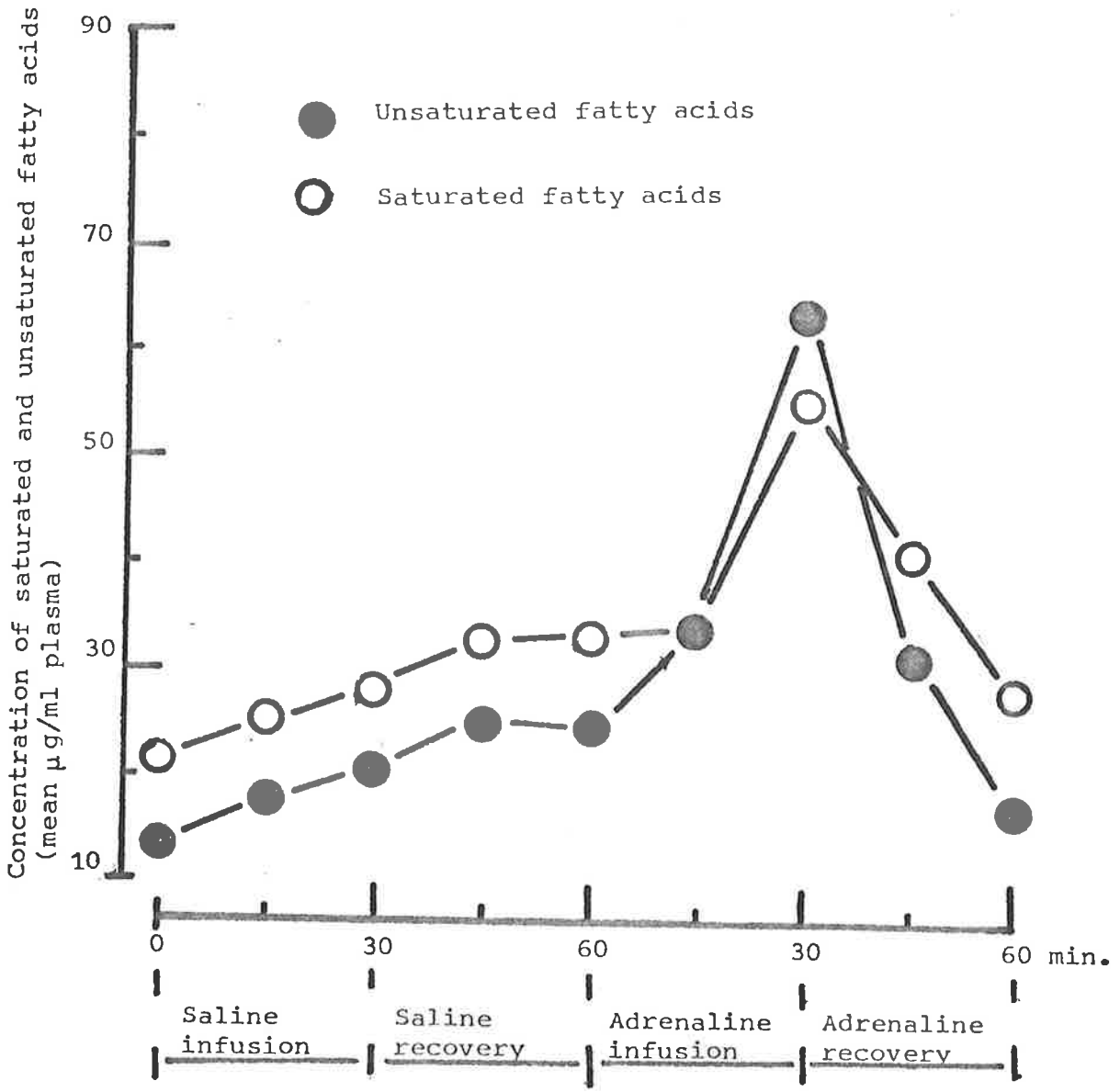
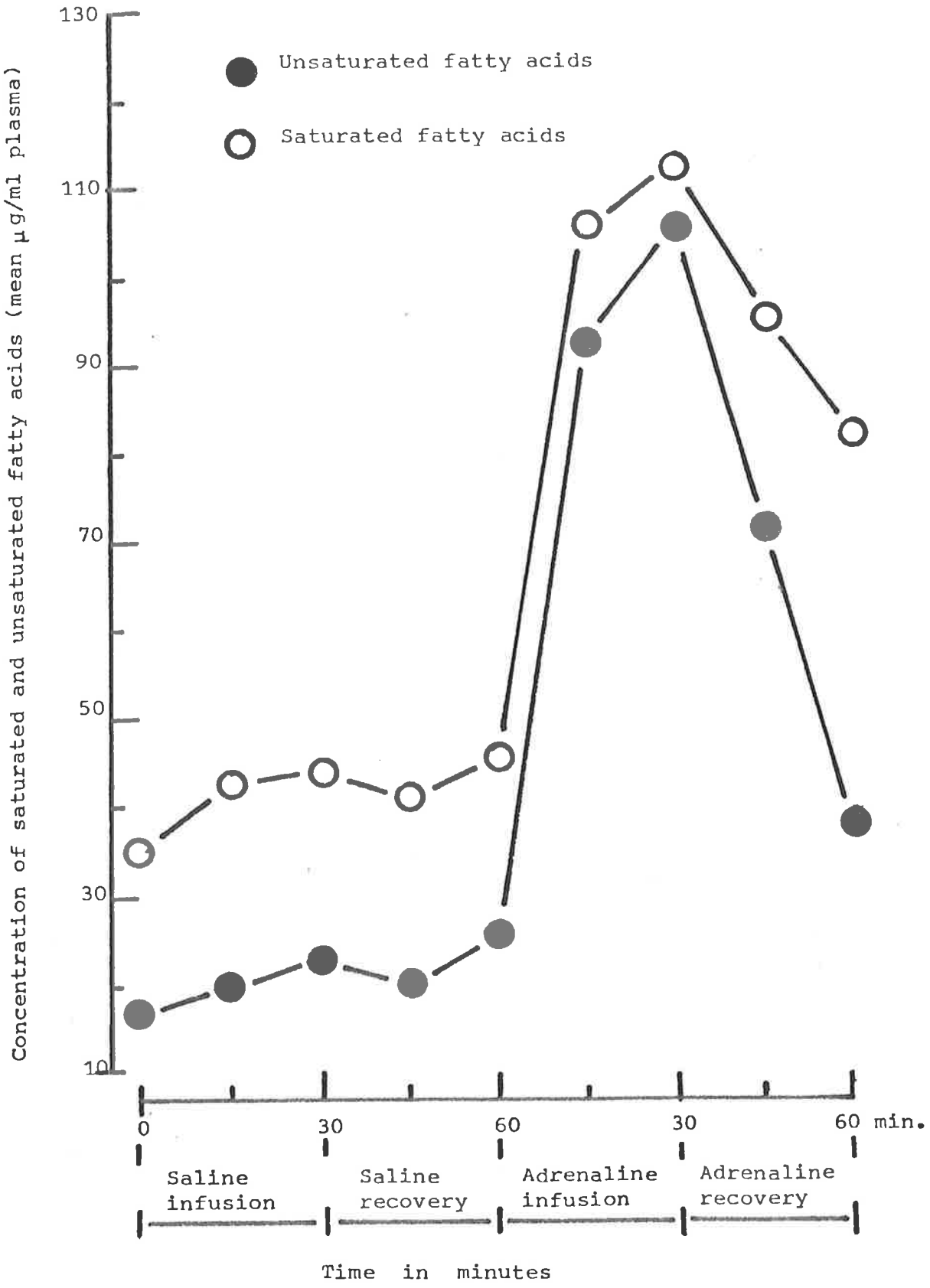

Concentration of saturated and unsaturated fatty acids (mean µg/ml plasma)
90
70
50
30
10
Unsaturated fatty acids
Saturated fatty acids
0
30
60
30
60 min.
Saline infusion
Saline recovery
Adrenaline infusion
Adrenaline recovery
Time in minutes

FIGURE 16 shows the effect of saline and adrenaline infusion on the concentration of plasma saturated and unsaturated free fatty acids in lambs (mean µg/ml plasma). Each point represents a mean for 9 animals.

FIGURE 16


Unsaturated fatty acids
Saturated fatty acids
Concentration of saturated and unsaturated fatty acids (mean µg/ml plasma)
130
110
90
70
50
30
10
0
30
60
30
60 min.
Saline infusion
Saline recovery
Adrenaline infusion
Adrenaline recovery
Time in minutes

(a) Adrenaline infusion at 30 min. significantly higher than saline recovery ($P < 0.001$).

(b) Adrenaline infusion at 30 min. significantly higher than 30 min. adrenaline recovery ($P < 0.001$).

(c) Saline recovery at 15 min. and 30 min. significantly higher than before infusion and 15 min. saline infusion period ($P < 0.001$).

(d) Saline recovery at 15 min. and 30 min. significantly higher than 30 min. adrenaline recovery ($P < 0.05$).

Table 83

Effect of adrenaline and saline infusion on the concentration of plasma free fatty acids in goats (mean µg/ml plasma)

Treatment	Time (mins.)	Total free fatty acid concentration µg/ml Feeding regimen Fed once daily	Fed twice daily	Treatment effect
Before infusion	0	(34.8) 3.578	(37.2) 3.643	(36.0) 3.611
Saline infusion	15	(48.3) 3.891	(37.7) 3.653	(43.0) 3.772
	30	(68.5) 4.241	(28.6) 3.28	(48.6) 3.899
Saline recovery	15	(68.3) 4.236	(48.6) 3.899	(58.4) cd 4.068
	30	(69.0) 4.247	(46.5) 3.842	(57.8) 4.044
Adrenaline infusion	15	(83.4) 4.410	(53.3) 3.922	(68.4) 4.166
	30	(143.3) 4.968	(96.9) 4.548	(120.1) a 4.758
Adrenaline recovery	15	(80.1) 4.382	(65.2) 4.191	(72.6) 4.286
	30	(49.9) 3.928	(42.0) 3.760	(46.0) b 3.844
Effect of feed		(76.4) 4.288	(52.4) 3.3887	(64.4) 4.087

			5%	1%	0.1%
SED Treatment means	0.0889	LSD	0.1907	0.2647	0.368
SED Feed x treatment means	0.1495				
SED Feed means	0.1739				

n = 4

N.B. All statistical analyses in Tables 83 to 89, 91 to 95 and 97 to 103 were performed on ln transformations of the original data. Original means are enclosed in brackets.

Table 84

The effect of adrenaline and saline infusion on the concentration of plasma free fatty acids in lambs (mean µg/ml plasma)

Treatment	Time (mins.)	Concentration of plasma free fatty acids µg/ml Feeding regimen Fed once daily	Fed twice daily	Grazing	Treatment effect
Before infusion	0	(52.3) 3.880	(49.4) 3.917	(51.5) 3.895	(51.1) 3.897
Saline infusion	15	(69.6) 4.182	(54.5) 4.007	(62.0) 4.03	(62.1) 4.073
	30	(64.1) 4.121	(64.8) 4.153	(71.6) 4.182	(66.8) 4.152
Saline recovery	15	(66.9) 4.309	(62.7) 4.151	(53.5) 3.931	(61.0) 4.074
	30	(82.6) 4.309	(69.0) 4.25	(61.8) 4.089	(71.4) 4.216
Adrenaline infusion	15	(180.8) 5.199	(198.5) 5.295	(138.4) 4.615	(172.6)a 5.037
	30	(229.3) 5.43	(188.8) 5.199	(239.1) 5.462	(219.1)a 5.364
Adrenaline recovery	15	(166.0) 5.043	(148.8) 4.909	(186.0) 5.191	(167.1) 5.048
	30	(106.9)bc 4.576	(112.7)bc 4.644	(134.4)bc 4.814	(118.0)bc 4.678
Effect of feed		4.542	4.503	4.468	4.504

			5%	1%	0.1%
SED Treatment means	0.1811	LSD	0.364	0.486	0.6346
SED Treatment x feed means	0.3875				
SED Feed means	0.2505				

n = 9

(a) Adrenaline infusion higher than saline infusion ($P < 0.001$).

(b) Adrenaline infusion (30 min.) higher than the recovery concentration (30 min.) ($P < 0.001$).

(c) Recovery from adrenaline (30 min.) higher than the saline recovery (30 min.) ($P < 0.05$).

(a) Adrenaline infusion at 30 min. significantly higher than saline infusion and recovery ($P < 0.001$).

(b) Adrenaline infusion at 30 min. significantly higher than adrenaline recovery at 30 min. ($P < 0.001$).

(c) Saline recovery at 30 min. and 15 min. significantly higher than saline infusion at 15 min. ($P < 0.05$).

(d) Saline infusion significantly higher than level before infusion ($P < 0.05$).

Table 85

Effect of adrenaline and saline infusion on the concentration of plasma saturated free fatty acids in goats (mean µg/ml plasma)

Treatment	Time (mins.)	Concentration of saturated FFA µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Treatment effect
Before infusion	0	(21.50) 3.068	(21.772) 3.0806	(21.64) 3.0743
Saline infusion	15	(29.0) 3.387	(21.9) 3.130	(25.4) 3.259
	30	(38.8) 3.681	(17.6) 2.877	(28.2) d 3.279
Saline recovery	15	(38.1) 3.657	(27.9) 3.362	(33.0) c 3.51
	30	(39.0) 3.689	(27.9) 3.330	(33.5) 3.509
Adrenaline infusion	15	(42.7) 3.737	(25.9) 3.252	(34.3) 3.494
	30	(66.4) 4.179	(46.1) 3.832	(56.2) a 4.006
Adrenaline recovery	15	(46.5) 3.845	(35.5) 3.595	(41.0) 3.720
	30	(31.1) 3.46	(25.9) 3.293	(28.5) b 3.377
Effect of feed		(41.5) 3.704	(28.6) 3.334	(35.0) 3.519

			5%	1%	0.1%
SED Treatment means	0.0735	LSD	0.1577	0.2188	0.3043
SED Feed x treatment means	0.1864				
SED Feed means	0.1713				

(a) Adrenaline infusion significantly higher than saline infusion ($P < 0.001$).

(b) Adrenaline infusion significantly higher than adrenaline recovery at 30 min. ($P < 0.001$).

(c) Adrenaline recovery at 30 min. significantly higher than saline recovery at 30 min. ($P \leq 0.001$).

(d) Saline recovery at 30 min. significantly higher than values at 0 time ($P < 0.05$).

Table 86

The effect of adrenaline and saline infusions on the concentration of plasma saturated free fatty acids in lambs (mean μg/ml plasma)

Treatment	Time (mins.)	Concentration of saturated FFA (μg/ml plasma) Feeding regimen: Fed once daily	Fed twice daily	Grazing	Treatment effect
Before infusion	0	(34.7) 3.493	(35.1) 3.586	(34.4) 3.512	(34.8) 3.531
Saline infusion	15	(46.8) 3.805	(40.0) 3.704	(40.6) 3.636	(42.5) 3.715
	30	(41.0) 3.691	(44.7) 3.800	(46.3) 3.767	(44.0) 3.753
Saline recovery	15	(43.2) 3.723	(44.1) 3.808	(36.0) 3.552	(41.1) 3.694
	30	(50.7) 3.865	(46.6) 3.849	(38.8) 3.643	(45.4) d 3.786
Adrenaline infusion	15	(100.3) 4.616	(105.5) 4.667	(112.4) 4.719	(106.0) a 4.667
	30	(117.4) 4.769	(102.0) 4.613	(118.9) 4.773	(112.8) 4.718
Adrenaline recovery	15	(97.1) 4.520	(88.5) 4.430	(100.5) 4.587	(95.3) 4.512
	30	(69.0) 4.151	(80.1) 4.297	(91.7) 4.451	(80.3)bc 4.300
Effect of feed		(66.7) 4.070	(65.2) 4.084	(68.8) 4.071	(66.9) 4.075

			5%	1%	0.1%
SED Treatment means	0.1139	LSD	0.229	0.306	0.399
SED Treatment x feed means	0.3098				
SED Feed means	0.2477				

(a) Adrenaline infusion significantly higher at 30 min. than saline recovery ($P < 0.001$).

(b) Adrenaline recovery significantly lower at 30 min. than at 30 min. infusion period ($P < 0.001$).

(c) Saline recovery at 30 min. significantly higher than adrenaline recovery at 30 min. ($P < 0.01$).

(d) Saline recovery at 30 min. significantly higher than before infusion and saline infusion at 15 min. ($P < 0.001$).

Table 87

Effect of adrenaline and saline infusion on the concentration of plasma unsaturated free fatty acids in goats (mean µg/ml plasma)

Treatment	Time (mins.)	Concentration of unsaturated FFA µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Treatment effect
Before infusion	0	(12.9) 2.559	(15.52) 2.742	(14.16) 2.651
Saline infusion	15	(19.3) 3.010	(15.8) 2.812	(17.6) 2.911
	30	(29.8) 3.427	(12.1) 2.417	(20.9) 2.922
Saline recovery	15	(30.2) 3.442	(20.7) 3.066	(25.5) 3.254
	30	(30.0) 3.413	(18.6) 2.972	(24.3) cd 3.192
Adrenaline infusion	15	(40.6) 3.718	(27.4) 3.239	(34.0) 3.478
	30	(77.0) 4.355	(50.8) 3.894	(63.9) a 4.125
Adrenaline recovery	15	(33.5) 3.534	(29.7) 3.423	(31.6) 3.478
	30	(18.8) 2.982	(16.1) 2.821	(17.4) b 2.901
Effect of feed		(34.9) 3.485	(23.9) 3.080	(29.4) 3.283

			5%	1%	0.1%
SED Treatment means	0.1050	LSD	0.2252	0.3126	0.4347
SED Feed x treatment means	0.1967				
SED Feed means	0.1663				

(a) Adrenaline infusion significantly higher than saline infusion ($P < 0.001$).

(b) Adrenaline infusion at 30 min. significantly higher than 30 min. adrenaline recovery ($P < 0.001$).

(c) Adrenaline recovery at 30 min. significantly higher than saline recovery at 30 min. ($P < 0.05$).

Table 88

Effect of adrenaline and saline infusions on the concentration of plasma unsaturated free fatty acids in lambs (mean µg/ml plasma)

Treatment	Time (mins.)	Concentration of unsaturated FFA µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Grazing	Treatment effect
Before infusion	0	(17.6) 2.812	(14.2) 2.710	(17.1) 2.812	(16.3) 2.778
Saline infusion	15	(22.8) 3.071	(14.5) 2.723	(21.4) 2.949	(19.6) 2.914
	30	(23.1) 3.114	(20.1) 2.986	(25.3) 3.125	(22.8) 3.075
Saline recovery	15	(23.7) 3.112	(18.5) 2.963	(17.5) 2.840	(19.9) 2.972
	30	(31.9) 3.308	(21.3) 3.073	(23.0) 3.097	(25.4) 3.159
Adrenaline infusion	15	(80.5) 4.395	(93.1) 4.541	(107.2) 4.646	(92.9)a 4.527
	30	(111.9) 4.710	(86.9) 4.381	(120.2) 4.768	(106.3)ab 4.619
Adrenaline recovery	15	(69.5) 4.159	(60.3) 3.934	(85.6) 4.395	(71.8) 4.163
	30	(37.9) 3.532	(32.6) 3.448	(42.7) 3.640	(37.7)c 3.540
Effect of feed		(46.5)	(40.2) 3.418	(50.9) 3.586	(45.9) 3.528

			5%	1%	0.1%
SED Treatment means	0.1639	LSD	0.3294	0.4396	0.5743
SED Treatment x feed means	0.4134				
SED Feed means	0.3151				

Table 89

Effect of adrenaline and saline infusion on the ratios of plasma saturated to unsaturated free fatty acids in goats (mean)

Treatment	Time (mins.)	Ratios saturated/unsaturated FFA Feeding regimen Fed once daily	Fed twice daily	Treatment effect
Before infusion	0	(1.664) 0.979	(1.035) 0.710	(1.349) 0.845
Saline infusion	15	(1.495) 0.911	(1.413) 0.878	(1.454) 0.894
	30	(1.302) 0.833	(1.748) 0.992	(1.525) 0.913
Saline recovery	15	(1.258) 0.812	(1.370) 0.861	(1.314) 0.836
	30	(1.374) 0.854	(1.476) 0.901	(1.425) 0.877 c
Adrenaline infusion	15	(1.029) 0.705	(1.036) 0.706	(1.033)a 0.706 b
	30	(0.875) 0.619	(0.948) 0.665	(0.912)ab 0.642
Adrenaline recovery	15	(1.377) 0.866	(1.193) 0.785	(1.285) 0.826
	30	(1.682) 0.978	(1.683) 0.978	(1.682)b 0.978
Feed mean		(1.299) 0.822	(1.358) 0.846	(1.329) 0.834

			5%	1%	0.1%
SED Treatment means	0.0373	LSD	0.0800	0.1110	0.1544
SED Feed x treatment means	0.1128				
SED Feed means	0.1065				

(a) Adrenaline infusion significantly lower than saline infusion ($P < 0.001$).

(b) Adrenaline infusion significantly lower than adrenaline recovery at 30 min. ($P < 0.001$).

(c) Saline recovery at 30 min. significantly lower than adrenaline recovery at 30 min. ($P < 0.001$).

Table 90

The effect of adrenaline and saline infusion on the ratios of free saturated/free unsaturated plasma fatty acids in lambs (means)

		Ratios saturated/unsaturated FFA			
		Feeding regimen			
Treatment	Time (mins.)	Fed once daily	Fed twice daily	Grazing	Treatment effect
Before infusion	0	2.059	2.536	2.099	2.231
Saline infusion	15	2.163	2.825	2.133	2.374
	30	1.832	2.365	2.035	2.077
Saline recovery	15	1.897	2.415	2.116	2.143
	30	1.853	2.246	1.815	1.971
Adrenaline infusion	15	1.253	1.140	1.078	1.157a
	30	1.068	1.314	1.018	1.133a
Adrenaline recovery	15	1.451	1.759	1.254	1.488
	30	1.937b	2.401b	2.347b	2.228b
Feed effect		1.724	2.111	1.766	1.867

			5%	1%	0.1%
SED Treatment means	0.1677	LSD	0.3371	0.4498	0.5876
SED Treatment x feed means	0.3404				
SED Feed means	0.2022				

(a) Adrenaline infusion lower than saline infusion ($P < 0.001$).

(b) Adrenaline infusion at 30 min. significantly lower than 30 min. adrenaline recovery ($P < 0.001$).

During adrenaline recovery the ratios increased to a value significantly higher ($P < 0.001$) at 30 min. than at 30 min. adrenaline infusion and also significantly higher ($P < 0.05$) than at 30 min. saline recovery period.

Saline infusion had no significant effect on the ratios of saturated to unsaturated free fatty acids in lambs (Table 90). Adrenaline infusion significantly reduced the ratios of saturated to unsaturated fatty acids ($P < 0.001$) in the three feeding groups. The ratios were lowest at 30 min. infusion period except for the group fed twice daily, whose lowest ratio was at 15 min. infusion period. Feeding regimen had no significant effect on these ratios.

During adrenaline recovery period, the ratios increased to a value significantly higher (at 30 min.) than the value at 30 min. adrenaline infusion ($P < 0.001$). This value was not significantly different from the ratios obtained during saline infusion, although it was slightly higher.

These results indicate that adrenaline infusion increases the proportion of unsaturated fatty acids to the total fatty acids, and that on termination of the infusion the concentration of unsaturated fatty acids declines faster than the saturated fatty acids.

4.4.1.3 Individual FFA in goats and lambs

(a) Stearic acid

Table 91 shows that adrenaline infusion for 30 min. significantly increased the concentration of plasma free stearic acid in both groups of goats. The concentration after 15 min. infusion was not significantly different from the concentration during the 30 min. saline recovery.

Saline infusion increased the concentration of stearic acid significantly ($P < 0.01$) over the concentration before saline infusion.

The concentration of this fatty acid continued to increase during the 30 min. saline recovery period to levels significantly higher ($P < 0.001$) at 30 min. than after 30 min. saline infusion.

During the 30 min. adrenaline recovery, the concentration of stearic acid decreased to a level significantly lower ($P < 0.001$) than at 30 min. adrenaline infusion and also significantly lower than the concentration at 30 min. saline recovery ($P < 0.05$), but significantly higher ($P < 0.01$) than the concentrations at rest.

Feeding regimen had only a slight effect on the response to saline and adrenaline infusion. The group fed once daily had a slightly higher concentration of stearic acid in all sampling periods.

The data in Table 92 indicate that saline infusion had no significant effect on the concentration of stearic acid in plasma of lambs. On the other hand, adrenaline infusion increased the concentration of stearic acid significantly ($P < 0.001$) in all groups. The concentration continued to rise during the recovery period except in the group fed once per day where the concentration declined slightly after the 30 min. recovery period. Feeding regimen had no effect on the concentration of free stearic acid.

(b) Oleic acid

In goats (Table 93), adrenaline infusion increased the concentration of free oleic acid in plasma significantly ($P < 0.001$) at 15 min. and 30 min. when compared to the concentration at 30 min. saline recovery period in the two groups.

Oleic acid concentration increased significantly ($P < 0.05$) during saline infusion at 30 min. and during 30 min. saline recovery period ($P < 0.01$) in the two groups.

During adrenaline recovery period the concentration of oleic acid decreased to a level significantly lower ($P < 0.001$) at 30 min.

than at 30 min. infusion period and significantly lower ($P < 0.05$) than the level at 30 min. saline recovery period, but significantly higher ($P < 0.05$) than before saline infusion.

Feeding regimen had no significant effect on the concentration of oleic acid, although the group fed once daily had a higher concentration of this fatty acid on all occasions.

In lambs (Table 94) saline infusion did not affect the concentration of oleic acid in plasma significantly. Adrenaline infusion significantly ($P < 0.001$) increased the concentration of free oleic acid to a more than threefold level.

On cessation of adrenaline infusion it fell rapidly and at 30 min. recovery was significantly lower ($P < 0.001$) than the maximum attained during infusion, although it was still significantly ($P < 0.05$) higher than at the end of saline recovery period.

Feeding regimen had no significant effect on the concentration of free oleic acid. The paddock group, however, had a slightly higher concentration during adrenaline infusion.

(c) Ratios stearic/oleic acid

In goats (Table 95) adrenaline infusion for 30 min. decreased the ratios of stearic acid to oleic acid significantly ($P < 0.001$) in the two groups.

During adrenaline recovery period, the ratios increased to a level significantly ($P < 0.001$) higher at 30 min. than at 30 min. infusion period. These values were not significantly different from those obtained during the saline infusion or recovery period.

Feeding regimen and saline infusion had no significant effect on these ratios.

Saline infusion did not affect the ratios of stearic to oleic acid in all feeding regimen of lambs (Table 96). Adrenaline infusion

significantly ($P < 0.001$) decreased the ratios to half the value observed during saline infusion in all feeding groups.

During the recovery period the ratios increased to a level significantly higher ($P < 0.001$) at 30 min. than after 30 min. adrenaline infusion. This value was not significantly different from the ratios during saline infusion.

(d) Palmitic acid

Table 97 shows that adrenaline infusion in goats significantly ($P < 0.001$) increased the concentration of palmitic acid at 30 min. over the concentration observed during saline infusion. The concentration at 15 min. adrenaline infusion was not significantly different from that observed during saline infusion.

Saline had no significant effect on the concentration of palmitic acid. However, during saline recovery 30 min. a significantly higher ($P < 0.05$) concentration of palmitic acid than before saline infusion was apparent.

During adrenaline recovery period, palmitic acid concentration declined to a level significantly ($P < 0.001$) lower at 30 min. than at 30 min. adrenaline infusion. This level was not significantly different from that during saline infusion or recovery, but it was significantly higher ($P < 0.05$) than the concentration observed before saline infusion.

Feeding regimen had no significant effect on the concentration of palmitic acid, although in the group fed once daily it was slightly higher than in the other group on all occasions.

Saline infusion in lambs (Table 98) had no significant effect on the concentration of palmitic acid in plasma in all feeding groups.

Adrenaline infusion increased the concentration of palmitic acid

significantly ($P < 0.001$) in all feeding groups; the highest concentration was attained after 30 min. in two groups, whereas the group fed twice daily was highest after 15 min.

During the recovery period the concentration of palmitic acid declined to a level significantly lower at 30 min. than at 30 min. infusion period ($P < 0.001$), but was significantly higher ($P < 0.05$) than at 30 min. saline recovery period.

For individual groups the concentration was higher at 30 min. adrenaline recovery than at 30 min. saline recovery, but this difference reached significance ($P < 0.01$) only in the grazing group.

(e) Palmitoleic acid

Table 99 shows that adrenaline infusion and feeding regimen had significant effects on the concentration of free palmitoleic acid in goats. Adrenaline infusion significantly ($P < 0.001$) increased the concentration of palmitoleic acid at 30 min. when compared to the concentration during saline infusion. However, the concentration at 15 min. infusion period was not significantly different from the values observed during saline infusion.

During adrenaline recovery palmitoleic acid concentration declined to a level significantly ($P < 0.001$) lower at 30 min. than the concentration at 30 min. adrenaline infusion and significantly ($P < 0.05$) lower than at 30 min. saline recovery, but not significantly different from the control (0 min.) level.

Saline infusion had no significant effect on the concentration of palmitoleic acid, although there was a slight increase over the control level.

The group of goats fed once daily had a significantly higher ($P < 0.001$) overall palmitoleic acid concentration than the group fed twice daily. The concentration at 30 min. adrenaline infusion

was significantly higher for the goats taking their food once daily than for those fed twice daily.

In lambs (Table 100) saline infusion had no significant effect on the concentration of palmitoleic acid in all groups. Adrenaline infusion increased the concentration of palmitoleic acid significantly ($P < 0.001$) in all groups, the highest concentration being attained after 30 min. in two groups and the group fed twice daily attaining the highest concentration after 15 min. infusion.

During the 30 min. adrenaline recovery period the concentration of palmitoleic acid declined to a value significantly lower ($P < 0.001$) at 30 min. than the concentration at 30 min. infusion period. This value was significantly higher ($P < 0.01$) than the concentration at the 30 min. saline recovery period.

(f) Linoleic acid

In goats (Table 101) adrenaline infusion increased the concentration of plasma linoleic acid but the rise was not statistically significant. The concentration was highest at 30 min. adrenaline infusion. On termination of adrenaline infusion, the concentration of linoleic acid declined to pre-adrenaline infusion level.

Saline infusion and feeding pattern had no effect on the concentration of this fatty acid.

Table 102 shows that saline infusion had no significant effect on the concentration of linoleic acid in all three feeding groups of lambs. Adrenaline infusion significantly ($P < 0.001$) increased the concentration of linoleic acid in all three feeding groups. The concentration was highest after 30 min. infusion period.

During recovery period the concentration of linoleic acid decreased to a value significantly lower at 30 min. than the concentration at 30 min. adrenaline infusion period ($P < 0.001$). This value

FIGURE 17A shows the effect of saline and adrenaline infusion on the concentration of individual plasma free fatty acids in goats (mean, µg/ml plasma). Each point is a mean for 4 goats.

FIGURE 17 A

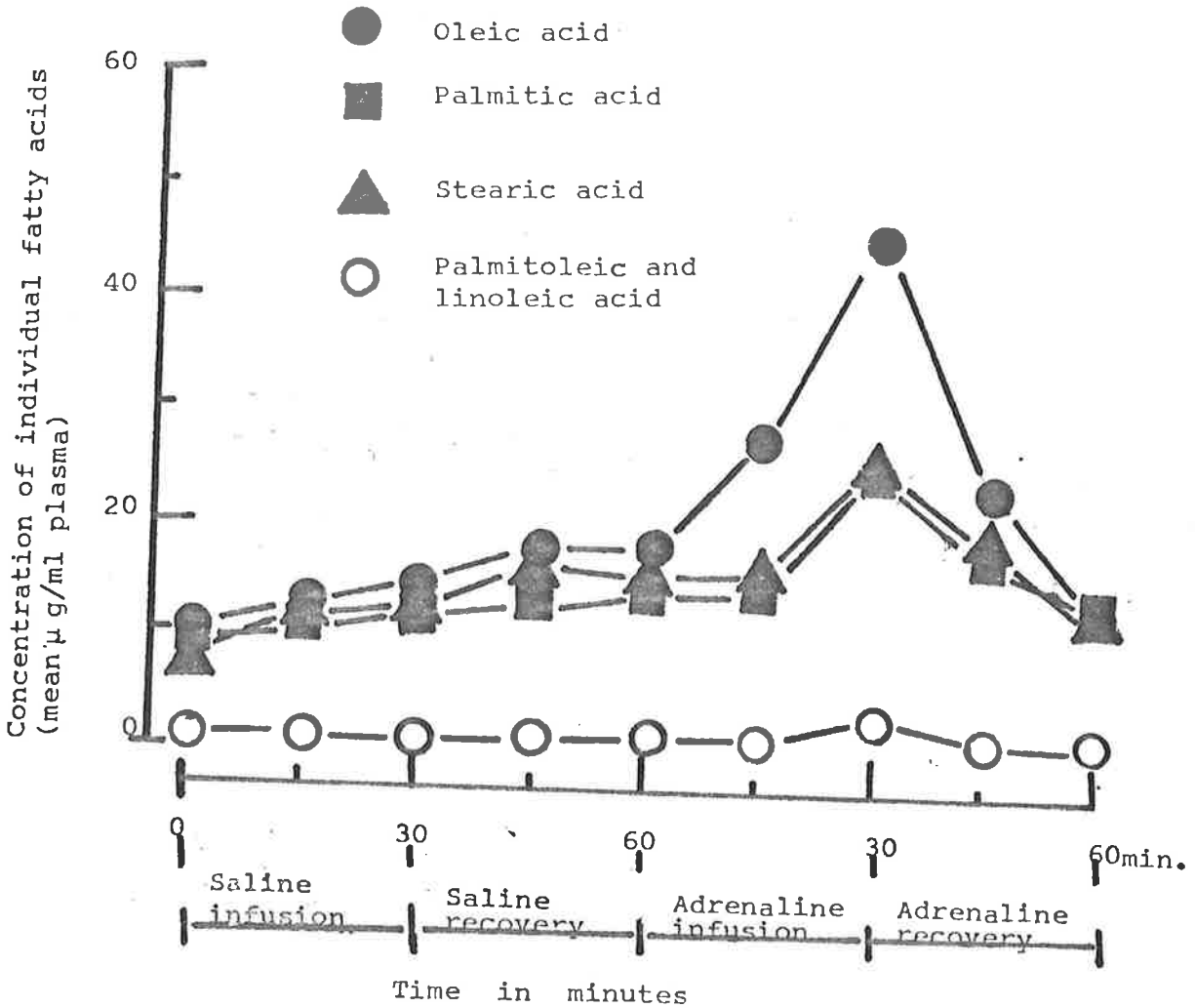

Oleic acid
Palmitic acid
Stearic acid
Palmitoleic and linoleic acid
Concentration of individual fatty acids (mean µ g/ml plasma)
60
40
20
0
0
30
60
30
60min.
Saline infusion
Saline recovery
Adrenaline infusion
Adrenaline recovery
Time in minutes

FIGURE 17B shows the effect of saline and adrenaline infusion on the percentage concentration of individual plasma fatty acids in goats (mean W/W).

Each point represents a mean for 4 animals.

FIGURE 17B

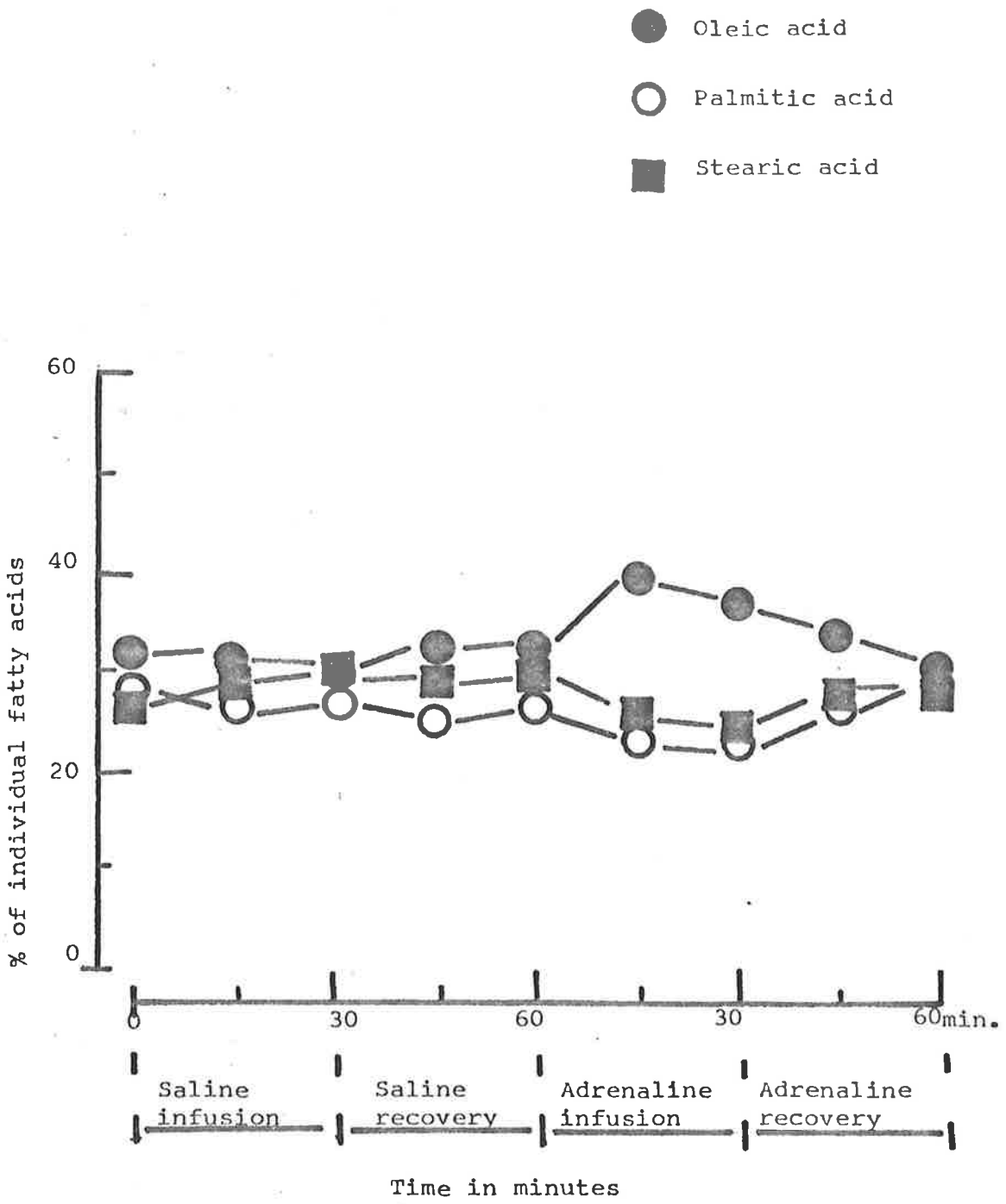

Oleic acid
Palmitic acid
Stearic acid
60
40
20
0
% of individual fatty acids
0
30
60
30
60min.
Saline infusion
Saline recovery
Adrenaline infusion
Adrenaline recovery
Time in minutes

FIGURE 18A shows the effect of saline and adrenaline infusion on the concentration of individual plasma fatty acids in lambs (mean μg/ml plasma). Each point is a mean for 9 animals.

FIGURE 18A

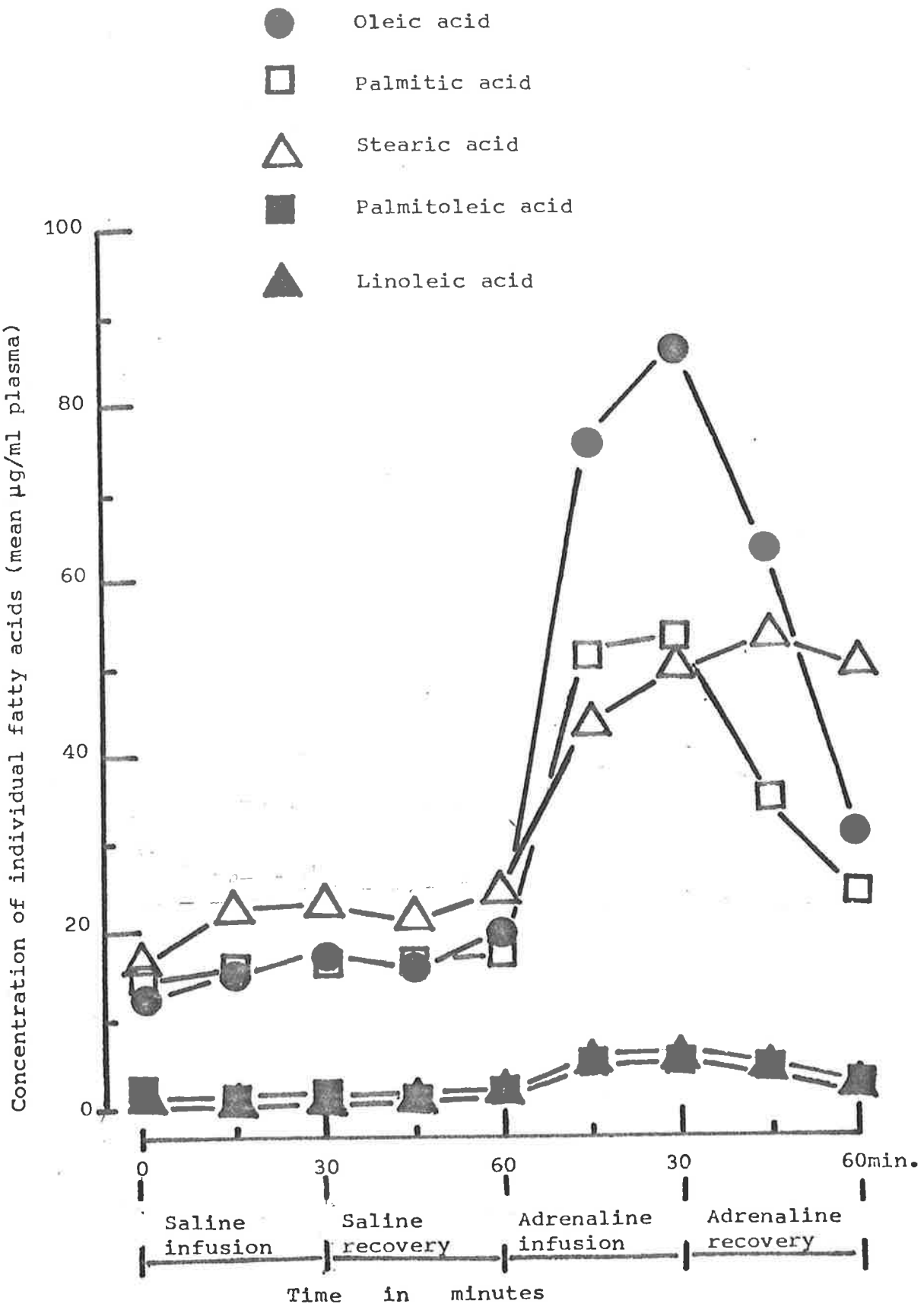
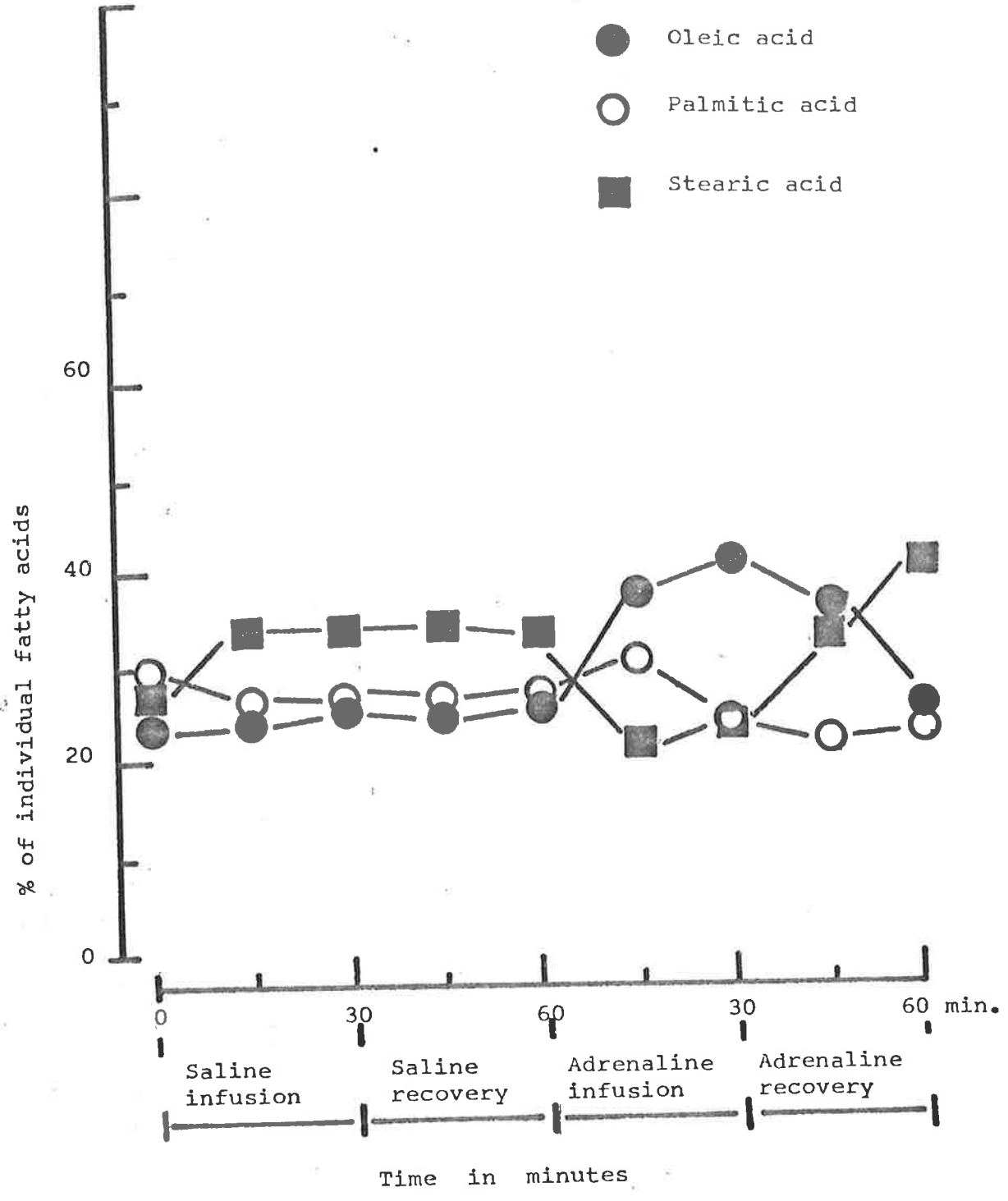

Oleic acid
Palmitic acid
Stearic acid
Palmitoleic acid
Linoleic acid
Concentration of individual fatty acids (mean µg/ml plasma)
100
80
60
40
20
0
0
30
60
30
60min.
Saline infusion
Saline recovery
Adrenaline infusion
Adrenaline recovery
Time in minutes

FIGURE 18B shows the effect of saline and adrenaline infusion on the percentage concentration of 3 individual plasma fatty acids in lambs (mean W/W).

Each point represents a mean for 9 animals.

FIGURE 18B


Oleic acid
Palmitic acid
Stearic acid
% of individual fatty acids
60
40
20
0
0
30
60
30
60 min.
Saline infusion
Saline recovery
Adrenaline infusion
Adrenaline recovery
Time in minutes

(a) Adrenaline infusion at 30 min. significantly higher than saline infusion ($P < 0.001$).

(b) Adrenaline infusion at 30 min. significantly higher than 30 min. adrenaline recovery ($P < 0.001$).

(c) Saline recovery at 30 min. significantly higher than 30 min. adrenaline recovery ($P < 0.05$).

(d) Saline recovery at 15 min. significantly higher than 15 min. saline infusion ($P < 0.001$).

(e) Saline infusion significantly higher than before infusion ($P < 0.01$).

(f) Adrenaline recovery at 30 min. significantly higher than before infusion ($P < 0.01$).

Table 91

Effect of adrenaline and saline infusion on the concentration of plasma free stearic acid in goats (mean µg/ml plasma)

Treatment	Time (mins.)	Stearic acid concentration µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Treatment effect
Before infusion	0	(8.623) 2.264	(9.330) 2.391	(8.977) 2.300
Saline infusion	15	(13.21) 2.635	(10.13) 2.408	(11.67) 2.522 e
	30	(17.55) 2.905	(8.57) 2.187	(13.06) e 2.546
Saline recovery	15	(19.39) 3.013	(13.9) 2.700	(16.64) d 2.856
	30	(18.82) 2.979	(13.10) 2.604	(15.96) c 2.792
Adrenaline infusion	15	(20.74) 3.034	(11.83) 2.530	(16.29) 2.782
	30	(30.71) 3.420	(22.03) 3.125	(26.37)a 3.272
Adrenaline recovery	15	(22.99) 3.133	(16.83) 2.880	(19.91) 3.006
	30	(13.30) 2.655	(11.80) 2.534	(12.55)bf 2.594
Feed means		(19.59) 2.972	(13.53) 2.621	(16.56) 2.796

			5%	1%	0.1%
SED Treatment means	0.0802	LSD	0.1720	0.2388	0.3320
SED Feed means	0.2067				
SED Feed x treatment means	0.2218				

Table 92

Effects of adrenaline and saline infusions on the concentration of plasma free stearic acid (C18:0) in lambs (mean µg/ml plasma)

		Concentration of stearic acid (C18:0) µg/ml plasma			
		Feeding regimen			
Treatment	Time (mins.)	Fed once daily	Fed twice daily	Grazing	Treatment effect
Before infusion	0	(16.5) 2.709	(17.8) 2.931	(17.0) 2.774	(17.1) 2.805
Saline infusion	15	(25.9) 3.163	(21.9) 3.114	(21.4) 2.967	(23.1) 3.081
	30	(22.7) 3.075	(23.1) 3.167	(23.9) 3.049	(23.3) 3.097
Saline recovery	15	(21.0) 3.015	(24.1) 3.221	(19.0) 2.896	(21.3) 3.044
	30	(26.6) 3.176	(24.8) 3.244	(21.5) 3.02	(24.3) 3.146
Adrenaline infusion	15	(40.2) 3.712	(43.5) 3.795	(47.7) 3.874	(43.8) a 3.794
	30	(53.3) 3.984	(47.4) 3.877	(46.1) 3.816	(48.9) a 3.893
Adrenaline recovery	15	(55.8) 3.971	(48.2) 3.825	(56.4) 4.017	(53.5) b 3.938
	30	(42.5) 3.576	(51.0) 3.785	(57.2) 3.916	(50.2) b 3.759
Effect of feed		(33.8) 3.376	(33.5) 3.44	(34.5) 3.7	(33.9) 3.395

			5%	1%	0.1%
SED Treatment means	0.1512	LSD	0.3039	0.4055	0.5298
SED Treatment x feed mean	0.4077				
SED Feed means	0.3245				

(a) Adrenaline infusion significantly higher than saline infusion ($P < 0.001$).

(b) Adrenaline recovery significantly higher than saline infusion or saline recovery ($P < 0.001$).

(n) 9 lambs

(a) Adrenaline infusion at 30 min. significantly higher than saline infusion and recovery ($P < 0.001$).

(b) Adrenaline recovery at 30 min. significantly lower than adrenaline infusion at 30 min. ($P < 0.001$).

(c) Adrenaline recovery at 30 min. significantly lower than 30 min. saline recovery ($P < 0.05$).

(d) Saline infusion at 30 min. significantly higher than before infusion ($P < 0.01$).

(e) Adrenaline recovery at 30 min. significantly higher than before saline infusion ($P < 0.05$).

Table 93

Effect of saline and adrenaline infusions on the concentration of plasma free oleic acid in goats (mean µg/ml plasma)

Treatment	Time (mins.)	Concentration of oleic acid µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Treatment effect
Before infusion	0	(10.383) 2.432	(10.662) 2.456	(10.523) 2.444 e
Saline infusion	15	(14.6) 2.749	(12.0) 2.547	(13.3) 2.648
	30	(21.1) 3.095	(9.6) 2.192	(15.4) d 2.797
Saline recovery	15	(20.2) 3.051	(17.2) 2.888	(18.7) 2.969
	30	(22.5) 3.133	(15.2) 2.787	(18.9) 2.960
Adrenaline infusion	15	(33.4) 3.524	(23.3) 3.088	(28.4) 3.306
	30	(49.7) 3.910	(41.7) 3.714	(45.7) a 3.812
Adrenaline recovery	15	(25.6) 3.276	(23.6) 3.201	(24.6) 3.238
	30	(14.7) 2.745	(12.5) 2.594	(13.6) bce 2.669
Effect of feed		(25.2) 3.185	(19.4) 2.877	(22.3) 3.031

			5%	1%	0.1%
SED Treatment means	0.1042	LSD	0.2236	0.3102	0.4314
SED Feed means	0.1798				
SED Feed x treatment means	0.2078				

(a) Adrenaline infusion significantly higher than saline infusion ($P < 0.001$).

(b) Adrenaline recovery significantly lower at 30 min. than adrenaline infusion at 30 min. ($P < 0.001$).

(c) Adrenaline recovery at 30 min. significantly higher than saline recovery at 30 min. ($P < 0.05$).

Table 94

Effect of adrenaline and saline infusion on the concentration of plasma free oleic (C18:1) acid in lambs (mean µg/ml plasma)

Oleic acid concentration µg/ml plasma

Treatment	Time (mins.)	Feeding regimen: Fed once daily	Fed twice daily	Grazing	Treatment effect
Before infusion	0	(13.2) 2.531	(11.7) 2.521	(13.0) 2.569	(12.6) 2.540
Saline infusion	15	(18.0) 2.844	(12.7) 2.594	(16.0) 2.689	(15.6) 2.709
	30	(17.8) 2.855	(16.7) 2.816	(19.2) 2.868	(17.9) 2.846
Saline recovery	15	(19.2) 2.904	(15.3) 2.784	(13.8) 2.604	(16.1) 2.764
	30	(23.7) 3.002	(18.2) 2.895	(17.0) 2.827	(19.6) 2.908
Adrenaline infusion	15	(65.9) 4.196	(75.8) 4.336	(85.2) 4.438	(75.6) a 4.323
	30	(89.8) 4.492	(72.0) 4.196	(98.3) 4.568	(86.7) a 4.419
Adrenaline recovery	15	(56.9) 3.944	(50.7) 3.757	(69.4) 4.149	(59.0) 3.950
	30	(32.1) 3.329	(26.9) 3.231	(34.5) 3.427	(31.2) bc 3.329
Effect of feed		(37.4) 3.344	(33.3) 3.237	(40.7) 3.349	(37.1) 3.310

			5%	1%	0.1%
SED Treatment means	0.1692	LSD	0.3381	0.4511	0.5929
SED Treatment x feed means	0.4319				
SED Feed means	0.3319				

Table 95

Effect of adrenaline and saline infusion on the ratios of plasma stearic acid to free oleic acid in goats (mean)

Treatment	Time (mins.)	Ratio stearic/oleic acid Feeding regimen Fed once daily	Fed twice daily	Treatment effect
Before infusion	0	(0.831) 0.605	(0.875) 0.629	(0.853) 0.617
Saline infusion	15	(0.912) 0.641	(0.887) 0.628	(0.899) 0.635
	30	(0.848) 0.607	(1.039) 0.705	(0.943) 0.656
Saline recovery	15	(0.968) 0.675	(0.822) 0.599	(0.895) 0.637
	30	(0.906) 0.631	(0.847) 0.607	(0.876) 0.619
Adrenaline infusion	15	(0.606) 0.472	(0.572) 0.448	(0.589) 0.460 a
	30	(0.607) 0.473	(0.549) 0.436	(0.578) 0.455 a
Adrenaline recovery	15	(0.877) 0.626	(0.713) 0.538	(0.795) 0.582
	30	(0.933) 0.653	(0.986) 0.674	(0.959) b 0.663
Effect of feed		(0.832) 0.597	(0.802) 0.580	(0.817) 0.588

			5%	1%	0.1%
SED Treatment means	0.0364	LSD	0.0781	0.1084	0.1507
SED Feed means	0.1058				
SED Feed x treatment means	0.1119				

(a) Adrenaline infusion significantly lower than saline infusion and recovery ($P < 0.001$).

(b) Adrenaline recovery at 30 min. significantly lower than adrenaline infusion ($P < 0.001$).

Table 96

Effect of saline and adrenaline infusion on the ratios of plasma free stearic to free oleic acid in lambs (means)

Treatment	Time (mins.)	Ratios stearic acid/oleic acid Feeding regimen Fed once daily	Fed twice daily	Grazing	Treatment effect
Before infusion	0	1.214	1.581	1.264	1.353
Saline infusion	15	1.405	1.796	1.374	1.525
	30	1.266	1.473	1.237	1.325
Saline recovery	15	1.132	1.598	1.369	1.366
	30	1.225	1.496	1.246	1.322
Adrenaline infusion	15	0.613	0.581	0.566	0.587 ab
	30	0.604	0.797	0.498	0.633 ab
Adrenaline recovery	15	1.042	1.133	0.991	1.055
	30	1.452	1.810	1.671	1.644
Effect of feed		1.106	1.363	1.135	1.201

SED Treatment means	0.1498	LSD	0.3011	0.4018	0.5249
SED Treatment x feed means	0.2813				
SED Feed means	0.1387				

(a) Adrenaline infusion significantly lower than saline ($P < 0.001$).

(b) Adrenaline infusion significantly lower than adrenaline recovery at 30 min. ($P < 0.001$).

(a) Adrenaline infusion at 30 min. significantly higher than saline infusion and recovery ($P < 0.001$).

(b) Adrenaline infusion at 30 min. significantly higher than adrenaline recovery at 30 min.

(c) Saline recovery at 30 min. significantly higher than before infusion ($P < 0.01$).

(d) Adrenaline recovery at 30 min. significantly higher than before infusion ($P < 0.05$).

Table 97

Effect of adrenaline and saline infusion on the concentration of plasma free palmitic acid in goats (mean µg/ml plasma)

Treatment	Time (mins.)	Palmitic acid concentration µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Treatment effect
Before infusion	0	(11.193) 2.501	(10.347) 2.429	(10.770) 2.466
Saline infusion	15	(13.22) 2.645	(9.44) 2.343	(11.33) 2.494
	30	(17.49) 2.917	(7.34) 2.102	(12.42) 2.510
Saline recovery	15	(15.25) 2.763	(12.10) 2.572	(13.68) 2.668
	30	(16.63) 2.870	(12.56) 2.586	(14.60) c 2.728
Adrenaline infusion	15	(18.20) 2.905	(11.50) 2.481	(14.85) 2.693
	30	(30.55) 3.419	(21.51) 3.082	(26.03) ab 3.250
Adrenaline recovery	15	(19.86) 3.035	(16.17) 2.840	(18.02) 2.938
	30	(14.98) 2.755	(12.11) 2.566	(13.54) d 2.660
Effect of feed		(18.27) 2.914	(12.84) 2.571	(15.56) 2.743

			5%	1%	0.1%
SED Treatment means	0.0784	LSD	0.1682	0.2334	0.3246
SED Feed x treatment means	0.1568				
SED Feed means	0.1753				

(a) Adrenaline infusion significantly higher than saline infusion ($P < 0.001$).

(b) Adrenaline infusion significantly higher than adrenaline recovery at 30 min. ($P < 0.001$).

(c) Adrenaline recovery at 30 min. significantly higher than saline recovery at 30 min. ($P < 0.05$).

Table 98

Effect of adrenaline and saline infusions on the concentration of plasma free palmitic acid (C16:0) in lambs (mean µg/ml plasma)

		Palmitic acid concentration µg/ml plasma				
		Feeding regimen				
Treatment	Time (mins.)	Fed once daily	Fed twice daily	Grazing	Treatment effect	
Before infusion	0	(15.47) 2.761	(14.49) 2.738	(14.13) 2.699	(14.70) 2.733	
Saline infusion	15	(16.99) 2.864	(14.52) 2.727	(16.14) 2.785	(15.88) 2.792	
	30	(13.57) 2.678	(18.69) 2.948	(18.99) 2.953	(17.09) 2.860	
Saline recovery	15	(18.82) 2.915	(16.60) 2.863	(13.84) 2.672	(16.42) 2.816	
	30	(20.71) 3.034	(18.49) 2.946	(14.39) 2.726	(17.86) 2.902	
Adrenaline infusion	15	(49.22) 3.914	(52.59) 3.979	(53.67) 3.990	(51.83) 3.961	a b
	30	(53.61) 3.994	(46.63) 3.802	(61.30) 4.108	(53.85) 3.968	ba
Adrenaline recovery	15	(35.99) 3.537	(34.80) 3.524	(34.85) 3.504	(35.21) 3.522	
	30	(21.08) 3.012	(24.64) 3.193	(28.18) 3.358	(24.63) 3.193	c
Effect of feed		(27.27) 3.190	(26.83) 3.193	(28.39) 3.199	(27.50) 3.194	

			5%	1%	0.1%
SED Treatment means	0.1179	LSD	0.2370	0.3162	0.4131
SED Treatment x feed mean	0.2564				
SED Feed means	0.1693				

(a) Adrenaline infusion significantly higher at 30 min. than saline infusion and recovery ($P < 0.001$).

(b) Adrenaline infusion significantly higher at 30 min. than adrenaline recovery at 30 min. ($P < 0.001$).

(c) Adrenaline recovery at 30 min. significantly lower than saline recovery at 30 min. ($P < 0.05$).

(d) Once feeding significantly higher than twice feeding ($P < 0.001$).

Table 99

Effect of adrenaline and saline infusion on the concentration of plasma free palmitoleic acid (C16:1) in goats (mean µg/ml plasma)

Treatment	Time (mins.)	Concentration of free palmitoleic acid µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Treatment effect
Before infusion	0	(1.078) 0.731	(1.336) 0.848	(1.207) 0.792
Saline infusion	15	(2.195) 1.146	(1.065) 0.705	(1.630) 0.925
	30	(3.822) 1.571	(0.805) 0.580	(2.314) 1.076
Saline recovery	15	(2.690) 1.305	(1.150) 0.763	(1.920) 1.034
	30	(2.439) 1.227	(1.546) 0.917	(1.992) 1.072
Adrenaline infusion	15	(2.554) 1.267	(1.663) 0.963	(2.108) 1.115
	30	(5.492) 1.867	(2.243) 1.153	(3.868) ab 1.510
Adrenaline recovery	15	(2.748) 1.316	(1.801) 1.030	(2.275) 1.173
	30	(2.110) 1.130	(1.020) 0.697	(1.565) c 0.914
Effect of feed		(3.006) d 1.354	(1.412) 0.851	(2.209) 1.102

			5%	1%	0.1%
SED Treatment means	0.0647	LSD	0.1388	0.1926	0.2679
SED Feed means	0.0705		0.1512	0.2099	0.2919
SED Feed x treatment means	0.0956		0.2051	0.2846	0.3958

(a) Adrenaline infusion significantly higher than saline infusion ($P < 0.001$).

(b) Adrenaline infusion significantly higher than adrenaline recovery at 30 min. ($P < 0.001$).

(c) 30 min. adrenaline recovery significantly higher than 30 min. saline recovery ($P < 0.05$).

Table 100

Effect of adrenaline and saline infusion on the concentration of plasma free palmitoleic acid (C16:1) in lambs (mean µg/ml plasma)

Treatment	Time (mins.)	Palmitoleic acid concentration µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Grazing	Treatment effect	
Before infusion	0	(1.075) 0.723	(1.015) 0.686	(1.432) 0.879	(1.174) 0.762	
Saline infusion	15	(1.514) 0.902	(1.280) 0.742	(1.294) 0.818	(1.362) 0.822	
	30	(1.719) 0.971	(1.319) 0.832	(1.980) 1.075	(1.672) 0.959	
Saline recovery	15	(1.619) 0.940	(1.015) 0.680	(1.724) 0.961	(1.453) 0.860	
	30	(2.111) 1.109	(1.329) 0.836	(1.350) 0.845	(1.597) 0.930	
Adrenaline infusion	15	(4.986) 1.785	(4.537) 1.709	(5.326) 1.820	(4.950) 1.771	a b
	30	(6.107) 1.939	(4.143) 1.556	(5.874) 1.916	(5.375) 1.804	b a
Adrenaline recovery	15	(4.131) 1.616	(2.781) 1.289	(5.259) 1.832	(4.057) 1.579	
	30	(3.042) 1.380	(2.336) 1.173	(2.854) 1.275	(2.744) 1.276	c
Effect of feed		(2.922) 1.263	(2.195) 1.056	(3.010) 1.269	(2.709) 1.196	

			5%	1%	0.1%
SED Treatment means	0.1046	LSD	0.2102	0.2805	0.3665
SED Treatment x feed mean	0.2217				
SED Feed means	0.1413				

Table 101

Effect of adrenaline and saline infusion on the concentration of plasma free linoleic acid in goats (mean µg/ml plasma)

Treatment	Time (mins.)	Concentration of linoleic acid µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Treatment effect
Before infusion	0	(1.179) 0.779	(1.536) 0.931	(1.358) 0.858
Saline infusion	15	(1.75) 0.981	(1.72) 0.984	(1.73) 0.982
	30	(2.30) 1.182	(1.21) 0.783	(1.76) 0.982
Saline recovery	15	(2.47) 1.241	(1.69) 0.989	(2.08) 1.115
	30	(1.83) 1.033	(1.60) 0.950	(1.71) 0.992
Adrenaline infusion	15	(1.79) 1.013	(1.52) 0.891	(1.65) 0.952
	30	(5.97) 1.849	(2.99) 1.325	(4.48) 1.587
Adrenaline recovery	15	(2.94) 1.369	(3.08) 1.405	(3.01) 1.387
	30	(1.35) 0.829	(1.93) 1.043	(1.64) 0.936
Effect of feed		(2.55) 1.187	(1.97) 1.046	(2.26) 1.117

SED Treatment means	0.1059
SED Feed means	0.0817
SED Feed x treatment means	0.1338

Table 102

Effect of adrenaline and saline infusion on the concentration of plasma free linoleic acid (C18:2) in lambs (mean µg/ml plasma)

Treatment	Time (mins.)	Linoleic acid (C18:2) concentration µg/ml plasma Feeding regimen Fed once daily	Fed twice daily	Grazing	Treatment effect	
Before infusion	0	(1.52) 0.909	(1.47) 0.898	(1.71) 0.944	(1.57) 0.917	
Saline infusion	15	(2.35) 1.193	(1.34) 0.848	(2.10) 1.071	(1.93) 1.037	
	30	(1.93) 1.068	(1.44) 0.873	(2.39) 1.16	(1.92) 1.033	
Saline recovery	15	(2.61) 1.281	(1.60) 0.952	(2.04) 1.094	(2.09) 1.109	
	30	(2.76) 1.281	(2.13) 1.125	(1.92) 1.063	(2.27) 1.156	
Adrenaline infusion	15	(4.71) 1.741	(5.44) 1.85	(6.81) 2.024	(5.65) 1.872	a
	30	(6.79) 2.04	(4.94) 1.742	(6.53) 2.008	(6.09) 1.930	a
Adrenaline recovery	15	(3.24) 1.426	(3.59) 1.472	(5.42) 1.854	(4.08) 1.584	
	30	(1.32) 0.727	(2.17) 1.136	(2.80) 1.306	(2.10) 1.057	b
Effect of feed		(3.03) 1.296	(2.68) 1.211	(3.52) 1.392	(3.08) 1.299	

			5%	1%	0.1%
SED Treatment means	0.1202	LSD	0.2416	0.3224	0.4212
SED Treatment x feed means	0.2289				
SED Feed means	0.1177				

(a) Adrenaline infusion significantly higher than saline infusion ($P < 0.001$).

(b) Adrenaline recovery at 30 min. significantly lower than adrenaline infusion ($P < 0.001$).

Table 103

Effect of adrenaline and saline infusions on the concentration of plasma protein in goats (mean g/100ml plasma)

Treatment	Time (mins.)	Concentration of plasma protein g/100ml plasma Feeding regimen Fed once daily	Fed twice daily	Treatment effect
Before infusion	0	(6.9) 2.067	(7.3) 2.116	(7.1) 2.092
Saline infusion	15	(6.8) 2.0541	(7.3) 2.1127	(7.050) 2.0834
	30	(6.8) 2.0541	(7.4) 2.1271	(7.100) 2.0906
Saline recovery	15	(6.8) 2.0541	(7.2) 2.0994	(7.00) 2.0767
	30	(6.6) 2.0278	(7.1) 2.0857	(6.85) 2.0567
Adrenaline infusion	15	(6.8) 2.0541	(7.5) 2.1383	(7.15) 2.0962
	30	(6.8) 2.0541	(7.1) 2.0857	(6.95) 2.0699
Adrenaline recovery	15	(6.6) 2.0278	(7.5) 2.1383	(7.05) 2.0831
	30	(6.8) 2.0541	(7.2) 2.1029	(7.0) 2.0785
Effect of feed		(6.750) 2.0475	(7.287) 2.1113	(7.019) 2.0794

SED Treatment means 0.01055

SED Feed means 0.07776

SED Feed x treatment means 0.06500

n = 4 goats

Table X

Effect of Saline and Adrenaline infusion on the concentration of plasma FFA in goats and sheep

(µg/ml) - & % proportion (w/w)

Component	Animal Species	Saline					Adrenaline			
		Time in minutes								
		0	15	30	45	60	15	30	45	60
Total FFA	Goats n=4	36.0	43.0	48.6	58.4	57.8	68.4	120.1	72.6	46.0
	Sheep n=9	51.1	62.1	66.8	61.0	71.4	172.6	219.1	167.1	118.0
C18:0	Goats	8.98	11.67	13.1	16.6	15.9	16.3	26.4	19.9	12.5
	%	(25)	(27.1)	(26.9)	(28.5)	(27.6)	(23.8)	(22.0)	(27.4)	(27.2)
	Sheep	17.1	23.1	23.3	21.3	24.3	43.8	48.9	53.5	50.2
	%	(33.5)	(37.2)	(34.9)	(34.9)	(34.3)	(25.4)	(22.3)	(32.0)	(42.5)
C18:1	Goats	10.5	13.3	15.4	18.7	18.9	28.4	45.7	24.6	13.6
	%	(29)	(30.9)	(31.7)	(32.0)	(32.7)	(41.5)	(38.1)	(33.9)	(29.5)
	Sheep	12.6	15.6	17.9	16.1	19.6	75.6	86.7	59.0	31.2
	%	(24.6)	(25.1)	(26.8)	(26.4)	(27.5)	(43.9)	(39.6)	(35.3)	(26.4)
C18:2	Goats	1.4	1.7	1.8	2.1	1.7	1.6	4.5	3.0	1.6
	%	(3.8)	(3.9)	(3.7)	(3.6)	(2.9)	(2.3)	(3.7)	(4.1)	(3.6)
	Sheep	1.6	1.9	1.9	2.1	2.3	5.6	6.1	4.1	2.1
	%	(3.1)	(3.1)	(2.9)	(3.4)	(3.2)	(3.3)	(2.8)	(2.5)	(1.8)
C16:0	Goats	10.8	11.3	12.4	13.7	14.6	14.9	26.0	18.0	13.5
	%	(29.9)	(26.3)	(25.6)	(23.4)	(25.3)	(21.8)	(21.6)	(24.8)	(29.4)
	Sheep	14.7	15.9	17.1	16.4	17.9	57.8	53.9	35.2	24.6
	%	(28.8)	(25.6)	(25.6)	(26.9)	(25.1)	(30)	(24.6)	(21.07)	(20.9)
C16:1	Goats	1.21	1.6	2.3	1.9	2	2.1	3.9	2.3	1.6
	%	(3.4)	(3.8)	(4.7)	(3.3)	(3.4)	(3.1)	(3.2)	(3.2)	(3.5)
	Sheep	1.2	1.4	1.7	1.5	1.6	4.9	5.4	4.1	2.7
	%	(2.3)	(2.2)	(2.5)	(2.4)	(2.2)	(2.8)	(2.5)	(2.4)	(2.3)
Total Sat.	Goats	21.6	25.4	28.2	33	33.5	34.3	56.2	41.0	28.5
	%	(60)	(59.1)	(58)	(56.5)	(59.9)	(50.1)	(46.8)	(56.5)	(61.9)
	Sheep	34.8	42.5	44.0	41.1	45.4	106.0	112.8	95.3	80.3
	%	(68.1)	(68.4)	(65.9)	(67.4)	(63.6)	(61.4)	(51.5)	(57)	(68.1)
Total unsat.	Goats	14.2	17.6	20.9	25.5	24.3	34.0	63.9	31.6	17.4
	%	(39.4)	(40.9)	(43.0)	(43.6)	(42)	(49.7)	(53.2)	(43.5)	(37.8)
	Sheep	16.3	19.6	22.8	19.9	25.4	92.9	106.3	71.8	37.7
	%	(31.9)	(31.6)	(34.1)	(32.6)	(35.6)	(53.8)	(48.5)	(42.9)	(31.9)
Ratio sat/unsat	Goats	1.35	1.45	1.53	1.3	1.43	1.0	0.9	1.3	1.7
	Sheep	2.23	2.37	2.1	2.14	1.97	1.157	1.13	1.5	2.23
Ratio C18:0/ C18:1	Goats	0.85	0.9	0.94	0.89	0.88	0.59	0.58	0.79	0.96
	Sheep	1.35	1.53	1.33	1.4	1.32	0.59	0.63	1.06	1.64
C14:0	Goats %	1.42	1.21	1.61	1.93	2.18	2.42	1.92	1.68	1.41
	Sheep %	1.94	1.82	2.12	1.35	1.62	5.33	5.88	4.21	2.38

was not significantly different from the concentration attained during saline recovery period.

Feeding regimen had no significant effect on the concentration of linoleic acid. However, the concentrations were slightly higher for the grazing group during adrenaline infusion and recovery than for those fed in pens.

4.4.1.4 Plasma protein in goats

Table 103 shows that neither treatment nor feeding regimen had an effect on the concentration of plasma protein. However, the group of animals fed twice daily had slightly higher concentrations of plasma protein than the group fed once daily.

4.4.2 Discussion

The data presented for both sheep and goats are in agreement with the current concept of the roles of catecholamines in FFA mobilization. Adrenaline infusion at a rate of 10 µg/kg for 30 minutes in all animals provoked a rise of plasma FFA. This was due to a significant increase of all six major fatty acids (palmitic, palmitoleic, stearic, oleic, linoleic and myristic acid and some minor fatty acids), released by lipolysis.

Lipolysis is a cyclic AMP-dependent process. The initial event following the addition of a lipolytic agent (in this case, adrenaline) is an increase in cyclic AMP production caused by stimulation of a membrane-bound adenyl cyclase. Cyclic AMP, the concentration of which is determined mainly by the relative activity of adenyl cyclase and cyclic nucleotide phosphodiesterase, activates a protein kinase (Corbin and Krebs, 1969; Huttnen et al., 1970; Robinson et al., 1971). This protein kinase transfers the terminal phosphate from ATP to the triglyceride lipase (a hormone-sensitive enzyme) which is

thereby activated. The activated enzyme then hydrolyses the tissue triglycerides into FFA which diffuses into blood vessels, is bound to albumin, and then transferred to other organs for utilization. Adrenaline and other catecholamines also increase the blood flow to the tissues and cause an increase in tissue oxygen consumption (Mjøs et al., 1971).

4.4.2.1 Effect of saline infusion on total plasma FFA

Saline infusion induced a slight increase in the concentration of plasma FFA in lambs and a significant increase in goats. The increase could be due to the stress imposed on these animals by handling and probably there is some effect of saline, which might disturb the blood volume and ion balance. Similar effects of saline infusion on plasma FFA have been reported (Sidhu and Emery, 1971, 1972 in lactating cows; Basset, 1971 in sheep). The significant effect in goats could have arisen from their greater sensitivity to handling.

4.4.2.2 Effect of adrenaline infusion on total plasma FFA

During 30 min. infusion of adrenaline, the increase in plasma FFA concentration in both species was significant. This observation agrees with those reported for non-ruminants and ruminants. A three-fold increase for lambs and twofold increase for goats after a 30 min. adrenaline infusion is in accord with the findings of Etherton et al., (1977) in tissue culture studies where they observed a one to two-fold increase in medium FFA when subcutaneous fat tissues from sheep and steers were incubated with adrenaline. Basset (1970) reported a seven-fold increase in the concentration of plasma FFA 30 min. after intravenous infusion of adrenaline 30 μg/kg (50 μg/min) for 30 min. in sheep.

The higher response than that shown in the present study could be due to the greater amount of adrenaline infused (30 μg/kg vs 10 μg/kg). Radloff and Schultz (1966) working with goats observed an increase in plasma FFA following the injection of adrenaline in high dosage.

The present findings contrast with those of Adrouni and Khachaduriani (1968) and Khachaduriani *et al.* (1966) who observed only slight increases in FFA either in the medium when tissues from sheep were incubated with adrenaline or noradrenaline or in plasma when sheep were injected with these hormones. However, this poor response may be the result of their having used a single intravenous injection. Basset (1970) observed that a single intravenous injection of adrenaline gave a significantly lower response than infusion of the same amount over 30 min. in sheep.

The lower response to the same amount of adrenaline in goats than in lambs in the present study could be due either to the lesser sensitivity of goat tissue to adrenaline, or to the failure of FFA to enter the circulation because of re-esterification by the adipose tissues. Species differences in their responses to catecholamines have been reported.

Rudman *et al.* (1963) observed a lack of response to adrenaline and noradrenaline by rabbits, guinea pigs and domestic pigs while rats, dogs and man showed a higher response.

Etherton *et al.* (1977) observed a seven-fold greater lipolysis in the fat tissues of dairy steers compared to sheep.

To check for probable re-esterification of FFA formed during adrenaline infusion by adipose tissues, measurement of glycerol release together with FFA would have given a better index of lipolysis. A higher proportion of plasma glycerol as compared to FFA would be

indicative of re-esterification because glycerol released during lipolysis is not re-utilized for glyceride synthesis within adipocytes but freely diffuses into the blood for metabolism in other tissues (Steinberg et al., 1965).

Another possible cause for the lower response in goats is that they may have smaller adipocytes than lambs. In rats Holmn et al. (1975) observed that the large fat cells gave a higher lipolytic response to noradrenaline than the small fat cells from the same animal.

Similar findings in man were reported by Arner and Ostman (1978). Since adipocyte sizes were not studied in this work, and as there is no information concerning comparative adipose cellularity between the two species, it is not possible to resolve this point.

There is also a possibility that body fat content may have modified the response. Although of the same age, the goats were smaller than the lambs and contained less fat.

4.4.2.3 Effect of feeding pattern

Feeding pattern had no significant effect on the response to adrenaline infusion; however, the twice daily fed group seemed to display a lower lipolytic response to adrenaline infusion than those fed once daily. The reason for this could be some modification of adipose tissue. Twice daily feeding could enhance re-esterification in the adipose tissue. Sidhu and Emery (1972) observed a re-esterification in cows fed large amounts of concentrates as compared to those fed normal roughage diets during noradrenaline infusion. This was indicated by the lower level of FFA released relative to glycerol. In the present case measurement of glycerol release would have given a clearer picture of events in adipose tissues.

4.4.2.4 Plasma FFA after termination of adrenaline infusion

On termination of adrenaline infusion the concentration of plasma FFA declined significantly in the two species. The decline was similar to those reported by Basset (1970) in sheep, those of Sidhu and Emery (1972) in cows, and those of Jurand and Oliver (1970) in man. The rapid decrease could be due to rapid re-esterification of the FFA which was facilitated by the presence of glucose and insulin. Hertelendy et al. (1966), Radloff and Schultz (1966), and Basset (1970) have observed an increase in plasma glucose concentration during adrenaline infusion. Glucose is required for re-esterification as it provides the glyceride moiety of the triglyceride (Steinberg and Vaughan, 1965). During adrenaline infusion in sheep Basset (1970) observed an inhibition of insulin secretion despite the increase in plasma glucose concentration, whereas on termination of the infusion there was a rapid increase in plasma insulin level. This increase in insulin secretion would facilitate re-esterification of the FFA to triglyceride. Insulin has lipogenic effects on adipose tissues as it facilitates the uptake of glucose by increasing the rate of glucose transport through the cell membrane (Crofford and Renold, 1964).

The differences in the concentration of FFA attained 30 min. after cessation of adrenaline infusion in goats and lambs indicates species differences in their ability to re-esterify the FFA formed. In goats the concentration attained 30 min. after cessation of adrenaline infusion was 38% of the concentration 30 min. after adrenaline infusion, while that of lambs was 53% of the concentration 30 min. after adrenaline infusion.

Another possible reason could be that the levels of glucose as well as of insulin were slightly lower in lambs than in goats,

which would affect the rate of re-entry of FFA to the adipose tissue. The metabolism or clearance of adrenaline could be lower in lambs than in goats. Blood concentration of adrenaline during infusion would have been useful in the interpretation of these results.

4.4.2.5 Effect of saline infusion on individual fatty acids

The data presented in Tables 92, 94, 98, 100, 102 and Fig. 18 for lambs, and Tables 91, 93, 97, 99, 101 and Fig. 17 for goats, and summarized in Table X for both goats and lambs, indicate that the major components of plasma FFA for both species before, during and after adrenaline infusion were oleic, palmitic, stearic, palmitoleic and linoleic acids, while myristic, linolenic and other fatty acids were minor components.

(a) Stearic acid

At rest and during saline infusion, stearic acid was the main fatty acid in lambs contributing 35% of the total which confirms other reports (Garton, 1967; Adrouni and Khachaduriani, 1968; Leat et al., 1973).

These authors found a higher concentration of stearic acid in both blood lipids and in adipose tissues of ruminants than in monogastric animals. This is due to the hydrogenation of C18 poly-unsaturated fatty acids in the diet by the rumen micro-organisms (Garton, 1960; Moore et al., 1969; Cramer and Miller, 1976).

The contribution of stearic acid to the total plasma FFA in goats during the same period was from 25% before saline infusion to 28% after saline infusion. This contribution was slightly lower than the percentage found in sheep and this suggests a species difference in stearic acid content. Differences in the percentage concentration of stearic acid in ruminant species have been reported. Leat (1966)

found that of the ruminant species, adult sheep had higher proportions of stearic acid in plasma FFA than either cows or goats. He reported 34.9% stearic acid for sheep, 23.1% for goats and 22.6% for the cows. These values agree with the present findings.

(b) Oleic acid (Tables 93 and 94)

The percentage contribution of oleic acid at rest and during saline infusion was also different between the two species. Lambs had lower values ranging from 25% at rest to 27.5% after saline infusion, whereas goats had 29% and 33% respectively. Again this finding shows a species difference in the proportion of oleic acid in plasma FFA. Leat (1966) observed a slightly higher percentage of oleic acid in the plasma FFA of goats and kids than in sheep and lambs.

The proportions of other fatty acids to total FFA were similar for the two species, although the proportion of total unsaturated fatty acids was slightly higher in goats than in lambs, and the ratio of saturated to unsaturated fatty acids was lower in goats than in lambs. This may arise from differences in the type and population of rumen micro-organisms and probably the level of stearil desaturase in the tissues of these two species.

During saline infusion, a significant increase in the concentration of oleic and palmitic acid was observed in goats, while there was only a slight increase in lambs. This suggests that when goats are stressed they mobilize oleic and palmitic acids at a faster rate than the other fatty acids.

4.4.2.6 Effect of adrenaline infusion on individual fatty acids

Adrenaline infusion for 30 min. increased the concentration of the five main fatty acids significantly viz. palmitic, stearic, oleic, palmitoleic and linoleic acids, whereas there was only a slight increase

in myristic and linolenic acids in the two species. The proportion of the individual fatty acids to the total fatty acids was affected differently. In both species the proportional concentration of stearic acid decreased with adrenaline from 27.6% to 22.0% for goats and from 34.3% to 22.3% in lambs, while the proportion of oleic acid increased from 32.7% to 41.5% in goats and from 27.5% to 43.9% in lambs, 15 min. after adrenaline infusion. The proportion of palmitic acid decreased from 25.3% to 21.8% in goats, while in lambs it increased from 25.1% to 30.0% in the 15 min. after adrenaline infusion, then decreased to 24.6% after 30 min. The proportions of palmitoleic and linoleic acids were not affected during adrenaline infusion.

The present findings are within the range of those reported for non-ruminants and ruminants. Spitzer and Gold (1962) observed a higher elevation in the proportion of oleic and linoleic acids and a decrease in the proportion of stearic and palmitic acids when dogs were infused with adrenaline and noradrenaline. Similar observations were reported by Rothlin et al. (1962) in man and dog and by Jurand and Oliver (1970) in man when adrenaline and growth hormone were infused. However, the present finding contradicts that of Meinertz (1962) of a relatively lower proportion of oleic acid in the fatty acids released when rat epididymal fat pads were incubated with adrenaline compared to the proportion of this fatty acid in the tissue triglyceride.

Comparable results in sheep are those of Adrouni and Khachaduriani (1968) who observed a decrease in the proportion of stearic acid to total fatty acids and an increase in the proportion of oleic acid, while the proportion of palmitic acid remained constant.

The reason for these findings could be that adrenaline infusion

preferentially affects the mobilization of fatty acids from tissues which are rich in oleic acid such as the subcutaneous adipose tissues which are higher in oleic acid (37%) and lower in stearic acid (10% - 20%) than the perinephric tissues which have up to 30% stearic acid (Duncan and Garton, 1967; Duncan et al., 1971).

The findings of Etherton et al. (1977) could also support this reasoning as they observed a higher lipolytic activity in subcutaneous tissues of steers than that of perinephric tissues incubated with adrenaline.

The increase in the proportion of oleic acid and of unsaturated fatty acids after adrenaline infusion could be due to the fact that unsaturated fatty acids are transported across cell membranes at a greater rate than others. Hollenberg and Angel (1963) observed a greater release of shorter chain and unsaturated fatty acids than those saturated and with longer chains. Oleic acid is known to be more hydrophilic than stearic acid and thus its rate of transportation is higher.

Another possible reason suggested by Jurand and Oliver (1970) was that the structure of oleic acid is more nearly ideal for a first class binding site on albumin. Furthermore, the increase in the proportion of oleic acid over stearic acid, could arise from an increase in the activity of stearil desaturase in the adipose tissues converting stearic acid into oleic acid which would then diffuse into the blood. An increase in oleic acid and a decrease in stearic acid in sheep tissues, and an increase in plasma oleic acid relative to stearic acid during starvation (reported by Jackson and Winkler, 1970) would support the hypothesis of increase in the conversion of stearic acid to oleic acid in adipose tissues.

Rothlin et al. (1962) have shown that the composition of plasma

FFA depends on the concentration of plasma FFA.

A reduction in FFA concentration induced by administration of glucose or insulin in man and dog resulted in a decrease in the proportion of oleic acid and an increase in the proportion of stearic acid, while the reverse occurred when FFA concentration was increased by the injection of noradrenaline.

The proportion of oleic acid increases whenever the concentration of FFA is elevated. Jackson and Winkler (1970) observed an increase in the proportion of oleic acid in sheep when the concentration of FFA was increased during fasting. Similar findings in sheep were reported by Adrouni and Khachaduriani (1968) and by Wood et al. (1965) when the level of plasma FFA was increased during vigorous exercise.

Jurand and Oliver (1970) measured an increase in the proportion of oleic acid in human plasma when the concentration of plasma FFA was raised in hyperthyroidism, acute myocardial infarction and during prolongation of an overnight fast.

4.4.2.7 Individual FFA after termination of adrenaline infusion

On termination of adrenaline infusion, the concentration of each fatty acid in both species decreased rapidly, except that in lambs, stearic acid increased.

The proportion of oleic acid to total fatty acids decreased rapidly to the values observed before adrenaline infusion in both species, while the proportions of stearic acid increased to pre-adrenaline infusion levels in goats but reached a higher value in lambs. The proportion of palmitic acid increased in goats, while it decreased in lambs. The proportion of saturated fatty acids increased in both species to pre-adrenaline infusion levels, while that of unsaturated fatty acids decreased to values slightly lower than pre-adrenaline infusion values.

This rapid decline, especially of oleic acid, could be due to rapid re-esterification and possibly utilization by other organs for energy purposes. Hollenberg and Angel (1963) observed a preferential re-esterification of oleic acid compared to stearic acid. Miller et al. (1962) and Rothlin et al. (1962) observed a preferential utilization of palmitate and oleate by cardiac muscle. In sheep it has been reported that the entry rate of palmitate and of oleate into tissues increased as their concentration in plasma increased, whereas the entry rate of stearate was not affected (Annison et al., 1967).

It has been observed (in man and dog) that insulin and glucose administration cause a decrease in the proportion of oleic acid and an increase in the proportion of stearic and palmitic acids (Rothlin et al., 1962).

Adrenaline infusion increases the concentration of glucose, while the plasma insulin level increases on termination of adrenaline infusion (Setchel and McClymont, 1955; Alexander et al., 1968; Basset, 1970, 1971). The finding in the present study of a decrease in percentage of certain fatty acids and an increase in the proportion of others may mean that glucose concentration increased during adrenaline infusion and that insulin concentration increased on cessation of adrenaline infusion, these factors enhancing the pattern of re-entry of the fatty acids.

The continued increase in the concentration of stearic acid in lambs, but not in goats, after cessation of adrenaline infusion, suggests a species difference. The reason for this could be that fatty acids were mobilized from the less responsive tissues in lambs such as perinephric fat which is rich in stearic acid.

4.4.2.8 Effect of feeding pattern on the response to adrenaline infusion

Feeding regimen in the two species were shown to have no significant effect on the concentration of either total FFA or individual fatty acids, with one exception. The concentration of palmitoleic acid was found to be significantly higher in the once-fed compared to the twice-fed goats.

Goats and lambs fed once daily had a slightly higher concentration of total and of individual fatty acids, indicating that the adipose tissues from these animals were more sensitive to adrenaline infusion than were those fed twice daily.

No specific reason for this difference is apparent since food was withdrawn 24 hours before infusion and the animals had received the same amount of food before fasting. However, absorption of nutrients from the rumen may have been different for the two feeding regimen.

4.4.2.9 Effect of saline and adrenaline infusion on plasma protein

The concentration of plasma protein was not affected by saline or adrenaline infusion (Table 103). Thus it appears that no additional albumin was required for transportation of the increased plasma FFA. A slightly higher concentration of plasma protein was observed in the animals fed twice daily, but these animals had lower concentrations of plasma FFA.

4.4.3 Summary

i) Saline infusion induced a slight increase in the concentration of plasma FFA in lambs and a significant increase in goats, indicating that all animals were stressed during infusion and handling and that goats were more sensitive to these imposed

conditions than were lambs.

ii) Infusion of adrenaline (10 μg/kg live weight) for 30 min. increased the concentration of plasma FFA significantly in both species. The magnitude of increase was higher for lambs than for goats. This response agreed with the findings of Etherton et al. (1977) in steers and lambs, Basset (1970, 1971) in sheep and Raloff and Schultz (1966) in goats, but differed from those of Adrouni and Khachaduriani (1968) and Khachaduriani et al. (1966) in sheep.

The lower response in goats than in lambs indicated a species difference which may have resulted from re-esterification of FFA in adipose tissues of goats. Differences in the adipocytes between the two species could have contributed to the differences. Large fat cells are more sensitive to lipolytic hormones than small cells in rats (Holm et al., 1975) and in humans (Amer and Ostman, 1978). Another possibility for the species differences is that the fat content of goats is lower than lambs.

iii) On termination of adrenaline infusion the plasma FFA concentration declined significantly, conforming to the findings of Basset (1970) in sheep and Sidhu and Emery (1972) in cows. This may be accounted for by the re-esterification of FFA, facilitated by glucose released during adrenaline infusion (Basset, 1970; Hetelendy et al., 1966) and by insulin released on cessation of adrenaline infusion (Basset, 1970). The relatively higher concentration of FFA 30 min. after cessation of adrenaline infusion in lambs indicates differences in the re-esterification and/or utilization of FFA and possibly in the metabolism of adrenaline by the two species.

Individual free fatty acids

i) Of the two major C18 fatty acids, stearic acid formed the highest and oleic the lowest proportion of the total FFA in lambs at rest and during saline infusion. In goats the opposite was true, oleic acid forming a higher proportion than stearic acid. Goats also had a higher proportion of unsaturated fatty acids than lambs.

ii) Adrenaline produced an increase in the concentration of the five main fatty acids in both species. However, the proportion of the individual fatty acids to total FFA was affected differentially. Thus the proportion of stearic acid decreased with adrenaline infusion while that of oleic acid increased. The proportion of palmitic acid increased in lambs and decreased in goats. The ratio of total unsaturated to saturated fatty acids increased. This is in agreement with the findings reported for non-ruminants and ruminants; Spitzer and Gold, (1962) in dogs, Jurand and Oliver (1970) in man and Adrouni and Khachaduriani (1968) in sheep.

These changes may have resulted from either mobilization of fatty acids from tissues rich in oleic acid, or the more rapid transport across the cell membranes of oleic acid and unsaturated fatty acids (Hollenberg and Angel, 1963).

iii) The concentration of each fatty acid decreased on the termination of adrenaline infusion. The proportion of each fatty acid to total FFA was different in the two species. The proportion of oleic acid to total fatty acids decreased rapidly to pre-adrenaline infusion levels while that of stearic acid increased to pre-adrenaline infusion levels in goats, but was

found to be even higher in lambs.

The proportion of palmitic acid increased in goats and decreased in lambs. The proportion of saturated fatty acids increased in both species to pre-adrenaline infusion levels, while that of unsaturated fatty acids decreased.

This pattern of change suggests preferential re-esterification of oleic acid to stearic acid and has been reported (Hollenberg and Angel, 1963).

iv) Feeding pattern had no effect on the response to adrenaline infusion in the two species.

CHAPTER FIVE

CONCLUSION

CONCLUSION

Although some data concerning differences in fat content between lamb and goat carcasses have been published, very few comparisons have been made between growing goats and lambs, so the causes for the differences in fat content are not clear. The present work attempts to resolve the mechanisms underlying the differences in growing animals under controlled conditions.

Although the findings are not conclusive due to limits on time, they provide a starting point for further investigation.

Lambs in the present study were found to be bigger than goats of the same age and they also consumed more food than goats at the same age. However, goats were found to grow relatively faster (21%) than lambs from 2-7 months of age, they ate more proportionally to body weight and showed relatively greater weight gains for a given increment in food intake. The higher feed conversion efficiency observed in goats was associated with their ability to retain a greater proportion of dietary protein (35.8%) than lambs (27%) and with the lower fasting metabolic rate observed in goats than in lambs, which resulted in less energy wastage.

The findings on body composition support those reported in the literature in that fat is the most variable component of the body and the other components maintain a relatively constant relation to the fat free body weight. However, the widely accepted concept that body fat is primarily a function of body weight, with age having only a minor effect, was found to be applicable to lambs and not to goats since fat in goats was affected more by age than by weight, as indicated by the multiple regression equations.

The rate of increase in body fat per unit increase in body

weight was higher in lambs than in goats. This was associated with a decrease in fat mobilization while body weight and body fat increased as indicated by significant ($P < 0.01$) negative correlation coefficients (- 0.547 and - 0.496) between plasma FFA, body weight and body fat respectively for lambs. Among goats, although the correlation coefficients were not significant, they were positive (0.168 and 0.258) indicating that goats have higher circulating fatty acids per unit increase deposition of body fat and body weight.

The plasma concentrations of FFA indicated that both species mobilized more fat from the age of 1 to 2 months and this decreased with age. Lambs were found to have a higher concentration of plasma FFA than goats. The higher plasma FFA coincided with rumen development indicating a decrease in the efficiency of nutrient utilization by animals at this stage of growth.

Individual plasma fatty acids were similar in the two species and displayed similar patterns of change with age. That is, there were increases in the proportion of stearic and saturated fatty acids as the animal grew older.

This finding was consistent with rumen development leading to the hydrogenation of the polyunsaturated fatty acids. It also showed that rumen development in goats and lambs occurred at the same period of development. However, goat plasma FFA was less saturated than that of lambs indicating that the two species differ in hydrogenation capacity. This could result from differences in type and population of micro-organisms present in the rumen.

The increase in fatty acid mobilization after adrenaline unfusion indicated that goats and sheep are as responsive to catecholamines as other animal species reported in the literature. Lambs, however, mobilized more fat under the influence of adrenaline than goats, while

goats were more sensitive to mild stresses such as blood sampling than lambs.

The pattern of individual FFA mobilization under the influence of adrenaline infusion was similar in sheep, goats and in other species reported in the literature, indicating that preferential mobilization and/or utilization of oleic acid under stress is common to most mammals.

The higher water turnover rate of lambs relative to goats suggests that goats can survive better in semi-arid areas than sheep and thus when selecting animals for areas which are of marginal productivity, goats would be more suitable than lambs.

Although feeding frequency had no significant effect on most of the parameters investigated, the group fed twice daily had slightly higher growth rates, higher body fat content and lower food intake in both species. This indicates that increase in feeding frequency increases the efficiency of feed utilization slightly. When considering the cost of labour and time it is more appropriate to feed the animals once daily. Feeding once daily was also found to increase the proportion of unsaturated fatty acids in the plasma which is an advantage since the use of saturated fatty acids in food is being discouraged.

The lambs were genetically equipped to lay down and to mobilize more fat than goats. This would provide sheep with some biological advantage in a cold climate where fat is required both as insulation and as a food reserve. The goats would have less survival potential if they were without food in the cold than lambs. On the other hand, they would be better off in the heat because of lower water and energy turnover rates.

In summary:-

1) Goats had a faster growth rate, higher feed conversion efficiency and higher feed intake per kg body weight, and retained more dietary protein than lambs.
2) Lambs deposited more fat per unit of body weight increase than goats, and body fat in lambs was influenced by body weight with age having little effect. The opposite relationship was true for goats, in which age had a greater influence on body fat than body weight.
3) Lambs mobilized less fat under normal physiological conditions as their body weight and body fat content increased, while the opposite relationship was true for goats.
4) Although lambs mobilize more fat under the influence of adrenaline, goats are more sensitive to mild stresses like blood sampling and saline infusion.
5) Goats had lower metabolic and water turnover rates than lambs, which makes them more adaptable than lambs to drier areas where food is limited.

For better understanding of the differences between goats and lambs as far as body fat content is concerned, an investigation into the fattening phase of growth is necessary, since the present work was done in the pre-fattening phase of ruminant growth.

xxx	Statistically significant ($P < 0.001$)
xx	Statistically significant ($P < 0.01$)
x	Statistically significant ($P < 0.05$)
ns	Not significant

APPENDIX

TABLE A

CORRELATION COEFFICIENTS

	Body Protein	Body fat	Body water	Water turn-over	Total FFA	Total TG	Metabolic rate
Body weight							
Goats	xxx 0.9960	xxx 0.6770	xxx 0.9910	ns -0.2525	ns 0.1678	ns -0.2004	xx -0.5710
Lambs	xxx 0.9720	xxx 0.7160	xxx 0.9340	ns 0.1213	xx -0.5470	x -0.3270	ns -0.1090
Body protein							
Goats		xx 0.6096	xxx 0.9990	ns -0.2330	ns 0.1474	ns -0.1930	xx -0.5440
Lambs		xx 0.5310	xxx 0.9920	ns 0.1220	xx -0.5040	x -0.3020	ns -0.1360
Body fat							
Goats			xx 0.5770	ns -0.3330	ns 0.2576	ns -0.1662	xx -0.5966
Lambs			xx 0.4220	ns -0.0760	ns -0.4960	xx -0.2990	ns 0.0290
Body water							
Goats				ns 0.2240	ns 0.1371	ns -0.1895	xx -0.5296
Lambs				ns 0.1193	xx -0.4700	ns -0.2800	ns 0.1470
Water turnover							
Goats					x 0.3790	ns 0.1514	ns 0.2404
Lambs					ns 0.0160	ns 0.1350	ns 0.1714
Total FFA							
Goats						ns 0.0740	ns -0.3214
Lambs						xx 0.5080	ns 0.1070
Total TG							
Goats							ns 0.0740
Lambs							ns 0.0170

APPENDIX

TABLE Y

CLIMATIC CONDITIONS AT WAITE AGRICULTURAL RESEARCH INSTITUTE DURING THE EXPERIMENTAL PERIOD

	Mean monthly air temp. °C			Relative Humidity	Total rain-fall	Sun-shine (hrs.)	Mean Solar Radiation
	Max.	Min.	Ave.				
May 1977	17.7	10.8	14.3	69.3	55.4	4.36	10.09
June 1977	14.3	8.7	11.5	75.7	62.0	2.14	7.02
July 1977	14.7	8.4	11.5	66.6	30.0	5.13	8.60
Aug. 1977	18.3	10.9	14.5	59.7	30.4	5.55	10.56
Sept. 1977	17.4	8.8	13.1	60.2	47.4	6.41	14.40
Oct. 1977	22.4	12.6	17.5	55.2	48.8	7.04	18.07
Nov. 1977	23.8	13.2	18.5	55.5	38.7	9.04	24.17
Dec. 1977	27.3	16.6	22.0	48.8	11.6	9.39	26.10
Jan. 1978	26.7	15.3	21.0	54.3	1.8	9.70	26.52
Feb. 1978	27.7	15.7	21.7	54.0	8.2	9.89	24.26
March 1978	25.9	15.9	20.9	54.5	4.2	7.66	19.26

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