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INTERNATIONAL SYMPOSIUM: DAIRY GOATS

Status of World Literature on Dairy Goats, Introductory Remarks[1,2,3]

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ABSTRACT

In response to wide interest in the United States and around the globe, a world literature search has been initiated with this symposium. A representative selection of some 240 publications on goat management from various countries is included with this introduction. They are intended to aid efforts of the first National Research Council Committee on nutrient requirements of goats, projects of the Agency for International Development and United States Cooperative Extension, and research workers with dairy, meat, and Angora goats.

In the US and worldwide a rediscovery of the value of the goat – dairy, meat, Angora, and even the brush goat – has occurred in recent years. Farm advisors, extension dairymen, and county agents have been besieged for information on breeding, feeding, artificial insemination, genetics, diseases, showing, testing, and milk products of goats, but few English publications of research on goats were available. Past US dairy research and industry were concerned mostly with cows, while goats were of greater interest to people of Europe, the Middle East, India, Africa, and the Caribbeans. Therefore, the transfer and translation here of some of their research into the English literature is timely and will save duplicity of research efforts. The work of the invited foreign experts is of importance worldwide and has direct application to the goat industry of this country.

Goats can reduce brush encroachment in Africa, which is important in the control of the dangerous Tse-tse mosquito. Similarly, keeping ski slopes open in Austria and Switzerland is important to the tourist industry; forest fire breaks, e.g. in California, are important to forestry departments; mesquite and black brush control in some areas of the US Southwest is important to cattlemen and sheep farmers. Goats can do these jobs best.

Cheese making from goat milk is of national economic importance in many countries, e.g., France, Switzerland, Norway, Greece, Italy, and the Middle East, while the US is just beginning to recognize goat milk and its products as acceptable alternatives to cow milk and products. Many states, however, do not have milk laws and health codes which permit direct sale of milk from a goat herd. Some states have not recognized that goats and cows have reached the certified free status from tuberculosis and brucellosis and that the sale of raw goat and cow milk would pose no human health hazards when produced under sanitary, low bacteria, and odor free conditions.

Most US animal nutrition and feeding literature states that needs of goats may be deduced and extrapolated from literature on dairy cows, sheep, and beef even though anatomical, physiological, pathological, veterinary, biochemical, genetic, and behavioral differences, some considerable between the three ruminant species, are becoming known.

Some countries, e.g., Turkey, the Balkans, India, Greece, Italy, Israel, are concerned about

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[3] Members of the Symposium Committee on Dairy Goats: K. L. Turk (Cornell), D. E. Pritchard (Ohio State), R. W. Hemken (Kentucky), B. R. Baumgardt (Pennsylvania State), T. H. Blosser (USDA), M. Loewenstein (Georgia), and G.F.W. Haenlein (Delaware), Chairman.

damaging effects of goats on trees and woodlands, but goat farmers in Switzerland and Germany have demonstrated that productive dairy goats and excellent forests can coexist under proper management.

The US is interested in helping Third World countries in improving their people's health and food production and has placed a number one priority on small ruminants, specifically goats. However, the expertise has been lacking in the US.

This 1979 international symposium on dairy goats can help much, but it is not the first for the American Dairy Science Association; a forerunner was in 1977 at the 72nd meeting of the ADSA at Iowa State University with the proceedings published in the Journal of Dairy Science in 1978. Dairy goats are a part of the American dairy industry – commercial, institutional, or private – and the Journal of Dairy Science is a major US research organ on dairy goats as well as on dairy cows. There have been other important symposia and congresses around the world dealing with dairy goats, and some are listed.

1) 1921 – Second International Congress on goat husbandry at Wageningen, Netherlands.

2) 1930 – Third International Congress on goat husbandry at Antwerp, Belgium.

3) International Congresses on Animal Reproduction and Artificial Insemination, 1956 at Cambridge, England; 1961 at Hamburg, West Germany; 1964 at Trento, Italy; 1968 at Paris, France; 1972 at Munich, West Germany; 1976 at Krakov, Poland.

4) 1964 – FAO Seminar on Goat Raising Policies in the Mediterranean and Near East Regions at Rome, Italy.

5) 1971 – Second International Conference on Goat Husbandry at Tours, France.

6) 1972 – International Symposium on Dairy Goats and Sheep at Tel Aviv, Israel.

7) World Congress on Animal Production, 1972 at Madrid, Spain; 1973 at Melbourne, Australia.

8) 1976 – First Annual Dairy Goat Symposium at University of Illinois, Urbana.

9) 1976 – Symposium of Sheep and Goat Practitioners at Fort Collins, CO.

10) 1976 – Symposium on Smallholder, Livestock Production and Development at the Institute of Technology MARA, Shahalam, Malaysia.

11) 1976 – International Livestock and Research Training Center Conference on the Role of Sheep and Goats in Agricultural Development, Winrock, AR.

12) 1977 – Symposium of the American Dairy Science Association on Dairy Goats at Iowa State University, Ames.

13) 1977 – Symposium of the American Society of Animal Production on Management of Reproduction in Sheep and Goats at University of Wiconsin, Madison.

14) 1977 – International Livestock and Research Training Center Conference on the Potential of the World's Forages for Ruminant Animal Production, Winrock, AR.

15) 1978 – International Livestock and Research Training Center Conference on the Role of Ruminants in Support of Man, Winrock, AR.

16) 1978 – Symposium on International Programs of the American Dairy Science Association and American Society of Animal Production at Michigan State University, East Lansing.

17) 1979 – International Workshop on the Development of Goats in Asia at the Indian National Research Institute for Dairying, Karnal, India.

Besides these important international events concerned mainly or partially with goats, an international subcommittee on the nutrient requirements of goats of the Committee on Animal Nutrition of the US National Research Council was instituted a few years ago consisting presently of O.P.S. Sengar, India; S. N. Singh, India; C. Devendra, Malaysia; M. Shelton, Texas; J. E. Huston, Texas; and G.F.W. Haenlein, Delaware, Chairman, for writing the first edition on the nutrient requirements of goats. This symposium will aid that effort. From the bibliographies following the 14 papers of this symposium, progress is substantial on assembling world literature on goats.

A representative list of general topics selected from a present file of over 2700 titles follows this introduction (1 to 240). The sources are dispersed worldwide, and access is sometimes hard. The subject matter distribution of publications on goats is approximately as follows:

1) nutrient requirements, 347 titles; 2) nutrition and feeds, 469 titles; 3) milk composition and production, 643 titles; 4) breeding and genetics, 493 titles; 5) health and diseases,

262 titles; 6) products of dairy, meat, and Angora goats, 121 titles; and 7) general management, 427 titles.

It is the hope of this symposium's organizers, its supporters, and the officers of the ADSA that these papers will contribute substantially to better nutrition for children, hungry, and sick people worldwide, and will help to satisfy the interest of a growing industry in the United States.

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9

Trends in Dairy Goats

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ABSTRACT

Gain in importance of the dairy goat industry of the United States from 1960 to 1978 is evidenced by increases in membership of goat associations (482 to 10,680), official shows (72 to 653), and herds on official test (none to 1611). Number of registered dairy goats increased from 3,611 in 1955 to 32,459 in 1976. There also is evidence of increased research and development by universities and private industry. Continued efforts are required to assure maximum efficient use of the dairy goat as a contributor to the world food supply.

INTRODUCTION

"The dairy goat industry is growing by leaps and bounds." "The number of persons keeping dairy goats is increasing rapidly." "There is an unsatisfied demand for product." All of these phrases are heard frequently by those associated with dairy goats.

There is surprisingly little documentation concerning growth of the industry; however, there is evidence of increased numbers of dairy goats in the world (8), there are more dairy goat shows, and more purebred dairy goats are being registered (2) each year. Data on research and development of the dairy goat and its contribution to the world food supply are lacking.

From the introduction of milk-type goats to the US in the 1600's to the present, the dairy goat has provided food for man and survived both willful and unknowing attempts to eradicate or besmirch them through propagation of inaccurate information regarding their eating habits. Perhaps no other food producing animal ever has received such unfair publicity.

DAIRY GOAT HUSBANDRY GROWTH

Dairy goats first were registered as purebreds in the US as a result of a Mrs. Stevens wanting to exhibit them at the 1904 World's Fair (10). This led to formation of the American Milch Goat Record Association that same year; this name was changed in 1965 to the American Dairy Goat Association, headquartered in Spindale, NC.

Objectives and socioeconomic levels of persons who have become active in the dairy goat field have risen. Goat breeders and milk producers might be categorized as: 1) commercial units earning their sole income from dairy goats and products; 2) semicommercial units that derive a portion of their income from dairy goats and products but earn outside income from other enterprises such as farming, factory, office, or service jobs, etc., and 3) hobbyist, by far the greatest in numbers, that raise dairy goats for family togetherness, fellowship with other goat raisers, challenge and relief from the tedium of regular work, and the thrill of showing at fairs and exhibits. Enthusiastic persons enter and leave each of these areas of goatkeeping for a variety of personal and economic reasons.

Outside the US (i.e., England, France, New Zealand, and Australia) goat breeders exhibit dairy goats extensively at shows. Most countries with dairy goat organizations have some form of production-testing record keeping. In countries of the world where goats are relatively numerous, they are bred and managed for their economic value in milk and meat production. Devendra of Malaysia (7) stated in 1975:

> Although the principal function of goats in the tropics is in meat production, they are also very useful for milk production. By comparison, the primary value of goats in temperate countries is in milk production. Nevertheless, goats as suppliers of meat and milk serve a most

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useful function in the availability of animal proteins, especially to the rural community. This contribution, small as it is, is significant in that these products are available to many who cannot afford to buy these products or, alternatively, are unable to get these by rearing cattle or buffaloes. It is suggested that the immediate objective should be the encouragement of goats for household milk production or small-scale dairying at the village level, especially in rural areas. Compared to cows, it will be obvious that goats will be nutritionally more economical because of their smaller size.

These observations apply also to the US. With exception of relatively few commercial milk producers (who also rely on sales of breeding stock to augment their milk income), dairy goats are kept mostly to supplement the family food supply.

Over the 65-yr history of the *Dairy Goat Journal*, a rather interesting phenomenon has occurred. In general, as economic conditions worsen, the dairy goat industry improves markedly. In times of good economic conditions, fortunes of the dairy goat usually have declined. However, since 1968 there has been a steady increase in the interest in dairy goats, regardless of economic conditions. This is verified by increase in numbers of subscribers and advertisers in the magazine and dairy goat book sales. It is also manifest in increasing numbers of dairy goat shows at local farms, area, county, and state fairs as in Table 1. The increase in numbers of purebred dairy goats being registered and enrolled in official milk testing programs (data in Tables 1 and 2) and the recent implementation of a dairy goat classification program are additional indicators of continually increasing activity in the dairy goat field in the US.

TABLE 1. Growth in membership, number of sanctioned shows, and number of herds on official production test, as reported by the American Dairy Goat Association (1).

Year	Association membership	Official shows	Herds on official test
1960	482	72	.....
1970	1,305	132	34
1975	6,615	349	663
1976	8,645	416	1,086
1977	10,798	540	1,371
1978	10,680	653	1,611

INDICATORS FOR THE FUTURE

There is less information and statistics on goat milk production and utilization in the US than from other countries. It appears that with the recent formation of the Coordinating Subgroup for Dairy Goats, development of the National Cooperative Dairy Herd Improvement Program, and the availability of computerized information from a large number of dairy goat records, there is greater recognition of the dairy goat as an economic animal.

The US government's Title XII program, through its allocation of funds for research with small ruminant animals, will assist participating academic and other institutions in performing substantial research with dairy goats on a well-organized, funded basis. Several universities and colleges have begun specific courses or programs of study relating to dairy goats. Some veterinary schools provide instruction specifically relating to dairy goats rather than including them in a general survey course. Projects of 4H in dairy goats are strong and active; Future Farmers of America are taking more interest in dairy goat projects.

The opportunity is expanding for business and industry to supply manufactured products for use in goatkeeping, from feeds and pharmaceuticals to buildings and equipment. Dairy goat keepers have little in the way of quality prepared feedstuffs, machines, and other needed items specifically designed for dairy goats. They generally have to adapt items made for other livestock and need products that will aid them in caring for their dairy goats. This also applies to competent veterinary services. Owners of purebred dairy goats expect to be able to obtain knowledgeable and skilled veterinary assistance.

Prices paid for dairy goats have increased dramatically in the US in recent years. The top price paid at the annual National Spotlight Sale of Dairy Goats, October, 1978, in Scottsdale, AZ, was $8,100. This sale averaged about $1,400 for the 20 dairy goats auctioned (6). In 1970, this sale averaged about $240 with the

TABLE 2. Increase in number of purebred dairy goats registered (all breeds) as reported by the American Dairy Goat Association (2).

Year	Number registered[a]
1955	3,611
1960	4,041
1970	6,792
1971	8,144
1972	11,284
1973	14,818
1974	19,373
1975	26,644
1976	32,459

[a]In 1977, the process of registration was being converted to computerization and accurate figures for 1977 and 1978 are not available.

top single sale price of $400 (4). Numerous individual dairy goats have sold for more than $1,000 in past years with some in the $2,000 range. Median prices are in the $150 to $500 range.

There are five recognized pure breeds of dairy goats raised in the US: French Alpine, LaMancha, Nubian, Saanen, and Toggenburg. Variations in physical appearance and color among breeds create personal preferences among breeders of dairy goats. Maximums of milk production by the best of each breed are relatively equal. Crossbred and grade does also may be high milk producers in commercial dairy and family herds. Leaders in milk production of all breeds produce 1360 kg or more with the top producer in the US giving 2608 kg milk and 92 kg butterfat in 305-day lactation (3). This 1960 record attests that there is great opportunity for research and development in selection and breeding to enhance the general milk producing capabilities of the dairy goat. The great need for such research is verified by Geerts in 1975 (9). The data comparing production records in 1960 to 63 with those in 1970 to 73 showed a small decrease in average daily milk yield. The data were obtained on 747 Alpine and 688 Toggenburg does on Advance Registry (AR) test. A New Zealand Saanen currently holds the world record in dairy goat milk production with just over 3175 kg milk in a 365-day lactation (5).

Although milk is the primary product in the US, goat cheese is being produced to meet a growing commercial demand. These American-made cheeses are of the Muenster and Cheddar varieties and generally are made from milk produced in the spring when there is most abundant supply of goat milk (11). Statistics of FAO (8) show that goat milk constitutes less than 2% of the total world milk production.

Most dairy goats are in family herds ranging from 3 or 4 to 20 to 40 dairy goats. In 1972, the US Department of Agriculture livestock census indicated about 3,500,000 goats in the US but with no designation of type of goat. The 1979 census contained for the first time several questions relating to milk production, number of dairy goats, and economic values. Results from the 1979 census will be interesting.

Exhibiting dairy goats in the show ring is popular. Ten years ago there were 218 shows officially sanctioned by the American Dairy Goat Association. The number in 1979 was about 625 (12). Dairy goat entries range from about 25 animals to approximately 1,000 entries at the National Dairy Goat Show and also annually at the Los Angeles County Fair, Pomona, CA.

The desirable dairy goat of today, which gives 3 to 4 liters or more of milk daily, is profitable and becoming more abundant. The people who breed and care for them are becoming more knowledgeable through experience and association with other breeders, organizations, and meetings. An increasing number of dairy goat educational seminars, symposia, and field days are being held across the country. Books and other publications relating to dairy goats have proliferated (13). A definite indicator of the interest and growth in the dairy goat field is the number of professionals at universities, colleges, and business, industry, and government organizations who are learning about dairy goats and who are able to teach and demonstrate to others proper husbandry specifically related to dairy goats.

The goat is in great demand world-wide for value of milk and meat because of its size, interactive compatibility with people, and because of its climatic and agronomic adaptability.

There are several large commercial goat dairies in the US. The largest is Laurelwood Acres Goat Dairy, in operation for more

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than 30 yr in the Los Angeles, CA, area, and then moving 10 yr ago to Ripon, CA. Laurelwood Acres milks between 800 to 1,000 dairy goats daily, serving a fluid milk market in middle and Southern California. It also manufactures and markets cheese. In addition, Laurelwood Acres sells breeding stock and has a facility for goat semen collection and marketing. Diamond Dairy Goat Farm in Portage, WI, milks about 450 dairy goats and supplies the Chicago, IL, area. Idelmar Farm, also of Portage, WI, milks about 350 dairy goats. Other commercial dairies milking from 50 to 150 dairy goats are located around the US.

More intensive development of markets will bring large numbers of persons into the dairy goat industry. With development of a goat milk processing plant in Yellville, AR, a number of persons are moving herds to this area to supply goat milk to the plant. Area residents also have begun milk production. This plant produces evaporated and powdered goat milk and markets these products through a national distributor. The California Goat Dairymen's Association at Turlock also manufactures evaporated milk and markets nationally through grocery stores.

Dairy goat research projects of magnitude include the Winrock International Livestock Training and Research Center, Morrilton, AR. Currently 140 dairy goats are being milked with a total herd of about 320 animals. The research plans at Winrock indicate world-wide interest in the future of the dairy goat as a highly desirable animal to help alleviate the need for animal protein.

The University of Georgia, Athens, and Southern Agriculture Corporation, Atlanta, GA, have combined to produce the most comprehensive investigative research and development program in goat milk product and marketing areas. An exhaustive study into the economics of dairy goat raising and the actual production of product (milk, ice cream, yogurt) and test marketing is being done.

Improvement in the dairy goat has been relatively disorganized in this country in the past 75 yr. Persons knowledgeable about genetics and other areas of animal husbandry have appeared on and subsequently disappeared from the scene. There has been little organized effort on the part of the industry to develop, promote, or market the dairy goat and its products on a national scale. The "chicken and egg" theory of marketing prevails, i.e., should the dairy goat be developed before the marketing plan or vice versa?

Too often the attitudes of university, business, and government personnel toward dairy goats are based on myths rather than well researched business and economic facts. In other countries, the dairy goat is generally an accepted animal and is recognized, developed, and promoted. There is great urgency for additional well planned, coordinated promotion and marketing programs for the dairy goat industry of the U.S. These programs, together with current planned research and development, should enhance the position of the dairy goat and its products. Cash income for the producer and quality products for the consumer will keep the marketing circle intact. Enlightened cooperation among all individuals and organizations concerned is required to establish the dairy goat in the economic scheme and to assure the provision of food for an increasingly hungry world.

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Composition and Characteristics of Goat Milk: Review 1968–1979[1]

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ABSTRACT

Research in the past decade has extended knowledge of composition of goat milk and of properties of its constituents. Goats of several European breeds produce milk of lower fat content in the tropics than in temperate zones. Fat, protein, and lactose contents of milk of dwarf goats are higher than those of other breeds. Fat globules of goat milk resemble those of cow milk in lipid composition and properties of the globule membrane, but goat milk lacks "agglutinin" which causes fat globules of cow milk to cluster when cooled. Five principal proteins of goat milk, α-lactalbumin, β-lactoglobulin, κ-casein, β-casein, and α_{s2}-casein, closely resemble their homologs in cow milk. Goat milk lacks a homolog of bovine α_{s1}-casein, the most abundant protein in cow milk. Caseinate micelles of goat milk contain more calcium and inorganic phosphorus, are less solvated and less heat stable, and lose β-casein more readily than bovine micelles. Activities of ribonuclease, lipase, and xanthine oxidase are less in goat than in cow milk. Goat milk contains more potassium and chloride but less orotic acid, N-acetyl neuraminic acid, folate, vitamin B_6, and vitamin B_{12} than cow milk. Little work in the past decade has been on nutritive value of goat milk for humans except to describe cases of folate deficiency in infants.

INTRODUCTION

This paper covers research on goat milk published in the past decade and some work omitted from the 1968 review by Parkash and Jenness (159); it does not deal with goat populations or milk production. No independent review of goat milk has appeared since 1968; most of the data on milk composition in the reviews by French (65) and Swaminathan and Daniel (222) were taken directly from Parkash and Jenness (159).

COMPOSITION

Table 1 presents data on gross composition of goat milk not in the 1968 review (159). Only data developed independently are included in the table. Thus, a figure is given for total solids only if it was measured independently, not by addition of constituents. Also, no data are given for lactose content calculated by difference. Except as noted, percents for protein represent crude protein, i.e., total nitrogen × 6.38, because that was all that was available in the original paper. In contrast, most of the protein percents in (159) represented true protein—i.e., 6.38 (total N - nonprotein N). The NPN (nonprotein N) averaged about 40 mg/100 ml in goat milk (159), which is equivalent to about .25% of "protein". Thus, most of the protein percents in Table 1 are probably about .25% higher than true protein. The protein contents of 3.76 and 3.74% given by Sachdeva et al. (199) for two Indian breeds are much lower than reported earlier by the same group (210) for milk of 10 Jamunapari does. The reason for this large inconsistency is not known.

Devendra (55) and Mba et al. (139) remarked on the lower fat content of milk produced by British Alpines, Anglo-Nubians, and Saanens in tropical environments as compared to that produced by the same breeds in temperate climates. The high contents of fat, protein, and especially lactose in the milk of the West African dwarf goat also is remarkable (5). Results were similar in my laboratory (91) for six specimens from pygmy goats in Oregon (also in Table 1). Milk composition of the dwarf strain of goat seems to differ markedly

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TABLE 1. Composition of goat milk reported 1968–1979.

Country	Animals Breed	Animals No.	No. of samples	Total solids	Fat	Crude protein	Lactose	Ash	Reference
				(%)					
Australia	Saanen	3	3	13.47	4.61	3.39	4.85	...	188
	Saanen	4	4	12.24	4.01	3.10	4.93	...	187
Finland	Finnish	23	79	12.55	3.90	3.52	4.48	.84	230
Germany	Improved Fawn	97	295	12.43	3.92	2.90[a]	4.01	...	71
India	Barbari	97	?	...	4.11	3.76[b]	4.80	.82	199
	Jamunapari	87	?	...	4.31	3.74[b]	4.72	.82	199
Italy	Sardinian		39	...	5.1	3.9	...	.71	184
Nigeria	Saanen	3	30	12.15	3.41	3.07	4.54	...	139
	Red Sokoto	2	24	15.28	4.86	4.38	4.72	...	139
	African Dwarf	4	48	17.87	7.10	4.71	5.58	...	139
Nigeria	African Dwarf	6	17	18.68	6.90	3.91	6.30	.82	5
Trinidad	British-Alpine	6	18	11.5	3.4	2.9	...	.78	55
	Anglo-Nubian	5	18	12.2	4.1	3.4	...	.79	55
USA	Pygmy	6	6	21.55	7.76	5.06[b]	5.35	.84	91
Yugoslavia	?	?	?	11.95	3.07	3.51	...	.88	57

[a]Not clear whether crude protein or true protein.

[b]True protein, i.e., 6.38 (Total N-NPN).

from that of all other breeds. One other report (233) of the composition of a single sample of milk of the African dwarf goat gives a lactose content of only 1.39%. The significance of this result cannot be evaluated properly, since no information is given on status of the animal, sampling procedure, or analytical methods.

Variations in energy and protein (from 75% to 125% of recommended standards) fed to Barbari and Jamunapari goats had little influence on milk composition but did affect yield considerably (199). The data from this study in Table 1 are means for nine groups of animals fed three levels of energy and three of protein.

Postruminal infusions of glucose or casein in lactating Saanens affected milk yield but not composition except that milk fat was decreased (from about 4.6% to 3.8%) by infusion of glucose at 4.5 g per day (187,188). Data in Table 1 from this study represent milk compositions from seven animals during periods when they were not receiving infusions.

Considerable changes in composition of the aqueous phase of milk preceded estrus by 1 to 4 days in goats (172). For five goats sodium increased from 19 to 37 mM and chloride from 49 to 59 mM; potassium decreased from 50 to 40 mM and lactose from 127 to 110 mM. Thus, there was a net increase of both anions and cations of about 10 mmoles per liter. The composition had returned to normal by onset of estrus. Fat, protein, and immunoglobulin concentrations did not change preceding estrus. Administration of exogenous estrogens to anestrous goats caused an increase in sodium and fall in potassium in milk, but lactose and chloride were not affected.

In healthy goats (and cows) milk yield and milk composition (Na, K, Cl, lactose) of the individual glands varied randomly from day to day but were always parallel (122). Thus, deviations in composition between glands could be used as an index of subclinical mastitis.

When goats were fasted for 24 h, yield of milk decreased drastically; sodium, chloride, fat, protein, and citrate contents increased, and lactose and potassium decreased (120). Osmolality remained constant. Oxytocin treatment of goats and, to less extent, frequent milking without oxytocin caused increases in sodium, chloride, and noncasein protein and decreases in potassium and lactose contents (120, 121).

In the work reported from Babraham in the three preceding paragraphs (120, 121, 122, 172), the concentration of lactose in the normal control milks was approximately 130

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mM, or about 4.4%, which is close to results by many other workers (Table 1; 159).

Patton (166, 167) and Patton et al. (170) found that infusion of the plant alkaloids, colchicine, vincristine, and vinblastine, or the plant lectin concanavalin A into the udder of lactating goats suppressed milk secretion temporarily. Apparently these agents interfere with the secretory process through interaction with microtubules of cells. As the gland recovers from the suppressing effect, fat and protein contents of the milk and size of the milk fat globules increase. Fat and protein each may increase by as much as 2% (from 3 to 5%). Patton (166) speculated that consumption of plant alkaloids by grazing goats may at times alter yield and composition of their milk. Presumably concanavalin A consumed by a goat would not have such an effect.

Table 2 summarizes gross compositions of milks of species of the subfamily Caprinae other than *Capra hircus*. Data for sheep (*Ovis aries*) are from one of several reports on milk of this species, but for the other species all data of which I am aware are in Table 2. Sampling of the 13 genera and 26 species of the Caprinae has not been extensive. Milks of most of the species have higher contents of fat and lower contents of lactose than goat milk. The data on muskox milk suggest that pronounced changes in composition of milk of this species occur during lactation.

LIPIDS

Fatty Acid Composition

A number of workers in the past decade have reported analyses of the fatty acid composition of goat milk fat (53, 54, 106, 145, 160, 230); this is essentially the fatty acid composition of the triglycerides, since the latter predominate quantitatively in the mixture. The data closely resemble those in (159). Klobasa and Senft (106) found slightly higher contents of the short and medium chain acids (C_4 to C_{14}) in goat colostral fat than in the fat of the later milk. Their data and those of Uusi-Rauva

TABLE 2. Composition of milks of Caprinae other than *Capra hircus*.

Species	No. of samples	Days postpartum	Total solids	Fat	Casein	Whey protein	Lactose	Ash	Reference
			(%)						
Oreamnos americanus (mountain goat)	1	56	...	5.7	11.4		2.8	1.2	116
Ovibos moschatus (muskox)	1	Colostrum	31.0	10.0	8.8	9.4	2.8	1.1	92
	1	1	21.5	11.0	3.5	1.8	3.6	1.8	223
	1	3–4	16.4	5.4	4.3	1.0	4.1	1.1	92
	5	ca. 120	27.1	10.9	11.9		2.1	1.2	17
	6	ca. 120	28.5	12.6	7.5	1.3	2.8	1.1	92
Hemitragus jemlahicus (Himalayan tahr)	20	?	...	9.8	5.8		3.3		186
Capra hircus aegagrus (bezoar)	4	5–20	17.0	5.7	3.0	4.3	5.7	.84	109
Ovis aries (domestic sheep)	6	1–2	19.3	7.8	5.0		5.5	.98	236
	6	21	18.2	8.4	4.3		4.7	.83	236
	6	49	18.4	7.8	4.9		4.4	.95	236
Ovis canadensis (mountain sheep)	2	90	34.0	16.0	12.1		3.4	1.3	42
	3	30–45	17.5	6.8	3.2		5.2	1.0	42
Ovis dalli (Dall's sheep)	8	21–168	26.7	11.2	9.4		4.6	1.1	47

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(230) for the fatty acid composition of mature milk are in Table 3.

Bickerstaffe et al. (26) determined proportions of positional isomers of *cis*- and *trans*-octadecenoate in milk fat of a goat. Eighty-six percent of the *cis*-$C_{18:1}$ acids were oleate (Δ9), but small amounts of acids with the double bond in positions 6 to 16 were also present. Among the *trans*-$C_{18:1}$ acids, vaccenate (Δ11) comprised 28% of the total and octadeca-14-enoate 10%. Trans acids with double bonds in positions 9, 10, 12, 13, 15, and 16 each constituted 7 to 8% of the total.

Several studies have dealt with the influence of dietary fat on fatty acid composition of goat milk fat. Delage and Fehr (53) found that lowering fat intake of goats from 1 g/kg to .4 g/kg per day depressed milk production, fat percentage, and yield of milk fat. The content of C_{12} to C_{16} acids increased significantly, and that of C_{18} acids decreased. Addition to the low fat diet of an oil, largely peanut, containing 63% oleic and 21.4% linoleic acids caused a dramatic increase in $C_{18:1}$ acid in milk fat at the expense of $C_{16:0}$ and $C_{18:0}$. In (54) these workers found that adding either stearate or linolenate to a defatted diet depressed the contents of C_{12} to C_{16} acids in milk fat and raised the C_{18} content. Dietary stearate increased $C_{18:0}$ and $C_{18:1}$ acids, whereas dietary linolenate raised contents of all four of the C_{18} acids: $C_{18:0}$, $C_{18:1}$, $C_{18:2}$, and $C_{18:3}$.

Australian workers (48, 145) have determined the influence of feeding fat encapsulated in formaldehyde-treated casein to protect it from alteration in the rumen and release in the abomasum. Feeding safflower oil in this way increased the content of $C_{18:2}$ acids in the goat

TABLE 3. Fatty acid compositions of goat milk lipids.

Acid	Cholesterol esters[a]	Phosphatidyl ethanolamine[b]	Phosphatidyl serine[b]	Total lipid[c,d]	
	(wt %)	(mole %)	(mole %)	(wt %)	
4:0				4.5	3.8
6:0				3.2	2.2
8:0				3.4	1.9
10:0	5.2			9.8	5.4
10:1	Tr				.2
12:0	4.2		Tr	4.1	2.5
12:1	1.0				
13:0	Tr				
13:1	.9				
14:0	9.2	.6	4.1	8.7	7.7
14:1	1.4				
15:0	1.3				
15:1	Tr				
16:0	39.3	10.0	38.7	21.9	21.3
16:1	Tr			1.8	
17:0	Tr			.9	
18:0	9.0	9.9	8.7	8.3	14.4
18:1	26.5	52.0	32.2	20.8	28.1
18:2	2.1	18.4	7.1	3.2	2.5
18:3		1.7			.7
20:0		2.8	1.2		
20:1		4.5	1.0		
20:2			3.8		
21:0			3.1		

[a]Keenan and Patton (103).

[b]Moore et al. (147).

[c]Uusi-Rauva et al. (230).

[d]Klobasa and Senft (106).

milk fat (145) from about 3 to about 15 moles %. However, feeding protected seed oil of *Stercula foetida* increased the ratio of 18:0/18:1 from .4 to 1.4 (48). *Stercula foetida* contains cyclopropene acids which apparently inhibit desaturases of the mammary gland; the result is that more 18:0 acid is incorporated in milk fat. Bickerstaffe and Johnson (25) had earlier demonstrated this effect by injecting sterculic acid intravenously into goats. Thus, by appropriate administration of dietary fat, milk fats with widely different compositions and properties can be produced.

Franzke et al. (63) found that goat milk fat contains about 280 mg β-keto acids/kg of fat. These ranged in chain length from 4 to 18 carbons. The most prominent were those with 16 and 18 carbons.

Sauvant et al. (202, 203) suggested genetic differences in fatty acid composition of goat milk fat. This conclusion was based on statistical analysis of the composition of milk fats of individual goats; actual data were not included in the publications.

Gattuso and Fazio (67) proposed use of the ratio $C_{10:0}/C_{6:0}$ for differentiating milks of cows, goats, and sheep, but Smeyers-Verbeke et al. (213) claimed that the statistical technique of linear discriminant analysis using the 15 principal fatty acids is superior to the $C_{10:0}/C_{6:0}$ ratio in differentiating these milks and their mixtures.

Bakke et al. (18) reported free fatty acid contents of 5.65 ± .58 and 2.67 ± .34 meq/liter in milks from two lines of goats selected for high and low "goat flavor" intensity in the milk. The difference was statistically significant; free fatty acid content seemed to account for 8 to 12% of the variation in flavor score.

Triglycerides

The mixture of triglycerides in milk fat can be separated by thin layer chromatography (70), by gas-liquid chromatography (29, 161), and by gel filtration (56). Glass et al. (70) used thin-layer chromatography on Silica gel G to show that milk triglycerides of 15 species of ruminants, including goats, separate readily into two distinct fractions; those of nonruminants did not so separate. The two fractions of ruminant milk fats have nearly the same C_{14} and C_{16} content, but one of them contains almost all of the butyrate, and the other is much richer in C_{18} acids.

Gas-liquid chromatography of goat milk triglycerides showed that they resemble those of other ruminant milks in having a wide spectrum of molecular weights (29, 161). Molecules with even numbers of acyl carbons predominate. The distribution of acyl carbon numbers exhibits maxima at C_{40} and C_{52} and a minimum at C_{48}. Milk fats of cows, sheep, and goats differ slightly in the patterns of distribution of acyl carbon numbers. The distribution of molecular weights deviates significantly from that expected if the fatty acids were incorporated randomly into the triglycerides. Using a combination of fractionation and analytical methods, Dimick and Patton (56) showed that no goat or cow milk triglyceride molecule contained more than one butyrate group. Thus, butyrate seems to be as widely distributed as possible among the triglycerides.

Analysis of the positional distribution of fatty acids in goat milk triglycerides showed that most of the short chains (C_4 to C_8) are esterified at the 3-position of the glycerol, and the longer chains (C_{10} or greater) are in the 1 or 2 position (134). This specific placement of fatty acids suggests that triglycerides are synthesized from a pool of long chain, 1,2-diglycerides. In triglycerides produced during dietary supplementation with safflower oil (145), linoleate was distributed evenly on all three positions for goats but predominantly at the 3 position in cows. The reason for this remarkable difference is not known. In other respects triglycerides of these two ruminants are much alike.

Phospholipids and Cerebrosides

Goat milk contains phospholipids at 30 to 40 mg/100 g (99, 129). This is equivalent to 8 to 10 mg/g of fat. About 40% of the total phospholipid in either goat or cow milk is in the skim milk (168, 179), and the remainder is in the fat globule membrane (FGM). All of the usual classes are present—phosphatidyl cholines (PC), phosphatidyl ethanolamines (PE), phosphatidyl serines (PS), phosphatidyl inositols (PI), and sphingomyelin (SP) (168). The kinds and proportions of the individual phospholipids are similar in skim milk and fat globule membrane. Patton et al. (170) reported the phos-

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pholipid composition of the fat globules (i.e., FGM) of goat milk was 25.5% PE, 27.6% PC, 9.6% PS, 1.4% PI, and 35.9% SP; and Kataoka and Nakae (99) found 33.3% PE, 25.7% PC, 6.9% PS, 5.6% PI, and 27.9% SP in two samples of total goat milk lipids. These compositions correspond closely with that of the total phospholipids of milks of seven other species (148). Abou-Dawood et al. (2) found bulked goat milk contained phospholipid at 33 mg/100 ml of which 9.3 mg was lecithin (PC), 16.2 mg cephalin (PE + PS), and 7.4 mg sphingomyelin (SP). Moore et al. (147) found that cephalins (PE + PS) represented 49.5% of the total phospholipids in one individual goat sample and 65.5% in one pooled sample. The individual goat sample contained no PS at all, and in the pooled sample 75% of the cephalins were PE and 25% PS. The fatty acid composition of these cephalins is compared with those of goat milk triglycerides and cholesteryl esters in Table 3.

Kayser and Patton (101) found the cerebrosides, glucosyl ceramide and lactosyl ceramide, were distributed between fat globule and skim milk fractions of goat milk. The total cerebroside content was 2.50 mg/100 ml (total phospholipid of this milk = 21.36 mg/100 ml) of which 56% was in fat globules and 44% in skim milk. The total glucosyl ceramide was .97 mg/100 ml and total lactosyl ceramide 1.53 mg/100 ml. The outstanding difference between the ceramides of fat globules and those of skim milk was that the former contained much higher amounts of long chain acids C_{20} to C_{24}. I know of no reports of gangliosides in goat milk, although they have been identified in bovine milk (83, 102).

Cholesterol and Its Esters

The cholesterol content of goat milk is usually in the range 10 to 20 mg/100 ml (220), although Azim et al. (16) reported only about 3 mg/100 ml. The content in colostrum is much greater—about 40 mg/100 ml (103). By far the greatest portion of cholesterol in goat milk is in the free state; only a small fraction is in the form of ester. Raphael et al. (189), for instance, reported averages from 15 milkings of one goat were 12.93 mg/100 ml (range 8.80 to 17.79) free cholesterol and .36 mg/100 ml (range .20 to .59) esterified cholesterol. On the average, 65.7% of the free and 42% of the esterified cholesterol were associated with fat globules (103). The fatty acid composition of goat milk cholesteryl esters (103) is in Table 3.

Fat Globules and Their Membranes

Little work has been significant since 1968 on size distribution of fat globules in goat milk. Singh et al. (209) found some increase in size and decrease in number of globules upon heating milks of cows, ewes, goats, and buffalo. Pasteurization at 61 C for 30 min increased average globule size in goat milk about 12% as a result of coalescence.

Knowledge of secretion of bovine fat globules and their membranes (FGM) has advanced significantly in the past decade. Two comprehensive reviews published in 1975 dealt almost entirely with the bovine species (9, 169). A few studies have included goats as well as cows, and, in general, the two systems resemble each other closely. Electron microscopic examination of cells of lactating mammary gland revealed no detectable difference between goat and cow in the manner and mechanism of secretion of the fat globules (237, 238), but Chiofalo et al. (43) seem to have found a distinctive difference between two breeds of Italian goats in thickness of the membrane.

The FGM appears to consist of plasma membrane of the secretory cell which has enveloped the fat globule at secretion. It contains a large number of protein constituents (some of which are enzymes), phospholipids, cerebrosides, gangliosides, and sterols (169). A few individual proteins have been isolated from the bovine system and characterized partially (22, 38, 215), but the protein mixture has by no means been resolved completely into individual entities. Singh et al. (211) found FGM proteins of goat had 1.64% sialic acid, 3.28% hexose, 2.83% hexosamine, and .17% phosphorus. Similar data were reported for FGM from cows and buffaloes. In SDS gel electrophoresis (which separates proteins by size), FGM's of these species exhibited similar patterns of about 15 components. Such patterns are not sensitive criteria for comparing proteins.

The phospholipid profile of FGM of both cows and goats resembles that of plasma membrane, particularly in the high content (20 to 25%) of sphingomyelin. No other membrane

of the cell has such a high content of this constituent (168, 169, 179). Some plasma membrane fragments occur in the skim milk portion. Whether part of this material was at any time part of the FGM and released therefrom subsequent to secretion of the fat globule is not known. Be that as it may, the material isolated from skim milk is similar in phospholipid and sterol composition and in enzyme content to both plasma membrane and FGM. In these respects also, the material isolated from goat skim milk was similar to that from the bovine (169).

Several enzymes generally associated with plasma membranes are in relatively high specific activities in preparations of bovine milk fat globule membrane (169). It seems likely that FGM of goat also has these enzymes, although they have not been sought. Jarasch et al. (87) established in bovine FGM a cytochrome similar to liver cytochrome b_5 as well as a NADH- and NADPH-cytochrome c reductase. These same components were in FGM preparations of several other species including goats (Moroccan dwarf goats).

Fat globules of goat milk do not cluster when milk is cooled. Apparently goat milk lacks the so-called "agglutinin" in bovine milk which causes fat globules in the milk of that species to cluster upon cooling (93). The agglutinin of cow milk is not species-specific; it binds to and causes clustering of milk fat globules of goats (93, 218).

PROTEINS

Nitrogen Distribution

Nitrogen distribution in goat milk has been studied little in the past decade. Singh et al. (210) reported that nitrogen distribution of samples from 10 Jamunapari does at 1 to 4 mo postpartum was .749 ± .40% total N, .534 ± .017% casein N, .172 ± .008% whey protein N, and .044 ± .014% nonprotein N. As previously indicated, total N (equal to 4.78% "protein") is much higher than that reported by the same group in another study (Table 1). The casein number (casein N/total N) of these samples was 71.3 similar to 70 to 74 reported in (159) and to numbers that can be calculated from newer data (57, 230). However, higher casein numbers in the range 77 to 79 have been reported (24, 98, 212). These resemble the casein numbers of cow milk which generally are 76 to 79 (calculated from data tabulated in reference 89). The six samples from pygmy goats analyzed in my laboratory averaged .840% total N, .658% casein N, .129% whey protein N, .053% nonprotein N, and casein number = 78.3. Thus, the majority of studies have found casein represented a smaller proportion of total N in goat milk than in cow milk, but a few have found similar casein numbers in the two species. It is not yet clear whether this difference in casein numbers reflects actual biological variation among goats or arises from systematic differences in analytical procedures. Grappin et al. (72) compared determination of protein content of cow and goat milk by dye-binding and infrared methods. Goat milk exhibited a significantly higher dye-binding capacity per unit of protein (1% more than cow milk) and a lower infrared absorption (4% less than cow milk). Thus, different calibration curves must be used for each species to measure milk protein content. Grappin et al. (72) found that the NPN contents of goat and cow milk were about 9% and 5% of the total N. This result for goat milk is the same as that reported by Kataoka and Nakae (98) but is higher than most other data (159; data in this review).

Principal Proteins

The five principal proteins of goat milk are β-lactoglobulin (β-lg), α-lactalbumin (α-la), κ-casein (κ-cn), β-casein (β-cn), and a casein that probably should be designated α_{s2}-casein (α_{s2}-cn). They are so named because they appear by composition and properties to be homologous to corresponding proteins of cow milk (30, 31, 235). Isolation and characterization of these caprine milk proteins can be referenced as β-lg (23, 176, 225), α-la (10, 41, 204), κ-cn (3, 110, 195), β-cn (193), and α_{s2}-cn (30, 194). Their amino acid compositions are in Table 4. Also given is an estimate of the degree of similarity between amino acid composition of each of the goat proteins and that of its corresponding bovine homolog. This is expressed as $S^{\Delta}Q$, which is calculated, $S^{\Delta}Q = \sum_j (\chi_{ij} - \chi_{kj})^2$, where i and k identify proteins being compared and χ_j is the content in moles/100 moles of the amino acids of type j. Marchalonis and Weltman (135), who devised this index of comparison, indicate that homo-

TABLE 4. Amino acid composition of isolated goat milk proteins.

	α_{s2}-Casein	β-Casein	κ-Casein	β-Lactoglobulin	α-Lactalbumin
	(residues per mole)				
Alanine	10	5	16	16	5
Arginine	6	3	5	3	1
Aspartic acid[a]	17	9	16	14	22
Cysteine	2	0	3	5	8
Glutamic acid[b]	45	43	26	24	13
Glycine	4	6	1	5	5
Histidine	5	5	4	2	3
Isoleucine	11	9	11	10	8
Leucine	12	20	8	21	13
Lysine	22	12	8	16	13
Methionine	4	6	1	4	0
Phenylalanine	8	9	4	4	4
Proline	18	33	19	8	2
Serine	14	15	13	6	6
Threonine	14	12	15	8	6
Tryptophan	2	1	1	2	4
Tyrosine	11	4	9	4	4
Valine	12	21	11	10	6
Total	217	213	171	162	123
Amide	?	?	21	15	17
Phosphate	7	5 or 6	2	0	0
S^ΔQ vs. Bovine homolog	25.9	8.8	13.1	2.7	3.9
References	194	193	52	23 176 181 225	41 126 204

[a]Includes asparagine.

[b]Includes glutamine.

logous protein pairs generally have S^ΔQ 100 or below. The S^ΔQ's of each of the goat proteins versus its cow counterpart are all well below 100; homology is high.

β-Lactoglobulin

In contrast to earlier reports of the absence of genetic polymorphs in goat β-lg (159), two groups have reported electrophoretic evidence for such polymorphs (128, 221), but none yet has been isolated or characterized.

Goat β-lg, like its bovine homologs, consists of a polypeptide chain of 162 amino acid residues. Its recently published complete sequence (181) confirms earlier end group and partial sequence analyses (36, 37, 119, 176) and reveals that it differs from bovine β-lg B at six positions including both terminal residues. The N-terminal Leu of bovine β-lg B is replaced by Ile, Asp 53→Asn, Asp 130→Lys, Ser 150 →Ala, Glu 158→ Gly, and Ile 162 →Val. Thus, goat β-lg has three less negatively charged and one more positively charged groups than bovine β-lg at pH's of 5 to 9. This difference in ionizable groups probably explains the difference that previously had been noted in titration curves of the two proteins (69, 225) and the slower electrophoretic mobility of goat β-lg in alkaline gels (176).

Structural differences between goat and cow β-lg's are indicated by the finding of Alexander and Pace (8) that goat β-lg is considerably less stable than the bovine variants to denaturation in urea, and by the demonstration by Phillips et al. (177) that goat and cow β-lg's can be distin-

guished clearly immunologically by the technique of microcomplement fixation. The size, shape, and overall conformation of goat β-lg are virtually indistinguishable from those of the principal bovine variants β-lgA and β-lgB by various ultracentrifugal and optical measurements (191, 226). Like the bovine β-lg's it binds about 2.5 moles sodium dodecyl sulfate per mole of protein, and the product aggregates to particles of larger size (191).

α-Lactalbumin

Goat α-la has been claimed to be heterogeneous electrophoretically (205) and compositionally (130), but neither claim has been substantiated by definitive data. The report of two variants having Lys and Ala as N-terminal groups (130) is difficult to understand in view of the finding of others that the N-terminal group of goat α-la is Glu (127, 204), the same as in bovine α-la. The C-terminal residue is Leu, identical to that of bovine α-la (127).

Goat α-la is devoid of methionine (41, 127, 204). In this respect it resembles sheep α-la but differs from all other α-la's yet described which contain one of three methionine residues. The complete amino acid sequence revealed 12 differences between goat α-la and bovine α-laB (the common variant in cattle of European origin) in the chain of 123 residues (127). One of these was at position 10 where goat α-la has Gln as in bovine α-laA (a variant in Indian cattle) instead of the Arg as in bovine α-laB.

Both low-salt (12) and high-salt (13) crystals of goat α-la have been prepared. However, attempts to prepare heavy-atom derivatives of the crystals suitable for high-resolution X-ray crystallography have not been successful.

Goat α-la crossreacts immunologically with other α-la's. It is clearly distinguished from bovine α-la by the technique of microcomplement fixation (200), by immunodiffusion (182), and by absorption of antibodies by columns of matrix-bound α-la (182).

Diffusion constant and sedimentation constant for goat α-la reported by Looze et al. (126). agree with those by Chaudhuri and Sen (41). The extinction coefficient at 280 nm $E_{1\,cm}^{1\%}$ = 17.3 reported by Schmidt and Ebner (204) is much lower than the 20.85 of (41). Probably 20.85 is correct, since it is close to that for bovine α-la and since both proteins have equal numbers of aromatic residues that absorb at 280 nm.

Various optical analyses have shown that the conformation of goat α-la is similar to that of the bovine homolog (112, 113, 216). The Tyr, Trp, and Lys groups seem to be about equally exposed in the two proteins (112). Goat, cow, and human α-la's exhibit similar tryptophan fluorescence but differ in this respect markedly from guinea pig α-1a; the difference is attributed to the replacement of Trp by Phe at position 60 in the latter (216). Goat α-la exhibits three spectral transitions detectable by changes in the absorption spectrum of tryptophan (113). These occur in the pH ranges 4.5 to 7.0, 4.2 to 3, and above 9.5.

κ-Casein

κ-Casein is the only one of the goat caseins for which the entire sequence of amino acids has been determined (52). It differs from its bovine counterpart in having a chain of 171 instead of 169 amino acids residues, Val and His being inserted at positions 132 and 133. Goat κ-cn, like the bovine homolog, has Phe in position 105 and Met in 106. Rennin (chymosin) hydrolyzes the molecule between these two residues producing the fragments called para-κ-casein (residues 1 to 105) and caseinomacropeptide (residues 106 to 171). There are 19 differences in sequence between cow and goat caseinomacropeptides and only 8 between the para-κ-caseins (141, 142). The specimen of goat κ-cn sequenced was from a single Alpine-Saanen doe (3). This goat evidently was heterozygous at the κ-casein locus because both Ile and Val were at position 119. This specimen of κ-casein was resolved into five distinct fractions of identical amino acid compositions but different carbohydrate contents.

β-Caseins

The β-caseins are quantitatively the major protein components of goat milk, but little work has been done to elucidate their properties.

Richardson and Creamer (193) isolated two goat β-caseins representing the most prominent electrophoretic bands in goat casein. These had identical amino acid compositions (Table 4) and differed only in having five and six phosphate groups, respectively. The authors called

these components β_1- and β_2-caseins, but they should be β-casein I and II, restricting Greek prefixes and their subscripts to designate the type of polypeptide chain in the molecule. Mácha (128) evidently found four electrophoretically distinguishable β-casein components in examination of caseins from 194 Czechoslovak White Polled goats.

α_s-Caseins

The fastest electrophoretic component of goat casein (in alkaline systems) represents a much smaller proportion of total casein than the α_{s1}-casein in bovine casein (159). Richardson et al. (194) isolated this component of goat casein and found that compositionally it is similar to the minor bovine casein formerly called "α_{s2}-, α_{s3}-, α_{s4}-, α_{s6}-caseins" but now designated simply as α_{s2}-casein (30, 31). One principal difference between α_{s2}- and α_{s1}-caseins is a disulfide linkage in the former and complete lack of disulfide or thiol in the latter. Bovine α_{s1}- and α_{s2}-caseins have polypeptide chains of 199 and 207 residues, respectively. Both have sequenced completely (31, 51). Their amino acid compositions differ markedly ($S^{\triangle}Q$ = 82). Although not many specimens from individual goats have been assessed critically for a protein homologous to bovine α_{s1}-casein, it appears likely that this protein may be missing completely from goat milk. Bogdanov et al. (27) reported finding two genetic polymorphs of α_s-casein in electrophoretic examination of casein from 52 goats.

Pelissier and Manchon (174) found peptides formed from goat or sheep casein by proteases were less bitter than those from cow casein. Peptides from cow α_{s1}-casein were most bitter of all. It was suggested that the lower bitterness in goat and sheep cheeses than in bovine cheeses is due to lower concentration of α_{s1}-casein (or total lack thereof) in the former.

The absence in goat casein of any electrophoretic component with the mobility of bovine α_{s1}-casein (11, 14, 64, 131, 178, 180, 230) makes it easy to detect adulteration of goat milk with cow milk. Aschaffenburg and Dance (11) showed that as little as 1% of cow milk added to goat milk could be detected by α_{s1}-casein band in gel electrophoresis.

Quantitation of Proteins

No complete quantitative analysis of individual proteins has been published for any sample or group of samples of goat milk. Only a few partial analyses are available. Johke et al. (95), using an immunoassay, found the mean β-lg content of two specimens of goat milk was 240 mg/100 ml. This is a little lower than 300 mg/100 ml reported by the same authors for about 20 specimens of cow milk. Ley and Jenness (118) calculated α-la contents of goat and cow milk were 220 and 120 mg/100 ml by assay of the ability to promote synthesis of lactose. Johke et al. (95) obtained almost exactly the same content (223 and 120 mg/100 ml for goat and cow milk) by immunoassay. These data indicate that goat and cow milks have similar contents of β-lg but that goat milk contains nearly twice as much α-la as does cow milk. Electrophoretic analyses of Stupnitskii and Il'chenko (221) indicated 20% α-la and 58% β-lg in goat whey protein, conflicting sharply with results of Johke et al. (95) and Ley and Jenness (118). An attempt at quantitation of a Sephadex G-200 gel filtration chromatogram of goat whey protein by Uusi-Rauva et al. (230) evidently was confused.

Bovine casein contains α_{s1}-, α_{s2}-, β-, and κ-components in the approximate ratio of 4:1:3:1 (50), but caseins of goat milk have not been quantitated adequately. Gel electrophoretic patterns indicate that the amount of α_{s2}-casein is much less than that of the β-caseins, but attempts to quantitate gel patterns have given conflicting results (7, 221). Unfortunately, κ-casein is not separated clearly from β-casein in the usual electrophoresis patterns. Pelissier and Manchon (174), in their paper on bitter peptides, mention having analyzed goat casein by determination of specific end groups. They state that less than 25% of the goat casein is the α_{s1}-component. Electrophoresis and isolation (11, 194) make it doubtful that there is any α_{s1}- at all in goat casein.

Caseinate Micelles

Casein in goat milk is sedimented less completely by centrifugation than that in cow milk. Cerbulis (39) reported that centrifuging for 60 min at 25 C and 30,000 rpm (Beckman model L 4 centrifuge) sedimented about 93% of the casein of Holstein milk but only about 81% of the casein of a lot of goat milk.

β-Casein dissociates from micelles at low

temperature, and this effect is much more marked in goat milk than in cow milk. Thus, O'Connor and Fox (154), using centrifugation at 78,000 × *g* for 1 h found 10% of the β-casein of goat milk soluble at 20 C and 25% soluble at 5 C. For cow milk the corresponding solubilities were 1 and 10%.

Electronmicroscopic analysis of goat caseinate micelles by Richardson et al. (196) confirmed (159). A few of the micelles are about 200 nm in diameter, easily sedimented, and electron dense, and the majority are below 80 nm in diameter. The proportions of small micelles is much greater than in bovine milk. The freeze-etch technique showed that goat, cow, and sheep micelles are composed of subunits of about 10 to 15 nm diameter.

O'Connor and Fox (155) analyzed milks of several species for casein, colloidal calcium, and colloidal inorganic phosphorus (P_i). The concentrations of colloidal elements were calculated as difference between concentrations in skim milk and in rennet whey. For nine samples of goat milk the ratio casein:colloidal Ca: colloidal P_i was 1:.044:.020, which is close to that which can be calculated from (88). This ratio indicates that goat micelles contain more Ca and P_i in relation to casein than do bovine micelles. For six samples of the latter, the data of O'Connor and Fox (155) give a ratio of 1:.031:.010. Richardson et al. (196) analyzed pellets obtained by high speed centrifugation of goat milk. Their data appear to indicate lower contents of micellar Ca and P_i than (155), but exact calculations cannot be made, because neither the casein content of the pellets nor the amount of soluble Ca and P_i associated with them was determined. Jenness (90) demonstrated high correlations between total calcium or total phosphorus and casein in milks of 33 species. Plots of Ca and P versus casein gave slopes of 35.4 mg Ca/g casein and 25.5 mg P/g casein; these slopes can be assumed reasonably to represent micellar Ca and P in the average micelle. The data for various lots of goat milk fall close to the regression line of the plots, indicating that the micelles are of close to average composition.

Solvation of caseinate micelles in 40 samples of goat milk, determined by Thompson et al. (224) by centrifugation at 68,000 × *g* for 35 min at 37 C and analysis of the pellet, averaged 1.60 g H_2O/g pellet with a range of 1.28 to 1.97. Bovine micelles were more highly solvated (mean 1.90 g H_2O/g pellet for 207 samples). Richardson et al. (196) reported solvations of 1.89 and 1.67 g H_2O/g pellet for cow and goat milk when they centrifuged at 330,000 × *g* (max) for 1 h at 30 C. Thompson et al. (224) found a high correlation (r = .89) between solvation at 37 C and heat stability at 135 C for 55 samples of milk from individual cows. Ten samples of goat milk exhibited low heat stability (maximum 180 s) consistent with their low solvation.

In summary, micelles of goat milk seem to differ markedly in several respects from those of cow milk. The difference is probably attributable to the absence of α_{s1}-casein from the goat.

"Minor" Proteins

Lactoferrin was isolated from goat milk by Oram and Reiter (156). Masson and Heremans (137) used immunological assays to determine lactoferrin and transferrin in milks of several species. Goat milk, like milks of cow and sow, contained 20 to 200 μg/ml each of lactoferrin and transferrin. By contrast, human milk has >2 mg/ml of lactoferrin and <50 μg/ml of transferrin. Rabbit milk has just the opposite situation, >2 mg/ml transferrin and <50 μg/ml lactoferrin.

Prolactin was in milks of all of the few species checked for it (132, 133). Malven (132) found by radioimmunoassay a mean prolactin concentration of 44 ± 5 (SE) ng/ml in 42 goat milk samples. Cow milk averaged 50 ± 1 ng/ml for 1078 samples.

Ford et al. (61) reported finding in goat milk a minor whey protein that binds folate. Since the folate content of goat milk is low (see later), the binding protein could be isolated readily by binding to an affinity column to which folic acid was attached. Rubinoff et al. (198) isolated and purified the folate-binding protein in this way. I calculate from their data that the milk contained about 12 μg/ml of this protein. It is a glycoprotein with about 22% carbohydrate. It binds 9.2 μg folic acid/mg of protein.

Goat milk contains immunoglobulins of the principal classes (see review, 53). As with other ruminants, the IgG's are in greatest concentrations. Pahud and Mach (158) with radioimmunoassays found 30 to 80 μg IgA, 10 to 40 μg

IgM, and 100 to 400 μg IgG/ml in goat mature milk. The concentrations in colostrum were much higher, .9 to 2.4 mg IgA, 1.6 to 5.2 mg IgM, and 50 to 64 mg IgG/ml. The ranges of content of these immunoglobulins are similar to those in cow and sheep milk and colostrum.

Introduction of viral and bacterial antigens into the mammary gland of lactating goats via the teat canal elicits an antibody response, and the content of immunoglobulins, principally of the IgG type, in the milk increases (146, 162, 163, 164, 165).

Miller and Ganges (144) found that goat milk (also human and cow milk and soy "milks") contains a protein component similar to the C_5 component of human complement. This component alters ("opsonizes") yeast cells so that they are ingested by human polymorphonuclear leucocytes.

Enzymes

Chandan et al. (40) included goats among five species in a study of lysozyme, lipase, and ribonuclease in milk. Three samples of goat milk averaged 25 μg of lysozyme, 425 μg of ribonuclease, and 39 μM/min of lipase/100 ml. The lysozyme content is in the low range characteristic of artiodactyls and is similar to that in (159). Ribonuclease activity is much less than that of cow milk and is comparable to (159). The lipase activity is about one-third that of cow milk which agrees with (159).

Three samples of goat milk averaged 47 $\mu moles\ s^{-1}\ ml^{-1}$ for lactic dehydrogenase and 50 $\mu moles\ s^{-1}\ ml^{-1}$ for malic dehydrogenase (105). These are comparable to those of cow milk but are much lower than activities of these enzymes in rabbit or rodent milks. In electrophoresis these samples of goat milk exhibited primarily one lactic dehydrogenase isoenzyme (LDH-1) and one malic dehydrogenase isoenzyme (M-MDH).

Hart et al. (78) confirmed (159) that xanthine oxidase is much less in goat milk than in cow milk. Twenty-five samples from five goats averaged 44 $\mu l\ O_2\ h^{-1}\ ml^{-1}$ (range 19 to 113) and 28 samples from five cows averaged 486 $\mu l\ O_2\ h^{-1}\ ml^{-1}$ (range 295 to 734). Feeding sodium molybdate caused a rapid rise in the Mo content of the milk of both species but did not affect xanthine oxidase activity in either of them. Thus, the low content of xanthine oxidase in goat milk does not appear to be from lack of molybdenum. The ingestion of up to 6 g of sodium tungstate by goats diminished the xanthine oxidase content of their milk (157). In some cases no xanthine oxidase at all could be detected when goats were so fed.

Two enzymes that probably are involved in the synthesis of glycoproteins have been found in and partially purified from goat colostrum. One catalyzes the transfer of N-acetylglucosamine from uridine diphosphate N-acetylglucosamine to glycoproteins. Johnston et al. (96) achieved a purification of this enzyme of 100 to 200-fold from goat colostrum. A soluble sialyl transferase which transfers sialic acid (neuraminic acid derivatives) from cytidine monophosphate-sialic acid to lactose or N-acetyllactosamine was purified partially from goat, cow, and human colostrum by Bartholomew et al. (21). Freshly secreted goat milk possesses the ability to synthesize triglycerides and phospholipids and to desaturate saturated fatty acids (44, 45, 46, 140, 232). The enzymatic systems responsible for this ability are located in cytoplasmic droplets that can be isolated by differential centrifugation of the milk (45, 232). These droplets also have the capacity to oxidize acetate and glucose to CO_2, to convert acetate to fatty acids, and glucose to glyceride glycerol (232).

Radioactively labeled phosphatidylcholine was hydrolyzed extensively to free fatty acids, lysophosphatidylcholine, and various uncharacterized water-soluble products when incubated with freshly secreted goat milk (124). Thus, various hydrolases (lipases) are active in such milk.

MINERALS AND SALTS

Major Salt Constituents

Analyses for principal salt constituents of goat milk are summarized in Table 5. Certain data in the table are questioned because they differ so much from the consensus. Some of the concentrations of P are indicated as representing total P and some inorganic phosphorus (P_i).

Goat milk has higher contents of potassium and chloride (although both vary considerably) than cow milk. (See cow milk in Table 5). The higher chloride content of goat milk was discussed in (159), but the higher K content was not emphasized. Konar et al. (107) demon-

TABLE 5. Principal minerals and citrate in goat milk.

Country	Animals Breed	Animals No.	Sample no.	Na	K	Ca	Mg	P	Cl	Citrate	Reference
				(mg/100 ml)							
Eire	?	9	9			151		86[a]			155
Egypt	?	?	50			136		61[b]	172		19, 20
England	Saanen-Welsh	14	11–23	44	180				153	98	120
	Saanen	4	4							ca 150	59
	Saanen	1	4							ca 180	173
	Saanen-Toggenburg	6	31	40	241				136	70[c]	107
Iran	?	4	?				11.5				192
Japan	?	2	2	51	212	137	14.5	106	161		100
	Toggenburg	2	31	41	190	133	36[d]	116	121		108
Philippines	Saanen	11	?			139		121			241
Trinidad	British-Alpine		16	53	164	85[c]	13	75[d]			55
	Anglo-Nubian		16	56	153	90[c]	10	82[d]			55
USA	?		1	39	242				202		77
	Pygmy	6	6			198		153		139	91
	Four breeds[e]		24		170	137	17	112			81
	?		4	38	193	138	21	95	204	151	28
Yugoslavia	Composite		3			123		98			57
Scotland	Ayshire (Cow) Bulk		12	58	140	118	12	95	104	176	234

[a]Inorganic P (Pi).

[b]Probably inorganic P (Pi) only.

[c]Seems very low.

[d]Seems very high.

[e]French Alpine, Nubian, Saanen, and Toggenburg.

strated a negative correlation between K and lactose for milks of cows, goats, sheep, and swine from their own work and published data from a few other species. Chloride is correlated positively with K and negatively with lactose, but Na is not correlated significantly with Cl, K, or lactose.

In three reports of physiological experiments with lactating goats, the milks of normal control animals were 15 to 20 mM in Na, 50 to 55 mM in K, and 40 to 50 mM in Cl (from graphs in references 121, 122, 172). These correspond to 35 to 46 mg Na, 195 to 215 mg K, and 160 to 178 mg Cl/100 ml; they are, in general, similar to those in Table 5. However, Linzell and Peaker (122) refer to one group of 60 samples from 25 healthy goats in which Na was only 13.0 ± .43 mM or 30 mg/100 ml; this is lower than all other reports. Harrison et al. (77) point out the nutritional disadvantage for human infants of the high K and Cl in goat milk (see section on Nutritive Value).

Citrate is a sort of harbinger of lactogenesis in goats (59, 173). Its concentration in mammary secretion increases sharply from virtually zero to the normal 150 to 200 mg/100 ml on the day of parturition. The low citrate content (Table 5) for ostensibly normal milk by two groups (107, 120) is puzzling. Konar et al. (107) reported citrate contents for cow milk averaging 190 mg/100 ml, and Linzell's (120) low citrate content is not typical (59, 173). Conceivably this low citrate in goat milk may involve greater biological variation than usually is considered, or it may reflect analytical, computational, or recording errors.

The total carbon dioxide and carbonate in five samples of freshly drawn goat milk was 3.4 mM; of this 1.9 mmoles/liter was in the form of bicarbonate ion (123). The pH of these five samples was 6.32 ± .062 which is slightly lower than the usual range (159). Hourly milking with the aid of oxytocin raised the pH and carbonate content of the milk.

Trace Elements

A monograph by Underwood (229) includes most published data on trace elements in milks including goat milk. Murthy's comprehensive review (151) deals only with bovine and human milks.

Table 6 presents data on Fe, Cu, Mn, Zn, and I contents of goat milk (6, 73, 100, 111). Colostrum is much higher in these elements than is mature milk. Zinc content varies greatly with zinc in the diet. Thus, Groppel and Hennig (73) fed two groups of goats diets containing 6 to 7 ppm Zn and 80 ppm Zn. Contents of Zn were ppm in dry solids, and I have converted them to a fresh milk basis of 12.5% total solids (Table 1). The goats receiving 6 to 7 ppm Zn produced milk containing 5.2, 3.0, 2.0, and 1.2 mg Zn/liter at 1, 14, 28, and 56 days postpartum; milk of those receiving 80 ppm Zn contained 7.5, 4.1, 4.6, and 2.4 mg Zn/liter at the same times postpartum.

Hart et al. (78) reported an average of 12.4 μg/liter of Mo in 25 samples of goat milk and 25.9 μg/liter in 27 samples of cow milk. Goats on a diet supplying 1.1 mg of Mo per day produced milk containing about 12 μg/liter; dietary supplementation to 13.0 mg Mo per day raised Mo in the milk to about 70 μg/liter.

Feeding of radioactive strontium, ^{85}Sr, to lactating goats resulted in some of it appearing in the milk. About 75% of this was in caseinate micelles with small amounts in fat globules, whey, and ultrafiltrate (84). Goats receiving .77% Ca in the diet excreted less of a dose of radioactive Sr in the milk than animals receiving .20% Ca in the diet (183). Intraruminal injection of 100 μCi of ^{203}Hg as methyl mercuric chloride into a goat resulted in appearance of only .28% of the dose in the milk (206). Likewise, administration of $^{203}Hg\ Cl_2$ or $^{203}Hg\ (NO_3)_2$ either orally or intravenously to goats resulted in appearance of only small fractions of the dose in the milk (82, 153).

Raber and Likussar (185) found a specimen of goat milk contained 2.6 mg borate/liter as compared to 1.1 to 2.2 mg/liter in three samples of cow milk and .42 mg/liter in one specimen of human milk.

When goats on a diet containing .08 ppm of selenium were injected with ^{75}Se-L-selenomethionine, about 10% of the radioactivity of the dose appeared in the milk, and of this about 70% was in the casein fraction (104).

MISCELLANEOUS CONSTITUENTS

Although an earlier report indicated an average orotic acid content of 63 mg/liter (74) in goat milk, recent analyses agree that content of this acid is only 10 to 20 mg/liter. Specific contents are 13 ± 7 mg/liter for six samples (115), 15 to 17 mg/liter for one sample (4), 12.2 ± 1.9 mg/liter for 120 samples (150), and 9.1 mg/liter (117). Cow milk contains seven or eight times more orotic acid than goat milk.

In 13 samples of goat milk Snoswell and Linzell (214) found a concentration of carnitine of 16.4 ± 1.6 mg/liter. About 30% was acetyl carnitine and the rest in the free state. Cow milk had about the same carnitine content as goat milk, but sheep milk contained about eight times as much.

Zulak et al. (243) found that the concentration of adenosine triphosphate (ATP) in freshly secreted goat milk was 19 mg/liter, but milk that had accumulated in the udder overnight had only about 6.2 mg ATP/liter. Fresh cow or

TABLE 6. Trace mineral content of goat milk.

Country	Breed	Time postpartum	Animals	Samples	Fe	Cu	Mn	Zn	I	Reference
					(mg per liter)				(μg/liter)	
Nigeria	Dwarf	1–5 days	10	5	2.46	3.14	.20	14.11	319.7	6
		2–18 weeks	10	17	.43	.28	.05	4.01	108.5	6
Egypt	?	?	26	26	.56	.13	.19	1.92		58
Greece[a]	?	?		56					22	111
Japan	?	4–5 mo	2	2	.65	.29				100

[a]From iodine deficient area.

human milk (not necessarily freshly secreted) had much lower contents of ATP (less than .5 mg/liter).

A sample of goat milk obtained 1 mo postpartum contained 1.6 mg phosphoserine, 8.3 mg phosphoglyceroethanolamine, and 54.6 mg phosphoethanolamine per liter (68). In sum these phosphate esters and the ATP (on the basis of 6.2 mg/liter) accounted for about 14.5 mg/liter of water-soluble ester-bound phosphorus. This is only 10% of the total such phosphorus in goat milk; about 50% is in the form of various nucleotides (159).

Ghadimini and Pecora (68) found that one sample of goat milk (1 mo postpartum) contained about 48 mg of free amino acids per liter. These included all of the amino acids ordinarily in proteins (only traces of Met and Trp) and small amounts of ornithine, citrulline, and γ-aminobutyric acid. Glutamic acid, glutamine, and glycine were in the highest percentages. Uusi-Rauva et al. (230) found a distribution of free amino acids in August goat herd milk similar to that of Ghadimini and Pecora (68) except for higher proportions of Val and Leu. They did not report the total free amino acid content. Ghadimini and Pecora (68) reported 47.7 mg/liter of taurine in their sample of goat milk. Thus, there was about as much taurine as all other amino acids in this sample. Milks of various species other than goat differ considerably in taurine content, and several species exhibit a pronounced decrease during lactation (190). Taurine may be of nutritional importance in early postnatal development (190).

Morrissey (149) found in nine samples of goat milk an average of 2.8 mg/100 ml of N-acetylneuraminic acid (NANA) bound to casein and 2.3 mg/100 ml bound to whey proteins. Cadman's (35) data for a single sample were 2.4 mg/100 ml in casein and 1.2 mg/100 ml in whey protein, but the sample also contained 2.7 mg/100 ml of dialyzable NANA. Cabezas et al. (34) found only about half of the neuraminic acid of goat milk was the N-acetyl compound. Considerable N-glycolyneuraminic and N,O-diacetylneuraminic were present.

Pennington et al. (175) reported a large cyclical variation in the progesterone content of goat milk. At estrus, milk progesterone was 1 to 2 ng/ml, but it rose rapidly within a few days following estrus and plateaued at 15 to 38 ng/ml in the middle of the cycle. High milk progesterone at 20 to 21 days postbreeding was an accurate indicator of pregnancy.

A number of studies have defined transmission of various drugs and chemicals into milk when administered to goats. These may be listed: pentobarbital and phenobarbital (143), propham isopropyl carbamate (171), permethrin (85), O-ethyl, S,S-diphenyl phosphorodithiolate (228), HCH isomers and DDT derivatives (231), sulfamethoxine (94), sulfadiazine (15), aflatoxins (136), benzylpenicillin, spiramycin, chloramphenicol, dehydrostreptomycin, and tetracycline (242).

PHYSICAL PROPERTIES

The osmolality of 11 samples of bulked goat milk reported by Linzell (120) was 297 ± 2.5 milliosmoles/kg H_2O. This is equivalent to a freezing point of −.552 C, which is not as low as near −.580 C found by most other workers (159).

Singh et al. (208) reported "total reducing capacities" of milks of goats, cows, and buffalo measured with acid ferricyanide. The reducing capacity of 20 samples of goat milk was equivalent to 2 μmole/ml of thiol groups and lower than that of cow or buffalo milks. Singh's results for cow milk are about 2.5 times greater than reported by this method for fresh cow milk in the United States (76).

Somewhat variable results for buffering of goat milk have been reported in the literature. The pH of maximum buffering and buffer index (dβ/dpH) at that pH are given as 5.3, .055 (one sample, 80); 5.5, .043 (four samples, 66); 5.3, .040 (50 samples, 98); and 5.25, .032 (five samples, 86). Cow milk exhibits maximum buffering at pH 5.5, and the dβ/dpH of mixed milk is of the order of .025 to .050 (66). Present data do not permit an unequivocal answer to the question of whether cow and goat milks differ in buffering properties. More detailed comparative analyses relating the dβ/dpH to composition would be necessary to decide this point.

Sharma and Roy (207) found an approximately linear relation between temperature from 5 to 70 C and electrical conductivity of 10 specimens of milk from Beetal goats averaging 13.1% total solids. At 25 C conductivity was .0062 ohm^{-1} cm^{-1}. This is similar to the .0052

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ohm^{-1} cm^{-1} for 26 samples from Egyptian goats (58) and for others in (159). It is much lower than the probably erroneous conductivity by Puri and Parkash mentioned in (159).

NUTRITIVE VALUE

This section deals with the nutritive value of goat milk for humans and particularly for human infants. It includes the few new data on the subject in the last decade and some older ones that were omitted from the 1968 review (159). Two new figures summarizing nutritional adequacy of goat milk are included.

Goat, cow, and human milks are, approximately isocaloric; each furnishes about 750 kcal/liter of energy. The outstanding difference is in the proportions of the energy derived from lactose and protein. In goat and cow milk, fat, protein, and lactose account for about 50, 25, and 25% of the energy, but in human milk they furnish 55, 7, and 38%.

Data on the nutritional adequacy of goat milk for human infants conventiently can be presented as a profile relating the content of various constituents to requirements. This method of presentation has been used by Hansen (75) for cow milk. The calculation for protein is made as follows: protein content, 3.3 g/100 g or 4.4 g/100 kcal; daily protein requirement, 1.8 g/100 kcal; and content/requirement, 4.4/1.8 = 2.4. Calculations are similar for other constituents. Figure 1 shows that a human infant fed solely on goat milk is oversupplied with protein in relation to calories.

In addition to quantity of protein, one also must consider quality—the balance of essential amino acids. Amino acid requirements of human infants have been determined and compiled by the FAO-WHO (239). Figure 2 shows this required profile for the essential amino acids (mg amino acid/g protein) plotted in relation to the profile of amino acids furnished by the protein of goat milk. Data for the goat milk amino acids are taken from the reports of Höller (79), Uusi-Rauva (230), and Wünsche (240), which agree fairly closely. Profiles for human and cow milk proteins are similar to those of goat milk. The three milks differ in proportions and kind of proteins, but the overall amino acid composition of the mixture of proteins is similar in all three. All three have a satisfactory balance of essential

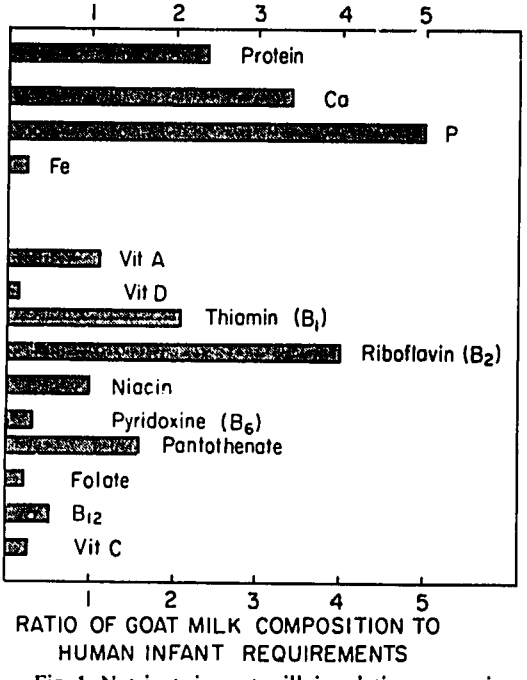

Fig. 1. Nutrients in goat milk in relation to requirements of human infants.

amino acids equalling or exceeding the FAO-WHO requirements for each amino acid.

A question often raised is whether goat milk proteins are digested more readily and their amino acids absorbed more efficiently than those of cow milk. Unquestionably, goat milk appears to form a softer, more friable curd when acidified. This may be due to the fact that little if any α_{s1}-casein is in goat milk. It seems logical that smaller, more friable curds would be attacked more rapidly by stomach proteases, but there does not seem to be any direct experimental evidence to support such a supposition.

Fomon and coworkers (60) have shown that human infants fed human milk, cow milk, and various vegetable formulas retain the same amount of N and grow at the same rate. Thus, proteins having different physical properties of curd forming seem to be utilized equally well. The only direct comparison of nitrogen retention from goat and cow milk that I know of was one by Daniels and Stearns in 1925 (159). They fed five infants (4 to 9 mo) alternately on formulas made from goat milk or cow milk. In all cases, retention of nitrogen was considerably less when goat milk was fed. These workers were, however, feeding more protein than used by Fomon (60) or than

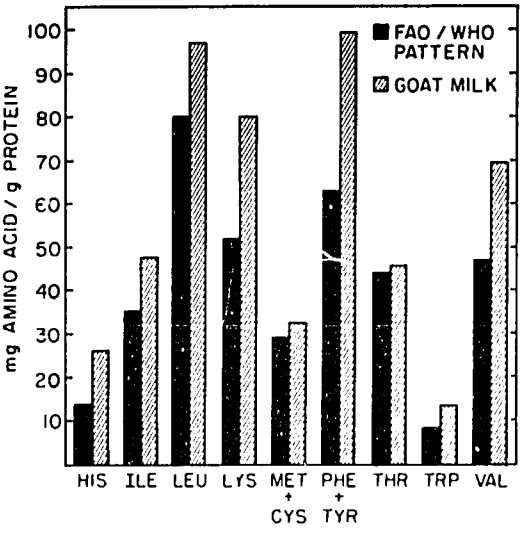

Fig. 2. Profile of essential amino acids in goat milk proteins in relation to requirements of human infants.

presently considered necessary for infants. The significance of their results is not clear. The soft curd of goat milk may be an advantage for adult humans suffering from gastrointestinal disturbances and ulcers.

Certain fatty acids (e.g., linoleic acid and arachidonic acid) are dietary essentials for humans, since our species lacks the capacity to synthesize them. At a bare minimum about .1% of the total energy intake should be from such acids. Both goat and cow milk fats contain adequate concentrations of these acids for human infants, although concentrations are slightly higher in some specimens of goat milk fat. In either of these milks linoleic acid furnishes about 1% of the total calories (Table 3).

Claims have been made (159) that the fat in goat milk is digested more readily than that of cow milk because the fat globules are smaller in goat milk. It is supposed that lipases can attack fat in goat milk more rapidly because of greater surface exposed. Actually, the range of fat globule size is similar in the two milks (under 1 to 10 μm), but goat milk contains a higher proportion of small globules. One would think that if fat globule size were a factor, then homogenized cow milk with the fat all reduced to globules of 1 to 2 μm would be digested much better than unhomogenized milk. Trout (227) reviewed the evidence some years ago and could find no experimental support that fat in homogenized milk is digested more rapidly. I think that in the presence of the bile salts in the gut, lipases attack fat rapidly and that the size of the fat globules in the diet is not limiting.

Nearly 20% of fatty acids of goat milk fat are in the category of short and medium chain length (4 to 12 carbons). Cow milk fat contains only 10 to 20% of fatty acids of this category. This difference may contribute to more rapid digestion of goat milk fat since lipases attack ester linkages of such fatty acids more readily than they do those of longer chains.

Human milk fat is absorbed more readily by infants than is cow milk fat (60). This difference is probably due to the difference in arrangement of fatty acids in the triglycerides. In human milk fat palmitic acid is primarily esterified in the 2-position of the triglycerides whereas in cow milk fat palmitic acid is distributed nearly equally among the three positions. The digestive and absorptive processes are favored greatly when palmitic acid is in the 2-position. The efficiency of absorption of goat milk fat has not been determined, but it would be expected to be similar to that of cow milk since the distribution of fatty acids over the positions in the triglycerides is similar.

One of the most important contributions of milk to human nutrition is the calcium and phosphate that it supplies. Goat milk contains about 1.2 g Ca and 1 g P/liter (Table 5); these concentrations are similar to those in cow milk. Human milk contains much less of these minerals with only about one-fourth as much Ca and one-sixth as much P. Figure 1 shows that goat milk provides a great excess of Ca and P in relation to energy to the human infant. Both are absorbed from goat milk by the human infant (159). Spur (217) found slightly more assimilation of Ca by rats from goat milk than from cow milk. The situation is much less favorable for iron, however. Most milks, even human milk, are deficient in iron content, and goat milk is no exception. Iron is absorbed and retained poorly. Iron is absorbed better from human than from cow milk. Iron absorption from goat milk does not seem to have been studied.

Harrison et al. (77) reported a human infant who grew poorly and suffered severe acidosis on a diet of undiluted raw goat milk. (Two siblings, aged 3 and 4 yr, were tolerating goat milk satisfactorily). The situation was corrected by

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feeding either a commercial formula or diluted goat milk. The authors attributed the difficulty to excessive intake of potassium and chloride and warned against use of undiluted goat milk for young human infants. Presumably the same warning should apply against undiluted cow milk, although as mentioned previously, the K and Cl contents of goat milk are higher.

Data on vitamin contents of goat milk, taken mostly from the summary of (159) and calculated in relation to caloric requirements, are graphed in Figure 1. (See 1, 61, 62, 114, 125, and 152 for additional vitamin analyses). They show that goat milk is adequate for the human infant in vitamins A and niacin and supplies generous excesses of thiamin, riboflavin, and pantothenate. It is, however, deficient in vitamins C, D, B_{12}, pyridoxine, and folate. Goat and cow milks are about equally deficient in vitamins C and D and must be supplemented with concentrates for infants.

Deficiencies in pyrodoxine, folate, and vitamin B_{12} have been recognized more recently. Cow milk contains more of these three vitamins than goat milk and satisfies requirements of the human infant adequately. Actual symptoms of deficiency of pyridoxine do not seem to have been reported for infants fed on goat milk. Vitamin B_{12} deficiency has been implicated in "goat milk anemia" that has been described for infants fed on goat milk (159). However, the major cause for this anemia is the lack of adequate folate in goat milk. Folate is necessary for synthesis of hemoglobin.

Ford and Scott (62) confirmed (159) that the folate content of goat milk is much lower than that of cow or human milk. Seventeen samples of goat milk averaged 6 μg/liter (range 2 to 11 μg/liter), whereas cow and human milks averaged 50 to 55 μg of folate per liter. In another study the same group (61) found in colostrum from seven goats an average folate content of 205 μg/liter (range 136 to 300 μg/liter). The concentration fell sharply and by day 14 averaged only 9.5 μg/liter. The low folate content of goat milk also was confirmed by Nicol and Davis (152). Braude (32) reported a case of megaloblastic anemia in an infant fed on goat milk, and Davidson and Townley (49) described folate deficiency in four infants fed for 6 to 8 mo on a diet principally of goat milk. All four infants in the latter study responded quickly to daily addition of .5 mg of folic acid to the diet. Weight gains were normal within a few days. Davidson and Townley (49) found structural abnormalities and disaccharidase (maltase, sucrase, and lactase) deficiencies in biopsies of the duodenal mucosa of these infants. All of these abnormalities were corrected by addition of folic acid to the diet.

Little new has been reported in the past decade on differences in allergic responses of humans to goat and cow milks. Saperstein (201) summarized the position (159) that there is extensive immunological crossreaction of cow and goat milk proteins. Thus, many cases of allergy to cow milk proteins are not benefited by shifting the patient to goat milk. As pointed out in this review, it now appears that a major protein component . . cow milk, α_{s1}-casein, is in only low amounts or entirely absent from goat milk. No one, to my knowledge, has attempted to ascertain if allergies to this protein occur in humans and, if they do, whether they can be cured by a diet of goat milk. A case of chronic enteropathy in infants due to feeding formulae based on cow milk was reported cured by shifting to goat milk (138).

No new feeding trials of goat milk in humans or any other animals have been reported in the past decade. The most definitive feeding study remains that conducted jointly by the USDA and Johns-Hopkins University in 1931 (66). Healthy human infants were fed for 12 wk on formulas of 1 part milk plus 2 parts water plus 5 g sucrose/100 cm^3 milk. Each infant received daily 2 cm^3 of cod liver oil and 10 cm^3 of orange juice. For four of the infants the formula was made with mixed herd goat milk, for three with Holstein milk, and for three with Jersey milk. Plots of the average cumulative gain over 12 weeks against milk calories consumed showed little to choose among the three milks in this regard. The gain per calorie consumed was the same. The ten infants from whom these data were secured grew normally and had no digestive disturbances during the time of the experiment. An unspecified number of other infants were started on the diets, but the data could not be used because of an outbreak of diarrhea in the nursery. This diarrhea developed among infants on each of the three milks, and the authors believed that it was not related to or caused by any of the three milks.

Another feeding study, not mentioned in

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(159), was in 1952 (129). It involved 38 children (20 girls and 18 boys) aged 6 to 13 yrs in an institution. All were served the same basic diet, but one group of 9 boys and 10 girls drank .946 liter of raw goat milk and another similar group .946 liter of raw cow milk daily for 5 mo. Both groups made excellent growth during the test, but the goat milk group surpassed the cow milk group to a statistically significant degree in skeletal mineralization or bone density, blood plasma vitamin A, and blood serum calcium. It had a slightly but not significantly greater concentration of blood hemoglobin; various other biochemical and structural measurements did not reveal a significant difference between the two groups.

A case of toxoplasmosis in an infant was attributed to transmission of the agent, *Toxoplasma gondii*, via unpasteurized goat milk (197). Some goats in the herd had positive serum antibody titers for this organism, but no positive isolations of it were from milk. In any event, the case is not an indictment of goat milk per se.

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Research on Goat Milk Products: A Review[1]

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ABSTRACT

This is a review of 136 publications pertaining to preparation of consumer products from goat milk. In many instances these publications do not report data from research but are descriptions of processes and practices in the manufacture of such products. A supplementary bibliography listing 183 publications is provided also. Most of these articles, or abstracts thereof, were scanned also, but their contents were not cited in the review.

This study of the literature shows that cheese is the only product made from goat milk which has been researched extensively. Few data are available on the manufacture of fluid milk products (low fat, fortified, or flavored), cultured products such as buttermilk or yogurt, frozen products such as ice cream or frozen yogurt, or butter, condensed milks, or dried milk products. While it can be claimed that data on the manufacture of these products from cow milk can be transposed to goat milk, experience has proven that such is not always possible. There is need for additional research on these products.

INTRODUCTION

World wide average milk production from goats is approximately 50 kg per doe per lactation if one-third of all goats have milk producing capability (43); they have potential for much greater productivity. The low production results from several factors, one of which is the small percentage of adult females kept for milk. Several additional causes have been discussed in other papers of this symposium. Aside from all those factors which may be associated with animal husbandry, there are two others which might be equally significant. These are a) lack of understanding of the nutrient harvest when animals are kept for milk as compared to when they are slaughtered for meat and b) inability to utilize milk in fluid form either directly as human food or for the manufacture of products exhibiting longer life or more desirable eating equalities. In this latter category, such factors as reduced bulk, increased protein concentration, reduced lactose content, and greater resistance to deteriorative effects of microbial growth are important.

It is the purpose of this paper to deal with these matters; the composition and nutritive properties of goat milk will be covered in detail in the final paper of this symposium. The relative proficiency of the goat as a producer of meat compared to its production of milk should be given serious evaluation, particularly in rural or underdeveloped areas where human needs for high quality protein cannot be provided. Admittedly an oversimplification, a comparison can be made between the utilization of that milk as human food or as food for the kids which are slaughtered for human food. In a normal lactation a doe's milk production may range from 200 to 1200 kg (56, 127). At a 400 kg per doe per lactation production, if used for human food, milk would furnish approximately 14,800 g protein (equal to 49 g/day for a 300-day lactation), 16,800 g carbohydrate (56 g/day), and 16,400 g fat (55 g/day) (25). This is roughly the protein and energy required to raise one kid to several months of age; at this time they would begin to accept other feedstuffs to promote growth to about 32 kg by 10 mo of age. If that kid then was slaughtered, it would provide a carcass weighing about 16 kg of which about 16% is inedible (bone, etc.), 20% is fat, and 64% is lean meat. The nutrient content of the edible portion amounts to about

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4500 g protein, 4000 g fat, and no carbohydrate (2). Both meat and milk would supply essential minerals and vitamins. The meat supplies significantly less nutrients and would have to be consumed in a comparatively short time. The labor in harvesting milk is much greater than that required in harvesting meat. Milk utilized directly as human food provides significantly more nutrients than that utilized for growing young animals. Why is not a greater amount so used when there is such a shortage of high quality protein? The answer has to be in the lack of knowledge and the inability to utilize milk in forms conducive to human consumption in a wide variety of circumstances. The purpose of this paper is to report research on products made from goat milk. Particular attention will be given to studies of products which have reduced bulk, increased protein concentration, reduced lactose content, and provided greater resistance to microbial deterioration.

RAW FLUID MILK SUPPLY

Research has been extensive relating to composition of milk produced by goats (22, 34, 37, 60, 87, 90). An excellent revew of those publications was prepared by Parkash and Jenness (100). Jenness is updating that review in this symposium. The data have brought out some characteristics of the goat milk supply which have had serious impact on the kind and amount of research on goat milk products. Those characteristics of greatest importance are a) wide variations in fat and protein content of milk, b) wide variations in quantity of milk available at different seasons of the year, and c) comparatively small volume of milk in total. An additional factor having significant influence in the United States is that only a small proportion of goat milk is Grade A quality.

For its utilization in the production of consumer products, flavor is the most important quality of milk. In the manufacture of some varieties of cheese a relatively strong "goaty" flavor is preferred (7, 121), but for most products the absence of characterizing flavor is necessary. Production of "goaty flavored" milk is, to some degree, an inherited trait (121). Further investigation would be beneficial.

A number of flavors objectionable in beverage milk are associated with the lipid system. Comprehensive reports (33, 81) have shown that the proportion of short chain (4 to 10 carbon) fatty acids in goat milk is approximately double that in cow milk (97). Synthesis of fat and condition of the fat globule membrane in goat milk have been studied extensively at Pennsylvania State University following publication of research (62) which showed that goat milk did not exhibit creaming characteristics similar to cow milk because of the absence of euglobulin in materials absorbed on the fat globule. The phospholipid and cholesterol content of skim milk, derived mainly from the surface of the lactating cell, was reduced greatly by short-interval milking (102). The cholesterol content of goat milk was 406 to 484 mg/100 g fat (equivalent to 10.8 to 16.3 mg/3.5 g fat in 100 g milk) (10) whereas cow milk had 7 to 15 mg cholesterol per 100 g 3.5% fat-corrected milk (97). The hypothesis "that phosphotydlcholine synthesis regulates development of fat droplets" was advanced in 1978 (79). Perhaps the most significant finding of these studies for goat milk flavor is that during 24-h aging at 2 to 4 C there was no or little increase in phospholipid and cholesterol content of the skim portion of cow milk, whereas the skim portion of goat milk showed significant increases in those constituents under similar conditions. This may be interpreted to mean that the fat globule membrane is less stable (80) in goat milk which could result in its being more susceptible to change of flavor.

The slightly lower lactose content and slightly to considerably greater chloride content (51, 100, 128) of goat milk as compared to cow milk frequently is noted in sensory evaluation as a slightly salty flavor. This probably would not bring about adverse criticism by regular consumers if day-to-day variation were minimal. As reported by James (59) the freezing point of retail samples of goat milk varied from −.550 to −.578 C.

A study by Perez-Dominguez (104) reported that about 60% of the goat milk samples had less than 10^6 leucocytes per milliliter and that the higher cell counts were in milk from low producers and animals in late lactation. Of these samples, only 5.2% contained mastitis pathogens. Nesbakken (95) reported that the milk from hand-milked goats averaged about one-third lower to cell count than that from herds machine milked. Current research (12,

13) is directed towards relating somatic cell numbers in goat milk to such testing procedures as the electronic somatic cell count, Wisconsin mastitis test, California mastitis test, and standard plate count. Cell counts tend to be higher in goat milk than in cow milk so that it is questionable if goat milk could meet "milk" standards (136).

BEVERAGE MILK

Relatively little has been published regarding processing and packaging goat milk as a beverage. There is need for such research because there is likely to be variation in flavor quality of raw milk, goat milk may be susceptible to off-flavor development, high somatic cell counts may be prevalent in goat milk supplies, and there seems to be wide day to day variations in goat milk composition (30, 59).

Research on goat milk products by the University of Georgia was developed around the belief that if there is to be a viable goat dairy industry, there is need for a family of products having customer appeal. In a 3-yr study of processed goat milk products, raw milk was collected for 5 days and then shipped over 1046 km in insulated, nonrefrigerated containers (76). This milk was collected from an 80-doe (5 breeds) herd managed by the Winrock International Livestock Research and Training Center at Morrillton, AR where it was cooled and held continuously at 1 to 2 C until shipped. The facilities were inspected regularly and met Grade A requirements; the product was approved for interstate milk shipment. No oxidized, rancid, salty, or offensively goaty flavored milk was detected in weekly shipments covering more than 2 yr. It was concluded (77) that if milk is collected from selected animals and properly handled and protected, off-flavors would not be a problem.

The beverage milk which has increased in consumer appeal in the United States in recent years is low fat, protein fortified milk. It was decided that goat milk processed for beverage usage would be of this type. Processing this product would permit accumulation of fat for ice cream or other high fat products. It provided a protein-enriched beverage of standardized composition, uniform from day to day. The product was pasteurized and homogenized in the same way that cow milk is processed to make it safe (136) and to add significantly to its shelf life— in Georgia milk carries a 10 day last-sale date. The experience of Malta (17) confirmed the necessity for pasteurizing goat milk as a public health measure; a case of toxoplasmoxis in an infant has been traced to consumption of raw goat milk (120). No Grade A nonfat dry goat milk is available for standardization of fluid milk products, so it was necessary to concentrate skim milk by low temperature evaporative condensing before adding it back to standardize the fat content. Composition of the milk was adjusted to 2% fat and 10.5% milk solids not fat (MSNF) before it was pasteurized (HTST), homogenized, and packaged in 946 ml containers. The milk was fortified with Vitamins A and D as required by law.

Research on commercial sterilization and aseptic packaging of goat milk to provide a limited supply during the season of low production will be undertaken. Some factors influencing heat stability of goat milk have been studied (47, 71, 72). Burton (24) reported that goats milk heated to 94 to 120 C underwent the same color changes as cow milk, i.e., whitening followed by browning. Until such time as goat breeding habits can be altered to provide a uniform supply of milk throughout winter months, sterilization and storage may be the only procedure by which fluid milk can be made available for consumption in winter.

YOGURT AND OTHER FERMENTED MILKS

It would be logical to believe that yogurt and other fermented milks have been made from goat milk for centuries; published reports of research on the subject are relatively scarce. Several articles pertining to general procedures are available (3, 5, 38, 57, 67, 77, 78). Aggarwal (3) used goat milk containing 4.3% fat and 8.6% MSNF with incubation to the final pH in the consumer package. It was indistinguishable from cow milk yogurt made by the same procedure. Duitschaever (38) and Loewenstein et al. (77, 78) used milk with 2% fat for yogurt; and former added 4% MSNF, homogenized at 200 kg/cm^2, pasteurized at 80 C for 15 min, cooled to 45 C, and incubated the product in its final container. No stabilizer was included in the formulation; under those conditions the yogurt was significantly less viscous than cow

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yogurt made in a similar manner. Goat yogurt did not show any whey-off; consumers had no difficulty distinguishing it from cow milk yogurt but preferred its smooth body and sharp flavor. The goat yogurt showed more rapid development of lactic acid than cow yogurt (38).

Goat yogurt produced at the University of Georgia (5, 77, 78) was processed in a different manner. Both Swiss and sundae-style products were made. Milk standardized to 2% fat and 10.5% MSNF, pasteurized, and homogenized at the time and beverage milk was processed was used in yogurt manufacture. This was held in bulk 24 to 48 h; in the yogurt making process it was stabilized with 250 bloom gelatin in sufficient quantity (.25 to .7%) to give the desired viscosity, then repasteurized (86 C for 30 min), cooled to 42 C, innoculated, and incubated in the processing vat. When the desired acidity was developed, the product was cooled further to 22 C, fruit puree was added and mixed if desired, and the finished product was packaged and stored at 5 C. The final viscosity was attained after the product was chilled to holding temperature. In the manufacture of sundae-style yogurt, the usual practice was modified to the extent that instead of adding a fruit puree to the cultured milk, a preserved fruit flavoring was injected into the package just before the unflavored yogurt was added with a two stage mechanical filler (5). This research confirmed the findings of Duitschaever (38) that at the same composition goat yogurt was significantly less viscous than cow yogurt; this was of greater importance in sundae-style than in Swiss-style. In a comparison of the two styles of product, consumers preferred sundae-style about 4 to 1 (5). To produce the most acceptable product with the least amount of stabilizer, the MSNF content of the original milk base was increased to 12.0%. Sundae-style yogurt made in this manner had the highest acceptance rating in consumer evaluations (77).

The amino acid profile of goat yogurt was studied by Nazarova (94), Rasic et al. (118), and Duitschaever (38), who concluded that it did not differ significantly from cow milk yogurt. Hadland and Hoffman (55) found that high-temperature long-time pasteurization (80 C for 10 to 45 min), greater concentration of solids (to 13.5% TS), and homogenization (150 to 200 kg/cm^2 at 60 to 70 C) were helpful in increasing the viscosity of fermented goat milks. Several research reports (1, 38, 131) showed more rapid acid development in goat milk cultured with yogurt organisms than in cow milk under the same conditions. Prodanski (116) reported that acidity developed in the milk of different mammals at the time of coagulation was dependent on temperature of pasteurization and time of holding. Gorner et al. (54) reported on the volatile, flavor producing compounds formed in goat milk cultured with yogurt organisms.

FROZEN YOGURT

Extensive search of the literature failed to show any research with frozen yogurt made from goat milk except at the University of Georgia (18, 77, 78). Frozen yogurt is relatively new in the family of dairy foods and is made in two forms, soft-serve and hard frozen. Distributors frequently use the same mix in making both types. Frozen goat yogurt can have the same composition as frozen cow yogurt.

A high quality formulation acceptable to the consumer was 2.0% milk fat, 10.0% MSNF, 10% sucrose, 10% corn syrup solids (36 dextrose equivalent), and .5% soft-serve stabilizer. Since no nonfat dry goat milk is available, concentrated MSNF must be made; condensed skim is prepared most easily. It can be stored in frozen form if necessary. Any combination can be used of fresh or frozen goat milk, cream, skim, condensed skim, and yogurt culture together with the sweeteners and stabilizer which gives the desired composition. The mix is prepared as two combinations of ingredients; yogurt cultures show minimum activity in a milk base with high sweetener content. Sufficient fluid milk, skim, and/or water (if calculated as part of the formula) to permit complete dispersion of the sweetener and stabilizer is withheld from the yogurt base and processed as a separate entity. The remainder of the fluid milk, skim, cream, and concentrated milk are combined and pasteurized at 82 to 84 C for 30 min (if fat containing ingredients were not homogenized previously, they are preheated to 65 to 70 C, homogenized at 200 kg/cm^2, then completely pasteurized). The mix is cooled to 41 to 42 C, innoculated with 4% active yogurt culture (culture included as part of ingredients in calculations of formula), and incubated at 42

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C to a titratable acidity of 1%. During incubation fluid milk, sweetener, and stabilizer withheld previously (with care to get stabilizer completely dispersed) are combined and pasteurized at 80 C for 30 min, and cooled to 40 to 42 C. After pasteurization and incubation are complete, the two fluids are combined, cooled to <5 C, and pachaged. Best results will be obtained if mix is held 24 h before freezing as either soft-serve or hard frozen yogurt. Flavoring materials usually are added at the freezer; frozen yogurt should be drawn from the freezer at about 50% overrun with temperature of -5 to -6 C. Packaged mix may be frozen quiescently for long storage and/or distribution. The packaged mix will have a usable shelf life of 30 days if stored at 2 to 5 C and much longer if held at -25 C or below.

ICE CREAM

No references to research in ice cream made from goat milk have been found excepting those at the University of Georgia (76, 77, 78), and that work only involved application of general knowledge of ice cream making to utilizing goat milk and derivatives thereof as fat and MSNF in the formulations desired. Because goat milk products are significantly more expensive than comparable cow milk products, goat ice cream would have to be of premium quality to attract consumers. This decision was corroborated by experience. With the two major items of sale (milk and yogurt) being low-fat high-protein type products, excess fat was accumulated. Premium ice cream contains a high fat-to-MSNF ratio, thereby providing a market for the excess fat. It requires the manufacture of a specific mix formulation for each flavor produced.

The three formulations made, for the three flavors of ice cream, were:

1. French vanilla mix[2]: 14% fat, 10% MSNF, 18% sweetener (12% sucrose, 6% 36 dextrose equivalent (DE) corn syrup solids), 1.4% egg yolk solids, and .25% stabilizer-emulsifier.

2. Chocolate (or carob) mix: 14.6% fat (.6% cocoa fat), 9% MSNF, 20% sweetener (14% sucrose, 6% 36 DE corn syrup solids), 3% medium fat cocoa (or finely ground carob powder), and .22% stabilizer-emulsifier.

3. Premium white mix[3]: 15% fat, 10% MSNF, 18% sweetener (12% sucrose, 6% 36 DE corn syrup solids), and .25% stabilizer-emulsifier.

Fresh cream, frozen cream, and fresh milk were used as sources of fat and MSNF; concentrated skim was the only MSNF concentrate available. All were derived from raw goat milk received at weekly intervals; nearly all were pasteurized prior to incorporation in ice cream mix because of the time needed to accumulate an adequate volume for processing.

Processing of the mix and production of the frozen ice cream were accomplished in the usual manner: vat pasteurization at 72 C for 20 min, homogenization at 175 to 180 kg/cm^2 (single stage), cooling to <5 C, holding for 24 h at <5 C, freezing to 75 to 80% overrun at -5 C, packaging (round pint containers), hardening, and storing at -18 to -20 C. Three flavors were made—French vanilla, chocolate almond (broken pieces of almonds added to chocolate ice cream as it passed from freezer), and strawberry (3 to 1 cold pack sliced berries added to frozen ice cream). All were more highly flavored than competitive ice cream products.

Barnard and Aee (16) have published instructions for making homemade ice cream (custard type) from goat milk.

CHEESE

Cheese may have been one of the first manufactured foods consumed by man. History records its usage more than 4000 yr ago (4, 26, 67, 96). No one really knows when the first goat milk was made into cheese; that detail is academic. That in 1979 a large portion of the world's production of goat milk is made into cheese is of great practical importance (27, 35, 73, 91).

Varieties

The manufacture of goat cheese should be categorized most accurately as a "cottage industry" rather than a commercial industry. This has led to the development of numerous

[2] Fortified vanilla extract was added during freezing.

[3] Used when bulky flavors such as strawberries are added at freezer.

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varieties of cheese, many named for the town or locality in which produced. Agriculture Handbook No. 54 (4) describes over 400 varieties and list over 800 names of cheeses; a great number of these are, or can be, made from goat milk or from combinations of goat milk with milk from the cow, ewe, or buffalo. The following are representative of the numerous references to specific varieties of cheese made from goat milk: Portman et al. (115) Sainte-Maure; Cargouet (27) and Cargouet and Sorin (28) Sainte-Maure, Chabichou, Pyramide, Sellesur-Cher, Charente-Poitau; Rakshy and Hassan (117) Domiati type or Feta; Elias (40) Fr. Pat. 2,112,160, no name; Efthymiou (39) US Pat. 3,843,801; Bender-Vaillant (20) Sainte-Maure; Bottazzi (21) Pecorino romano, Caprini or Robiolini freschi; Lame and Hekmati (70) Khikki; Laiterie Cooperative de Saint-Saviol (69) Fr. Pat. 2, 278, 250, Saint-Saviol; Delforno (32) Caprino di Rimella, Orserva, Paglierina, Raschiera; Strauss Dairies, Israel (8) Eezit; Dozet (35) Kajmak; and Fredriksen and Steinsholt (48) processed goat milk cheese. In a number of these publications basic processing procedures are given; in a few the general composition of the product is shown. Less than half of the varieties listed in the articles cited are among the 800 named in Agriculture Handbook No. 54 (4).

Diversity

The large number of varieties of cheese made from goat milk have resulted in great diversity in the nature of the products. The milk from which it is made significantly influences the finished cheese. As previously mentioned, either pure goat milk or goat milk combined with that from other mammals may be used (32, 67, 70). Some varieties of farm cheese made from the milk of a few animals (16, 61, 91, 129) lack uniformity; other farm cheese varieties, where the herd is large or milk is collected from several farms (20, 61), may be quite consistent in composition but distinctive in flavor. Ricordeau and Mocquot (119) have pointed out how seasonal variations in the composition of goat milk are reflected in the yield of the cheese. Portmann et al. (114) and Steinsholt (130) showed that making cheese from partly skimmed or fat enriched milk resulted in significant differences in yield of cheese. A number of research reports (14, 15, 50) have shown that the flavor quality of the milk is reflected in flavor development in cheese; when a strong flavored milk was processed, it gave stronger flavored cheese. The intensity of the goaty flavor was correlated highly with the free fatty acid content (14, 15); some consumers preferred such flavor, but others preferred a milder flavor (7, 50).

There is evidence that the production of milk with strong "goaty" flavor is an inherited trait; where desired, certain breeding patterns should be followed (7).

The great number of goat cheese manufacturers supplying many local markets with a variety of types and ages of product have developed numerous processing and aging procedures. While some goat cheese is made from pasteurized milk (27, 40) most reports of processing do not include pasteurization (21, 39, 61, 91). The consumption of unpasteurized goat cheese has been identified as the cause of epidemics of Brucellosis (41, 132). Manufacturing techniques include wide variations in amount and species of organism used in culturing (39, 40, 52), incubation procedures (50, 91), and forming or pressing techniques (27, 69). Variations in aging time and conditions play a most important part in determining the flavor, body, and texture of cheese (21, 32, 61, 70, 91).

Goat cheeses, like all other cheeses, utilize a variety of microorganisms in manufacture and aging to produce the final flavor, body, and texture qualities. In many instances cheese is made without culture, relying on the natural flora to develop the acid needed to cause protein coagulation (52, 67). Some form of enzyme generally is used to cause casein precipitation (67, 91). Much of the varietal differences between cheeses is due to the physical and chemical changes during ripening or aging. Such changes (53, 58, 70) result from activity of microflora and enzyme systems in the cheese; for many varieties the nature of those systems is the result of cultures, chemicals, or flavor ingredients added to the curd prior to or at the early stages of ripening. Typical examples of such additives are cultures of blue-green or white mold of the *Penicillium* genera (species roqueforti or camemberti) or *Brevibacterium linens*; salt is incorporated in many varieties of cheese for the effect it may have on microflora activity as well as its flavor; and some herbs or

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spices are added to a few varieties to produce specific flavor effects (4, 21, 48, 67).

In discussing the numerous varieties of cheese made from goat milk, mention must be made of whey cheese. This type of product is especially popular in Norway (91) where the caramelized lactose in concentrated whey is combined with fat and whey proteins to make Gjetost cheese. Mysost, Gudbrandsdalsost, and Primost are made by the same basic process but by changing the blend of ingredients, including some cow milk products (67, 96). Ricotta is a cheese which may be made from goat cheese whey; cheeses of a similar nature have other names when made in other countries (4, 67). Broccio is a whey cheese made by combining goat milk with the whey from goat cheese (91).

Composition

While several of the articles relating to the manufacture of goat cheese do give definitive data on the composition of the final product, most do not. The best source of information on composition of goat cheese in general is Agriculture Handbook No. 54 (4), but, as mentioned, many of the local varieties are not listed in it. With the wide variation in the composition of milk, modifications in manufacturing procedures, and multitude of aging time and conditions, it is expected that goat cheese would have a wide range in composition. Portman and Pierre (111) reported that the pH at the time of molding Saint-Maure type cheese had a significant effect on composition of the finished product; the dry matter and calcium contents were reduced as the pH was lowered from 6.6 to 4.6.

Characteristics in Common

While there are wide variations in the flavor, body, texture, and specific nutritional qualities of goat cheeses, they have characteristics in common. Production is usually seasonal since a large volume of milk is available only 4 to 6 mo of the year (67). The varieties consumed without aging are available in limited supply during months of low milk production. Therefore, the manufacture of varieties which are aged, such as Feta, Romano, Domiati, etc. serve several important functions. They please the palate of those who prefer flavorful cheese, and they furnish a supply of milk based products even during the nonproductive season of the year. Most of the goat cheeses are made by procedures involving slow coagulation, curd remaining with whey until dipped into molds, and drying of the cheeses before ripening (91). Goat cheeses are, as are all cheeses, highly nutritious. They contain a high ratio of protein to calories (34) and have a liberal content of many minerals. Their content of fat soluble vitamins, proportional to their fat content, may be high or low. Many varieties of cheese contain higher concentrations of some water soluble vitamins, such as thiamin, riboflavin, and niacin, than does the milk from which cheese is made (2).

Problem Areas Currently Being Researched

Several current problem areas related to the manufacture of goat cheese have received special attention. A problem of great concern studied extensively in recent years is that of seasonal milk supply. The impact of 75% of the cheese milk being collected from April to September was pointed out by Saurais (125). Several approaches have been taken to solving the problem. The necessity for developing programs to give more uniform production all seasons was noted by Rulliere (123). What probably should constitute the main thrust of such a program, the synchronization of estrus by the progestogen sponge technique and the use of artificial insemination, was advocated by Fataux (44). Relief from the problem through such a program probably will be a long time developing.

In the meantime, goat cheese makers are experimenting with other ideas. One is freezing curd and holding it in frozen storage. Portmann et al. (115) experimented with curd from both raw and heat treated milk stored at −20 or −25 C for 3, 5, or 8.5 mo. Saint-Maure cheese was made from the stored curd and ripened for 3 wk. After 3-mo storage, the curd produced cheese with 90% scoring "good" or "intermediate". With the storage period extended, the proportion of "poor" cheese increased to 25 and 40%. Subsequent to the original tests a commercial lot of curd was prepared, wrapped in aluminum foil, and stored 4 to 6 mo at −18 C. All the cheese made from it was assessed "good". Following their initial success, Portmann et al. (113) added 1.6% salt to the curd

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before freezing and storing it; cheese made from this curd generally was less desirable in flavor than that made from fresh curd. Portmann later (110) made similar tests with several qualities of salt as well as ascrobic acid and butylated hydroxyanisole as additives to the curd being stored. The quality of salt was of no importance; the addition of the antioxidants produced no conclusive results. Tiersonnier (134) and Saurais (125) advised the frozen storage of curd as a means of combating the problem of seasonal milk supply.

The process of ultrafiltration developed in the 1960's (42) was adapted for treatment of cheese whey (45, 83, 88, 89) as a means of recovering valuable constituents and reducing the whey disposal problem. Maubois and Mocquot, with the collaboration of others (85), described the application of ultrafiltration to the production of a "precheese" fraction from goat milk which subsequently was made into cheese. The new technique resulted in increased yields without sacrifice in quality and provided other advantages. A French patent was issued from this research. Later reports (65, 66, 86) showed how the preparation of a milk protein concentrate by ultrafiltration was being utilized in the manufacture of Camembert, Saint-Paulin, Mozzarella, and cream type cheeses. Cargouet and Sorin (28) studied the manufacture of Sainte-Maure and Chabichou cheese by ultrafiltration. Dariani (31) has studied the manufacture of a cream cheese type product using ultrafiltration. One of the major advantages of this technique, as pointed out in these reports, was the possibility of holding the "precheese" material in frozen storage for later use in cheese manufacture. Such a procedure also has been used to prepare a spray dried precheese material which is reconstituted and made into cheese at a later date (66, 106). Thus, the application of ultrafiltration to cheesemaking procedures has made it possible to manufacture goat milk cheese even when the fluid milk supply is diminished.

Another problem in the manufacture of goat cheese which has received attention is the mixing of goat milk with other milks and identification of products made from mixtures. Mixing milks seems to be fairly common as a means of extending the supply of goat milk and of reducing the cost of the finished product. Properly labeled, such cheese undoubtedly has a place in the market; but if marketed as a pure goat milk product, such cheese could cause difficulties in digestion for some individuals. Maree (82) and Ruehl (122) have pointed out that a significant proportion of the human population exhibits distinct allergy to cow milk protein, although symptoms attributed to such an allergy frequently are not true protein antigenicity. It is not important to this symposium whether the allergic response is to the casein or a whey protein as Saperstein (124) has discussed. Proteins in goat milk differ from those in cow milk both quantitatively and qualitatively (29, 68, 74, 82, 92, 103). The extent to which goat milk may be used to alleviate allergy from cow milk protein has been questioned (82, 124) even though it is used widely for that purpose. A number of studies (11, 23, 46, 49, 105, 108, 109, 112) developed procedures for detecting cow milk protein in goat milk or goat cheese by polyacrylamide gel electrophoresis; adulteration of 5 to 10% could be detected. While this process does not give complete protection to those individuals who cannot tolerate cow milk protein, it does provide regulatory officials a tool with which to insure more accurate labeling of cheese.

French Patent No. 2,290,847 (135), detailing a procedure for continuous manufacture of curd for cheesemaking, has been granted.

Other Manufactured Products

No mention has been made of butter, condensed, evaporated, or dried milks from goat milk. While we are aware of the capability to make such products, our literature search failed to find any research on them. We have not conducted any tests on the products at the University of Georgia.

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Southern Agriculture Corporation's Experience in Marketing Goat Dairy Products[1]

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ABSTRACT

The market development and merchandising research by Southern Agriculture Corporation on goat milk products was the third phase of a three part pilot project also involving dairy goat breeding and management conducted by Winrock International Livestock Research and Training Center (Morrillton, Arkansas) and goat milk product development, manufacture, and evaluation by the Dairy Technology group of the University of Georgia.

The project extended over 3 yr; the research was an attempt to quantify the potential for the sale of goat milk products in a metropolitan market of over 1.5 million persons. Factors investigated as having real or possible influence on sales potential included number and kind of products offered for sale, fat and protein content of those products, characteristics of the market population, and price of the products (based on costs of ingredients, processing and packaging, and sales and delivery). The study did not produce absolute findings regarding the volume of sales of any product, but general conclusion indicated a potential sales volume of sufficient magnitude to justify movement toward development of a commercial dairy goat industry. Numerous problems requiring further attention before such development could become financially successful have been investigated.

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INTRODUCTION

The Southern Agriculture Corporation (SAC) established the dairy goat project in 1977 as an investigative prototypic venture. The basic goal of this pilot project was to determine whether subsequent development of a large, vertically-integrated, breeding/production/processing operation, involving limited resource, small producers could be profitable. This project goal corresponds to SAC's primary corporate objective: to increase small producers' incomes to $12,000 to $14,000 annually (in 1975 constant dollars) (1).

The pilot project was designed in three phases on tripartite arrangements with Winrock International Livestock Research and Training Center in Morrillton, AR, and the University of Georgia in Athens. The first phase was a joint venture with Winrock involving breeding and milk production in new facilities adjacent to the existing headquarters, Winrock's basic responsibilities consisted of design and construction of the facilities and daily production management.

The second phase involved development and manufacture of processed goat dairy products. Formulae development and processing have been by the Dairy Science Department of the University of Georgia on a research fee basis. The SAC assumed responsibility for marketing the goat dairy products in the Atlanta area as the third phase.

The purpose of this paper is to share SAC's experience in the marketing of SAprima brand goat dairy products in the context of this pilot project.

MARKETING OF GOAT MILK PRODUCTS

Background

Historically, the majority of goat milk products in the US have been sold on-farm or locally and have consisted primarily of fluid

milk sales. The few commercial goat operations which have ventured into retail outlets have concentrated on the health food channel and to less extent, cheese specialty stores.

Prior to SAC's entry, eight goat milk products were marketed in the southeastern region by six manufacturers. Available products consisted of fluid milk, condensed milk, yogurt, ice cream, cottage cheese, cream cheese, and hard and imported cheeses.

Pure Goat Products of Pennsylvania marketed the broadest product line: fluid milk, yogurt, ice cream, cottage cheese, and cream cheese. The Golden Fleece Dairy in Florida and Ozark Milk Products of Arkansas marketed whole fluid and condensed milk, respectively. Laurelwood Acres and two Wisconsin firms, Diamond Dairy Goat Farm and The Dairy Goat Farm Coop, marketed hard cheeses within the region. These manufacturers relied upon twelve distributors, three of which operate exclusively in the southeastern region.

Goat Dairy Product Market

The market for goat milk products is defined vaguely. Reliable figures regarding consumption of goat dairy products in the US do not exist. Moreover, no systematic merchandising efforts have been launched on a broad scale.

Detailed data for dairy cow products are available. Total US cow's milk production exceeds 55 billion liters annually with per capita consumption equalling .76 liter daily. The Atlanta metropolitan area alone consumes 442 million liters of milk and milk products annually.

Processors of goat milk generally suggest that fluid milk sales in metropolitan areas should reach .95 liter per wk per 1,000 population within 5 yr after a plant is established. However, few goat dairy plants manufacture products other than fluid milk. Their assertion, therefore, is that the market for goat dairy products is approximately .13% of per capita dairy cow product consumption in the US. On this assumption the Atlanta/Athens markets could support the production by only 70 goats.

On the other hand, Wes Nordfelt, the owner of Laurelwood Acres, the country's largest goat operation, believes inherent market potential is significantly greater. He contends that systematic market development, funded by allocating 4% of sales, should develop fluid milk consumption averaging 11 liters/wk/1,000 population. On this assumption the Atlanta/Athens markets could absorb the production of almost 900 goats.

However, substantially greater sales would be necessary to justify investment in a dairy processing plant. Therefore, SAC would have to penetrate into other metropolitan areas to assure economic viability if a commercial operation is undertaken.

Product Mix Rationale

Manufacturers of cow's milk products enjoy total flexibility in determining their product mix. Being a single item processor requires only adequate sales volume to support the company's production, manufacturing, distribution, and marketing activities.

Whole cow's milk contains 3 to 4% fat. Conversely, fat of individual dairy products ranges from .5 to 20%. Protein also varies significantly among products. The net result is that manufacturers of limited products always have a surplus or deficit of "milk solids nonfat" (MSNF). No problem occurs because of a national commodity market for concentrated fat and MSNF.

However, the situation confronting goat's milk processors is radically different. No opportunity to buy or sell concentrated goat milk fat or MSNF exists, and mixing constituents from cows and goats would be unethical and illegal unless explicitly labeled. Therefore, three basic options were available to SAC: 1) to manufacture fluid milk exclusively; 2) to manufacture fluid milk and cheese; or 3) to manufacture a carefully selected product line designed to optimize utilization of raw milk. The SAC management selected the third option to maximize sales potential and to optimize utilization of milk.

Segment Analysis

The SAC identified four possible market segments to be evaluated during this pilot project. They are special ethnic groups, age groups, special diet groups, and income groups. Each is discussed briefly.

Ethnic Groups. Although industry data reveal that whites purchase 95.2% of all yogurt consumed in the US, blacks, Hispanics, Italians, Eastern Europeans, and Middle Eastern indi-

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viduals normally exhibit higher residual responsiveness to dairy goat products than Americans of predominantly Western European ancestry. These populations are concentrated in Florida, New York City, Philadelphia, and Baltimore/Washington, DC.

Age. Infants and elderly are thought to be the heaviest nontherapeutic consumers of goat milk. Medical studies indicate that up to 37% of all American infants below 2 yr of age manifest varying degrees of gastrointestinal reaction to cow's milk. It is believed that a comparable reaction to goat's milk is rare.

Housewives purchase 76 to 81% by-products of all dairy items sold in the US. Other family members may be heavier consumers, but housewives make the buying decisions. Approximately 60% of both yogurt and ice cream is purchased by women 45 yr and older.

Income Groups. Premium priced food products are purchased most often by the nation's more affluent consumers. Approximately 63% of all yogurt, 39% of all ice cream, and 51% of all cheese is purchased by families having annual incomes above $10,000.

Special Diet Groups. Medical studies have determined that 3% of all black adults and 1% of all white adults in the US suffer from acute allergenic reaction to cow's milk and its processed products. Hospitalized patients requiring diets featuring maximum digestibility present additional potential for utilization of goat milk products.

Individuals oriented to health food represent an excellent opportunity for sale of goat products. This segment has been targeted by other goat dairy operations because of its high acceptance of premium priced products which provide "natural" ingredients and formulation.

Target Market Segment

The SAC targeted the health food segment for the marketing pilot. In addition to the reasons cited above, purchasers of health foods possess age and income characteristics similar to the profile of purchasers of cow's milk products. In 1972, 75% of health food users were aged 45 yr or older; more than 50% of this segment had annual incomes of $10,000 or greater.

The final and most compelling reason for selecting this segment was a highly specialized outlet in health food distributors and retail stores. The SAC management believed health food stores would offer least initial consumer resistance and access to a relatively stable, middle- to upper-income market.

Product Line

The SAC decided upon an initial product mix of 25% fluid milk, 50% yogurt, and 25% ice cream, a key factor in this decision being the desire to commence immediate production and marketing. Product formulation of yogurt and ice cream was deemed to be less difficult than for cheese and, therefore, provided a shorter lead time for market entry.

Considerable time and money was expended in determining a desirable brand name. "SAprima" was selected and registered. The SAC decided to manufacture a MSNF-fortified, low-fat milk rather than conventional, whole milk. Management believed a low-fat product would be well positioned within the health food channel, particularly attractive to that segment interested in reducing intake of fats. In addition, such a product would not compete head-on with other goat milk products since no low-fat product existed prior to SAC's entry. A low-fat product further would differentiate goat milk from cow products available in health food outlets and thereby further justify the premium price. State regulations permitted this product to be labeled "protein-fortified."

Initially SAC and the University of Georgia decided upon a "Swiss style" yogurt to facilitate market entry. However, they soon discovered consumers' preference for the sundae style yogurt. By late 1977 a sundae style product had been formulated. In conjunction with the University, SAC undertook a limited consumer test of SAprima's yogurt products. Testing was at health food stores in Atlanta and in Athens.

The total sample consisted of 1005 respondents. By October of 1977, SAprima Swiss style yogurt was ranked sixth of nine with 4.1% reporting the goat product as their "favorite brand". Dannon led with 49.7%, followed by Alta Deena with 20.4%, Home Made with 8.5%, Continental with 5% and Columbo with 4.4%.

Consumers overwhelmingly preferred the SAprima sundae style yogurt to the Swiss style with 83% selecting the former. Of those preferring the sundae style product, 86% cited flavor preference. This preference was based on the greater fruit and sweeter flavor.

The SAC introduced the SAprima sundae

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style yogurt in April, 1978. Flavors were peach, strawberry, black raspberry, and unflavored. Product was packaged in 8 oz cups.

Ice cream was packaged in pints. In 1978, three flavors were marketed: chocolate almond, French vanilla, and strawberry.

Distribution

Originally SAC contracted with a local jobber-distributor to distribute the product line. However, performance was poor, and management hired a sales manager in August, 1978, to oversee marketing and distribution of the SAprima line.

Retailers were required to carry the entire SAprima line. Their sales were guaranteed 100% by SAC, providing their markup did not exceed 20%. The SAC's marketing representative controlled each store's inventory and visited each account weekly.

Pricing

Wholesale prices were based on gross margins ranging from 8 to 13%. However, profit margins were calculated according to proforma manufacturing costs at 1.9 million kg. In April, 1978, SAprima's milk retailed at $1.19 per quart, yogurt at 46¢ per 8 oz cup, and ice cream at 98¢ per pint.

Promotion

Promotion was limited to posters at point of purchase keyed to the design of product packaging. The SAC conducted consumer sampling in key retail outlets several times a year.

DISCUSSION AND CONCLUSIONS

Introduction

As in any new venture, unexpected problems arose, and strategies were revised to address them. The key issues are discussed in each functional area, production, processing, and marketing.

Production

Less than 30% of the milk volume forecast actually was received by SAC in 1977. The reasons were attributable largely to start-up difficulties plus utilization of a herd containing all yearling, first lactation females. Mastitis also developed during the 1st yr of operation.

The herd numbered 130 does in 1977. It had increased to 160 in 1979. At this size the herd currently ranked among the largest of goat herds in the US. However, milk production per doe averaged only 635 kg.

This shortfall in production served as a serious constraint in SAC's ability to evaluate the market potential for a broad line of goat dairy products. The limited volume could support only local marketing through health food outlets, precluding test marketing in other channels such as supermarkets, cheese specialty stores, or novelty ice cream stores. In addition, SAC's volume of products was insufficient to contract with a regional distributor of health food products.

The second production issue related to the lack of year-round milk production. The SAC marketed no product during January, February, and March. The consequence of this lack of supply was that SAC lost shelf space every year during this period and was forced to resell accounts in April and compete again for adequate shelf space.

Processing

Product technological development by the University of Georgia proceeded significantly ahead of schedule. The SAprima product line currently included 21 forms and/or flavors of goat dairy items, although fewer than 50% have been marketed. Uniformly superior quality has been substantiated by a series of formal consumer evaluation studies and in-store product demonstrations (2).

Under SAC's contract with the University of Georgia the SAprima product was manufactured during the Dairy Department's "down-time", i.e., when cow's milk products were not being processed. On occasion, scheduling conflicts arose which delayed delivery to customers.

Infrequently, but on occasion, the yogurt product varied significantly, being either too liquid or too thick. When this was severe, the sales manager dumped the product; in addition to the obvious financial consequence, SAC's relationship with customers eroded because orders could not be filled.

Marketing,

The SAC developed a market estimate which

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was more conservative than Nordfelt's but significantly larger than the industry's: .95 to 1.32 liters per day or 6.6 to 9.3 liters per wk per 1000 population. This estimate was based on the hypothesis that fluid milk sales represent only 10 to 25% of total potential goat dairy products. Our limited experience supports this hypothesis. Under this scenario approximately 700 goats could be maintained profitably to supply the Atlanta/Athens markets with a full range of products. However, substantially greater sales would be necessary to support a new processing plant. This need would require SAC to target new segments within the Atlanta/Athens markets and/or to penetrate into other metropolitan markets to assure economic viability.

The SAC encountered extreme resistance by health food store managers to SAprima products containing processed sugar, stabilizers, and artificial food coloring. This problem forced seven major reformulations of the fruit flavored yogurts. Currently SAprima's fruit yogurts are manufactured with honey-based preserves and Kosher gelatin and vegetable gum stabilizers. Similar ingredient problems were encountered with the ice cream product, although consumer resistance was minimal. However, to gain entry to these outlets it was also necessary to reformulate the ice cream product with honey.

The honey reformulations increased the wholesale price structure by 18 to 22% for both the yogurt and ice cream. These additional costs necessitated price increases in June, 1978

Management decided to pass these costs on and, since summer of 1978, matched price increases of Pure Goat Products, SAC's primary competitor in the goat sector. Since SAC faced the constraint of limited production, pricing offered an opportunity both to control product demand and to test price sensitivity of goat dairy products in health food outlets. This strategy presented a risk. Pure Goat Products had been able to establish year-round production plus large markets to the ethnic segments in New York City.

Althouth it is too early to draw definite conclusions on just a single comparison, SAprima product usage increased significantly in an analysis of April sales in 1978 and 1979. Gross sales of low-fat milk equalled 749 liters in 1978 with 168 expired liters resulting in net sales of 581 liters. During April of 1979, gross sales increased 131% to 1717 liters. Net sales (after accounting for expired product) grew 108% from 581 to 1208 liters in the 12 mo.

The retail milk price of $1.19 per quart increased 20¢ during this period. However, the wholesale price rose only 10¢, thus expanding retailers' margins from 24¢ to 34¢.

In the case of yogurt, growth of net sales equalled 210% during the same period. The retail price rose 13¢ per cup to 59¢. Wholesale prices increased to 42¢ per cup, providing retailers a margin of 17¢ per unit, almost 100% increase in their unit profit. Ice cream sales are excluded from this analysis because of their seasonal peak in the summer; sales during April were minimal.

This experience tends to support the view that goat dairy products are relatively price insensitive compared to processed cow's milk products. The fact that retailers enjoyed an increased margin incentive during this period should not be discounted.

Conclusions

The SAC management continues to believe a commercial, large scale, vertically-integrated, dairy goat operation is an economically viable venture. However, development of such an operation will require considerably longer than envisioned originally.

Since SAC's experience has been limited, management's conclusions at this point are tentative at best. The key points are discussed.

1) Raw milk production represents the greatest constraint in development of such a venture. Therefore, an extensive merchandising effort is premature and will not be appropriate until: a) herd size approaches a minimum of 500 does and b) year-round milk production is achieved.
2) Given initial production constraints, the product line should be narrow and limited. The line should be designed both to optimize utilization of raw milk production and to provide a year-round supply of at least some products to retail outlets. Fluid milk and cheese appear to be the optimal combination since a) expired fluid milk can be converted to cheese (rather than being dumped) and b) manufacture of cheese can be scheduled to provide year-round supply of product to retail accounts.

3) Additional analysis must be made regarding the matching of individual goat dairy products to optimal retail channels. Based on SAC's experience, management believes fluid milk, plain yogurt, and assorted cheeses can be marketed effectively through health food outlets.

   Fruit-flavored yogurt and ice cream, due to the cost of honey-based sweeteners and fruit preserves, would be better channeled through different outlets a) provided milk production achieves the necessary volume (management believes advertising can build effectively the demand required to support product distribution through supermarkets); b) if additional opportunity exists to market soft and/or hard frozen yogurt mix and ice cream through specialty ice cream outlets; and c) if conventional yogurt and ice cream novelties also could be marketed through vending machine locations of high traffic.

4) Goat dairy products appear to be relatively price insensitive compared to cows' dairy products. This initial finding confirms the initial hypothesis. However, management believes penetration into the supermarket channel would dictate greater price competitiveness.

5) Contracting with a regional distributor/jobber represents the preferred distribution route initially. However, utilization of this approach requires higher production than SAC has achieved to supply regional distributors adequately.

   The distributor/jobber mode of distribution would provide an economical means of entry into new geographic markets. Once the line of products had been introduced, SAC could establish its own "store-door" distribution operation to establish the line and to expand sales.

The SAC's experience with its dairy goat pilot venture has led to the identification of several attractive market niches for dairy goat products. We must now turn our attention toward quantifying the market potential of these segments and overcoming the production and processing barriers to creating a commercially viable business.

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1 Anonymous. 1979. All data reported herein were obtained by personally communicating with individuals or organizations having firsthand knowledge on the subject; no official or published sources of information have been located.

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Indian Research on Protein and Energy Requirements of Goats

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ABSTRACT

Two decades of Indian research on protein and energy requirements of goats were reviewed. Protein requirements for minimum maintenance derived from endogenous urinary and metabolic fecal nitrogen excretion in nitrogen-free and low-nitrogen metabolism studies were 1.23 to 1.61 g digestible crude protein (kg body weight)$^{.75}$. Based on balance studies at maintenance, requirements were 3.13 to 3.83 g digestible crude protein/(kg body weight)$^{.75}$. The coefficient to predict utilizable protein from body weight for goats was .89. From digestibility trials, protein requirements for growth and maintenance were 4.52 g and 5.55 g digestible crude protein/(kg body weight)$^{.75}$, respectively, for pregnancy and maintenance. Protein requirements for lactation were 4.95 digestible crude protein/(kg body weight)$^{.75}$ and for 1 kg 4% fat-corrected milk 46.56 g digestible crude protein. Energy requirements for maintenance were 125 to 163 kcal digestible energy/(kg body weight)$^{.75}$; for growth and maintenance 232.83 kcal; for pregnancy and maintenance 221.79 kcal; for lactation 198 kcal; and for 1 kg 4% fat-corrected milk 1520 kcal.

INTRODUCTION

India has the largest goat population in the world. At 68 million in 1972, this number must have grown to 70 million by 1975 and should be getting closer to 74 million by 1980 (8). There has been, however, considerable controversy and dispute about promotion or demotion of these creatures. Their vices have been discussed more loudly than their virtues. They have been accused repeatedly of being public pests, of destroying all sorts of vegetation, and of causing erosion.

It has been only recently that the ability of goats to serve mankind, even under harsh ecological conditions, has been realized. The long-held prejudice and malice against them is being reconciled gradually as people become acquainted with goats.They have come to be recognized now as the most effective livestock for promoting health and economy of poor people in the developing countries of the world. This is especially true for countries of the tropics and subtropics where there are over 80% (315 million out of 391.6 million) of the goats in the world (5).

Economic gains which goats offer their owners in India have been assessed and reported adequately. They have a cost benefit ratio of 1:11.7 and an investment return rate (IRR) of over 30%, which by far exceeds any bank interest (22). The economic potentials of goats also have been documented by Moore (15), Rana (20), and Acharya and Patnayak (1). For goats to be involved more intensively in animal agriculture of the world, there must be a concerted effort for their overall development, including breeding, feeding, and management.

India, with limited feed resources, has the efficient feeding of goats as its priority (8, 20). Since goats are voracious eaters and may destroy vegetation indiscriminately, it has become necessary to restrict their grazing and browsing. The development of proper feeding standards for goats, therefore, has become of paramount importance to help them grow, reproduce, and produce well under stall feeding conditions (15).

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PROTEIN REQUIREMENTS FROM NITROGEN-FREE FEEDING STUDIES

Majumdar (11) was probably the first to conduct experiments on minimum protein requirements for maintenance employing endogenous urinary nitrogen (EUN) and metabolic fecal nitrogen (MFN) excretion methods on Jamunapari bucks. In the absence of a completely N-free roughage, he employed wheat bhoosa (chaffed wheat straw) and alkali-treated bagasse in two separate experiments. For the adequate supply of energy, vitamins, and minerals, a concentrate mixture of sago, sugar, and oils was used in both experiments. The ration comprised the following ingredients and parts on a dry basis: N-free/low-N roughage 666, sago dextrinized 257, sugar (crystalline and extra white) 40, oil mixture 12, salt mixture 12, mineral mixture 12, trace element mixture 1; the oil mixture consisted of cod-liver oil 20 parts, olive oil 20, peanut oil 60; the mineral mixture contained calcium carbonate 25 parts, sodium phosphate 35, potassium hydrogen phosphate 20, magnesium carbonate 19, sodium citrate 1; the trace element mixture consisted of ferrous oxide 180 parts, copper sulphate 50, cobalt chloride 20, manganese sulphate (anhydrous) 100, potassium iodide 15, sodium carbonate (anhydrous) 75, sodium thiosulphate 75, and starch 75.

In the first experiment of Majumdar (11) six adult Jamunapari bucks were fed the wheat bhoosa and concentrate mixture above. The animals selected wheat bhoosa in preference to the concentrate mixture; therefore, the two feeds had to be fed separately. The concentrate mixture was fed in the morning and wheat bhoosa in the afternoon. A period of 3 wk preceded the metabolism trial of 7 days during which daily excretions of N in urine and feces were measured.

The goats did not show loss of appetite, although the feeding time for the concentrate mixture was increased. The feces in almost all cases had loose consistency. One animal developed acute diarrhea and had to be excluded from the experiment. The intake of dietary components and their N contents were dry matter intake from concentrate mixture 42.7%, dry matter intake wheat bhoosa 57.3%, N content of concentrate mixture, .02%, N content of wheat bhoosa .30%, N content of the composite ration .18%.

Observations during this first experiment are in Table 1. Dry matter consumption remained reasonably large (2.81 kg/100 kg body weight (W)), and daily N excretion in urine and feces decreased during the precollection period to become practically constant (EUN = .054 g/kg W and MFN = .40 g/100 g dry matter intake).

In a second experiment wheat bhoosa of Experiment 1 was replaced by alkali-treated bagasse (11). The concentrate mixture remained the same. This change adversely affected appetite and promoted loose gummy feces in most animals. Only three animals could consume adequate amounts of the concentrate mixture to have an overall intake of 2.13 kg dry matter/100 W. Following a preliminary feeding period of 10 days, a 5-day metabolism trial was con-

TABLE 1. Average daily feed intake, EUN, and MFN excretion in Jamunapari goats with low-N diet.[a]

Item	Animal no. 1	2	3	5	6
Body weight, kg	31.5	42.3	34.2	31.5	41.9
Intake of concentrates, g DM	435.7	435.7	435.7	435.7	435.7
Intake of roughage, g DM	464.3	634.3	711.3	524.3	591.3
Total DM intake, g	900	1070	1147	960	1027
EUN excretion, g	1.61	2.31	2.08	1.67	2.16
EUN excretion/kg body weight, g	.051	.054	.061	.053	.051
MFN excretion, g	4.03	4.50	4.70	4.06	3.30
MFN excretion/100 g DM intake, g	.45	.42	.41	.42	.32

[a]Nitrogen content: .18% EUN = endogenous urinary nitrogen; MFN = metabolic fecal nitrogen, DM = dry matter; average daily DM intake/100 kg body weight (W) of 5 animals = 2.81 kg; average EUN excretion/W = .054 g; average MFN excretion/100 g DM intake = .40 g (11).

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TABLE 2. Average daily feed intake, endogenous urinary nitrogen (EUN), and metabolic fecal nitrogen (MFN) excretion in Jamunapari goats with N-free diet.[a]

Item	Animal no. 2	3	6
Body weight, kg	43.2	34.2	39.6
Intake of concentrates, g DM	500	450	500
Intake of roughage, g DM	362	310	360
Total	862	760	860
EUN excretion, g	2.26	1.70	2.00
EUN excretion/kg body weight, g	.052	.049	.050
MFN excretion, g	3.88	3.10	3.75
MFN excretion/100 g DM intake, g	.45	.41	.44

[a]Nitrogen content = .029%; average daily DM intake/100 W of 3 animals = 2.13 kg; average EUN excretion/W = .050 g; average MFN excretion/100 g DM intake = .43 g (11).

ducted, and observations are in Table 2. Intakes of ration components and their N contents were: dry matter (DM) intake from concentrate mixture 58.4%, DM intake bagasse 41.6%, N content of concentrate mixture .02%, N content in bagasse .04%, and N content of composite ration .03%.

In Table 2 overall dry matter consumption was 2.13 kg/100 W. The endogenous N in this study was reached in 10 days with an average .050 g/W that closely agreed with the .054 g/W of the previous experiment. The MFN .43 g/100 g DM intake was also close to the .40 g/100 g DM intake of the first experiment. The EUN and MGN of these two experiments averaged .052 g EUN/W or .1285 g/$W^{.75}$ and .41 g MFN/100 g DM intake.

This overall EUN .052 g/W was used for calculating minimum protein requirements for maintenance, for protein having a biological value of 50 (13). Minimum digestible crude protein requirement (DCP) = .052 × 6.25 × 2 g/W or = .065 kg/100 W. Expressed on a metabolic body weight basis for a 37.3 kg animal (37.30 kg W or $W^{.75}$ = 15.09 kg), this becomes 1.61 g/$W^{.75}$.

This protein requirement has been used for calculating utilizable protein: g UP = $K(W)^{.734}$. This value has been reported different for various species, i.e., .88 for farm animals in general (14) and .74 for sheep (28). The K's for goats are in Table 3. Their average is .89 and practically the same as given by Mitchell (14).

For assessing energy needs, the findings of Smuts (27), who considered a constant relationship between excretion of EUN and basal energy output of different species, also was used by Majumdar (11). This relationship suggested that 2 mg of EUN or 12.5 mg protein are equivalent to 1 kcal basal metabolic heat (2). Based on this relationship of EUN to basal energy metabolism and by the formula UP = .89 $(W)^{.734}$ for the utilizable protein, the digestible crude protein (DCP) (twice of the utilizable protein 50% biological value) and the basal metabolic heat (kcal) for goats of different body weights are in Table 4.

Studies of Singh and Mudgal (24) determined the endogenous urinary and metabolic fecal nitrogen for maintenance requirements of protein in castrated Beetal bucks. In the first trial with five animals, the N-free diet contained .027% N. The concentrate mixture consisted of sago, sugar, peanut oil, cod-liver oil, olive oil, mineral mixture, and common salt containing .035% N. Alkali-treated bagasse contained .015% N.

In the second trial with five animals, the low-N diet contained .104% N. The concentrate mixture was the same as before, but wheat bhoosa had .209% N.

Methods for measuring EUN and MFN were the same as used by Mukherjee and Kehar (16) with cattle and by Majumdar (11) with goats. The DCP requirement for maintenance was calculated from EUN and MFN by the method of Crampton and Harris (4).

In the N-free diet the EUN g/$W^{.75}$ was .10,

TABLE 3. Determination of K in utilizable protein (UP) = K $W^{.734}$ for predicting endogenous urinary nitrogen (EUN) (11).

Animal no.	Body weight	EUN Excreted	EUN Expressed as protein (EUN X 6.25)	K	Utilizable protein UP = .89 X $W^{.734}$	Deviation
	(kg)	(g)	(g)		(g)	(%)
1	31.5	1.61	10.1	.80	11.2	+11.3
2	42.3	2.31	14.4	.92	14.0	- 3.2
3	34.2	2.08	13.0	.97	11.9	- 8.5
5	31.5	1.67	10.2	.80	11.2	+ 9.5
6	41.9	2.16	13.5	1.03	13.8	+ 2.2
2	43.5	2.26	14.1	.89	14.2	+ .4
3	34.5	1.70	10.6	.79	12.0	+12.6
6	39.9	2.00	12.5	.95	13.3	+ 6.5
Average	37.4			.89		

the MFN g/100 g DM intake .396; in the low-N diet the EUN g/$W^{.75}$ was .097, the MFN g/100 g DM intake .445; averaging .098 g EUN/$W^{.75}$ and .42 g MFN/100 g DM intake, which is comparable to results of Majumdar (11).

The DCP requirement for maintenance was 106 g/100 W for N-free diets and 128 g/100 W for low-N diets. The average was 117 g/100 W.

Majumdar (12) also determined digestible protein requirements for maintenance from balance studies. He conducted four metabolic trials with rape cake as the sole concentrate and wheat bhoosa as the sole roughage for six adult Jamunapari bucks. Calcium as $CaCO_3$ and phosphorus as Na_2HPO_4 also were provided when necessary to keep the experimental subjects in Ca and P balance. Protein intake was varied to bring the N balance from an initial negative to positive. Of these four trials, the first one, which had negative Ca, P, and N balances, was rejected. Nutritional balances, as recorded in the remaining three trials, are in Table 5.

TABLE 4. Prediction of maintenance requirements of protein for goats from utilizable protein (UP) = .89 $W^{.734}$ and of energy requirements for different body weights.[a]

Weight	Utilizable protein from equation UP = .89 X $W^{.734}$	Digestible protein	Basal metabolism	Basal metabolism
(kg)	(g)	(g)	(kcal/day)	(kcal/kg)
10	4.8	9.6	386	38.6
15	6.5	13.0	520	34.7
20	8.0	16.0	642	32.0
25	9.9	19.8	791	31.6
30	10.8	21.6	864	28.8
35	12.1	24.2	968	27.7
40	13.3	26.7	1067	27.7
45	14.6	29.1	1164	25.9
50	15.7	31.4	1250	25.1

[a]Basal metabolism per $W^{.734}$ works out to be 71.2 kcal (11).

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TABLE 5. Intakes and balances of nitrogen (12).[a]

Animal no.	Trial 1				Trial 1A				Trial 1B			
	Body weight	Intake	Outgo	Balance	Body weight	Intake	Outgo	Balance	Body weight	Intake	Outgo	Balance
	(kg)	(g)			(kg)	(g)			(kg)	(g)		
1	17.9	6.07	7.48	−1.41	20.8	11.80	10.03	+1.77	20.8	10.39	9.20	+1.19
2	13.1	4.84	5.10	− .26	32.6	14.97	14.63	+ .34	29.0	13.66	11.35	+2.31
3	21.8	7.10	8.61	−1.51	24.9	13.57	11.79	+1.78	25.8	13.58	11.97	+1.61
5	22.2	6.66	8.64	−1.98	26.3	13.02	11.06	+1.96	25.4	13.05	12.37	+ .68
6	24.5	7.43	9.16	−1.73	26.3	12.91	11.26	+1.65	25.4	13.46	11.21	+2.25
Average	19.9				26.2				25.3			

[a]Overall average body weight = 23.80 kg; average body surface area $W^{.75}$ = 10.78.

These N balance data were subjected to five different treatments, graphical, statistical, percentage utilization, Harris-Mitchell formula, and DM intake relationship to determine the requirements of N.

Graphical Method

This method was described by Leitch and Duckworth (10) for man and employed by Majumdar (11) with goats and Bhargava (3) with buffalo. The N balance data of Table 5 were converted to mg N/W (Table 6) and plotted against daily intake for the individual animals. Lines joining these points cut th ordinate at two points, a and b, which represent the daily minimum and maximum N intakes (mg), that would result in zero balances in N equilibrium. The average of the two gives the mean N requirement in mg/W per day.

The a (minimum) and b (maximum) for the animals 1 to 5 in this study were: 433, 454; 390, 429; 430, 431; 407, 464; 402, 404; they averaged 424.40 ± 22.40 mg N/W.

When expressed per metabolic body size ($W^{.75}$), the requirements on 23.80 W ($W^{.75}$ = 10.78) and 66% digestibility of feed protein were: 937 mg N/$W^{.75}$ or 5.86 g CP/$W^{.75}$ or 3.87 g DCP/$W^{.75}$ or .122 kg DCP/100 W.

Statistical Method

This method is based on a close relationship between N intake and outgo. The N requirement can be approximated statistically by the regression of outgo on intake (29). The N intake (X) is taken as the independent variable and the N outgo (Y) as the dependent one for individual animals. The regression coefficient is calculated by analysis of covariance to estimate differences among animals.

The N requirement is determined as the

TABLE 6. Intakes and balances of nitrogen, mg/kg body weight (12).[a]

Animal no.	Trial 1			Trial 1A			Trial 1B		
	Intake	Outgo	Balance	Intake	Outgo	Balance	Intake	Outgo	Balance
	(mg)								
1	339	418	−79	567	482	+85	500	443	+57
2	370	390	−20	459	449	+10	471	391	+80
3	326	395	−69	545	473	+72	526	464	+62
5	300	389	−89	495	420	+75	514	487	+27
6	303	375	−71	491	428	+63	530	441	+89

[a]Body weight of Table 5.

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minimum N intake by the regression equation $y = \bar{y} + b(x - \bar{x})$ where $\bar{y}$ and $\bar{x}$ represent averages of Y and X and the requirement, R, is the point of intercept of the above lines, represented by the formula:

$$R = \frac{y - b\bar{x}}{1 - b}$$

The N requirements are estimates and are subject to errors of sampling. An idea of the magnitude of the standard error is, therefore, necessary for assessing accuracy of requirements by the formula:

$$V(R) = \left(\frac{1}{n(1-b)^2} + \frac{(\bar{y} - \bar{x})^2}{\Sigma(X-\bar{x})^2 \ (1-b)^4} \right) S^2$$

where S^2 is residual sum of squares and the square root of this variance is the standard error.

In this case (Table 6) N requirements were 417 mg N/W with a standard error of estimate of 16.3. When converted to CP and DCP for a 66% digestibility of feed protein, requirements per $W^{.75}$ on the basis of 23.80 kg body weight (body surface area 10.78) result in 921 mg $N/W^{.75}$, or 5.76 g $CP/W^{.75}$, or 3.80 g $DCP/W^{.75}$ or .120 kg DCP/100 W.

Percentage Utilization Method

This method uses the formula:

$$\text{N requirements, g} = \text{N intake} \pm \left(\frac{\text{N balance}}{\text{\% utilization}} \times 100 \right)$$

with + and − signs for animals with − and + N balances.

Data of Table 6 were analyzed by this formula. The percentage utilization of N of individual animals averaged 69.8 (Table 7). The N requirement/W was 424.1 mg/W.

When converted for metabolic body size $W^{.75}$, requirements for 23.80 kg body weight (surface area 10.78) with 66% digestibility of feed protein result in 936 mg $N/W^{.75}$ or 5.85 g $CP/W^{.75}$ or 3.86 g $DCP/W^{.75}$ or .122 kg DCP/100 W.

Harris-Mitchell Method

The Harris-Mitchell formula (9) as reported by Sen (21) determines:

$$\text{N requirement} = \frac{\text{EUN} + \text{MFN}}{\text{BV} \times \text{TD}},$$

TABLE 7. Requirements of nitrogen from percentage utilization method (12).[a]

Animal no.	N Intake	N Balance	N Utilization	N Requirement/kg body weight
	(mg)	(mg/kg)	(%)	(mg)
1	339.1	−78.9	...	...
	567.3	+85.1	71.9	448.9
	499.5	+57.2	84.8	432.1
2	369.5	−19.8	...	...
	459.2	+10.4	33.7	428.3
	471.0	+79.7	98.0	389.7
3	325.7	−69.3	...	...
	545.0	+71.5	64.2	433.6
	526.4	+62.4	65.6	431.3
5	300.0	−89.2	...	...
	495.1	+74.5	83.9	406.3
	513.8	+26.8	54.2	464.6
6	303.3	−70.6	...	...
	490.9	+62.7	71.1	402.6
	529.9	+62.7	70.3	403.7
Average			69.8	424.1

[a]N utilization (%) were derived from the retained N as exhibited by the balance data when expressed as percent of additional N intake above the amount producing a negative N balance.

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where BV is the biological value and TD is the true digestibility of the ration protein (in decimals).

The nitrogen requirements thus obtained for the different animals, average 378.78 mg N/W as in Table 8.

On metabolic body size $W^{.75}$ requirements for 25.73 kg body weight (surface area 11.42) and 66% feed protein digestibility result in 853 mg $N/W^{.75}$ or 5.33 g $CP/W^{.75}$ or 3.52 g $DCP/W^{.75}$ or .111 kg DCP/100 W.

Requirements from DM Intakes

Requirements of energy and protein also can be assessed grossly from DM intakes for 1 kg DM = 2.75 Mcal DE with 62.50% DM digestibility or 1 kg DM = 2.44 Mcal DE with 55.40% digestibility and 1 kg TDN = 4.4 Mcal DE.

Majumdar's data (11) of DM intake have been used for this calculation. Although not planned, DM intake was of the order of maintenance. The average digestibility in balance trials by Singh and Sengar (55.40%) (26) was used in the pooled data. For calculating the protein requirement, 1 Mcal DE = 25 g DCP was used. The information is in Table 9.

From the energy requirements of 163 kcal $DE/W^{.75}$, the DCP requirement has been calculated from the equivalence 1 Mcal DE = 25 g DCP as protein requirement = 4.075 g $DCP/W^{.75}$ or = .129 kg DCP/100 W.

ENERGY AND PROTEIN REQUIREMENTS BASED ON METABOLISM TRIALS AND N BALANCES

Singh and Sengar (26) reported from N balance data of metabolism experiments involving two breeds of goats (Barbari and Jamunapari) the maintenance requirements of protein (DCP) employing the 1) graphical, 2) statistical, 3) percentage utilization, 4) Harris-Mitchell, and 5) DM relationships methods. With the Harris-Mitchell formula, the EUN and MFN of Majumdar (11) were used. The requirements (DCP) as arrived at by the different methods, for 26.36 W or body surface area $W^{.75}$ = 11.63 were by the graphical method (eight animals) 133.5 g and 3.03 g; by the percentage utilization method (39 observations) 128.5 g and 2.91 g; by the Harris-Mitchell method (83 observations) 114.7 g and 2.60 g; and in average 125.5 g and 2.85 g DCP.

Graphical Method

The N balance data of three metabolism trials with six animals are in Tables 10 and 11 and are plotted in Figure 1. The minimum a and maximum b intakes that would result in zero balances and at which the animal would be in N equilibrium were from intercepting points on ordinates for animal 6, 304 and 305 mg; animal 95, 318 and 338 mg; animal 372, 332 and 340 mg; animal 373, 377 and 395 mg;

TABLE 8. Requirements of nitrogen by the Harris-Mitchell formula method (12).

Animal no.	Body weight	EUN	MFN	BV	TD	N Requirement
	(kg)	(g)		(%)		(g)
1	20.8	1.04	2.93	52.5	92.6	8.17
2	32.6	1.63	3.39	41.2	87.0	14.02
3	24.9	1.25	3.31	50.9	91.7	9.76
5	26.3	1.32	2.86	50.6	93.1	8.87
6	26.3	1.32	2.77	48.5	91.8	9.19
1	20.8	1.04	2.59	52.7	87.9	7.84
2	29.0	1.45	3.61	58.2	92.8	9.37
3	25.8	1.29	3.52	50.3	93.8	10.19
5	25.4	1.27	2.90	48.5	76.6	11.21
6	25.4	1.27	3.37	55.3	92.5	9.06
Average	25.73[a]	1.29	3.12	50.9	90.0	9.77

[a]Body surface area $W^{.75}$ = 11.42; average N requirement/kg body weight (W) = $\frac{9.77 \times 1000}{25.73}$ = 378.78 mg.

EUN = endogenous urinary nitrogen; MFN = metabolic fecal nitrogen; BV = biological value; TD = true digestibility.

TABLE 9. Energy requirement deduced from dry matter (DM) intakes (12).[a]

Animal no.	Body surface area $W^{.75}$	DM Intake
		(g)
1	9.74	714
2	13.64	826
3	11.15	807
5	11.61	697
6	11.61	674
1	9.74	632
2	12.50	880
3	11.45	858
5	11.31	706
6	11.31	822
Average	11.42	762

[a]Animal weights as in Table 8; DM digestibility of 55.40% reported by Singh and Sengar (26) has been used to calculate the factor for DE; 1 kg DM = 2.44 Mcal DE; average energy requirements = 1858.30 kcal DE per $W^{.75}$ = 163 kcal DE.

animal 374, 394 and 460 mg; animal 379, 369 and 370 mg; average 358.5 mg ± 13.05 N/W.

When expressed on metabolic body size $W^{.75}$ requirements for 26.36 kg body weight (surface area 11.63) and 68% digestibility of feed protein were 813 mg N/$W^{.75}$ or 5.08 g CP/$W^{.75}$ or 3.45 g DCP/$W^{.75}$ or .109 kg DCP/100 W.

Statistical Method

Data of Table 11 were analyzed by this method, and the N requirement was 362.50 mg N/W with a standard error of estimate of 11.32. Converted to $W^{.75}$ for 26.36 W (surface area 11.63) and 68% digestibility of feed protein, the requirements were 822 mg N/$W^{.75}$ or 5.14 g CP/$W^{.75}$ or 3.50 g DCP/$W^{.75}$ or .111 kg DCP/100 W.

Percentage Utilization Method

The data of Table 11 were analyzed as in Table 12 with an overall average of 76.12% N utilization.

The average N requirement was 365.30 mg/kg W. Converted to metabolic body size for 68% digestibility of ration protein, the requirements were 828 mg N/$W^{.75}$ or 5.18 g CP/$W^{.75}$ or 3.52 g DCP/$W^{.75}$ or .111 kg DCP/100 W.

Harris-Mitchell Method

In the absence of our own EUN and MFN, they have been borrowed from Majumdar (11, 12). The N requirements thus obtained for different animals are in Table 13.

When expressed per metabolic body size $W^{.75}$ = 12.49 for 29.32 kg body weight and 69% digestibility of feed protein, the requirements would be 704 mg N/$W^{.75}$ or 4.40 g CP/$W^{.75}$ or 3.04 g DCP/$W^{.75}$ or .096 kg DCP/100 W.

TABLE 10. Intakes and balances of nitrogen per day (26).[a]

Breed	Animal no.	Trial 1				Trial 2				Trial 3			
		Body weight	In-take	Out-go	Balance	Body weight	In-take	Out-go	Balance	Body weight	In-take	Out-go	Balance
		(kg)	(g)			(kg)	(g)			(kg)	(g)		
Jamuna-pari	6	38.00	11.45	11.55	− .10	39.20	14.54	12.46	+2.08	43.20	18.94	15.20	+3.74
	95	37.20	10.49	11.50	−1.01	37.10	14.51	13.53	+ .98	37.25	17.43	13.33	+4.10
Barbari	372	21.30	5.26	6.67	−1.41	22.00	7.24	7.47	−. .23	26.00	10.39	9.02	+1.37
	373	18.10	4.48	6.69	−2.21	21.53	8.07	8.74	− .67	22.00	9.36	8.35	+1.01
	374	17.00	4.32	6.41	−2.09	17.93	8.07	8.61	− .54	19.00	9.27	7.72	+1.55
	379	17.50	4.31	6.46	−2.15	20.17	7.95	7.46	+ .49	20.00	9.11	7.39	+1.72
Average		24.85				26.32				27.91			

[a]Overall average body weight: 26.36 kg and body surface area $W^{.75}$ = 11.63.

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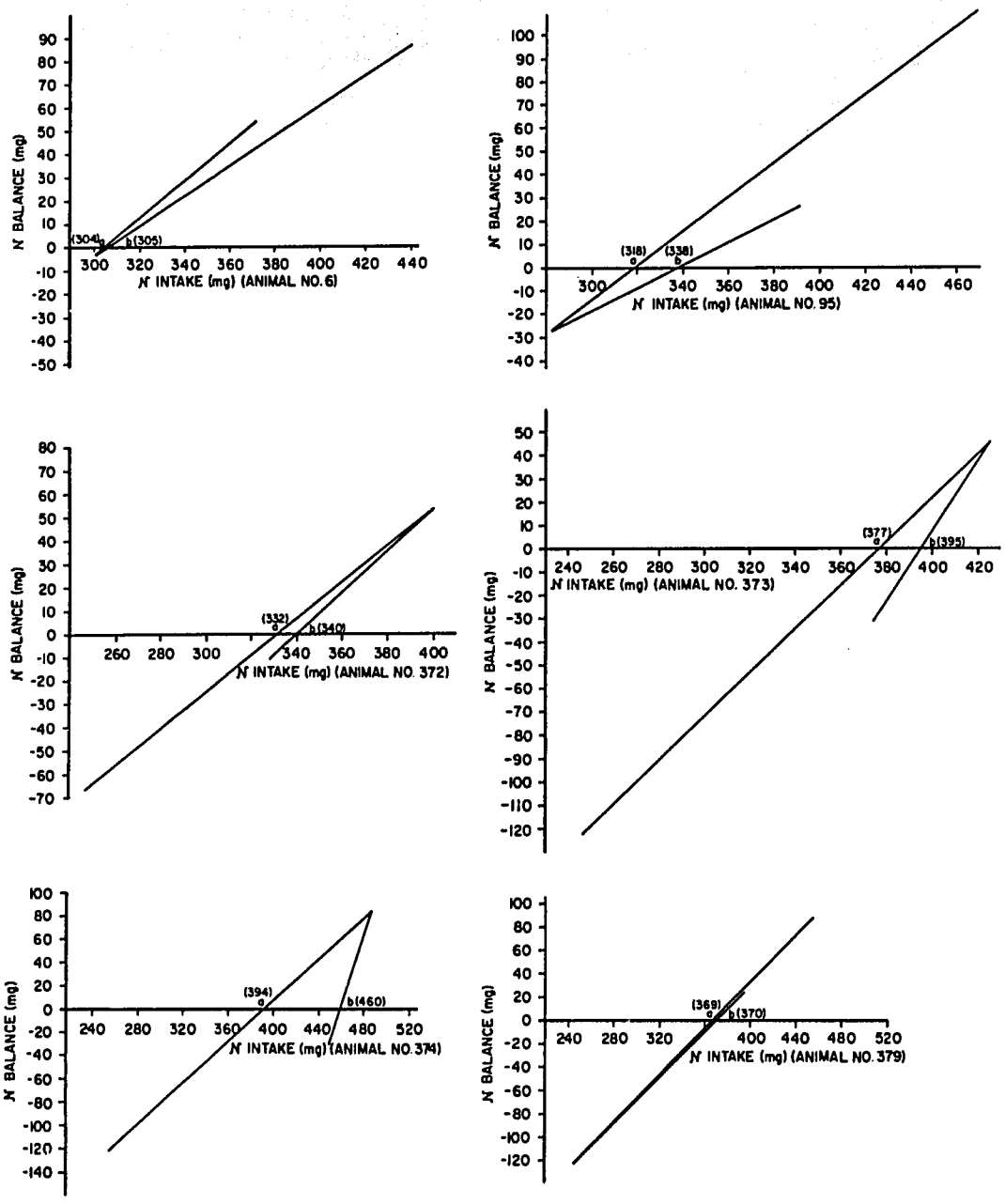

Figure 1. Nitrogen balances for animals No. 6, 95, 372, 373, 374, and 379 in relation to nitrogen intakes.

Requirements from DM Intakes

The requirements of energy and protein also have been derived from DM intakes as explained above for the Majumdar data (11). The information is in Table 14. For calculating the protein requirement, 1 Mcal DE = 25 g DCP has been used.

Resulting for energy and protein, respectively, are energy = 138.93 kcal DE/$W^{.75}$ and protein = 3.47 g DCP/$W^{.75}$ or .110 kg DCP/100 W.

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TABLE 11. Nitrogen intakes and balances per kilogram body weight (26).[a]

Animal no.	Trial 1			Trial 2			Trial 3		
	Intake	Outgo	Balance	Intake	Outgo	Balance	Intake	Outgo	Balance
	(mg)								
6	301	304	− 3	371	318	+53	438	352	+ 86
95	282	309	− 27	91	365	+26	468	358	+110
372	247	313	− 66	329	339	−10	400	347	+ 53
373	248	370	−122	375	406	−31	425	380	+ 45
374	254	377	−123	450	480	−30	488	406	+ 82
379	246	369	−123	394	370	+24	456	370	+ 86

[a]Animals of Table 10.

REQUIREMENTS BASED ON FEEDING TRIALS

Realizing limitations of metabolism trials and balance studies for determining nutrient requirements (23), Singh and Sengar (25) used feeding trials for determination of energy needs for different physiological and productive functions. Protein requirements have been determined from relationships between digestible energy (DE) and digestible crude protein (DCP). The high and medium energy groups getting medium protein (by Morrisons' standards for sheep), representing practical conditions, were considered. The study involved growing, reproducing, and lactating animals. Their per day intakes of energy and protein are in Table 15. The equivalence of each Mcal DE works out to be 25 g DCP, compared to 19.4 g of Crampton and Harris (4).

TABLE 12. Nitrogen requirements on the basis of the percentage utilization method (26).

Animal no.	Average body weight (3 trials)	Nitrogen intake per kg	Nitrogen balance per kg	Nitrogen utilization	Nitrogen requirement per kg
	(kg)	(mg)		(%)	(mg)
6		301.3	− 2.6		
	40.13	370.9	+ 53.1	80.0	304.5
		438.4	+ 86.6	65.0	305.2
95		282.0	− 27.1		
	37.18	391.1	+ 26.4	49.0	337.2
		467.9	+110.0	73.7	318.6
372		246.9	− 66.2		
	23.10	329.0	− 10.5	67.8	344.5
		399.6	+ 52.7	77.9	331.9
373		247.5	−122.1		
	20.54	374.8	− 31.1	71.5	418.3
		425.4	+ 45.9	94.4	376.8
374		254.1	−122.9		
	17.98	450.1	− 30.1	47.3	513.7
		487.9	+ 81.6	87.5	394.6
379		246.3	−122.8		
	19.22	394.1	+ 24.3	99.5	369.7
		455.5	+ 86.0	99.8	369.3
Average				76.12	365.3

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TABLE 13. Nitrogen requirement based on the Harris-Mitchell formula (26).[a]

Animal no.	Body weight	EUN[b]	MFN[b]	BV[b]	Digestibility True	Digestibility Apparent	Nitrogen requirement
	(kg)	(g)		(%)			(g)
6	39.20	2.04	3.58	53.73	98.55	73.93	10.61
95	37.10	1.93	2.91	40.73	98.48	78.43	12.07
379	20.17	1.05	2.23	50.07	94.72	66.67	6.92
6	43.20	2.25	4.29	60.72	89.39	66.74	12.05
95	37.25	1.94	4.09	65.27	89.04	65.58	10.37
372	26.00	1.35	2.48	54.68	91.53	67.66	7.65
373	22.00	1.14	2.27	51.39	91.88	67.63	7.22
374	19.00	.99	2.32	56.38	92.99	67.96	6.31
379	20.00	1.04	2.14	59.54	90.59	66.85	5.90
Average	29.32[a]	1.53	2.92	54.72	93.02	69.05	8.79

[a]Body surface area $W^{.75}$ = 12.49 when average weight = 29.32 kg; average N requirement per kg body weight $= \frac{8.79 \times 1000}{29.32} = 299.80$ mg.

[b]EUN = endogenous urinary nitrogen; MFN = metabolic fecal nitrogen; BV = biological value.

Requirements from DM Intakes

An adult flock of 300 animals involving 84 Jamunapari (A), 72 Beetal (B), 72 Barbari (C), and 72 Black Bengal (D) was housed separately as large breeds (A and B) and small breeds (C and D) with community feeding arrangements. For large and small breed groups and overall, respectively: average body weights (kg) 25.80, 16.65, 21.23; average metabolic body size $W^{.75}$, 11.45, 8.25, 9.89; DM intake/animal (g), 703.1, 531.1, 628.4; DM intake/100 W (kg), 2.72, 3.19, 2.96; TDN intake/animal (DM digestibility 60%) (g), 421.86, 318.66, 377.04; DE intake/animal (TDN x 4.40) (kcal), 1856.2, 1402.1, 1659.0; DE intake/$W^{.75}$ (kcal), 162.11, 169.95, 167.75; and DCP intake/$W^{.75}$ (g), 4.05, 4.25, 4.20.

These energy and protein intake data do not pertain to specific production purposes. They include maintenance and production of the animals, some growing, some pregnant, and some in lactation.

TABLE 14. Energy and protein requirements derived from dry matter (DM) intakes (26).

Animal no.	Body weight	Body size $W^{.75}$	DM intake	Digestion coefficient	Digestible DM/TDN	Digestible energy	DE/$W^{.75}$
	(kg)		(g)	(%)	(kg)	(kcal)	
6	39.20	16	873	59	517	2276	145
95	37.10	15	10	56	398	1752	117
379	20.17	10	543	52	284	1251	131
6	43.20	17	1048	64	675	2970	176
95	37.25	15	997	52	519	2285	152
372	26.00	12	605	52	316	1390	121
373	22.00	10	555	50	280	1230	121
374	19.00	9	565	57	320	1409	155
379	20.00	9	522	55	285	1254	133
Average	29.32	13	713	55	399	1758	139

TABLE 15. Daily intake of energy and protein by different goats (25).[a]

Breed	Age	Daily TDN intake	DCP intake	DE	DCP intake per Mcal DE
		(g)		(Mcal)	(g)
		High energy-medium protein diet			
Jamunapari	Up to 6 mo	157	17	1	24
	Up to 10 mo	239	23	1	22
	Up to 14 mo	277	25	1	20
	Adult, breeding, and lactating	846	79	3	21
Barbari	Up to 6 mo	174	18	1	23
	Up to 10 mo	212	22	1	23
	Up to 14 mo	214	26	1	27
	Adult, breeding, and lactating	576	60	2	24
	Average of 8 groups				23
		Medium energy-medium protein diet			
Jamunapari	Up to 6 mo	151	20	1	30
	Up to 10 mo	236	29	1	28
	Up to 14 mo	269	30	1	25
	Adult, breeding, and lactating	728	84	3	26
Barbari	Up to 6 mo	157	20	1	28
	Up to 10 mo	191	24	1	29
	Up to 14 mo	193	23	1	28
	Adult, breeding, and lactating	519	66	2	29
	Average of 8 groups				28

[a]Average digestible crude protein (DCP) intake per Mcal digestible energy (DE) = 25.00 for 16 groups.

Energy and Protein Requirements for Maintenance

Rajpoot (19) and coworkers involved a total of 13 healthy adult nonproducing animals on a ration of gram bhoosa (dry roughage) and alfalfa (green roughage) for 8 wk.

Gross energy of intake and excretion was determined with a bomb calorimeter. Gains and losses in body weight during the 8 wk were considered as storage of net energy in the form of fat and were accounted for from the ingested amounts by the conversion factor of 9.0 kcal/g gain. To convert the same into gross energy, we employed the recommendation of Garrett et al. (7), 100 GE = 76 DE = 62 ME = 35 NE.

Maintenance requirements for protein were calculated from energy intake (1 Mcal DE = 25 g DCP) (Table 16). The maintenance requirements for energy and protein were 125.0 kcal DE/$W^{.75}$ and 3.13 g DCP/$W^{.75}$, respectively.

Energy and Protein Requirements for Growth

Rajpoot (19) and coworkers estimated growth requirements of energy and protein involving 35 kids of different breeds (Jamunapari (A), Beetal (B), Barbari (C), and Black Bengal (D)), ages, and body weights (Table 17). These were maintained on a liberal ration of concentrate mixture (barley 25%, corn 20%, peanut oil meal 30%, gram 5%, wheat bran 8%, molasses 5%, chalk 2%, salt 2%, and mineral

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TABLE 16. Energy and protein requirements for maintenance (19).[a]

No. of observations and weight range	W and $W^{.75}$	Daily gain in body weight	Total energy intake	Energy voided in feces	DE	DE for gain	DE for maintenance	$DE/W^{.75}$	$DCP/W^{.75}$
— (kg) —		(g)	(kcal)						(g)
4 (10–20)	13.31 (6.97)	25.0	2317	831	1486	489	997	143	3.6
5 (20–30)	25.72 (11.42)	62.8	4217	1443	2774	1227	1547	135	3.4
2 (30–40)	32.34 (13.56)	97.0	5167	1730	3436	1896	1541	114	2.8
2 (40 and above)	46.77 (17.89)	108.0	6464	2423	4041	2111	1930	108	2.7
Average	29.54 (12.67)							125	3.1

[a]W = kg body weight, DE = digestible energy, DCP = digestible crude protein.

mixture 3%), and roughages (gram bhoosa and green napier) for 8 wk. From the total energy ingested, the maintenance part was subtracted to arrive at the energy required for gain.

The protein requirement of these growing animals was calculated from energy intake (1 Mcal DE = 25 g DCP) as usual.

The consolidated requirements of energy and protein for growth, irrespective of stage of growth, were 7.88 kcal DE and .195 g DCP/g gain.

Energy and Protein Requirements for Pregnancy

Rajpoot (19) and coworkers used 10 goats of the Jamunapari (A), Beetal (B), Barbari (C),

TABLE 17. Energy and protein requirements of growing animals (19).[a]

No. of animals	Body weight	Metabolic body size $W^{.75}$	Daily weight gain	DE intake	DE for maintenance	DE for gain	DE per g gain	For growth + maintenance per $W^{.75}$ DE	DCP
	(kg)		(g)	(kcal)					(g)
2 (A)	12.03	6.46	79	1519	808	711	9.00	235	4.6
11 (B)	17.29	8.48	121	2043	1060	983	8.12	241	4.7
7 (C)	11.64	6.30	87	1486	788	698	8.02	236	4.6
15 (D)	9.27	5.31	67	1165	664	501	7.48	219	4.3
Average			88			723	7.88	233	4.5

[a]A = Jamunapari, B = Beetal, C = Barbari, D = Black Bengal, W = kg body weight, DE = digestible energy, DCP = digestible crude protein.

and Black Bengal (D) breeds, each on a liberal diet from the beginning of the 3rd mo of pregnancy to kidding time. Their ration included concentrate mixture, gram bhoosa, and green jowar and were caged individually during the 5th mo of pregnancy. Body weights just before and after kidding along with weights of kids, placenta, and placental fluids were recorded. Gains and losses in body weight from the 3rd mo of pregnancy to immediately after kidding was accounted for from the ingested amounts (9 kcal/g fat). The requirement of protein (DCP) was derived again from the energy requirement 1 Mcal DE = 25 g DCP (Table 18).

The 221.79 kcal DE and 5.55 g DCP/$W^{.75}$ represent the total requirements (maintenance + pregnancy) of goats with a mean body weight of 30.38 kg and gaining during pregnancy 61.75 g/day during the last 2 mo of gestation.

Energy and Protein Requirements for Lactation

Rajpoot (19) and coworkers determined requirements of lactation in a feeding trial with 19 animals (4 Jamunapari, 5 Beetal, 5 Barbari, and 5 Black Bengal) on a liberal diet starting at the stage of advanced pregnancy. They were fed a concentrate mixture, gram bhoosa, and green alfalfa. Toward the end of the second mo of lactation they were caged individually for 10 days for recording of energy intake and outgo. The total energy requirements of the lactating animals were calculated and apportioned separately for milk (4% FCM) and maintenance during lactation.

The requirements of protein (DCP) for lactation were calculated again from energy intake (1 Mcal DE = 25 g DCP) and the formula of Gaines and Davidson (6). The relevant determinations were: average body weight of 19 animals 28.90 kg; metabolic body size $W^{.75}$ 12.47; DE intake per day 4511.17 kcal; body weight gain + .32 g; DE equivalent of gain $\left(\frac{\text{gain (g)} \times 9 \times 76}{35}\right)$ 6.25 kcal; milk (5.22% fat) production per day 1131 g; 4% FCM 1340 g; DE equivalent of FCM per day $\left(\text{FCM kg } \frac{(700 \times 76)}{35}\right)$ 2037 kcal; DE equivalent of milk production 2043 kcal; W/kg gain balance of DE intake for maintenance per day (minus DE equivalent of milk production and gain) 2467 kcal; DE for working maintenance per $W^{.75}$ 4.95 g.

Synthesis and incorporation of energy and protein into milk can be calculated directly. According to Opstvedt (18), 700 kcal need to be considered for each kilogram of 4% FCM.

$$\text{Milk energy} = \frac{\text{FCM (kg)} \times 700 \times 76}{35} \text{ kcal DE}$$

$$\text{and per kg FCM} = \frac{1 \times 700 \times 76}{35} \text{ kcal DE} =$$

TABLE 18. Energy and protein requirements of pregnancy (19).

No. of observations and breed[a]	Body weight	Metabolic body size $W^{.75}$	Daily gain in body weight	Daily gain for pregnancy	Total DE intake	DE for body weight gain	DE for maintenance + pregnancy	Per $W^{.75}$ DE	Per $W^{.75}$ DCP
	(kg)		(g)		(kcal)				(g)
10 (A)	37.09	15.03	−6	68	3536	−117	3653	243	6.1
10 (B)	36.30	14.79	13	72	3589	254	3334	225	5.6
10 (C)	27.94	12.15	12	57	3003	235	2768	228	5.7
10 (D)	20.20	9.53	13	50	2073	234	1819	191	4.8
Average	30.38			61.75				222	5.6

[a]A = Jamunapari, B = Beetal, C = Barbari, D = Black Bengal, W = kg body weight, DE = digestible energy, DCP = digestible crude protein.

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1520 kcal DE/kg 4% FCM, and = 1246 kcal ME/kg 4% FCM if ME = 82% of DE according to NRC (17).

According to Crampton and Harris (4) 125 g of protein is needed for synthesis of 100 g milk protein. Thus, each kilogram of goat milk containing 3.725% protein (average of four breeds) will require $\frac{\text{protein (g) in milk} \times 125}{100}$ g DCP and per kg FCM = $\frac{37.25 \times 125}{100}$ g DCP, which is = 46.56 g DCP/kg 4% FCM. No allowance has been made for the varying fat percentage in milk as there is little or no relationship between milk fat and protein (4, 18). Opstvedt (18) has a small correlation (r = .13) between them.

CONCLUSIONS

From Table 19 the maintenance requirement for protein (DCP) of goats, calculated by different methods from balance data of Majumdar (12) ranged from 3.52 to 4.08 g with an average of 3.83 g/$W^{.75}$ and from 3.04 to 3.52 g with an average of 3.40 g/$W^{.75}$ in the studies of Singh and Sengar (26). The overall average of the two studies is 3.62 g of DCP/$W^{.75}$ per day.

The requirement from feeding trials (19) was for maintenance 3.13 g DCP/$W^{.75}$, which is

TABLE 19. Summary of energy and protein requirements of goats from India research.

Sources	Requirements/$W^{.75}$/day	
	Digestible energy	Protein (DCP)
	(kcal)	(g)
Majumdar based on EUN studies at minimum maintenance (11)		1.61
Singh and Mudgal (1978) based on EUN studies at minimum maintenance (23)		1.23
Majumdar based on balance studies at maintenance (12)		
Graphical method		3.87
Statistical method		3.80
Percentage utilization method		3.86
Harris-Mitchell method		3.52
Derived from DM intake	163	4.08
Average		3.83
Singh and Sengar based on balance studied at maintenance (26)		
Graphical method		3.45
Statistical method		3.50
Percentage utilization method		3.52
Harris-Mitchell method		3.04
Derived from DM intake	138.93	3.47
Average		3.40
Rajpoot et al. based on feeding trials for different functions (19)		
Based on DM intake for maintenance + production	168	4.20
Based on digestibility trials for		
Maintenance	125	3.13
Growth and maintenance	232.83	4.52
Pregnancy	221.79	5.55
Lactation maintenance	198	4.95
Milk production/kg 4% FCM	1520	46.56

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close to those from balance studies. Requirements of energy and protein for milk production by goats were 1520 kcal DE (ME = 1246.40 kcal) and 46.56 g DCP per kg 4% FCM in these experiments.

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Composition and Yield of Goat Milk as Affected by Nutritional Manipulation[1]

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ABSTRACT

This report deals with the influence of quantity and nature of roughages and concentrates on milk yield and composition by goats producing 500 to 900 kg milk per year, particularly the influence of crude fiber and crude protein. Forages with most voluntary intakes and milk yielding capabilities were legumes (alfalfa, red clover) and Italian ryegrass. Milk production was highest with green forages and hay pellets. Corn silage feeding reduced milk yields by 5 to 14% and hay of medium quality by 15 to 25%. Supplementary concentrates during midlactation increased intakes of dry matter and energy and milk production. Milk protein percentage was increased, but milk fat contents were lower. Increased intakes of energy raised percentages of palmitic acid and decreased carbon-18 acids. Low lipid contents (<1% of dry matter) in the total ration reduced milk production, fat percentages, and carbon-18 fatty acids in milk fat. Formaldehyde-treated oil-meals improved milk production. Concentrates at 400 g/kg milk instead of 200 g improved milk production by 20 to 25% in early lactation and by 7.5% in midlactation. Because of persistency, the feeding plan giving most economic returns during the whole cycle of reproduction seems to be a medium 200 to 400 g concentrates per day in late pregnancy and a high 300 to 400 g/kg milk during lactation.

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INTRODUCTION

Knowledge of factors affecting production and composition of goat milk has progressed over the last 10 yr. Attention was to factors in feeding which are important to farmers who want to make the most of the milking potential of their animals and to consumers whose concern is that feeding does not modify dietetic and organoleptic characteristics of goat milk and its products except to improve them.

Rations for goats, like those for other ruminants, are composed of roughages and concentrates. The influence of quantity and nature of these two types of feeds on milk production and composition will be examined during stages of lactation and whole cycles of production. Most results were in goats producing about 500 to 900 kg milk per year and kept in production systems with well controlled feeding, not on poor pastures and ranges where few means are available to change quantity and quality of feeds.

GOAT CHARACTERISTICS

Main characteristics of goat milk were published by Parkash and Jenness in 1968 (25). Total solids contents of goat milk are variable, and in France averages of dry matter of goat and cow milks are the same (6). The percentage of short chain fatty acids (from $C_{6:0}$ to $C_{12:0}$) is high in goat milk fat whereas that of C_{18} fatty acids is low. The structure of triacylglycerols in goat and cow milk is similar (19, 20, 21).

Goat milk contains a little less casein than cow milk; it is lower in proteose-peptones and richer in nonprotein nitrogen (25, 37). Lactose content is generally lower in goat milk; mineral composition is similar to cow milk except potassium and chloride contents are slightly higher in goat milk (30). Goat milk does not contain carotenoid pigments and only small amounts of vitamins B_6 and B_{12}.

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INFLUENCE OF INTAKE AND NATURE OF FORAGES

The basic diet of goats is composed of one or several green or stored forages (hay, silage, dried forage pellets) offered restricted or ad libitum. With 96 Alpine goats, de Simiane (33) compared six green forages, two ryegrasses, one orchardgrass, and three fescues; quality of forage dry matter affected the quantity of milk produced. There was a negative correlation between milk production and crude fiber content of the forage and a positive correlation between milk yield and the net energy of the forage. The crude protein content of the forage had only a small effect, whereas the dry matter content of green forages up to 16% had a favorable effect. The influence of the nature of forages (species, variety, number of cut, growth stage, and storage method) on milk production in goats depended on forage intake and net energy content of the forages.

According to Huguet et al. (13), the addition of hay to a diet of green forages did not improve milk production. This was because the supply of hay did not increase the intake of total dry matter of roughages. Skejvdal (35), who added hay to a grass silage diet, and Opstvedt (24), who included grass silage into a ration based on hay, obtained the same results. However, in the latter study addition of grass silage to the diet increased percentages of fat and protein and production of fat-corrected-milk by 5% while lactose contents remained unchanged.

Table 1 shows four green forages ranked according to their intake and their milk yielding capability for goats (34). Legumes, red clover, alfalfa, and, to less extent, ryegrass enabled high milk yields exceeding those on other grasses, tall fescue, and orchardgrass. The differences were from intakes of these forages (23, 33). Intake and milk yielding capability of each forage varied for varieties. Variation in crude fiber content seemed the cause of differences in feed consumption and milk production of the goats. Number of cuts and growth stage of the green forage affected intake.

Few experiments in goats have compared forages according to type of storage. Green feeding and pelleted hay produced most milk. Sole corn silage feeding reduced by 5 to 14% the milking performance, and legume hay of medium quality lead to larger reductions compared to green feeds or pelleted hay (33). Milk protein percentage seemed little affected by type of storage of the forage. Milk fat content was a little more affected by forage storage. Corn silage and green forages produced slightly higher milk fat percentages than hay. The nature of the forage had greater effects on goat milk production and composition of the milk because of differences in intake and digestibility related to crude fiber.

TABLE 1. Ranking of first growth forages according to their intake and milk yielding. Forages offered with 25 to 35% refusals (33).

	.7 kg DM concentrates/day added				.35 kg DM concentrates/day added			
			Milk yield				Milk yield	
Forage	No. of determinations[a]	Ingestion	Fat corrected milk (3.5%)	Persistency	No. of determinations[a]	Ingestion	Fat corrected milk (3.5%)	Persistency
Italian ryegrass	19	105%	106%	++	3	111%	113%	++
Orchardgrass	9	83%	90%	++	4	70%	82%	+
Fescue	5	97%	92%	++	...	...	...	...
Red clover[b]	13	108%	100%	+++	7	108%	104%	+++
Base 100 = average of the four forages		78.4 g/kgW$^{.75}$	3.33 kg			87 g/kgW$^{.75}$	3.20 kg	

[a]Weekly averages for 6 to 12 goats.

[b]Red clover followed 3 wk after the grasses.

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INFLUENCE OF SUPPLY OF CONCENTRATES

When goats receive forages produced on the farm, concentrate feeds are used to adjust energy, protein, and mineral balance of the ration. Thus, concentrate feeds represent the best means for the farmer to modify feeding, quantitatively and qualitatively.

Effect of Concentrate Amounts During Midlactation

Supplementary supplies of concentrates, even when reducing consumption of forages, generally increase intake of dry matter and energy. In Table 2 goats received different amounts of concentrates to satisfy 15% more or 15% less than their total requirements. Milk production was improved by almost 20% by the diet high in concentrate. Milk fat contents were slightly lower and protein and lactose contents higher (30, 31). A supplementary supply of energy led to more positive energy balances and energy reserves in the goat. Weights increased. In partition of energy between milk secretion and storage reserves, it appears that with a large amount of concentrates the part of energy stored as compared to that secreted in the milk is increased. At this stage of lactation, reconstitution of reserves takes priority to milk production, and maintenance of high production (i.e., its persistency) requires overfeeding of energy to the goats. Kondos (14) confirmed this by pointing out that during midlactation increase of milk yield is accompanied by weight gain.

These metabolic events relate to variations in the fatty acid composition of milk fat. When energy intake increases without modifying ratios of forage to concentrate, percentages of palmitic acid increase and those of C_{18} acids, especially stearic and oleic acids, decrease. : percentages of short chain fatty acids ($C<_{16}$) tend to increase. These results on milk fatty acid composition tend to be reversed when the proportion of concentrates in the diet increases and that of forage decreases.

The amount of acetic acid available from the rumen for milk synthesis is greater with energy-high than low-energy diets. Among the acids synthetized from acetic acid in the udder (C_4 to C_{16} acids), those with the higher carbon number, such as palmitic acid, are favored most by a large availability of acetic acid. However, increasing the concentrate portion of the diet tends to decrease the percentage of acetic acid in the rumen. Consequently, although the amount of milk fat is changed little, as milk production and milk fat contents vary in the opposite direction, the more or less abundant supply of concentrates has important effects on the fatty acid composition of milk lipids.

Conversely, underfeeding energy tends to increase mobilization of lipid reserves rich in C_{18} fatty acids. Nonesterified fatty acids increase in blood (Table 3). Accordingly, percentages of stearic and oleic acids in milk lipids are higher.

TABLE 2. Effect of amounts of concentrates on milk performance of goats in midlactation (30).[a]

Diet	Concentrate supply: High	Concentrate supply: Low
Total intake (kg DM/day)	2.51	2.25*
Forage intake (kg DM/day)	1.36	1.71**
Concentrate intake (kg DM/day)	1.21	.64***
Milk production (kg/day)	3.45	2.91**
Fat content (%)	2.73	2.85
Protein content (%)	3.01	2.83*
Lactose content (%)	3.79	3.65*
Persistency of milk production (% decrease/week)	2.77	3.55*
Energy balance (MJ/day)	+25.34	+18.8*
Average weight gain (g/day)	+32.1	+20.5*
Blood plasma NEFA (mg/100 ml)	45.9	51.2
Energy in milk (MJ/day)	8.99	7.73*
Energy in weight gain (MJ/day)	1.13	.71*
Energy in weight gain/energy in milk (%)	12.6	9.1

[a]From wk 9 to wk 27 of lactation, 32 Alpine goats were given alfalfa hay ad lib and concentrates: 350 g/kg milk in diet "high" in concentrates; and 175 g/kg milk in diet "low" in concentrates.

*$P<.05$ of difference between high and low.

**$P<.01$ of difference between high and low

***$P<.001$ of difference between high and low.

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TABLE 3. Effect of energy of diet on milk production and composition of milk fat (8).

Item	Diets[a] Low in energy	High in energy	Significance of effect of diet
Milk production (kg/day)	2.73	2.95	***
Fat content (%)	2.99	2.78	***
Fat production (g/day)	80.4	82.0	NS[b]
Percentage of fatty acids:			
$C_{8:0} - C_{14:0}$	28.9	30.3	**
$C_{16:0}$	27.9	30.7	***
$C_{18:0} + C_{18:1}$	23.8	19.8	***

[a]Diets: Alfalfa hay and concentrates in the same proportions in two diets. Diets high and low in energy provided 115% and 85% of goat requirements (forage/concentrate ratios are identical).

[b]NS, not significant.

**$P<.01$.

***$P<.001$.

Increase of milk yield following supplementary supplies of concentrates depends on variation of energy consumption. For goats producing 500 to 900 kg milk per year, a supply of concentrates not exceeding 600 to 800 g dry matter per day seldom leads to reduction of forage intake but sometimes increased it (30). Effects on milk production and composition were marked. When concentrates exceeded 800 g dry matter per day, effects were there but less marked. Results were similar in (24).

When varying amounts of concentrates were added to goat diets, differences in milk production and composition may be explained by changes in proportions of dietary components and energy supplies. In an experiment with three diets – 1) good alfalfa hay ad libitum and a restricted supply of concentrates, 2) alfalfa hay exposed to bad weather conditions for 15 days (resulting in a poor quality hay) and a high supply of concentrates to provide the same energy supply as in diet 1, 3) the poor quality hay of diet 2 and restricted supply of concentrates of diet 1 – energy supplies of diets 1 and 2 were the same and substantially higher than those of diet 3. Results of this experiment are in Table 4. At the same intakes of energy, production of fat-corrected-milk was not affected by proportions of hay to concentrate, whereas the milk fat content was higher when the portion of concentrates in the diet was high. Milk protein and casein contents, and accordingly cheese yields, were not affected by the proportions of hay to concentrates at the same energy, but they decreased nonsignificantly when energy was lowered.

Thus, it appears that supplementary supplies of concentrates affect milk production and composition through elevation of energy intakes rather than through a change in the feed composition of the diet.

Effect of Concentrate Amounts during Early Lactation

In early lactation, supplies of concentrates improve milk production as during midlactation (Figure 1). Effects on milk fat contents are minimal and on protein contents slightly negative (21, 22), which differs from results during midlactation. Effects of concentrate supplies are marked during early lactation but decrease during lactation.

TABLE 4. Effect of diet on production and composition of goat milk (29).

Item	Diets[a] G-L	P-H	P-L	Significance of effect of diet
Energy intake (MJ/day)	12.65	12.80	9.11	***
Milk production (kg/day)	3.00	2.88	2.17	*
Fat-corrected milk (4%) production (kg/day)	2.48	2.45	1.89	*
Fat content (%)	2.84	3.0	3.13	***
Protein content (%)	2.76	2.77	2.64	NS[b]
Casein content (%)	1.93	1.95	1.83	NS

[a]G-L alfalfa hay, good quality, ad lib plus limited concentrates.; P-H alfalfa hay, poor quality, ad lib plus high amount of concentrates; P-L alfalfa hay, poor quality, ad lib plus limited concentrates.

[b]NS, not significant.

*$P<.05$.

***$P<.001$.

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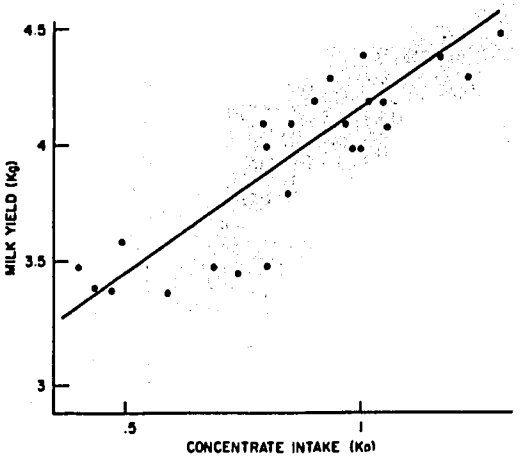

Figure 1. Effects of concentrates on milk production of goats in early lactation; (averages of 8 to 12 Alpine does; 4th to 5th week of lactation) (30).

Effects of Composition of Concentrates and Energy Concentration

When energy concentrations of concentrate mixtures were raised during midlactation by replacing feeds high in crude fiber (bran, alfalfa meal) (21) with feeds high in starch (grain), milk production and composition (milk fat content, protein content, fatty acid composition) changed little, but fat reserves increased. It is likely that results would have been different if the animals had been in negative energy balance as in early lactation. In (21), reducing cellulose and lignin contents of concentrates without modifying the crude fiber content tended to decrease milk yield slightly.

Lipid Contents of Concentrates

They may influence milk production and milk fat contents may be influenced by lipid contents of concentrates. Composition of these lipids can affect fatty acid composition of milk fat. Low lipid contents (<1% of dry matter in the total ration reduced milk production and milk fat percentages, whereas protein contents did not seem to be affected (4). In addition, the fatty acid composition of milk lipids was changed. The percentages of C_{18} fatty acids, especially stearic and oleic acids, were lower while fatty acids with short chains were raised. As milk C_{18} fatty acids come more from the diet in ruminants (11, 38), effects of reducing dietary lipid supplies on milk fat content and fatty acid composition of milk fat are not surprising.

Milk production, milk fat content, and percentages of C_{18} fatty acids were reestablished by adding animal fat or plant oil to the concentrates (Table 5) (4, 21).

A 2% ether extract content in the feed dry matter seems to be a minimum below which milk fat is reduced. This corresponds to about 1 g lipids per kilogram live weight (22).

Incorporation of large amounts of fat in the concentrates did not increase milk production and milk fat content but reduced them when fat in concentrates exceeded 7 to 10%, in particular if the fat was unsaturated (21). This excess tends to disturb cellulolysis in the rumen and subsequently reduces production of acetic acid, the precursor of acids synthesized in the udder.

TABLE 5. Effect of type of fat added in diet on goat milk composition (29).

Item	Diets[a] Basic	Animal fat added	Soybean oil added	Oxidized animal fat added	Significance of effect of diet
Fat content (%) (g/kg)	2.5	2.92	3.05	2.72	***
Protein content (%)	2.8	2.84	2.85	2.82	NS[b]
Peroxide index	77	76	75	69	NS

[a]Basic diet: alfalfa hay plus concentrates, low in lipids; in the other diets, 5% fat was added in concentrates.

[b]NS, not significant.

***$P<.001$.

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Several studies (4, 5, 9) showed that the longer the chain of dietary fatty acids the larger their secretion in milk. Lauric acid added to the diet is not secreted as much in milk as stearic acid. Any addition of lipid to the diet affects the fatty acid composition of milk fat, but the extent is limited because of the intense hydrogenation of dietary fatty acids in the rumen. Plant oils, rich in linoleic and linolenic acids, increase the percentages of stearic and oleic acids, those of linoleic and linolenic acids only slightly, but they decrease percentages of shorter chain acids, especially myristic and palmitic acids. To eliminate the detrimental effects on dietary lipids in the rumen, Astrup et al. (2), on the basis of Australian studies (32), used fat protected against the action of rumen microflora, particularly against microbial hydrogenation, by coating the lipids in formaldehyde-treated casein. This protected oil tended to improve milk production and fat. Percentages of linoleic and linolenic acids were higher, more than 10% against normally 2 to 3%. Results have been similar in cows (3, 15, 26).

Addition of oxidized fat with a high peroxide index did not increase the degree of oxidation of lipids secreted by the goat udder (21). As in Table 5, the peroxide index remained unchanged. Thus, lipids added to concentrates, protected or not, represent a valuable means for changing the fatty acid composition of milk fat.

Protein Contents of Concentrates

Lindhal (17, 18) showed the advantage of supplying protein through concentrates when the basic ration was deficient in protein; effects on milk production were favorable. However, milk yield was not affected by supplementary supplies of protein in concentrates when the forage was sufficient in protein.

In experiments during midlactation, the protein supply, in particular of concentrates, only slightly affected milk production and composition as requirements of the goats generally were satisfied (21). Crude protein concentration of total rations should range (like in cows) between 13 and 16% of dry matter, depending on kind of dietary proteins, milk yield, and lactation stage of the goats.

During early lactation, goats, particularly the high yielding ones, seem to be sensitive to protein content of the diet. As their appetite is low at that time, forage intake is reduced. Accordingly, protein supplementation through supplies of concentrates is important. During early lactation, the protein supply of goats should be slightly higher than that calculated by Institut National Recherche Agronomique (29, 30). Goats, like cows, are likely to be underfed protein, since amounts of amino acids absorbed by the intestine are probably lowest around parturition because of low intakes of dry matter (27).

Goats seem to be sensitive to sources of protein. They use nonprotein-nitrogen, such as urea (1, 10), well and even better when the diet also contains sufficient quantities of fermentable energy, such as starch, to enable an optimum synthesis of microbial proteins in the rumen.

To meet the large protein requirements of high yielding goats during early lactation, it seems advantageous to use some sources of protein of which a large fraction might not be wasted in the rumen. A mixture of formaldehyde-treated soybean and rapeseed meals should enable goats to improve milk production and milk protein contents during the first weeks of lactation (21). Improvement of milk production in this way will be accompanied by large decreases of weight after parturition (36). Overfeeding of protein does not improve milk protein percentage but increases the nonprotein-nitrogen and urea content of milk (12, 28).

Effects of Other Components of Concentrates

No information seems available on effects of minerals and vitamins on composition of goat milk and its mineral and vitamin contents. As the udder of ruminants excretes medicinal and toxic substances, goat milk may contain pesticides when they are in the diet (16). Likewise, when the goat ingests feeds contaminated by aflatoxin, mycotoxin is secreted in the goat milk in a modified form (7).

EFFECTS OF FEEDING PLANS ON LACTATION

Feeding during Gestation

Concentrate supply during late gestation has marked influence on milk production and composition during early lactation (Table 6) (30). With alfalfa hay fed ad libitum to Alpine goats weighing 58 kg at mating and 600 g concentrates (grains, middlings, soybean and

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TABLE 6. Effect on milk yield of concentrate supply before parturition in goats (30).[a]

Item	Concentrate supply[b] Low (150 g/day)	High (600 g/day)	Significance
Milk production (kg/day)	2.99	3.76	$P<10\%$
Fat content (%)	4.10	4.44	$P<5\%$
Energy balance (MJ/day)	−2.47	−4.49	$P<5\%$
Blood plasma NEFA (mg/100 ml)	90.8	110.8	$P<10\%$

[a]Thirty-two goats given alfalfa hay ad lib; averages of first 8 wk of lactation.

[b]During last 8 wk of pregnancy.

peanut oil meals, minerals, and vitamins) instead of 150 g during the last 6 wk of gestation led to improvement of milk production (26%), milk fat percentage (11%), and amounts of stearic and oleic acids (31%) during the first 8 wk of lactation (30). The results can be explained by larger fat reserves at parturition of the goats. The higher milk yield during early lactation was from mobilization of body reserves confirmed by more nonesterified fatty acids in blood and by a more negative energy balance.

The quantity of concentrates allotted during late gestation has to be adjusted according to the quality of the forage so as to obtain an energy and protein supply representing about 100 to 200% of the requirements for maintenance. It is the energy supply and not the concentrate supply during late gestation which influences goat milk production (Figure 2). Underfeeding during late gestation has a direct effect on milking performance during early lactation. When intake corresponded to 60 to 70% of requirements, goats often were subject to more or less severe pregnancy toxemia which disturbs the onset of lactation and may cause deaths. Feeding during late gestation affects during early and midlactation (Table 7).

Feeding during Early Lactation

Like during late gestation, feeding during early lactation affects milk production during the first weeks of lactation and during midlactation. Experiments with 32 Alpine goats (Tables 7 and 8) supplying concentrates at 400 g/kg milk during the first 8 wk of lactation instead of 200 g enabled goats to improve milk production by 7.5% during the 9th to the 27th wk. Thus, long effects of diets offered to goats should be taken into account in establishing feeding plans during lactation.

Feeding Plan Before and Just After Parturition

The last 8 wk of gestation and the first 8 wk of lactation are crucial for milk production during the whole lactation. In addition, accidents of nutritional origin, pregnancy toxemia, ketosis, and milk fever, may disturb the onset of lactation in goats.

For 32 Alpine goats, four feeding programs were compared (30). Concentrate supplies during last gestation were high 600 g/day, low 150 g/day and during early lactation, high 400 g/kg milk, low 200 g/kg milk. As in Australia with Saanen goats (14), the best milk performances and the most satisfactory economic results (Figure 3) during early lactation were with diet high-high, closely followed by diet low-high. A large supply of concentrates during late gestation and early lactation is efficient, but the supply must involve the following points: sufficient intake of forage, maintenance of concentrate feeding not too high, and progressive changes of diets (22).

In another experiment based on the same principle as the previous one but including a

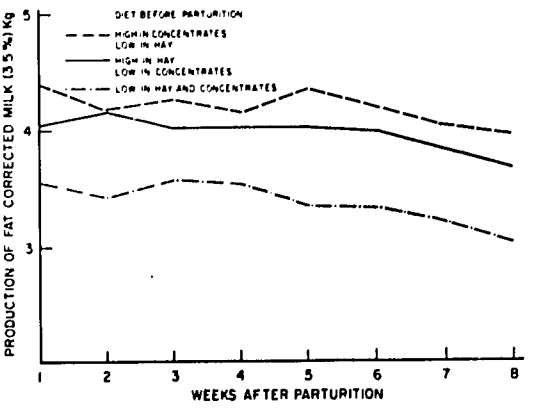

Figure 2. Effect of diet in late pregnancy on milk yield in early lactation (averages of 8 Alpine goats) (30).

TABLE 7. Effect of supply of concentrates in late gestation on milk production of goats during midlactation (30).[a]

Item	Concentrate supply High	Concentrate supply Low
Gestation		
Concentrate intake (g/day)	600	150
Alfalfa hay intake (g/day)	1395	1652
Energy balance (MJ/day)	+8.93	+6.50
Lactation		
Fat-corrected milk production (3.5%) (kg/day)	2.93	2.79
Energy in weight gain/ energy in milk (%)	9.33	12.39

[a]From 9th to 27th wk; 32 goats given alfalfa hay ad lib.

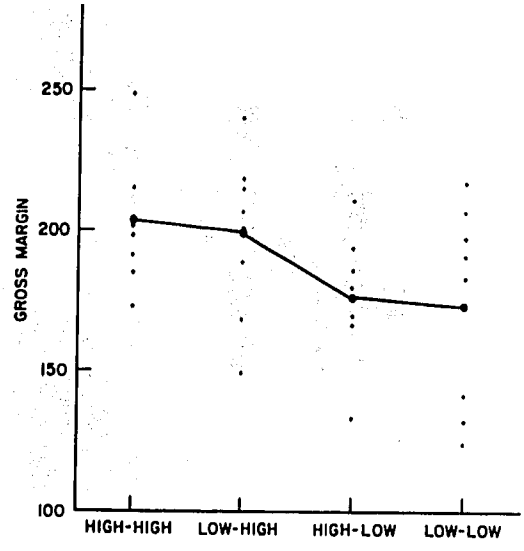

Figure 3. Income over feed cost for goats fed 4 ration programs 2 mo before and 2 mo after parturition (each point represents 1 goat; the first "high" or "low" concentrate feeding refers to the time before parturition, the second to that after parturition) (30).

third period (9th to 27th wk of lactation) goats received alfalfa hay ad libitum and restricted or large amounts of concentrates: during the last 8 wk of gestation (high 700 g/day, low 200 g/day); during the first 8 wk of lactation (high 400 g/day per kg milk, low 200 g/day per kg milk); and from the 9th to 27th wk of lactation (high 350 g/day per kg milk, low 175 g/day per kg milk) (22). Figure 4 shows the performance of the eight groups according to the eight feeding programs corresponding to the eight combinations between high (H) and low (L) concentrates during the three successive periods.

It was not group HHH, receiving large amounts of concentrates throughout the experiment, which exhibited the highest cheese-making yields but group LHH, receiving small amounts of concentrates during late gestation. The lactation performance of HLH was slightly lower, but cheese-making yields were similar. The feeding costs of group HHH

TABLE 8. Effect of supply of concentrates in early lactation on milk production of goats in midlactation (30).[a]

Item	Concentrate supply High	Concentrate supply Low
Lactation (wk 1 to 8)		
Concentrate intake (g/kg milk)	400	200
Milk production (kg/day)	3.91	2.84
Lactation (wk 9 to 27)		
Milk yield (kg/day)	2.96	2.75
Energy in weight gain/ energy in milk (%)	10.03	11.69

[a]Thirty-two goats offered alfalfa hay ad lib and the same amount of concentrates per kilogram milk in midlactation.

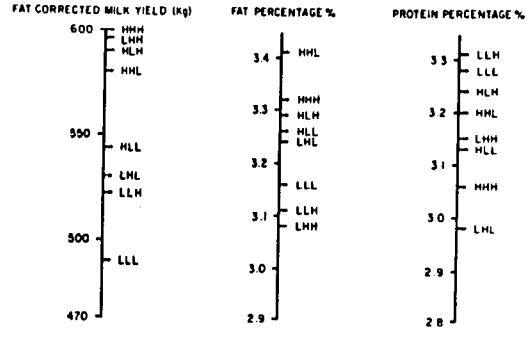

Figure 4. Effect of feeding programs on milking performance of 8 groups of Alpine goats during the first 189 days of lactation after being fed "high" or "low" concentrates in late pregnancy and early and midlactation (30).

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were the highest, and the gross margin accordingly was lower than of groups HLH and LHH (22). This experiment showed that for best economic results, it is not necessary to give large amounts of concentrates throughout the year. Thus, optimum performance during lactation can be achieved in different ways. The farmer's choice will be based on availability of forages and milk price variations over the year. Milk protein is affected little by feeds, but higher energy of the diet may improve cheese yields 1 to 1.5% (8) and lower urea and non-protein-nitrogen contents in milk (37).

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Research on Goat Nutrition and Management in Mediterranean Middle East and Adjacent Arab Countries[1]

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ABSTRACT

Research was reviewed on structural characteristics of digestive systems, feeding, nutrition, body characteristics, lactation, milk composition, growth, production, reproduction, management systems, and farm economics of goats in the Near and Middle East. Damascus goats are the largest in the area; Kil goats, native to Turkey, are with 16 million the most numerous although least productive in milk and meat. Angoras are raised for mohair. Birth weights, growth rates, kidding rates, and milk yields are most in Damascus goats, followed by Malta and Kilis goats, with Kil and Angora goats last. Different milk nursing, kid and doe feeding systems are discussed. Urea can substitute successfully for part of the protein in rations. Kid carcasses are leaner and tastier than similar lamb carcasses. Carob pods and distillers dried grains can be used successfully in goat rations in relatively large proportions. Single-purpose goats made more money than dual purpose goats, and larger goat farms (200 goats) were more profitable than smaller units (80 goats). Practical research data, written in native languages, are hidden in little accessible annual reports in Turkey, Cyprus, and others.

INTRODUCTION

From the dawn of civilization, the goat as a domesticated animal has provided mankind with food and fiber without demanding much in return. In many parts of the world goats exist neglected and uncared for, but their contributions even under hard conditions are significant, particularly to the underprivileged who, in turn, remain fairly unnoticed and neglected themselves in human societies.

The area of the Near East has a sizable goat population of 70 million, slightly more than 15% of the world goat population, producing about 30% and 15% of the goat milk and meat produced in the world (Table 1). Even though there are many goats in the area, there is little scientific goat husbandry. Instead, the systems have been running in traditional patterns of "scavengerism" with an economic philosophy of getting something out of nothing. Under these conditions production has been seasonal, based on feed inputs from seasonal, common pasture, and vegetative cover of marginal lands, supported by grazing on cereal stubbles and by wintering on cereal straw. Goat populations have been increasing, however, through random breeding, even under high mortality rates. Production per animal has not been increasing because of lack of selection and because grazing lands have been needed more for food crops for the growing human population. The traditional link between a farmer's prestige in society and the size of his herd has been an obstacle to more rational goat production.

The ability of goats to relish vegetation that is not consumed readily by other livestock has been abused by man, and goats have been driven more to marginal lands and forests. Experts have labeled goats destructive to vegetation and recommended their ban, overlooking the potential for beneficial production integrated into a feed-livestock economy and ignoring the landless marginal farmers who benefit from low-cost goat farming and could balance feed inputs from marginal land with supplements.

The objective of this paper is to review research data available from this region on the digestive physiology, feeding, nutrition, and management of goats.

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TABLE 1. Goat population and its products in the Near East (27).

Country	Population (1000)	Milk[a]	Meat[a]
Algeria	2,220	138	870
Cyprus	395	36	295
Egypt	1,393	8	104
Greece	4,524	413	4,088
Iraq	3,600	62	1,050
Israel	142	26	103
Jordan	490	14	415
Kuwait	89	5	26
Lebanon	330	18	200
Libya	1,250	14	540
Marocco	4,940	25	1,000
Oman	197	9	79
Qatar	48	9	20
Somalia	8,212	145	2,067
Saudi Arabia	775	40	800
Sudan	11,592	370	1,740
Syria	985	74	453
Tunisia	950	50	517
Turkey	19,000	640	6,478
Yemen (North)	7,600	128	2,500
Yemen (South	1,260	24	400
Total	69,992	2,246	24,745
World	410,343	6,548	145,208

[a]1000 tons.

DIGESTIVE SYSTEM OF GOATS ON THE NEAR EAST

Relative water-filled volume of stomach compartments and their combined empty weights in Angora and Kil goats and Ak-Karaman sheep are in Table 2. Although sheep weighed more than Angora goats, the empty stomach weights were lighter in sheep than in goats. The trend of heavier stomach weight was the same in Kil goats. Relative proportions of water-filled rumen volume to total stomach volume were 76, 77, and 81% in Angora, Kil goat, and sheep. The absolute volumes of omasum and abomasum in Angora goats were larger than in sheep. Volume, weight, and shape of stomachs vary with feed intake, nature of diet, and feed consumption behavior.

Anatomical differences between sheep and goats are in the captions in Figures 1 to 10, which compare rumen, reticulum, omasum, and abomasum for both species based on 100 samples each (30). Most striking are the shape of the caudoventral blind sac of the rumen, courses of right and left coronary grooves, shape of the rumen papillae and reticular cells, and absence of the fourth lamina in the omasum in goats.

Additional differences are in the size and secretory nature of cells of the cardiac gland and less numerous spiral ducts in the pylorus gland in goats compared with sheep.

BODY PRODUCTION OF NEAR EAST GOATS

Table 3 shows body measurements, weights, and sizes of goat breeds in the Mediterranean Middle East.

Damascus (Shami) is the largest of all goat breeds with long legs, pendulous ears, bulged Roman nose, and generally red or reddish brown color. Ash color and different colors in combination with white patches also can be observed. Polledness is the dominant feature. This dairy breed, resembling the Nubian of Africa, is spread mainly in and around Syria, Lebanon, and Cyprus.

Malta goats originated on the Mediterranean island of Malta and spread into the surrounding

TABLE 2. Comparison of volume, weight, and size of stomach compartments in goats and sheep (30).

Item	Goat		Sheep
	Angora	Kil	(Ak-Karaman)
Number of animals	10	10	10
Body weight, kg	36.6	38.1	38.8
Empty weight of 4 stomachs, kg.	1.31	1.57	1.22
Volume of 4 stomachs[a], liter	18.64	27.54	22.73
Volume of rumen, liter	14.18	21.34	18.54
Volume of reticulum, liter	1.6	2.1	1.6
Volume of omasum, liter	.75	1.01	.55
Volume of abomasum, liter	2.15	2.86	2.04
Length of abomasum, cm	30.4	...	33.5
Breadth of abomasum, cm	21.0	...	18.2

[a]Water filled; 4 stomachs = rumen plus reticulum plus omasum plus abomasum.

countries of Greece and Turkey. Malta dairy goats, developed from crossing Nubian and Spanish Murcian goats, are finer in features and lighter in weight than Damascus. They have short, shiny hair, reddish brown or black with white patches.

Halep (Aleppo) goats, triple purpose (milk, meat, and hair) breed, originated from the mountainous regions of Syria and spread over the entire area, particularly Syria, Jordan, Lebanon, Israel, Iraq, and southern Turkey. They are smaller in size than the Damascus but

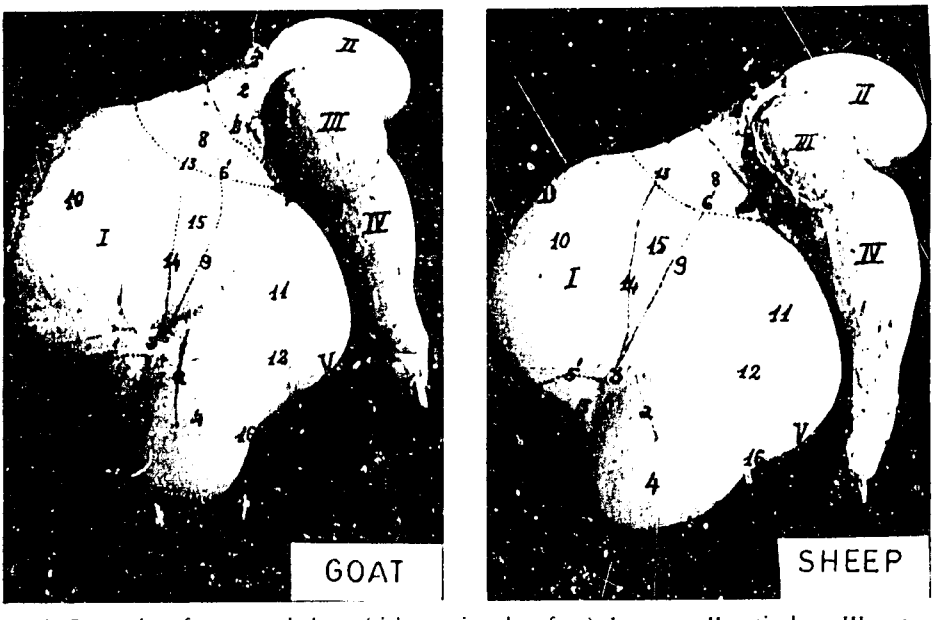

Figure 1. Stomachs of goats and sheep (right or viceral surface). I, rumen, II, reticulum; III, omasum; IV, abomasum; 3, caudal groove; 4, caudoventral blind sac; 5, caudodorsal blind sac; 11, ventral sac; 12, right caudoventral coronary groove; 15, insula ruminalis, an islet formed by right longitudinal groove (9) and its accessory groove (14); a, blood vessel, a branch of the right ruminal artery. The caudoventral blind sac is longer and narrower in goats; the right caudoventral coronary groove reaches up to the ventral border and across to the left side, but the left one is shorter in goats; blood vessels are less prominent and mostly on dorsal half; distance between the two grooves is shorter and insula ruminal is narrower; the left longitudinal groove runs more caudodorsal as compared to sheep [30].

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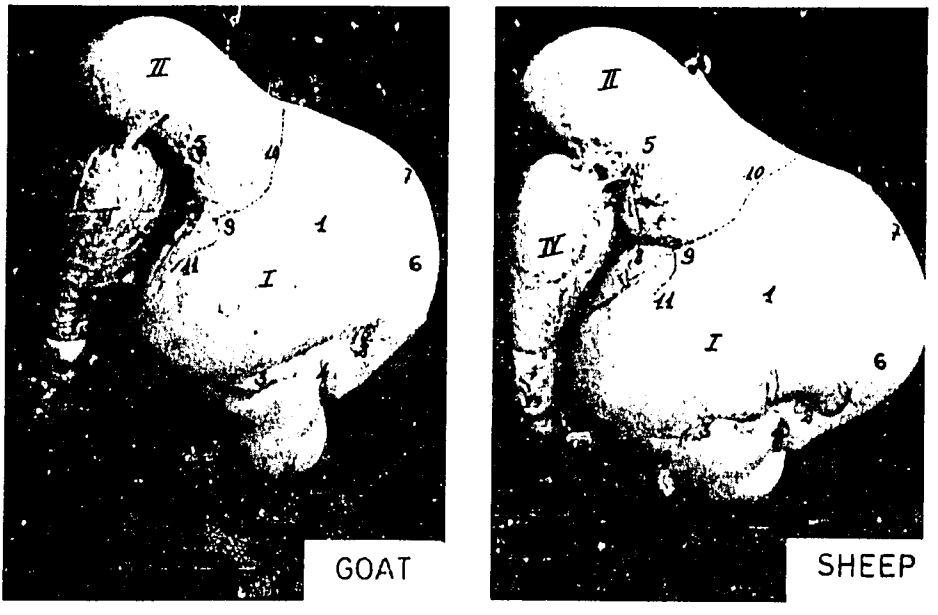

Figure 2. Stomachs of goats and sheep (left or parietal surface). I, rumen; II, reticulum; III, omasum; IV, abomasum; 3, left caudoventral coronary groove; 4, right caudal groove [30].

are stronger, with long and broad hanging ears. They have mostly horns, unlike Damascus goats. Usual colors are coffee, ash, and black.

Kilis goats originated from the southern eastern provinces of Turkey, Kilis county, and, at 100,000 in number, are widespread. They were developed from crossing Turkish native black Kil goats and a high milk-yielding variety of Halep goats in the border area between Turkey and Syria. The most dominant color of

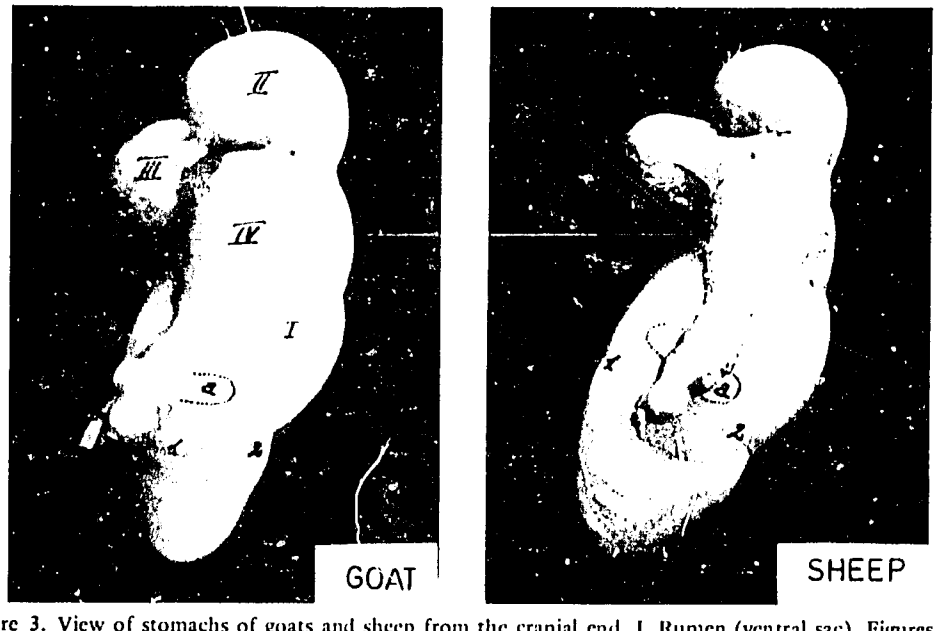

Figure 3. View of stomachs of goats and sheep from the cranial end. I. Rumen (ventral sac). Figures show the distances between 1 and 2, and ends of the right and the left caudoventral coronary grooves [30].

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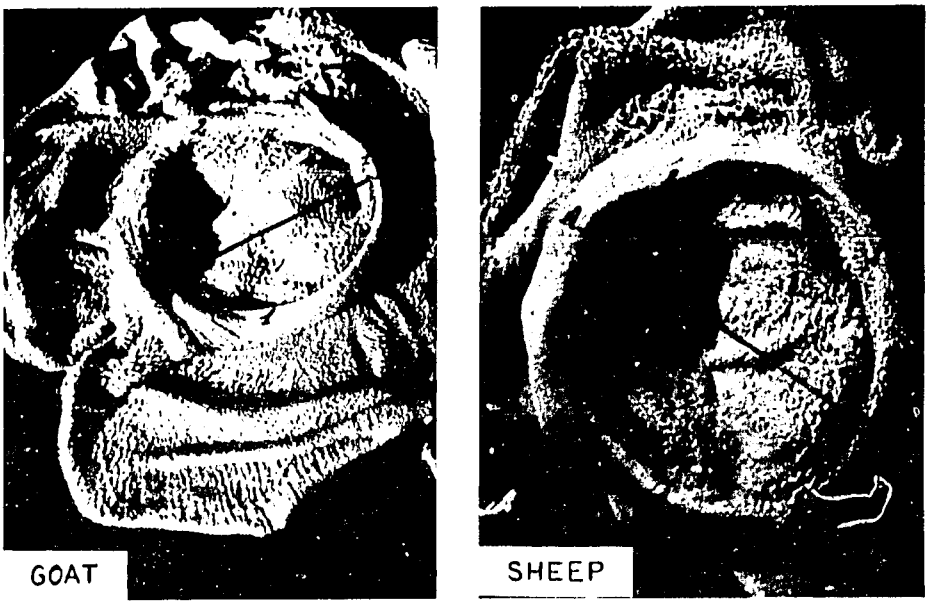

Figure 4. Interior of the caudoventral blind sac of rumen in goat and sheep. A, pillar of the caudal groove; 1, 2, are the pillars of the right and left caudoventral grooves; the figure shows the distance between A and B and the nature of the area in between [30].

Kilis goats is black; however, mixed and ash colors also are observed. The body of Kilis goats is long and compact with broad and long hanging ears. These goats come with or without horns in equal numbers. In females horns are thin and short.

Kil goats, the native, black, hairy goats of Turkey, are abundant with a population of

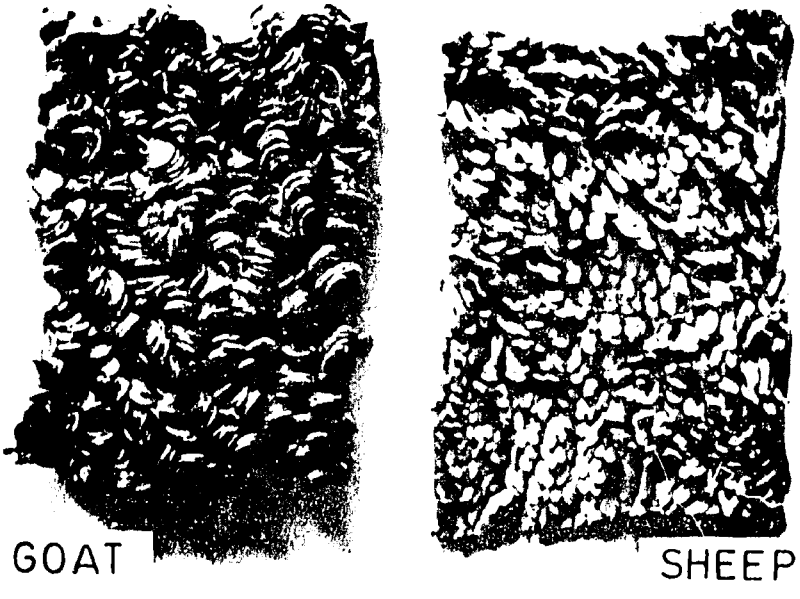

Figure 5. Rumen papillae in the goat and the sheep (cranial sac) [30]. The free ends are more broad like leaves and round in goats, in sheep more narrow like tongues. The color of the epithelium of the rumen is deep honey colored in goats, dark brown to blackish in sheep; the color of the serosa is light grey in goats (Angora), bluish white in sheep (Ak-Karaman).

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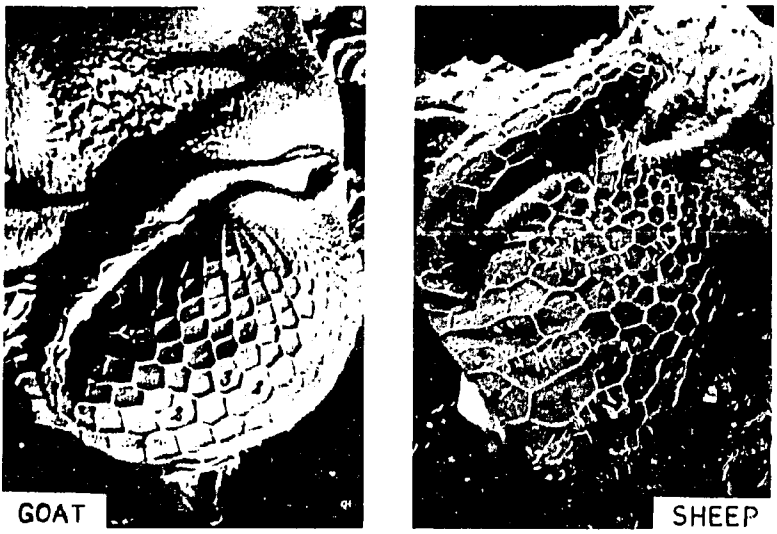

Figure 6. Reticular cells of different shapes formed by the epithelial folds of reticulum in goats and sheep. 1, reticular cell wall; 2, secondary reticular cell wall; 3, reticular cell; 4, parallel vertical reticular cell walls in the goat [30]. Secondary cell partitions are fewer and less prominent in goats; the area between the lower half of the esophageal groove and the right third of the reticuloruminal fold is full with papillae in goats, but with reticular cells in sheep.

about 16 million. They have horns, are relatively smaller in body size than other dairy goats, and are well adapted to mountainous areas. Kil goats are everywhere in Turkey, the Mediterranean, south and eastern and north eastern Aegean, and northwestern parts with mild winters, good rainfall, forests, and marginal mountainous lands with shrubs. Milk yield of these goats is below typical dairy goats, but they are kept primarily for milk, then for meat and hair. Production is seasonal with short lactations because of dependence on seasonal pasture.

Angora goats originated in the steppe regions of Turkey with cold winters and dry hot summers and are concentrated mainly around Ankara and adjacent 14 provinces of central Anatolia. They are smaller than other breeds and are not adapted well to mountainous regions. They primarily are raised for mohair; milk is reserved for the kids.

Production

Birth weights and growth rates of Near East goat breeds are in Table 4. Birth weight in the Damascus breed is highest and in the Angora breed lowest, reflecting their respective adult weights. In native Kil and Kilis goats, birth weights are medium with much variation between herds; birth weights in well-managed herds are higher. In many instances birth weights of twins in these breeds are similar or more than those of single born kids. Growth rates of kids born lighter catch up with weight of kids with heavier birth weights within a few months. Kids of Malta goats, even though born lighter than Damascus goats but with same birthweights as Kil or Kilis goats, grow faster and outgrow other heavy breeds during the first 3 mo

Prolificacy, as measured by kidding rate, is highest in the Damascus breed, closely followed by Malta goats (Table 5). However, in triplet and quadruplet births, the Malta goat is not behind, and they transmit this character in their crossbreds (Table 5). Kil goats have a poor kidding rate. However, they improve in crossbreeding with Malta goats.

Lactation performance of Near East goat breeds are in Table 6. Damascus have the highest milk yield followed by Malta and Kilis, Kil goats being the lowest with about 100 kg per lactation of about 140 days. However, when Kil goats are crossed with Saanen or Malta goats, the crossbreds increase milk production almost to high yielding breeds, not

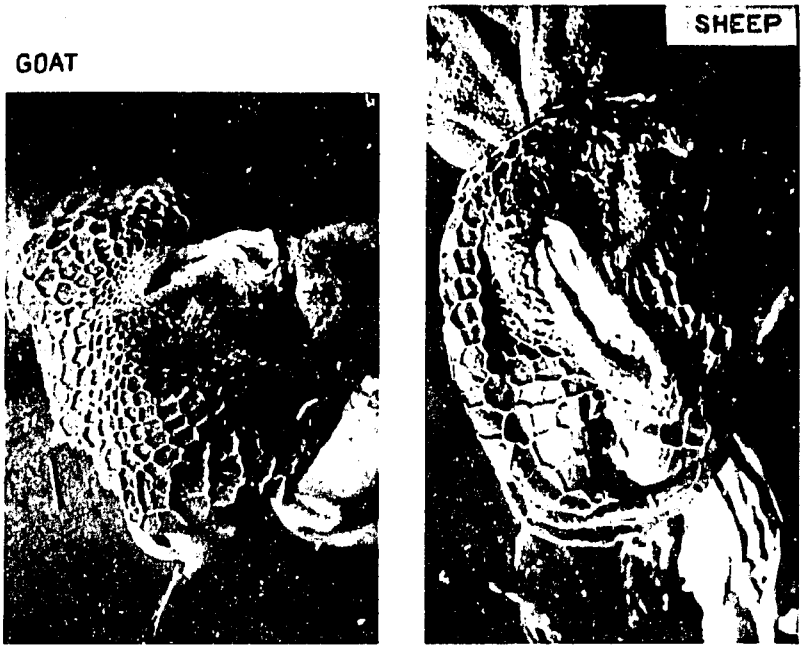

Figure 7. Interior of reticulum in goats and sheep. 1, 2, upper third of the reticuloruminal fold; 2, 3, lower half of the oesophageal groove [30]. Wall thickness of reticulum is greater in goats than in sheep; muscular bands are thinner in sheep.

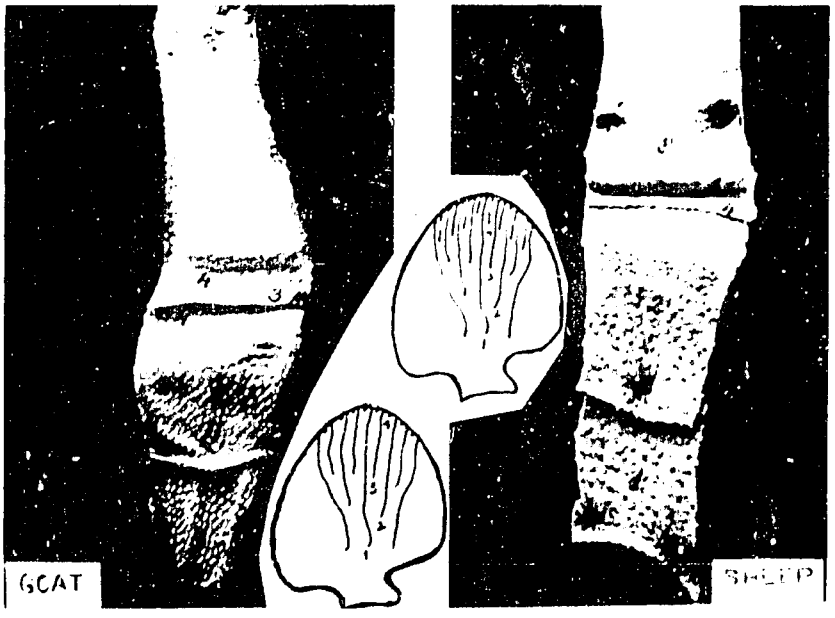

Figure 8. Laminae omasi of different sizes formed by the longitudinal folds (leaves) in the interior of omasum in goats and sheep. 1, first lamina (largest); 2, second lamina (large); 3, third lamina (medium); and 4, fourth lamina (small) [30].

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Figure 9. Omasum opened from the dorsal end in goats and sheep. 5, 6, right and left margins of the fundus omasi; 9, right lip of the ventral end of the oesophageal groove; 10, caudal end of fundus omasi [30]. Dot like papillae are numerous in goats; the connection between fundus omasi and ventral end of esophageal groove is not end to end but notched in goats; the omasal shape is longer and more oval compared to sheep (Figure 2).

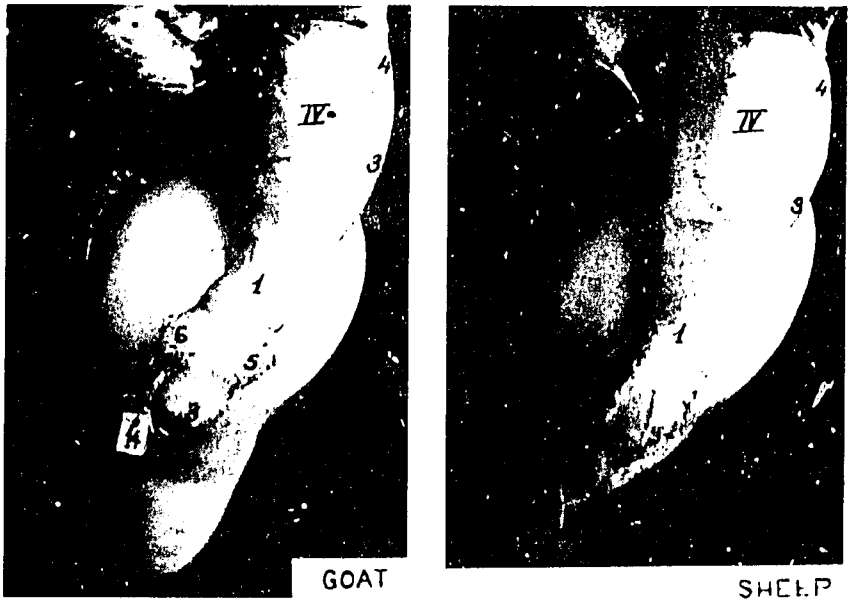

Figure 10. Abomasum of goats and sheep (right view). IV, abomasum; 2, cranial 1/4th of the curvature major; 3, caudal 3/4th of the curvature major; 4, as the cranial part goes over the caudal part of the curvature major, an arch is formed in goats as against an angle formed in sheep; 5, 6, ballooning of the caudal part of the curvatures major and minor [30]. The abomasum is shorter and broader in goats; the curvature major is straight and forms a convex curve towards the pyloric region. The cardiac gland is more mucin secreting and the area is relatively smaller; delomorph cells of the gland ducts are prevalent and denser as compared to sheep [30]. The fundus glands contain a thin layer of dissimilar gland areas. The spiral ducts of the pyloric gland are less frequent, the corpus glandulae is wider, and the laminae propriamucosa are thicker [30].

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TABLE 3. Average body characteristics of goat breeds in Turkey, Syria, and adjacent Middle East.[a]

Breed	Female live wt.	Height at withers	Body length	Heart girth	Circumference of Cannon bone	Reference
	(kg)	(cm)				
Kilis	...	64.7	83.8	76.3	8.6	58
Kilis	39–62	65.0	69.4	82.4	8.7	50
Kil	39.8	69.4	89.1	79.2	8.4	44
Kil	35–55	60–71	60–72.5	73–86.5	7–9	57
Malta	...	66.6	72.0	31.5	8.4	53
Damascus (Shami)	55–60	72.5	...	...	...	56
Aleppo (Halep)	...	66–72	61–68	72–78	8–8.5	10
Angora	30–40	53.8	57.3	74.8	6.9	11
Saanen (from Germany)	...	62–70	63.5–74.5	85–94	8.5–9.5	46
Saanen	50	66.1	75.6	83	8.5	52
Kilis X Saanen	57.5	71.8	73.2	87.3	9.0	21
Kil X Saanen	...	66.6	73.4	63.4	8.3	45
Kil X Malta	...	67.3	71.4	79.9	8.3	45

[a]Nubian goats in upper Egypt and Sudan weight 50 to 60 kg and have wither heights of 70 to 75 cm (43).

only in increasing daily yield but also by lengthening lactation (Table 6). Angora is the poorest milk yielder with about .5 kg a day for about 100 days; fat percentage of the milk is 5.6. The average fat percentage of Kil and Kilis goat milk during lactation is 4.5.

Tables 7, 8, 9, and 10 show composition of colostrum and regular goat milk; physical, chemical constants of milk fat; milk fat globules; and comparisons with sheep milk. Solids, solid-not-fat (SNF), protein, ash, specific gravity, and titratable acidity are highest in the first colostrum secreted after parturition. These decrease through day 4 to normal. Fat percentage in colostrum is high at the beginning and then falls; in some instances fat gradually rises and then falls. Lactose in colostrum does not seem to show any definite pattern of rise and fall. There may be breed differences in the time for colostrum to become normal milk; in Angoras it seems to take longer. Although solids, fat, SNF, and lactose are higher in normal sheep milk than in goat milk, there seem to be no differences in composition between their colostrums. In composition of milk, the solids, fat, protein, and lactose percentages are higher in the low yielding breeds. Variability of fat and SNF in sheep and goat milk seems to be more than in cows. Physical and chemical constants of goat milk fat, specifically melting point and fatty acid number, are lower in goats than in sheep. The relative sizes of fat globules, from Turkish (35) and Egyptian (26) studies and distribution of fat globules by number and weight are in Table 10.

RAISING OF KIDS

Growth studies (7) of kids at Cyprus showed that they can be weaned satisfactorily without deleterious effects 33 days after being fed 50 kg of milk. Although kids receiving higher daily amounts of milk grew faster than those receiving less, the latter group increased its growth rate during the postweaning period, and there were no differences between the groups in average daily gains from birth to 140 days.

In another experiment (49), average daily gain from birth to 3 mo or 6 mo of Malta x Saanen kids, weaned in 4 wk after 74 kg milk or in 8 wk after 121 kg milk, did not show significant differences. All groups started to consume concentrate and roughage ad libitum from 3 wk on. Eker et al. (16) also observed no significant difference in 6-mo average daily

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TABLE 4. Average birth weight and growth of kids of goats in Turkey and Cyprus.

Sex, birth[a]	Birth wt.	Development of body wt. 1 mo.	Development of body wt. 3 mo.	Reference
	(kg)			
Kilis:				
F-S	2.7	...	12.0	22[b]
M-S	3.1	...	12.0	
F-Tw	2.5	...	11.9	
M-Tw	2.5	...	12.0	
F-S	3.2	8.1	10.0	50[c]
M-S	3.6	8.7	11.4	
F-Tw	3.1	7.8	11.7	
M-Tw	3.6	7.3	11.9	
Kil:				
F-S	2.5	...	11.4	48
M-S	2.6	...	12.1	
F-Tw	2.8	...	11.3	
M-Tw	3.0	...	12.5	
F-S	2.4	...	...	45
M-S	2.8	...	...	
F-Tw	3.1	...	...	
M-Tw	3.1	...	...	
Malta:				
F-S	2.4	7.6	16.2	53
M-S	3.4	10.2	21.0	
F-Tw	3.1	7.2	14.2	
M-Tw	2.8	7.2	16.2	
Damascus:				
F, M-S	4.7	...	...	8
F, M-Tw	4.0	...	...	
Angora:				
F-S	2.3	...	...	9
M-S	2.6	...	...	
F-S	3.1	7.6	15.1	53
M-S	3.5	9.7	18.9	
Saanen:				
F-Tw	2.7	7.2	13.6	46
M-Tw	3.2	8.0	17.5	
F-S	3.1	6.0	13.4	46
M-S	3.7	7.6	14.6	
F-Tw	3.0	6.2	13.5	
M-Tw	2.8	6.5	14.0	
Kilis X Saanen:				
F-	3.0	...	15.9	18[d]
M-	3.2	...	16.8	
F-S	3.1	7.4	16.7	45
M-S	3.3	8.3	17.5	
F-Tw	2.6	6.4	15.1	
M-Tw	2.7	6.9	17.3	

(Continued)

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TABLE 4. (Continued) Average birth weight and growth of kids of goats in Turkey and Cyprus.

Sex, birth[a]	Birth wt.	Development of body wt. 1 mo.	Development of body wt. 3 mo.	Reference
	(kg)			
Kil X Malta:				
F-S	2.6	7.2	16.0	45
M-S	3.0	8.1	19.2	
F-Tw	2.7	6.2	12.9	
M-Tw	2.8	6.7	16.1	
Kil X Saanen:				
F-S	2.9	...	12.4	48
M-S	2.9	...	13.0	
F-Tw	3.2	...	11.0	
M-Tw	3.0	...	14.7	
Kil X Malta:				
F-S	2.7	...	11.9	48
M-S	2.9	...	13.0	
F-Tw	3.0	...	11.8	
M-Tw	2.9	...	12.8	

[a]F = female; M = male; S = single; Tw = twin.

[b]6 mo: 16.6, 18.0, 16.7, 19.1; 1 yr: 22.0, 29.0, 22.4, 30.0; 2 yr: 28.6(F-S), 31.3 (F-Tw); 3 yr: 35.0 (F-S), 33.3 (F-Tw); 4 yr: 40.0 (F), 39.0 (F-Tw) kg.

[c]6 mo: 15.9, 18.2. 14.7, 16.9 kg.

[d]6 mo (F): 24.2; 1 yr: 35.5; 2 yr: 41.9; 3 yr: 52.0; 4 yr: 57.5 kg.

gains between kids gradually weaned in 12 wk after 87 or 124 kg of milk (Table 11).

To raise kids with a minimum of milk replacer, an experiment (12) compared daily gain for a 90-day experimental period between two groups of kids, weaned either in 40 days with 6 kg of milk replacer or in 33 days with 2.65 kg of milk replacer. The kids always had access to hay and a 12% protein concentrate mixture. No difference in average daily gain between the groups was observed.

In average daily gain studies (3) after birth for lambs and kids with free access to suckling, lambs grew faster than the kids, even though the amount of milk consumed by lambs was not higher, but their solid feed consumption was higher than that of the kids (Table 12). Of course, milk of Chios sheep had more solids than that of Damascus goats (3). During 31 to 45 days, when animals had limited access to suckling, lambs improved their intake of solid feed over kids and grew faster than kids. The superiority of growth rate in lambs over kids accelerated thereafter; at 120 days lambs were about 8 kg heavier than kids. The experiment also indicated faster development of fore stomachs in lambs, resulting in earlier functioning in sheep than in goats.

MANAGEMENT ON LACTATION PERFORMANCE

Studies on the effects of a 2-, 35-, or 70-day suckling on performance of lactating Damascus show no significant differences in full lactation yields among the groups as a result of suckling duration (40) (Table 13).

Lactating goats with kids having 70 days continuous or partial (8 h) access to suckling showed no difference in 150-day total milk yield as a result of different suckling regimes (32). Of course, milk suckled was less and, consequently, commercial milk was more in the partially suckled group. Likewise, even though the 70-day body weight was higher in continuous suckling kids, there was no significant

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TABLE 5. Prolificacy of goats in Turkey, Syria, Cyprus, and adjacent areas.

Breed	Average kidding performances			Reference
	No. of births	Twinning rate	Litter size	
		(%)		
Kilis	104	26.9	1.27	57
Kilis	257	31	1.31	19
Kilis	55	23	1.23	50
Kil	400	15	1.15	48
Malta[a]	59	42.3	1.84	53
Angora	1141	2	1.02	9
Damascus[b]	56	53.6	1.91	8
Saanen	94	42.5	1.46	52
Saanen	42	40.0	1.40	51
Saanen	46	41.0	1.41	46
Kilis X Saanen	170	27.0	1.27	19
Kilis X Saanen	74	54.2	1.54	54
Kil X Saanen	34	56.0	1.56	48
Kil X Malta[c]	18	61.0	2.05	48

[a]Triplets, 18.7%; quadruplets, 1.6%.

[b]Triplets plus quadruplets, 17.8%.

[c]Triplets, 22.0%.

difference between the groups in 150-day body weight; the 8-h suckling group accelerated their postweaning growth to even up with the other group.

Effects of numbers of daily milkings were studied (4, 17), but although yields of 4% fat-corrected-milk were greater for three milkings a day compared to two milkings a day, and higher for two milkings a day as compared to one milking, differences were variable. Composition of milks also did not show conclusive differences.

TABLE 6. Average lactation performance of goats in Cyprus, Syria, Turkey, and adjacent countries.

Breed	No. of lactations[a]	Milk yield	Lactation periods	Fat	Daily milk yield	Reference
		(kg)	(days)	(%)	(kg)	
Kilis	76 (6)	95–441[b]	102–343	...	.8–3.2	50
Kilis	77 (7)	281	260	3.9–6.1	1.1	57
Kilis	208 (7)	80–642	260	4.3	1.1	20
Kil	31 (2)	74–145	123–164	4.7	.5–1.0	57
Angora	5 (1)	35.3–68.2	98	5.4–5.6	.4–.5	35
Damascus	97 (1)	523	269	4.1	1.9	40
Malta	46 (4)	59–484	86–224	...	.7–3.2	53
Saanen	30 (4)	139–863	133–364	...	.9–3.0	51
Saanen	44 (3)	99–573	102–284	2.9–4.6	.6–2.8	46
Kil X Malta	9 (1)	75–457	168–318	...	.4–1.4	44
Kil X Saanen	17 (1)	138–507	312–329	...	1.4	44
Kilis X Saanen	170 (7)	272–1268	215–383	3–5.9	2.3	21

[a]Number of successive lactations in parentheses.

[b]Range of observations.

TABLE 7. Composition of goat colostrum and comparison with sheep colostrum in Turkey.

Post-partum	Solids	Fat	SNF	Protein	Lactose	Ash	Specific gravity	Acidity (Soxhlet-Henkel)
(h)	(%)							
				Kilis X Saanen (n=17) (55)[a]				
0	29.4	11.3	18.4	13.9	2.98	1.09	1.0503	16.2
12	21.1	8.8	13.1	8.5	3.6	.93	1.0378	13.2
24	18.5	8.1	11.3	6.4	3.8	.88	1.0363	10.7
36	16.7	6.2	11.1	5.6	4.5	.90	1.0373	10.6
48	16.2	6.1	10.1	5.1	3.9	.89	1.0367	10.0
60	15.5	5.2	10.3	5.2	4.2	.93	1.0372	10.2
72	15.1	5.1	10.0	4.9	4.0	.90	1.0362	9.9
				Angora (n=5) (35)				
0	28.2	4.6	23.6	17.8	4.6	1.22	1.0815	16.5
24	26.2	6.8	19.5	14.1	4.1	1.23	1.0670	15.2
48	23.8	8.7	15.2	10.3	3.9	.96	1.0540	12.8
72	25.2	12.2	13.1	8.2	3.9	.91	1.0420	11.6
96	20.9	9.6	11.4	6.1	4.4	.85	1.0425	11.9
				Kivircik sheep (n=2) (1)				
0	26.0	7.8	18.2	13.9	3.1	1.13	1.0564	25.0
72	14.7	3.5	11.8	5.21	5.6	1.0	1.0433	11.1
				Awassi sheep (n=9) (25)				
0	30.3	9.8	20.5	14.4	5.2	.9	...	...
72	15.3	4.4	10.9	6.3	3.7	.8	...	...

[a]Breed, number of animals, and reference.

FEEDING AND NUTRITION OF GOATS IN THE NEAR EAST

Analyses (15) of proximate composition and nutrient digestibility of roughages (alfalfa hay, grass hay), cereal feed grains (barley), and protein supplements (vetch seed and linseed cake) showed that the digestibility of fair to good alfalfa hay with 19% crude protein and 34% crude fiber was not markedly different from that in tables of standard feed composition and nutrient utilization. Also, digestibilities of nutrients in concentrates were around the usual in the literature and show no marked differences with digestibilities in other ruminant species. A comparison of digestibilities of organic matter, crude protein, and crude fiber in grass and alfalfa hay between sheep and goats from research data in Turkey (13, 14, 15, 29, 31, 36) showed no marked differences between species. However, in Sudanese studies (23), no differences in digestibilities of crude fiber and dry matter of alfalfa and mixed grass hays (*Dianthium annulatum)* were found between desert sheep and goats, but significantly lower crude fiber digestibilities of mixed desert grass hay (*Dactyloctenium aegypt., Ergostispilosa, Aristiada* sp.) in sheep were reported. However, greater negative nitrogen balances in sheep than in goats may have had an influence.

Pregnant goats, during their last 7 wk before parturition, were fed diets containing either 3.75 Mcal of metabolizable energy (ME)/kg or 4.8 Mcal ME/kg feed per day (5, 8) (Table 14). According to the US National Research Council recommendations, the prepartum requirement for 60 kg sheep with lower prolificacy and milk production than goats is 3.97 Mcal ME/day. The results showed no statistically significant differences in kidding rate, weight gains of goats before or after parturition, birth weight of kids, or first 6 wk milk yield and feed intake of lactating goats (Table 14).

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TABLE 8. Average composition of goat and sheep milk in the Mediterranean Middle East.

Solids	Fat	SNF	Protein	Lactose	Ash	Specific gravity	Titratable acidity
(%)							
Kilis (n=17) (59)[a]							
12.6	4.2	8.45	3.2	...	.78	1.0302	7.2
Kilis X Saanen (n=17) (55)							
12.2	4.0	8.20	3.6	3.8	.83	1.0309	8.7
Kil (n=5) (33)							
15.1	5.5	9.60	4.8	4.0	.79	1.0360	9.5
Angora (n=7) (35)							
15.9	6.0	9.97	4.4	4.8	.75	1.0338	8.9
Damascus Mixed (n=5) (41)							
15.4	6.1	8.90	...	...	...	1.0303	...
Egyptian Baladi (n=6) (47)							
...	4.0	8.27	3.3	...	...	1.0310	7.2
Ak-Karaman sheep (n=9) (25)							
17.0	6.3	10.67	4.7	5.1	.84	1.0390	9.7

[a]Breed, number of animals, and reference.

Three groups of 37, nearly 3-mo-old kids were fed pelleted diets with crude protein contents of 10.9, 14.7, or 16.6% ad libitum for 18 wk and had free access to ground straw and water (39). Weight gains, protein intake, and concentrate pellet intakes for the entire trial increased significantly for each increase in protein of the diet. Straw intake remained constant in all groups. As feed intake increased with increased protein, the higher protein

TABLE 9. Average physical and chemical constants of milk fat in Turkish goats and sheep.

Solidifying point (C)	Melting point	Refractive index (at 40C)	Reichart-Meissl value	Polenske value	Saponification no.	Iodine no.	Fatty acid no.
Saanen X Kil (n=17) (55)[a]							
18.6	33.8	1.4584	27.25	7.3	235	30.6	15.1
Kil (n=5) (34)							
17.6	35.5	1.4540	26.84	4.8	241	29.6	...
Ak-Karaman sheep (n=9) (24)							
17.6	37.6	1.4543	31.88	3.1	240	31.3	19.6

[a]Breed, number of animals, and reference.

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TABLE 10. Average size of fat globule and its differential distribution in Turkish Angora goat milk (35).[a]

Size distribution in 100 globules in milk[b,c]			Percent in 100 g milk fat		
Diameter	At mid-lactation	At end of lactation	Diameter	Mid-lactation	End lactation
(μ)	(%)		(μ)		
0–1	21.2	21.4	0–3	14.3	19.7
1–2	33.3	30.2	3–6	58.9	63.6
2–3	18.7	23.1	6–9	26.8	16.7
3–4	14.7	17.2	...	...	...
4–5	7.0	4.2	...	...	...
5–9	5.2	4.0	...	...	...

[a]Average milk fat was 6.0% at middle; 6.6% at end of lactation.

[b]In other reports (26): fat globules with diameters of 1.5, 3.0, 4.5, 6.0, and 7.5 μ, the respective percentages were 28.4, 34.7, 19.7, 11.7, and 4.4 in goat milk; 28.7, 39.7, 17.3, 12 ', and 2.0% in sheep milk; and 10.7, 32.6, 22.1, 17.9, and 12.2% in cow milk.

[c]Number of globules/ml milk in midlactation, 10.6 million; end lactation, 14.6 million.

intakes were matched by higher energy intakes, partly helped by apparent good palatability of the high protein rations.

In another experiment with 169 kids (2), an increase in dietary protein from 12.9% to 20% had similar significant effects on weight gains of male kids (.21; .25 kg/day). However, females or castrates showed smaller responses to higher dietary protein. Feed conversion (kg feed/kg gain) was significantly less in the male group (4.9; 4.8) and highest in females (5.3; 5.4) (castrates: 5.0).

In studies on effects of castration, Louca et al. (39) found that during the first 100 days male kids grew significantly faster than females or castrates. However, during the next 100 days castrates increased rate of gain, and it became similar to that of males and higher than for females. Feed conversions for castrates, as well as for females, were still significantly higher than for males. During 227 to 318 days, castrates were no more different from males in daily weight gain or feed conversion.

Body weight gains of kids weighing 23 kg initially (32) and fed a ration with 15% soybean meal or an isonitrogenous ration with 2% urea

TABLE 11. Performance of kids raised on limited milk systems in Turkey.[a]

Item	Malta X Saanen kids		Kilis kids	
Total milk fed, kg	74	121	124	87
Weeks to weaning	4	8	12	12
Initial weight, kg	2.8	2.7	3.7	3.0
4 wk average daily gain, kg	.119	.130	.133	.116
8 wk average daily gain, kg	.133	.140	.152	.132
12 wk average daily gain, kg	.121	.137	.164	.128
6 mo average daily gain, kg	.103	.114	.110	.104
Total feed intake/kid, kg				
Concentrates, kg	49	47	62	58
Grass hay, kg	16.5	13.5	29	28
Green alfalfa, kg	...	...	106	100

[a]Kids had access to feed ad libitum from 3 wk. Milk fed ad libitum twice daily to the Malta X Saanen kids (16, 49).

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TABLE 12. Comparative feed intake intake and growth rates of Chios lambs and Damascus kids (3).[a]

Item	Lambs	Kids
No. of animals	27	28
Birth weight, kg	4.5	4.3
Live wt., kg at 30 days	11.2	10.4
at 45 days	14.0	12.2
at 120 days	33.3	25.0
Average daily gain, g		
to 30 days	223	203
31–45 days	186	121
46–120 days	261	179
to 120 days	223	168
Feed intake to 30 days, kg[a]		
milk	39.4	39.1
concentrates	.27	.14
hay	.22	.11
Feed intake, 30–45 days, kg[a]		
milk	10.1	13.1
concentrates	1.74	1.06
hay	1.32	.68

[a]Animals weaned at 45 days of age, with ad libitum suckling to 28 days and partial suckling from 29 to 45 days. After weaning they were fed ad libitum pelleted concentrates containing 16% crude protein.

replacing soybeanmeal completely did not differ significantly, although the urea fed group tended to have less gains (34.8 vs. 32.8 kg final weight) (6). The daily feed intake followed the same trends. However, feed required for gain was significantly higher in the urea-fed group.

Results of evaluations of carcass quality and meat taste of fattened and unfattened Sudanese desert goats of three different age groups and their comparison with sheep of similar stages and ages was studied by Galili et al. (28). Dressing percentage increased (40.4 to 54.1%) and stomach contents in percent of body weight decreased significantly (18.9 to 6.4%) as a result of fattening for 80 days. Dressing percentage of fattened goats increased with each increase in age similar to sheep. The percent bone in carcass decreased significantly (43.6 to 21.1%) and the area of longissimus muscle increased significantly (2.11 to 9.03 cm^2) as a result of fattening in all age groups similar to sheep, even though the longissimus

TABLE 13. Effect of early weaning on lactation performance of Damascus goats (40).[a]

Item	Days of suckling		
	2	35	70
Does, number	31	33	33
Milk yield, kg, 35 days	84**	102**	110**
Milk yield, kg, 70 days	176**	193**	238**
Milk yield, kg, 150 days	351NS[b]	366	406**
Milk yield, kg, full lactation	520NS	511NS	558NS
Kids suckled/goat, number	...	1.67	1.74
Lactation length, days	279	267	263

[a]All goats received concentrates ad libitum and .5 kg alfalfa hay/head up to six months.

[b]NS = no statistically significant differences in rows.

**$P<.01$.

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TABLE 14. Prepartum feeding on milking performance of Damascus goats (5,8).

Item	Daily prepartum feeding level (Mcal ME/goat) 3.75 (Medium)	4.8 (High)
Does, number	27[ab]	29[a] (27)[b]
Initial weight, kg	61.8	62.8
Final weight, kg	73.6	75.9
Weight gain, kg/day	.24	.28[NS]
Weight loss at kidding	14.4	14.1
Kids born/goat	1.93[NSc]	1.89[NS]
Mean birth weight, kg	3.95[NS]	4.08[NS]
Weight gain, g/day	26[NS]	36[NS]
Milk yield kg/day	2.56[NS]	2.38[NS]
Concentrate intake, kg/day	1.96	2.07
Roughage intake, kg/day	.78	.79

[a]Last 7 wk of pregnancy.

[b]First 6 wk of lactation.

[c]NS = no statistically significant differences in rows.

muscle area was broader (4.15 to 13.39 cm^2) and body fat percentage was higher in sheep of all age groups (8.9 to 45.2%) compared to goats of similar ages and fattening stages (5.5 to 29.7%). Taste tests of the meats indicated that young goats (4.0, 3.8, 3.2) were not only superior within their own age groups but were also superior to any sheep meat (3.8, 2.3, 2.4). In the sheep age groups, though, yearlings scored the highest for quality (3.5, 2.7, 3.2).

Studied were also carob pods, a feed produced all over the Mediterranean Middle East as fruits of a legume tree *(Ceratonia siliqua)* (41). Carob pod meal contains 4.5% crude protein and 5.7% crude fiber dry matter and was compared to crushed barley in kids at 0, 15, and 30%. Urea supplemented carob pod rations to equate crude protein contents of rations fed ad libitum for 90 days to three groups of 13 three-month-old kids which also received 200 g alfalfa hay/day. Results indicated no significant differences in daily gain (.22, .21, .22 kg), feed intake (1.11, 1.12, 1.26 kg/day), feed conversion (5.1, 5.5, 5.9 kg/kg gain), and dressing

TABLE 15. Effect of size of production unit on costs and return of goat farms (42).

Goats/farm	80	160	200
Milk yield (kg/female)	160	160	160
Kids raised per doe	2.0	2.0	2.0
Gross revenue/yr, C£	4,246	8,492	10,615
Variable costs, C£[a]	1,503	3,283	4,240
Feed cost, %	95.0	87.0	84.0
Fixed costs, C£[b]	1,357	2,195	2,587
Net profit, C£	1,385	3,014	4,328
Return to capital, %[c]	43.6	47.5	53.8

[a]Feed, veterinary, hired labor, interest on operating expenses; C£, Cypriot pound.

[b]Depreciation, replacement, rent, family labor, interest on capital investment.

[c]$\frac{\text{Net profit + interests}}{\text{capital investments}} \times 100.$

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percentages between the groups (58.0, 58.5, 58.4%).

In another experiment (41), a lactation trial was with three groups of 12 goats to study effects of incorporating carob meal at 0, 15, and 30% in a barley-oil seed meal control ration testing 15.8, 16.4, and 16.8% protein. No statistically significant differences between the treatment groups were observed in milk yield (211, 198, 202 kg), fat content of milk (4.2, 3.9, 3.9%), body weight gain (6.5, 5.8, 4.2 kg), and feed intake in goats (176, 177, 180 kg).

Distillers dried solubles (DDS), a by-product feed available in the Near East area, was studied for effects on growth performance of kids (37). The DDS with 33% crude protein and 26% crude fiber replaced a mixture of oil seed meals containing 33% crude protein at 0, 5, 15, and 30% in a typical concentrate mixture. The four equicaloric and isonitrogenous rations were fed to four groups of five kids for 70 days. Average daily gains decreased at each increase in DDS (129, 121, 87, 83 g). Feed intake (74, 70, 65, 61 kg) and feed conversion (8.2, 8.2, 12.0, 10.7 kg) did not show statistically significant differences between the four groups (37).

FACTORS AFFECTING ECONOMICS OF GOAT PRODUCTION

A study (42) monitored profitability of goat farming for different amounts and types of production with 80 goats in three groups. The extreme situations of 280 kg milk per goat with 1.3 kids or zero milk production with 3.4 kids per goat were dairy or meat emphasis, and does producing 160 kg milk with 2.6 kids represented dual purpose production situations. The 3.4 kids in the meat system were achieved by following a breeding method of 1.5 kiddings per yr. In such cases does had shorter lactations and were mated soon after weaning of kids. Strict milk or meat systems were superior to dual purpose meat plus milk systems, mainly due to relatively higher fixed costs for covering both areas.

In another study (42) to determine the effect of size of production unit on profitability of goat farming, increasing the number of animals per unit from 80 to 160 or 200 increased the rate of return to capital at each increase in the size of the goat farm (43.6, 47.5, 53.8%) (Table 15).

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Fiber Digestibility by Goats and Sheep[1]

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ABSTRACT

Browse appears to be important in the diet of goats, but no good explanations or reasons are in the literature. Digestibility data on browse in goats are few. Semi-arid natural tropical grass hay was consumed more by goats than sheep, but digestibility coefficients were similar between species except for crude fiber, which was digested better in goats. Rice straw was consumed more by goats than by sheep, and they digested it better than sheep. When rice straw was treated with alkali, its nutritive qualities improved and digestion between goats and sheep was similar. Goats appear to be better utilizers of poor roughages.

BROWSE IN GOAT NUTRITION

Special feeding habits of goats typical for the species differ from those of other ruminants and are the basis of much of the criticism directed at goats. It often is suggested that goats are destructive grazers, grazing more closely on bushes and grass, thereby reducing chances of plant regeneration from seedlings (17, 25, 28). However, Gihad (12) reported that these criticisms of the goat are really a result of overstocking and lack of good, scientific husbandry and management. Goats are able to graze short grass and to browse on foliage not normally eaten by other domestic livestock (2, 4, 8, 35). They can adapt to widely varying climatic and grazing conditions, rough country, and they prefer forage plants of that type of range. Their inquisitive feeding habits and selectivity make goats wander widely on their accustomed territory; therefore, when goats are mixed with cattle and sheep, it encourages them to widen their grazing preferences.

Bell (3) summarized the grazing choice of range plants by domestic livestock as in Table 1. Various kinds of livestock have preferences for the kind of forage best suited to their needs, although they overlap to a degree with range sites and conditions. Goats, being the most rugged grazers of domestic livestock, prefer browse plants and take approximately 60% of their diet in them; the other 40% is made up of grasses and selected forbs when available. Cattle and sheep will, on the other hand take approximately 10% of their diet from browse plants.

In Uganda, Wilson (39) studied the browsing behavior of East African goats and observed that only a small proportion of grass was eaten compared to trees and shrubs. More than half the browsing time was occupied with eating leaves and shoots of trees and bushes. Preferences of the goats were for succulent shoots about head height. McMahan (29) showed a significant difference in the relative amounts of browse and grass eaten by livestock. Browse and mast formed over 50% of the diet of the goat, which was different from diets of sheep and cattle. On pastures where browse was limited, grasses were eaten readily by goats.

Lindahl (26) reviewed that there was lack of agreement on the value of browse for goats. It has been recommended that the opportunity to browse or to nibble on cut browse sometimes helps to restore the appetite of goats that have gone off feed. However, browse does not contain any factor(s) necessary for the per-

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TABLE 1. Grazing choice of range plants by kinds of domestic livestock (3).

Plants	Grazing			
	Horses	Cattle	Sheep	Goats
	(%)			
Grass	90	70	60	20
Weeds	4	20	30	20
Browse	6	10	10	60

TABLE 2. Chemical composition of Zambian natural grass hay (12).

Nutrients	Dry matter basis
Dry matter, %	94.7
Organic matter, %	88.5
Crude protein, %	6.6
Crude fiber, %	37.9
Ether extract, %	1.7
N-Free extract, %	42.3
Ash, %	11.5

formance of milking goats not supplied by alfalfa hay when fed with an adequate supplementary concentrate.

These observations indicate that browse may form an important part of the diet of goats. Under field conditions goats may be used to convert otherwise useless browse plants into meat. Hood (19) in Zambia estimated the seasonal changes in the composition of browse (leaves). He stated that in young leaves, crude protein contents (9.2 to 15.2%) tended to be high and crude fiber (23.8 to 35.2%) low. There are fewer data available on digestibility of tropical browse species. The nutritive value of browse, therefore, is often assumed on the basis of crude protein contents. In the tropics, however, it is doubtful whether even goats can meet their nutritional requirements, because normally tropical herbages are high in crude fiber (37.9 to 50.6%) and low in crude protein (2.2 to 7.2%) contents (13, 18).

ROUGHAGE UTILIZATION AND FIBER DIGESTION BY GOATS

There is little green vegetation that goats will not eat. As a milk producer, the goat is often more effective where the available fodder is of such low quality that a cow barely can live (12). In Western countries there is a growing demand for goat milk for therapeutic use (27). As a meat producer, the goat has advantages that there is no religious barrier for eating goat meat and the dry palatable flesh of goats has a relatively high keeping quality.

Goats differ from other ruminants in their feeding habits, and they appear to have more rumen capacity than sheep (14). There is no evidence whether the goat has a digestive efficiency different from that of other ruminants that might account for its successful adaptation to poor environments. Available

TABLE 3. Daily intake of Zambian natural grass hay by goats and sheep (12).[1]

Item	Goats	Sheep
Initial weight, kg	25.3	60.8
Dry matter intake, g/day per animal	456.3	762.1
Intake, g/kg bodyweight $^{.75}$	40.5[a]	35.0[b]
Water intake, ml/day per animal	739	1505
Water intake, ml/g dry matter intake	1.63[a]	1.97[b]
Digestible protein intake, g/kg bodyweight $^{.75}$	1.16	1.03
TDN intake, g/kg bodyweight $^{.75}$	20.7	18.1
Net energy intake, g starch kg bodyweight $^{.75}$	11.6	10.2

[a,b]Averages in rows differ at $P<.05$.

[1] N = 12 each.

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TABLE 4. Apparent digestibility of Zambian natural grass hay by goats and sheep (12).

Item	Goats	Sheep
Dry matter	53.9	53.6
Organic matter	58.5	58.6
Crude protein	43.5	44.3
Crude fiber	60.3[a]	56.5[b]
Ether extract	62.4	61.0
N-Free extract	55.0	58.1
Gross energy	56.6	56.6

[a,b]Averages in row, differ at $P<.05$.

TABLE 5. Nitrogen utilization from Zambian natural grass hay by goats and sheep (12).

Item	Goats	Sheep
N Intake, g/kg bodyweight $^{.75}$/day	.42	37
Excretion, g/day:		
Fecal N	.24	.21
Urinary N	.39	.26
Total N	.53	.47
N Retention, g/day	-.11	-.10

literature suggests too few digestibility trials with goats.

Huston (21) ranked four ruminants in their ability to digest a common feed fed ad libitum. Cattle ranked significantly higher than the other three. Sheep, goats, and deer ranked in that order, but the differences between them were not significant ($P>.05$). He also contended that the smaller ruminants had less digestive ability.

Devendra and Burns (9) cite studies supporting that goats can digest tropical forages more completely than cattle. Crude fiber was utilized especially well by goats. They concluded that differences in digestive ability of goats of different types and in different areas are probable. Huston (22) found that certain breeds or strains of goats have anatomical dimensions favoring better digestion but that this is not necessarily a characteristic of the entire goat species.

Work by Gihad (12) focused on digestion of crude fiber by two breeds of goats (small East African and Egyptian Baladi) fed poor quality roughage (semi-arid natural grass hay of Zambia and Egyptian rice straw). The Zambian grass hay was dominated by low quality Hyparrhenia spp. cut during the flowering stage, field dried, and machine baled. Its composition is in Table 2. Voluntary intake by goats and sheep is in

TABLE 6. Dry matter composition of experimental feeds (15).

Nutrients	Rice straw[1]	Alkali-treated rice straw[2]	Concentrate mixture[3]
	(%)		
Crude protein	3.4	3.3	18.7
Ether extract	1.4	1.3	3.4
Crude fiber	39.5	34.2	7.3
N-Free extract	37.1	39.8	65.3
Ash	18.6	21.4	5.3
Neutral-detergent fiber	85.0	71.9	29.1
Acid-detergent fiber	62.6	58.9	12.3
Acid-detergent lignin	42.6	40.4	8.2
Acid-detergent ash	10.8	10.1	5.1

[1] Fed 400 g/goat per day; 600 g/sheep per day.

[2] Fed 500 g/goat per day; 700 g/sheep per day.

[3] Fed 225 g/goat per day; 330 g/sheep per day; in proportion to bodyweight $^{.75}$ requirements.

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TABLE 7. Daily dry matter and water intake by sheep and goats when fed rice straw or alkali treated rice straw (15).[1]

Item	Sheep		Goats	
	RS	ARS	RS	ARS
Number of animals	4	4	4	4
Average initial body weight, kg	45	45	27	27
Dry matter intake, g/day	815	885	592	657
g/kg $W^{.75}$	46.9[a]	50.9[b]	50.0[b]	55.5[c]
Water intake, ml/day	2200	3450	1480	2496
ml/g dry matter intake	2.7[a]	3.9[b]	2.5[a]	3.8[b]

[a,b,c]Means with different superscripts in rows differ at $P<.05$.

[1] RS = rice straw; ARS = alkali treated rice straw.

Table 3. Goats consumed more dry matter and less water than sheep. Goats and sheep digested the nutrients in hay similarly, except crude fiber was used significantly better by goats than sheep (Table 4). Both goats and sheep were in negative nitrogen balance (Table 5). The digestibilities agree with similar reports (20, 24, 32, 33). In further studies by Gihad (13, 14, 15) with standard procedures (1, 7, 10, 13, 16, 30, 31, 36, 37, 38), Baladi goats (four adult males) and Ossimi sheep (four) fitted with rumen cannulae were fed rice straw with supplemental grain or after alkali treatment (NaOH). The chemical composition of the feeds is in Table 6. Alkali treatment reduced crude fiber, neutral detergent fiber, acid detergent fiber, and acid detergent lignin, 5.27, 13.18, 3.71, and 2.22 percentage units of the dry matter content of rice straw.

Results of dry matter and water intake are in Table 7. Goats consumed more feed than sheep on a physiological body weight basis ($W^{.75}$) but drank similar amounts of water. Alkali treatment produced a 48% increase ($P<.05$) in water consumption by both species which agrees with (11, 23, 34).

Apparent digestibilities for the two straws in sheep and goats are in Table 8. Alkali treated straw was superior to rice straw in all aspects, which agrees with (5). Digestibility differences between goats and sheep were significantly in favor of goats (Table 9). Results were similar with in vitro digestion (Table 4 and Figure 1) showing better utilizations in rumen fluids from

TABLE 8. Apparent digestibility in sheep and goats fed alkali treated or untreated rice straw (15).[1]

Nutrients	Sheep		Goats	
	RS	ARS	RS	ARS
Dry matter, %	49.8[a]	63.6[c]	52.9[b]	65.6[d]
Organic matter, %	57.3[a]	71.1[c]	59.2[b]	72.4[d]
Crude fiber, %	53.1[a]	75.1[c]	63.3[b]	78.4[c]
Detergent fiber, %				
Neutral-detergent fiber	43.2[a]	64.1[c]	48.8[b]	65.7[c]
Acid-detergent fiber	38.9[a]	56.6[c]	44.2[b]	56.7[c]
Acid-detergent lignin	45.3[a]	66.0[b]	49.4[a]	67.8[b]

[a,b,c]Values in rows differ at $P<.05$.

[1] RS = rice straw; ARS = alkali treated rice straw.

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TABLE 9. Dry matter disappearance of rice straw and alkali treated rice straw by the nylon bag technique for sheep and goats (15).[1]

Incubation time	Sheep		Goats	
	RS	ARS	RS	ARS
	(%)			
12 h	10.3	26.4	11.7	26.3
24 h	15.8	32.8	16.6	34.5
36 h	24.4	46.2	28.7	45.9
48 h	26.6	52.2	33.8	53.7

[1] RS = rice straw; ARS = alkali treated rice straw.

TABLE 10. Cellulose digesting bacteria in rumen liquor from sheep and goats (15).[1]

	Rumen liquor plus biotin and B-vitamins		Rumen liquor plus yeast extract	
	Hours postfeeding		Hours postfeeding	
Animals	0	4	0	4
Sheep	1.8	2.2	1.3	.2
Goats	8.8	4.1	2.2	.4

[1] N X 10^5/ml liquor.

goats over sheep and agrees with (33). Pant et al. (33) studied in vitro digestibility of cellulose for sheep and goats and published significantly higher digestibilities for goats.

Microbial counts of cellulose digesting bacteria (Table 10) showed that goats had larger populations of cellulolytic bacteria than sheep in their rumens at 0 and 4 h after feeding.

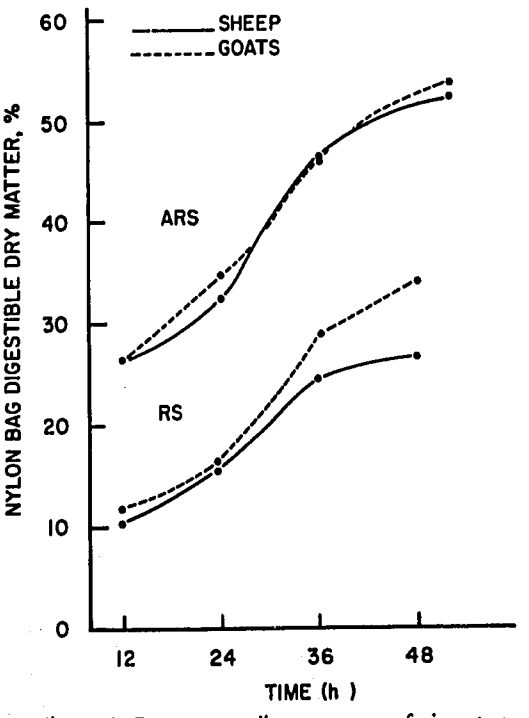

Figure 1. Dry matter disappearance of rice straw (RS) and alkali treated rice straw (ARS) by nylon bag technique for sheep and goats.

This may support the findings of goats being more efficient in digestion of crude fiber and being better utilizers of poor roughages, although goats and sheep seemed to have similar abilities to digest alkali-treated rice straw.

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Aspects of Urea Metabolism in Ruminants with Reference to the Goat[1]

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ABSTRACT

In goats and other ruminants, urea functions as a source of nitrogen for protein biosynthesis in the digestive tract. Ammonia can be absorbed in the digestive system when formed in excessive quantities and enhance formation of urea, or it can be derived from urea of blood plasma when its formation from feed sources is small. Entry rates of urea into plasma may vary from 4 to 80 μmol/min per $kg^{.75}$ body weight depending on dietary conditions. Urea formation is related to nitrogen intake of which approximately 70% passes into the urea pool of plasma. Irreversible losses of urea of plasma into the digestive tract vary between 10 and 90% depending on the protein to energy ratios of the diet. Entry of urea from plasma into the rumen appears to be a passive process which is sensitive to short-term changes of urea concentrations in plasma. Permeability of ruminal epithelium to urea may be altered by fermentation products of rumen (ammonia, carbon dioxide, volatile fatty acids). The influx of nitrogen into the rumen is related to needs for nitrogen of microbial populations and is associated with changes of renal excretion and tubular reabsorption of urea. Combined gastrointestinal and renal responses exert a synergistic effect on improved utilization of urea of plasma when uptake of dietary nitrogen is limited in goats and other ruminants.

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Urea is quantitatively the most important end product of nitrogen metabolism in goats. At least 70% of the N ingested daily passes through the urea pool of the body.

In most animal species urea is excreted almost entirely through the kidneys; thus, urea assumed a new function in those herbivores that developed microbial ecosystems in the anterior part of their digestive system. In this group of animals, which includes the goat, urea is not only a simple waste product of N metabolism but also an important precursor of protein biosynthesis. The new role of urea in these herbivorous species required new regulatory mechanisms to meet specific metabolic needs which were associated with the development of the forestomachs.

In addition to the new function associated with urea formed in the liver, important differences have developed in ruminants in provision of nitrogenous precursors for synthesis of urea. Whereas in monogastric animals precursors of urea synthesis mainly are derived from N metabolism of the body tissues, in ruminants more than 60% of N in plasma urea may derive from rumen ammonia (47). The extra ammonia delivered from the gastrointestinal tract and mainly from the rumen of these animal species provides an additional and important N load to the liver and may be critical when the detoxicating capacity of the liver is approached. Important features of urea metabolism in goats are illustrated schematically in Figure 1. Urea is formed from NH_3 and CO_2 through a four step ATP dependent cyclical process with citrulline and arginine as carrier compounds. Only one-half of the N of urea originates from free ammonia. Aspartate provides the other N by being the specific N donor in the conversion of citrulline to arginine.

A discussion of urea metabolism in the goat should include an analysis of the regulatory aspects of formation, elimination, and utilization of urea as far as they specifically are

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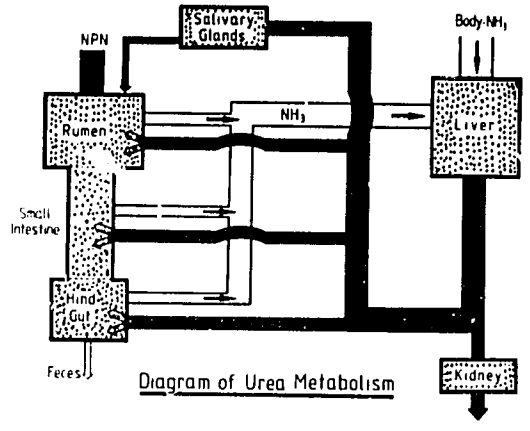

Figure 1. Diagrammatic illustration of urea metabolism in the goat. Taken into account is that only one-half of the urea N originates from free ammonia. The other half is provided as amino N by aspartate.

= Ammonia
= Urea

related to digestion in the forestomach. Since it is not possible to present complete coverage of all aspects on a comparable basis, this paper will be limited to a discussion of: 1) factors influencing urea entry in goats and other ruminants, 2) physiological significance of changes of kinetic parameters of urea metabolism, 3) mechanism and physiological significance of urea degradation, and 4) factors involved in the regulation of renal excretion of urea.

Because of no basic differences in urea handling and controlling urea metabolism between goats, sheep, and cattle, information from sheep and cattle will apply to goats where not directly obtained from goats.

The pertinent kinetic parameters of urea metabolism in this discussion are illustrated in Figure 2.

FACTORS INFLUENCING UREA ENTRY

Theoretical Considerations

When the total quantity of urea in the body remains unchanged, rate of urea entry (i.e. the quantity of urea sunthesized or liberated into the body pool per unit time (μmol/min per $kg^{.75}$ body weight) equals the rate of urea elimination. The system then is in equilibrium. Under these conditions entry rate of urea also may be denoted as total turnover rate or total flux rate. Total flux rate may be estimated from the dilution rate of a tracer dose of

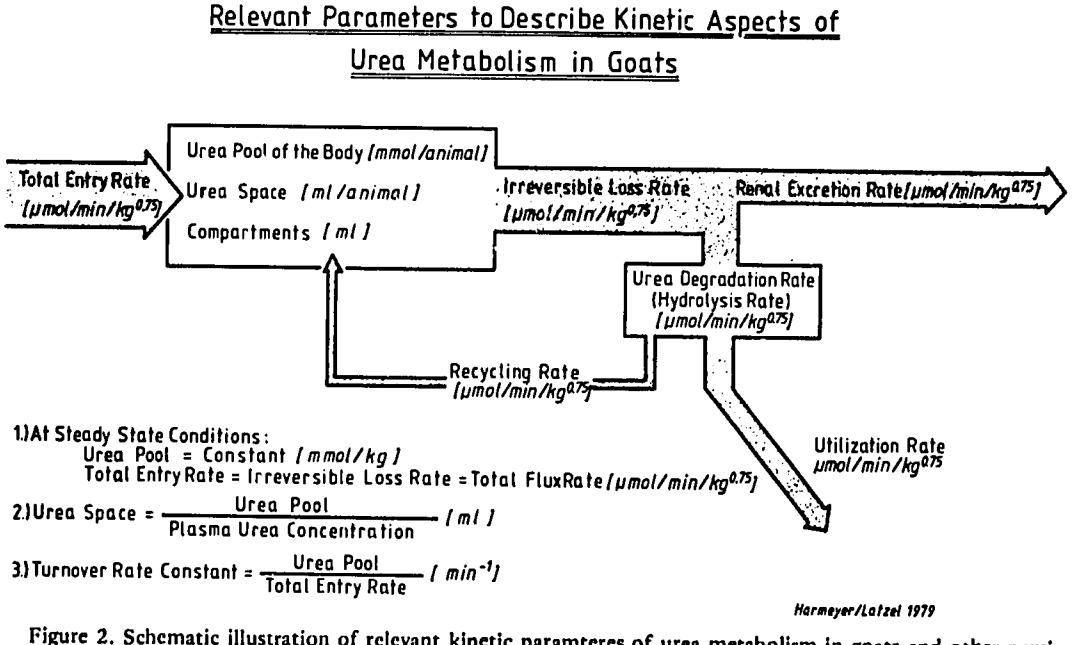

Figure 2. Schematic illustration of relevant kinetic paramteres of urea metabolism in goats and other ruminants.

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isotopically labeled urea administered intravenously, provided no recycling of the label occurs. With ^{14}C as a label, recycling is usually small (ca. 2 to 3% of total flux rate) (56, 58) and may be neglected. When [^{15}N] urea is used, recycling of the label in the goat may be substantial, amounting to 14% of total flux rate (42) and depending on feeding regimen. In this case, total entry of urea is greater than estimated from the dilution of the label. The sum of irreversible loss and recycling equals total flux rate of urea when recycling occurs. This is illustrated in Figure 2. Irreversible loss of urea, measured by use of ^{14}C-labeled urea, will serve as a suitable estimate of total flux rate because of the low recycling of ^{14}C.

Daily N Intake as Determinant of Urea Entry Rate

Measurements of total turnover of urea provide information for evaluating the rate of protein and nitrogen metabolism in the ruminant. Total turnover of urea in goats, sheep, and cattle has been estimated under various dietary conditions. General features of urea kinetics can be considered from this information. Total entry rate of urea may change by a factor of more than twenty. Total entry, for example, may be as low as 3.7 (μmol/min per $kg^{.75}$) in sheep fed 450 g chopped wheat straw plus 50 g alfalfa/day with 3.5% crude protein (6) and may rise to 82.6 (μmol/min per $kg^{.75}$) in a lactating Jersey cow fed a 19% crude protein 1:1 corn silage/corn meal diet supplemented with urea (55). The wide range of total turnover of urea reflects the particular ability of ruminants to adapt nitrogen metabolism to different dietary conditions. In temperate or semiarid zones having dry and wet seasons, wild grazing ruminants may have their feed confined during the dry season to a poor quality high roughage diet with low content of crude protein. A sudden change in feeds from high roughage to diets of high content of crude protein after rainfall results in increased N consumption. Similar changes take place when high producing ruminants are fed at a rate above maintenance. Rate of urea entry and daily N intake may vary within the same range.

Compilation of data from various authors on ruminant species, covering a broad spectrum of different diets, shows that the daily N intake is the major determinant of entry rate of urea (μmol/min per $kg^{.75}$). Correlation between daily N intake and total flux rate of urea accounts for 77% of the variation. Figure 3 contains these results from experiments in which dietary N was provided to the animals in various forms and routes. This relationship describes most of the variation, regardless of which type of nitrogen is fed (natural protein or NPN) or what feeding schedule is applied (feeding hourly or twice daily) or by which route N is supplied to the animal (orally or abomasal infusion). From Figure 3 ammonia N absorbed from the rumen exerts a similar stimulatory effect on urea synthesis as does amino acid N absorbed from the small intestine. The data representing different dietary conditions, compiled in Figure 3, give further rise to the consideration that urea synthesis in the body is not affected greatly by the route of dietary N transport to the liver. For example, if larger proportions of soluble proteins or NPN are fed which are degraded readily in the rumen and which enhance ammonia absorption from the rumen, an immediate effect on urea production can be expected. The greatest part of ammonia absorbed from the rumen is taken up directly by the liver before it enters the systemic blood, and it stimulates urea production directly (88). When no excess N is offered with the feed, probably more time elapses before amino acid N, which is absorbed from the small intestine, contributes to urea production by the liver. Response on urea synthesis is similar for both dietary conditions. The arabic numbers that mark individual estimates in Figure 3 refer to the sequence number in Table 1 in which the corresponding dietary conditions are listed.

An elevation of total urea entry of 17.8 μmol/min per $kg^{.75}$ can be calculated when daily intake of nitrogen increases by 1 g/$kg^{.75}$ (Figure 3). The intercept of the relationship represents the basal metabolic turnover rate of urea (zero N intake) which is equivalent to 5.31 μmol/min per $kg^{.75}$. This figure appears to apply to most domestic ruminant species. When feed was withheld from goats and sheep for 2 days, estimated basal turnover rates of urea were higher (15.3 and 15.9 μmol/min per $kg^{.75}$) than rates from Figure 3 (6, 23). It is not certain whether the basal metabolic rate of turnover represented by Figure 3 is equivalent to that measured after 2 days of starvation. The

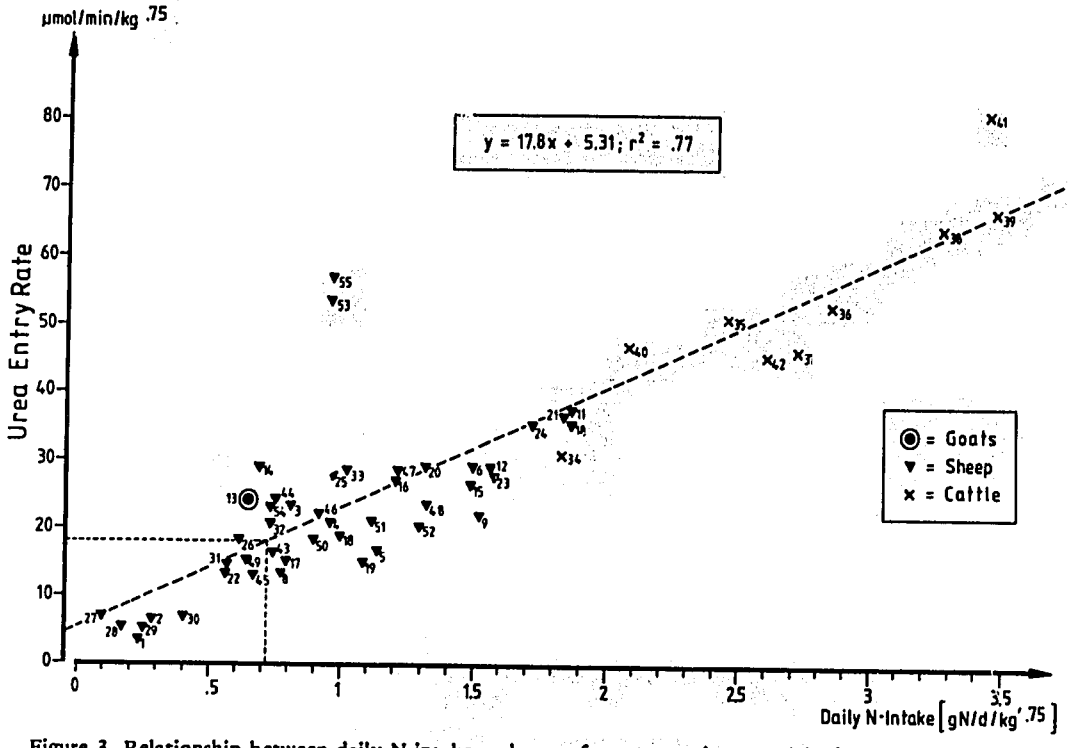

Figure 3. Relationship between daily N intake and rate of urea entry in goats (●), sheep (▾), and cattle (x) (6, 14, 15, 23, 24, 47, 54, 57, 58) (Table 1).

basal rate of urea turnover may decrease further when the period of starvation is extended.

The presence of a basal metabolic rate of turnover is responsible for the increase in percentage of daily N intake which passes the urea pool when daily N intake is reduced. The percentage of ingested N entering the urea pool of the body exceeds 100% when N intake is reduced below .75 g/day per $kg^{.75}$.

From the data the amount of daily N intake is the major determinant of urea synthesis. Source of ingested N and site of N absorption from the digestive tract do not affect greatly the rate of urea synthesis.

Urea Turnover and Plasma Urea Concentration

Information on urea entry and on intensity of N metabolism can be obtained from N intake. The question arises as to the usefulness of measuring urea concentration of plasma for similar information.

Urea concentration in plasma is positively related to daily N intake (6, 42) and may serve as an index of urea entry rate. However, changes of urea concentration in plasma do not always reflect changes of total entry rate of urea, and measurements of urea concentration in plasma occasionally lead to erroneous conclusions (Figure 4).

It appears that urea concentration rises from .50 to 8.7 mmol/liter when the crude protein content of the ration fed to goats ad lib is elevated from 3.0 to 19.8% (42). The 17-fold increase of urea concentration was accompanied by a 6-fold increase of urea entry rate (from 5.6 to 35.6 μmol/min per $kg^{.75}$) (42). It may be unexpected that urea concentration in plasma in goats or sheep rises by 30% (from 5.2 to 6.8 mmol/liter) when feed is withheld for 2 days (23, 24). This increase of urea in plasma from starvation was accompanied by a 37% decline of total entry of urea from 24.0 to 15.3 μmol/min per $kg^{.75}$. Prior to these experiments, the animals were fed ad lib a hay-concentrate ration of 13.5% crude protein. Observations by others (12) have been similar.

It may be surprising that urea in plasma

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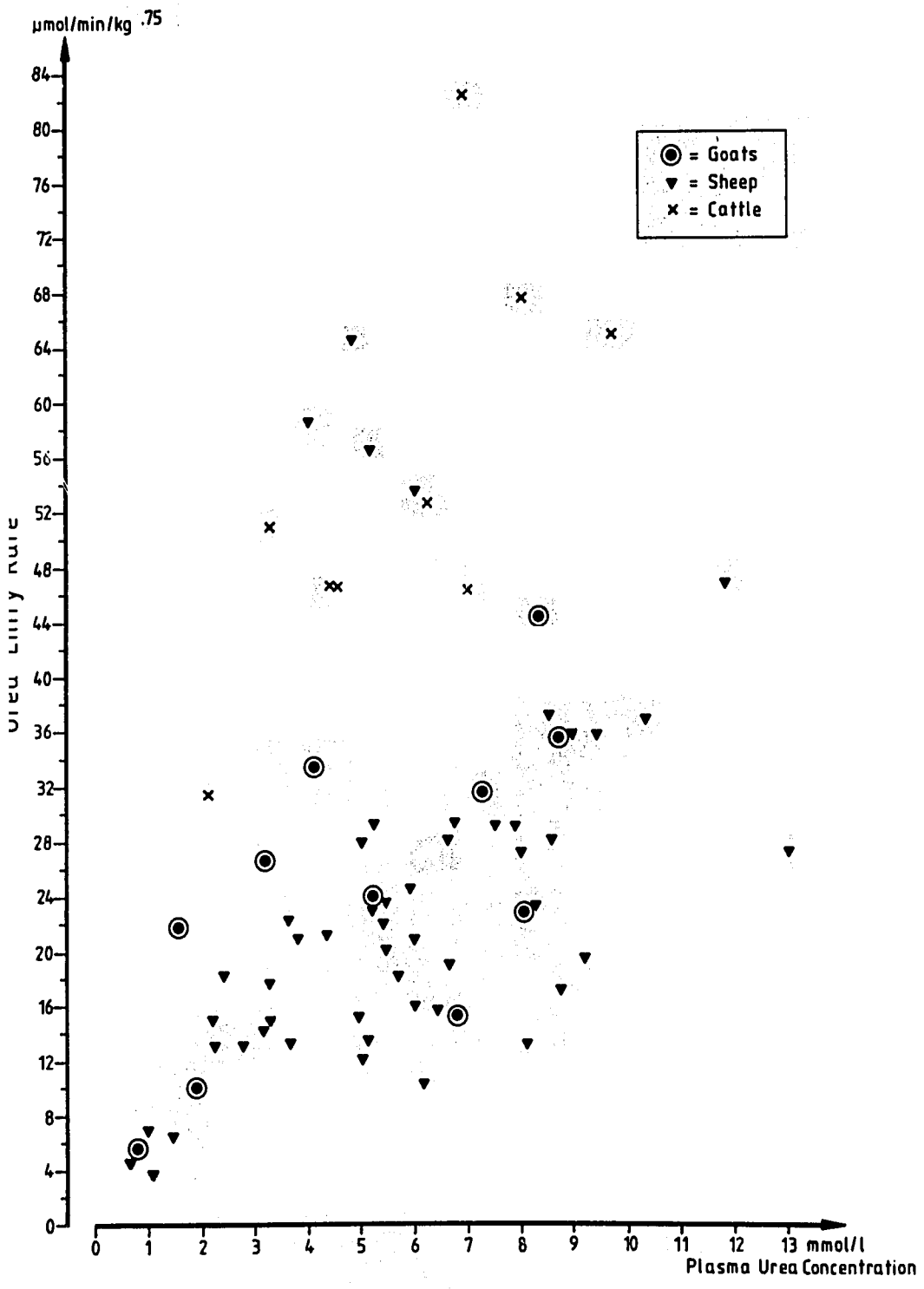

Figure 4. Relationship between plasma urea and urea entry rate in goats (●), sheep (▾), and cattle (x) (6, 14, 15, 23, 24, 42, 47, 54, 55, 56, 58, 61).

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TABLE 1. Dietary conditions during measurements of total entry of urea in goats, sheep, and cattle. Sequence numbers refer to results in Figure 3.

Sequence no.	Species	Body weight	Intake g/day	Crude protein Content	Feeding regime	Reference
		(kg)	(airdry or DM)	(%)		
1	sheep	26	450 g chopped wheat straw, 50 g alfalfa, minerals	3.5	hourly, 0700 to 1900 h	(6)
2	sheep	30.4	500 g wheat chaff	4.5	hourly, 0700 to 1900 h	(6)
3	sheep	40.9	300 g alfalfa, 300 g wheat grain	13.5	hourly, 0700 to 1900 h	(6)
4	sheep	34.8	500 g chopped alfalfa	17.0	hourly, 0700 to 1900 h	(6)
5	sheep	29.9	800 g wheat chaff, 200 g chopped alfalfa	9.0	hourly, 0700 to 1900 h	(6)
6	sheep	35.2	800 g alfalfa	17.0	hourly, 0700 to 1900 h	(6)
7	sheep	27.3	700 g alfalfa	27.3	hourly, 0700 to 1900 h	(6)
15	sheep	21.8	800 g alfalfa	17.0	hourly, 0700 to 1900 h	(6)
8	sheep	50 to 65	790 g bromgrass pellets	20	hourly	(47)
9	sheep	50 to 65	1580 g bromegrass pellets	20	hourly	(47)
10	sheep	50 to 65	1420 g bromegrass pellets, 20 g urea into abomasum	26	hourly; urea continuously	(47)
11	sheep	50 to 65	1420 g bromegrass pellets, 20 g urea into rumen	26	hourly; urea continuously	(47)
12	sheep	50 to 65	1270 g alfalfa pellets	26	hourly	(47)
13	goat	50	concentrates, saccharose, hay, rye	13.5	twice daily	(23)
14	sheep	69.6	straw ad lib (3:2:4:5)	13.5	twice daily	(23)
23	sheep	35.3	800 g alfalfa	23	hourly	(56)
24	sheep	34.0	800 g alfalfa	23	hourly	(56)
25	sheep	50	concentrate hay ad lib	17.5	twice daily	(24)
26	sheep	50	1300 g synthetic protein free diet + urea	15	twice daily	(24)
27	sheep	61.7	500 g wheat straw, 200 g saccharose (basal diet)	2.0	hourly	(54)
28	sheep	61.7	basal diet + 12.5 g casein into abomasum	3.4	hourly	(54)
29	sheep	61.7	basal diet + 25.0 g casein into abomasum	4.9	hourly	(54)
30	sheep	61.7	basal diet + 50.0 g casein into abomasum	7.7	hourly	(54)
31	sheep	61.7	basal diet + 75 g casein into abomasum	10.3	hourly	(54)
32	sheep	61.7	basal diet + 100 g casein into abomasum	12.9	hourly	(54)
33	sheep	61.7	basal diet + 150 g casein into abomasum	17.3	hourly	(54)
34	Jersey cows[a]	430	129 g/kg$^{.75}$ corn meal (88%) molasses (5%) (basal diet (DM)	8.9	twice daily	(55)
35	Jersey cows[a]	430	127 g/kg$^{.75}$ basal diet + 2.1% urea (DM)	12.2	twice daily	(55)
36	Jersey cows[a]	430	140 g/kg$^{.75}$ basal diet + 3.1% urea (DM)	12.8	twice daily	(55)

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37	Jersey cows[a]	430	113 g/kg$^{.75}$ basal diet + 4.1% urea (DM)	15.1	twice daily	(55)
38	Jersey cows[a]	430	121 g/kg$^{.75}$ basal diet + 5.2% urea (DM)	16.9	twice daily	(55)
39	Jersey cows[a]	430	130 g/kg$^{.75}$ basal diet + 6.2% urea (DM)	16.7	twice daily	(55)
40	Jersey cows[a]	430	93 g/kg$^{.75}$ corn silage (DM)	14.0	twice daily	(55)
41	Jersey cows[a]	430	113 g/kg$^{.75}$ corn silage/ground corn (1:1)	19.0	twice daily	(55)
42	Jersey cows[a]	430	81 g/kg$^{.75}$ corn silage/ground corn (1:3)	20.0	twice daily	(55)
43	sheep	40	400 g dried grass	18.4	hourly	(60)
44	sheep	40	400 g dried grass + 400 g saccharose	9.2	hourly	(60)
45	sheep	47.9	1000 g:rolled barley + ground alfalfa + dried molasses (70+7+2) (basal diet) + 21 parts starch	10.0	continuously	(14,15)
46	sheep	47.9	1000 g:basal diet + starch + soybean (79+14+7)	13.5	continuously	(14,15)
47	sheep	47.9	1000 g:basal diet + starch + soybean (79+7+14)	17.7	continuously	(14,15)
48	sheep	47.9	1000 g:basal diet + starch + soybean (79+4+21)	21.1	continuously	(14,15)
49	sheep	47.9	Corresponds to No. 45 but treated with formalin	10.0	continuously	(14,15)
50	sheep	47.9	Corresponds to No. 46 but treated with formalin	13.6	continuously	(14,15)
51	sheep	47.9	Corresponds to No. 47 but treated with formalin	17.1	continuously	(14,15)
52	sheep	47.9	Corresponds to No. 48 but treated with formalin	20.3	continuously	(14,15)
53	sheep	41	500 g wheat straw + 100 g casein	17.4	hourly	(61)
54	sheep	41	400 g dried grass + 400 g saccharose	9.7	hourly	(61)
55	sheep	41	500 g wheat straw + 100 g casein into abomasum		hourly	(61)

[a]Milking 6.7 to 10.0 kg/day.

increases from 5.0 to 5.7 mmol/liter when a soy protein diet (17.5% crude protein) is replaced by a protein-free 100% urea N diet (16.0% crude protein equivalent) whereas urea entry drops from 28.0 to 18.3 μmol/min per $kg^{.75}$ (24). Lack of relationship may be demonstrated also when feed intake is changed from ad lib to restricted feeding. Urea concentration remains unchanged (5.25 ± .2 mmol/liter) when consumption is reduced to 50% of ad lib (47). Entry rate of urea decreased from 22.0 to 13.5 μmol/min per $kg^{.75}$ (Figure 4). The absence of correlation indicates that factors other than urea concentration of plasma control entry rate of urea and urea concentration is not a suitable index for predicting entry rate of plasma urea.

Urea concentration in plasma has been of value for prediction of other parameters of N metabolism. When different herbage diets were fed to sheep, urea concentration could be used as an index to predict N utilization (9). There is also information from monogastric animals which shows that urea concentration may serve as an index for assessing the nutritional value of proteins for different levels of production (4).

Relationship Between Plasma Urea Concentration and Urea Pool

Changes of urea concentration in plasma coincide with changes of the urea pool in the body as estimated from the curve of radioactivity with time from intravenous injections of ^{14}C labeled urea. In kinetic terms, the urea pool is controlled by the ratio of the rate constants of urea entry and irreversible loss. If the rate constant of urea entry exceeds the rate constant of irreversible loss, the urea pool increases and vice versa.

In goats urea concentration and urea pool of plasma increase about 10-fold from .82 to 8.63 mmol/liter and from .41 to 4.94 mmol/kg body weight when the crude protein content of the diet is raised from 3.0 to 14.8% (42). In sheep, a 20-fold change of urea pool size has been reported, ranging from .30 to 6.30 mmol/kg of body weight, which corresponds to changes of urea concentrations from 1.45 to 11.8 mmol/liter (6). Feeding rations with increasing content of crude protein to goats or other ruminants produced proportionate increases of body urea pool and urea concentration in plasma (6, 42, 54, 55) (Figure 5).

A close relationship between plasma urea concentration and body urea pool is supported by the observation that urea diffuses easily across most cell membranes and may be expected to be distributed equally between various compartments of body water (urea space) (3, 24). The water space in which urea is dissolved in goats represents a constant fraction of about 50% of body weight for many dietary conditions (16); however, data in Figure 5 show exceptions also. Lack of a close relationship between the two parameters may be explained in two ways. First, tracer estimates of urea pool are associated with technical errors, or, second, physiological relationship is not close between body urea pool and plasma urea concentration. Indications of technical errors derive from calculations of urea space, which range from 20% (6) to more than 90% (55) of the body weight (Figure 5). Urea space in ruminants may not be constant under different dietary conditions (24, 28, 29). More information is needed on physiological variation between plasma urea concentration and urea pool and possible adaptive changes of urea space induced by dietary conditions. The conclusion from Figure 4 is that urea concentration of plasma does not always appear a reliable index of estimates of body urea pool from isotope dilution techniques.

SIGNIFICANCE OF CHANGES OF UREA TURNOVER RATE CONSTANT

Urea flux rate, urea pool size, and urea concentration of plasma respond to dietary changes, particularly to increased daily N intake. Furthermore, relationship is not close between urea turnover and plasma urea concentration which indicates regulatory control of urea metabolism in goats and other ruminants. For simplicity, the total urea in the body will be regarded as a one compartment pool. Those fractions which are not mixed rapidly are excluded from consideration, i.e., urea in the kidney, bladder, and gastrointestinal tract (5). The entry rate of urea (μmol/min per $kg^{.75}$) estimated from the dilution curve of [^{14}C] urea (single injection) is given by the product of the urea pool (μmol/$kg^{.75}$) and the turnover rate constant (min^{-1}) (22) as:

$$\text{Total Entry Rate} = \text{Urea Pool} \times \text{Turnover Rate Constant} \quad [1]$$

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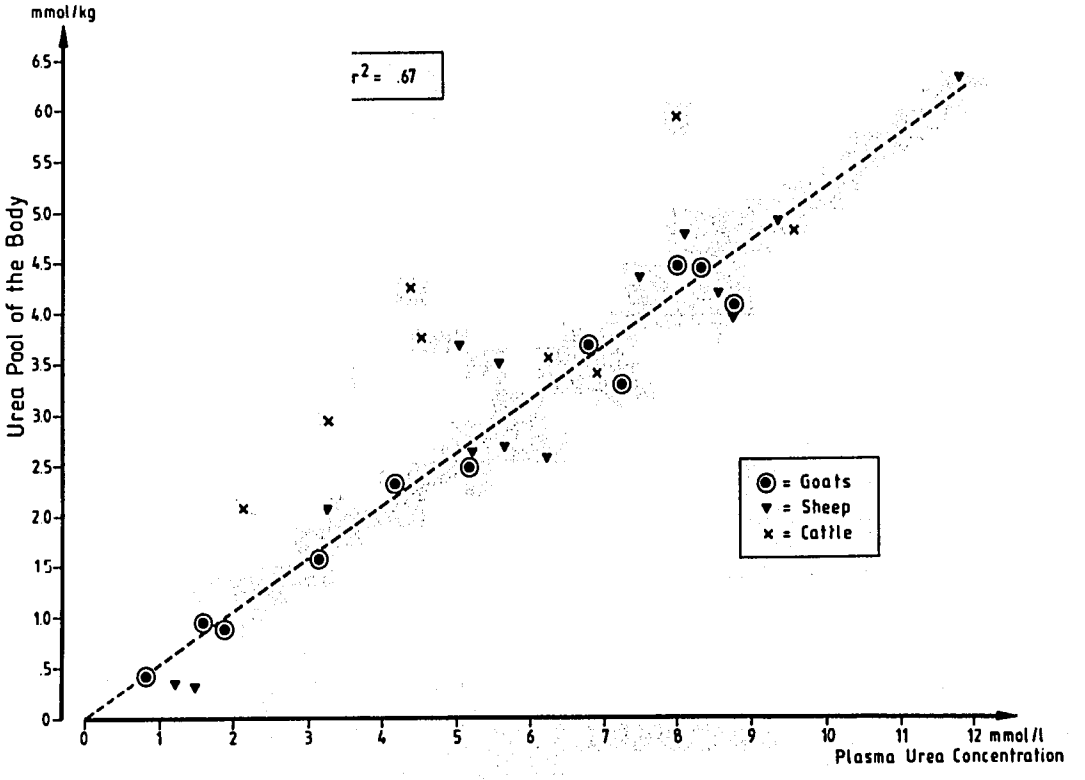

Figure 5. Relationship between urea concentration in plasma and body urea pool in goats (●), sheep (▾), and cattle (x) (6, 20, 23, 24, 42, 55, 56, 61, 84).

The turnover rate constant denotes that fraction of the urea pool which is turned over per unit time. The turnover rate constant describes the properties of organs involved in elimination of urea from the body pool. When the turnover rate constant is large, the elimination of urea from the body pool is facilitated, and vice versa.

Thus, changes of the turnover rate constant reflect changes in the urea-eliminating properties of kidneys, the gastrointestinal tract, or both. The lack of linearity between urea concentration of plasma and urea entry rate, which was shown, indicates that the turnover rate constant varies with the physiological handling of urea by the kidneys and the gastrointestinal tract under different dietary conditions and may not be constant (Table 2). Ruminants, including goats, are able to control excretion of urea by altering the excreting functions of the kidneys, by changing the ability of the gastrointestinal tract to hydrolyze urea, or by changing the functions of both organs.

Urea Degradation and Relationship to Entry Rate and in Intake

In ruminants, entry rate of urea (mmol/day per animal) when measured by isotope dilution techniques is usually higher than rate of renal excretion. The difference between total turnover and renal excretion represents that fraction of urea entry degraded in the body by urease activity of the gastrointestinal tract. The mucosa of the gastrointestinal tract of ruminants (17, 37, 62) and ruminal and intestinal microbes (43, 44, 48) contain urease activity; that of the mucosa appears to be of bacterial origin also (62). By washed, live ruminal goat mucosa bathed in urea containing saline, 50 to 90% of the urea was degraded to ammonia and CO_2 before it reached the solution bathing the mucosa surface while passing from blood to the lumen side (41). In lactating goats (50 kg body weight) fed a saccharose-supplemented concentrate diet containing 13.5% crude protein, 8.6 g of urea/day were degraded in the body,

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TABLE 2. Changes of rate constants [min^{-1}] of urea turnover in goats, sheep, and cattle at different dietary conditions.

Animal	Estimated range of rate constants 10^{-3} min^{-1}	Source of dietary variation	Reference
Goats	from 2.5 to 10.1	crude protein and energy	(42)
Goats	from 1.7 to 3.7	feed amount intake	(23)
Sheep	from 1.0 to 3.9	feed amount intake	(23)
Sheep	from 1.9 to 4.7	crude protein and energy	(6)
Sheep	from 1.5 to 3.8	type of protein and energy	(23)
Cattle	from 2.5 to 3.8	type and amount of crude protein and energy	(55)

which was equivalent to 40% of the daily N intake (20, 84).

The quantity of urea hydrolyzed in animals fed ad lib is modified by dietary factors, particularly by the crude protein content of the feed (42). The quantity of urea degraded in goats (17 kg body weight) decreased from 7.6 to 1.7 g N/day when the crude protein content of the diet was lowered from 12.3 to 4.3% and total entry of urea decreased from 19.1 to 1.8 g N/day. The smaller quantity degraded at reduced intakes of protein generally constitutes an increasing proportion of total urea turnover and nitrogen intake (Figures 6, 7). This implies that renal excretion of urea is reduced absolutely and relatively when protein contents of the diet are lowered. Figures 6 and 7 indicate that the quantity of urea degraded in sheep is the same as in goats fed similar diets. Urea degradation appears to decrease even more than linearly when contents of crude protein increase above 12% (Figure 7).

If a concentrate-hay ration (18% crude protein) at maintenance (50 kg animals) is replaced by a protein-free urea diet (11.5% crude protein), then urea hydrolysis in the gastrointestinal tract decreases from 11.7 to 8.8 g N/day. The smaller quantity represents 76% of daily N intake compared to 64% on the higher protein diet (22, 23). The amount of urea degraded in the body may be increased by dietary manipulations which do not affect rumen fermentation directly. Moctar (54) kept sheep (62 kg) on a low protein (2%) basal diet of wheat straw plus saccharose. Increasing amounts of casein in six successive quantities ranging from 1.6 to 20.3 g casein N/day were infused continuously into the abomasum for 7 days. The crude protein content of the diet was raised by the infusions from 2 to 17.3%. The infusions stimulated endogenous degradation of urea from 5.4 g N/day (no casein) to 13.2 g N/day (20.3 g casein). The change in urea degradation represented a decrease from 87% to 52% of urea entry. The inverse relationship between urea degradation and its percentage of urea entry indicates a regulatory mechanism which appears to benefit the ruminant. The

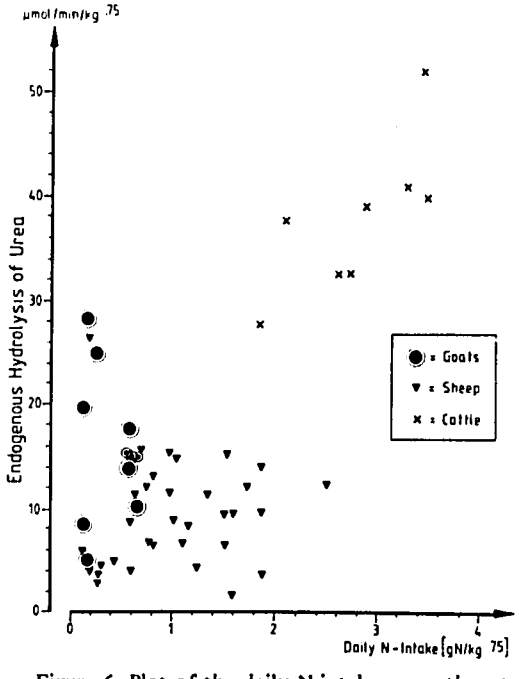

Figure 6. Plot of the daily N intake versus the rate of urea degradation in goats (●), sheep (▾), and cattle (x) (6, 23, 24, 42, 47, 54, 56, 58).

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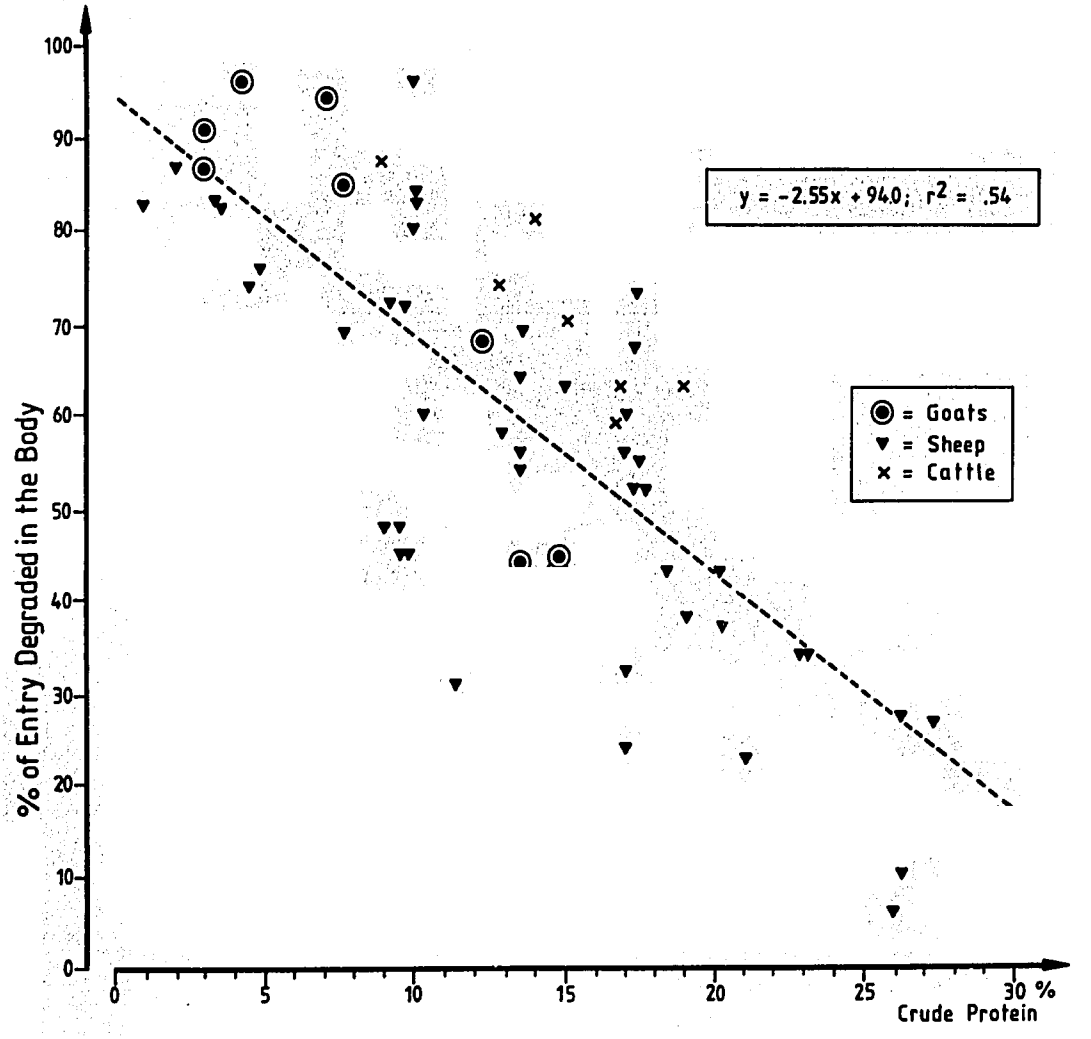

Figure 7. Relationship between crude protein content of diets and rate of urea degradation in the body as percent of total urea entry rate in goats (•), sheep (▾), and cattle (x) (6, 23, 24, 42, 47, 54, 55, 56, 58, 84).

relationships hold over a wide range of dietary conditions, regardless of whether N is supplied to the rumen as feed protein (6), NPN (55) supplied into the abomasum as urea N (47), as protein N (54), or if it is supplied directly into the blood as urea N (22) (Figure 7), provided sufficient energy is present. This indicates a mechanism which controls the partition of total urea flux rate into renal and gastrointestinal pathways according to dietary needs.

Feeding level is another factor which influences return of urea to the gastrointestinal tract. In studies of Kennedy and Milligan (47) the intake of alfalfa pellets (20% crude protein) was restricted to 50% of ad lib intake (reduction from 1.58 to .79 kg/day). Urea concentration in plasma (5.25 mmol/liter) was almost unaffected by the dietary manipulation. Entry rate of urea diminished from 18.5 to 11.4 g N/day, but urea degradation by ruminal mucosa decreased from 13.9 to 6.1 g/day, corresponding to 70 and 50% of entry rate at the two respective dietary intakes. Endogenous degradation of urea is reduced further when feed is withheld from goats or sheep for 2 to 3 days (6, 23, 84). The quantity of urea degraded decrea es from 8.0 N/day to almost zero (23).

Several conclusions can be drawn from this analysis of urea kinetics. The absence of a linear relationship between total entry rate and urea concentration in plasma under various dietary conditions indicates that the turnover rate constant of urea may vary. The marked variation of turnover rate constants, particularly with changing N consumption, demonstrates that elimination of plasma urea by kidneys and the gastrointestinal tract is not much regulated by urea concentration in plasma but mainly by changing the eliminating properties of one or both organ systems. Elimination rates of plasma urea appear to be controlled by adaptive processes involving changed permeability of the gastrointestinal mucosa to urea and of excretory functions of the kidneys.

MECHANISM AND SIGNIFICANCE OF UREA DEGRADATION

Houpt (37) reported from experiments with sheep on a low protein diet that 52% of the urea N (2.5 mmol/kg body weight intravenously injected) was retained in the body instead of being excreted in the urine. Nitrogen retention from urea administration decreased to 22% when the diet was no longer supplemented with carbohydrates, which indicates dietary effects on urea degradation. Conclusions from studies with lactating and nonlactating goats with ^{14}C-labeled urea were similar (7, 8). Measurements of radioactivity as $^{14}CO_2$ in expired air showed that 43% of urea entry rate was hydrolyzed in the body. A term of "rumen clearance" (7) proved to be a useful introduction. An inverse relationship between the extent of renal and rumen clearances indicates specific and perhaps independent mechanisms of urea handling by the kidneys and gastrointestinal tract (7, 8). The authors suggested that increasing amounts of feed protein and elevated ammonia concentrations in rumen may depress urea entry from blood into rumen, which points to the regulatory control of urea degradation by intermediates of rumen fermentation (31). The mechanisms of transfer of urea from blood into the gastrointestinal tract of goats were studied after intravenous injections of 100 μCi of ^{14}C-labeled urea and 1.0 to 2.0 g of unlabeled urea administered 1 to 3 h later (19). Urea concentrations in plasma were raised from 3.3 to 6.5 mmol/liter. According to the amounts of expired $^{14}CO_2$, the quantity of urea hydrolyzed remained unaffected by an elevation of urea concentration. Evidence for a nonlinear relationship between the net movement of urea across the rumen epithelium from blood to the lumen side and the concentration difference between the two surfaces emerged also from in vitro studies (17). The net influx of urea was saturated when urea concentrations in the solution bathing the serosal surface exceeded 2.5 mmol/liter.

Evidence of Urea Transfer into the Rumen being a Simple Diffusion

Little support, however, for active movement of urea from blood into rumen came from studies of Houpt and Houpt (40, 41) using the washed pouch of goats. Urea concentrations in plasma were raised by intravenous injections of urea. Net urea influx into the pouch increased linearly with the increased differences in concentration between blood and the solution inside the pouch. The conclusion was that urea movement into the rumen was simple diffusion and was confirmed by in vitro and in vivo studies (13). Urea degradation in goats increased linearly when the urea concentration in plasma was raised from 2.3 to 9.2 mmol/liter. Net urea movement across isolated ruminal mucosae was related linearly to differences in concentration from 4.2 to 33 mmol/liter.

Regressions have been linear between amount of urea degraded in the body (22), in the rumen (41, 51, 52), and plasma urea concentrations elevated by intravenous infusions. Urea degradation is controlled by the differences in concentration of urea between blood and gastrointestinal tract when urea concentrations are raised by intravenous injections of urea. In none of these studies were urea concentrations varied by changing dietary conditions.

Control of Urea Degradation by Dietary Factors

Urea transference from blood to the gastrointestinal tract might not be controlled by urea concentration in plasma alone (86, 87). Upper limits of urea concentration in blood were 6.0 mmol/liter in sheep and 4.0 mmol/liter in cattle; above these limits, urea transfer was no longer related linearly to urea concentrations in plasma. Elevation of plasma urea above these concentrations did not further increase rumen

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ammonia. The results can be interpreted as an inhibitory effect of rumen ammonia on urea entry into the rumen. More evidence is derived from experiments with changing dietary conditions. When feed was withheld from goats and sheep for 2 days, urea concentrations in plasma rose by 44% from 5.2 to 7.7 mmol/liter, but urea degradation in the body declined from 4.7 μmol/min per kg$^{.75}$ to almost zero (12, 23, 84). Relationships between rate of urea degradation and urea concentrations in plasma were inverse in goats which were adapted to a low protein diet (12). The change from a control hay diet to a low protein, high energy diet (sugar beet pulp plus straw) resulted in a 30% decrease of urea concentrations in plasma from 4.0 to 2.8 mmol/liter and in a 4-fold increase in urea degradation from .11 to .42 mmol/min per animal. Factors affecting the extent of urea hydrolysis in the body were amount and digestibility of feed energy (60). A basal hay diet with 18.4% protein hay supplemented for weeks with 400 g sucrose/day which lowered the crude protein content to 9.2%. Urea concentration in plasma dropped from the additional supply of energy, but urea degradation in the body increased by 140% from 7.0 to 16.8 μmol/min per kg$^{.75}$. In Figure 8 reflux of urea

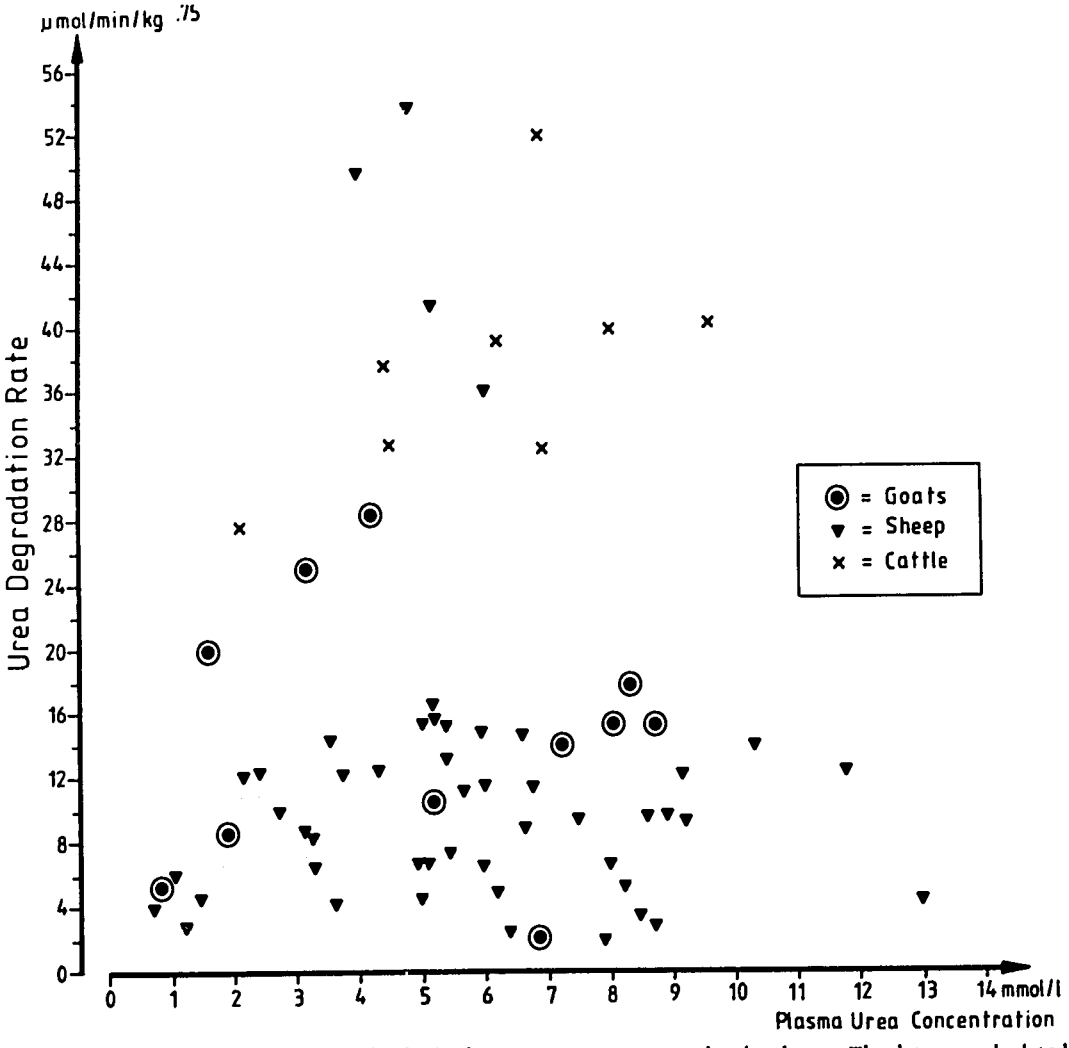

Figure 8. Plot of urea degradation in the body versus urea concentration in plasma. The data are calculated from experiments in which the urea concentration in plasma was changed by intravenous infusions of urea and by changing the dietary conditions (6, 14, 23, 42, 47, 55, 56, 58, 61).

into the gastrointestinal tract can be either high or low at all urea concentrations between 2 and 9 mmol/liter.

Changing Permeability of the Gastrointestinal Tract to Urea

Return of urea to the gastrointestinal tract is facilitated when low protein-high energy diets are offered, i.e., when there is need for additional nitrogen in the rumen. This requires a functional change of gastrointestinal structures and is interpreted as a change of permeability to urea. The permeability coefficient, P, represents a measure of the ease with which a substance penetrates gastrointestinal membranes. It denotes the ratio of flux of a substance/concentration difference.

$$P = \frac{\text{Flux } (\mu\text{mol/cm}^2 \text{ per min})}{\text{Concentration difference } (\mu\text{mol/cm}^3)} = \left[\frac{\text{cm}}{\text{min}}\right] \quad [2]$$

Permeability of an organ system per kilogram metabolic weight can be described as:

$$P_0 = \frac{\text{Flux } (\mu\text{mol/min per kg}^{.75})}{\text{Concentration difference } (\mu\text{mol/cm}^3)} = \left[\frac{\text{cm}^3}{\text{min/kg}^{.75}}\right] \quad [3]$$

From equation [3] P_0 is a clearance term. In case P_0 is applied to urea degradation in the body, the endogenous clearance may be used as a measure of permeability of the gastrointestinal tract to urea. As intraruminal and intestinal urea concentrations approach zero, the difference in concentration included in equation [3] equals the urea concentration in plasma. The surface area of the digestive tract is assumed to be constant. Calculations of endogenous urea clearance show that it has 10-fold variation when dietary conditions are varied (Figure 9). An increase of endogenous urea clearance in goats was from 1.73 to 9.0 ml/min per $kg^{.75}$. This corresponds to diets with 12.3 and 3.0% crude protein, respectively. Withholding feed for 2 days lowered the gastrointestinal clearance in goats from 2.0 to .3 ml/min per $kg^{.75}$ consistently (23, 84), which indicates an adaptive decrease in permeability of the digestive surface to urea. Gastrointestinal permeability to urea was increased also in lactating Jersey cows (55).

Factors Controlling Net Transpepithelial Flux of Urea to the Forestomach

The ability of various ruminal metabolites to cause changes of permeability of rumen epithelium to urea was recognized in 1961 (31). It was suggested that rumen ammonia might inhibit urea entry from blood into the rumen (31). The elevation of rumen ammonia from .2 to 2.5 mmol/liter was related inversely to the ammonia concentration in the rumen prior to a plasma urea load (80). Transfer of urea into the washed pouch in which ammonia concentration was kept low was, however, always related linearly to changes of urea concentration in plasma (83). Rumen ammonia was elevated from 6.8 to 10.7 mmol/liter and plasma urea from 5.4 to 7.9 mmol/liter by changing feed from bromegrass to alfalfa pellets (47, 76). Urea entry into the rumen was reduced from 9.8 to 1.3 g/day despite increased urea in plasma. Increasing rumen ammonia after withholding feed for 2 days can be responsible for reduced urea degradation in goats and sheep (23, 80). Figure 10 shows the relationship between gastrointestinal clearance of urea and rumen ammonia. It is assumed that ammonia concentrations in rumen exert control on urea passage from blood into the rumen. The weak realtionship indicates other dietary factors which may be responsible also for changes of permeability of rumen epithelium to urea.

Urease activity of rumen epithelium has to be considered. Net urea entry into the pouch of goats filled with rumen fluid is inhibited 10- to 20-fold by inactivating the urease activity of the wall of the pouch (37, 41). Bacterial urease activity of the rumen epithelium is suppressed by increasing ammonia concentrations in the rumen (45).

Other products of rumen fermentation have stimulated urea transfer into the rumen, e.g., CO_2 and volatile fatty acids, especially butyrate, followed by propionate and acetate (75). Changes of permeability of rumen epithelium due to fermentation products in the rumen provide effective means to regulate the extent of endogenous N influx into the rumen in relation to N requirements of microbial popula-

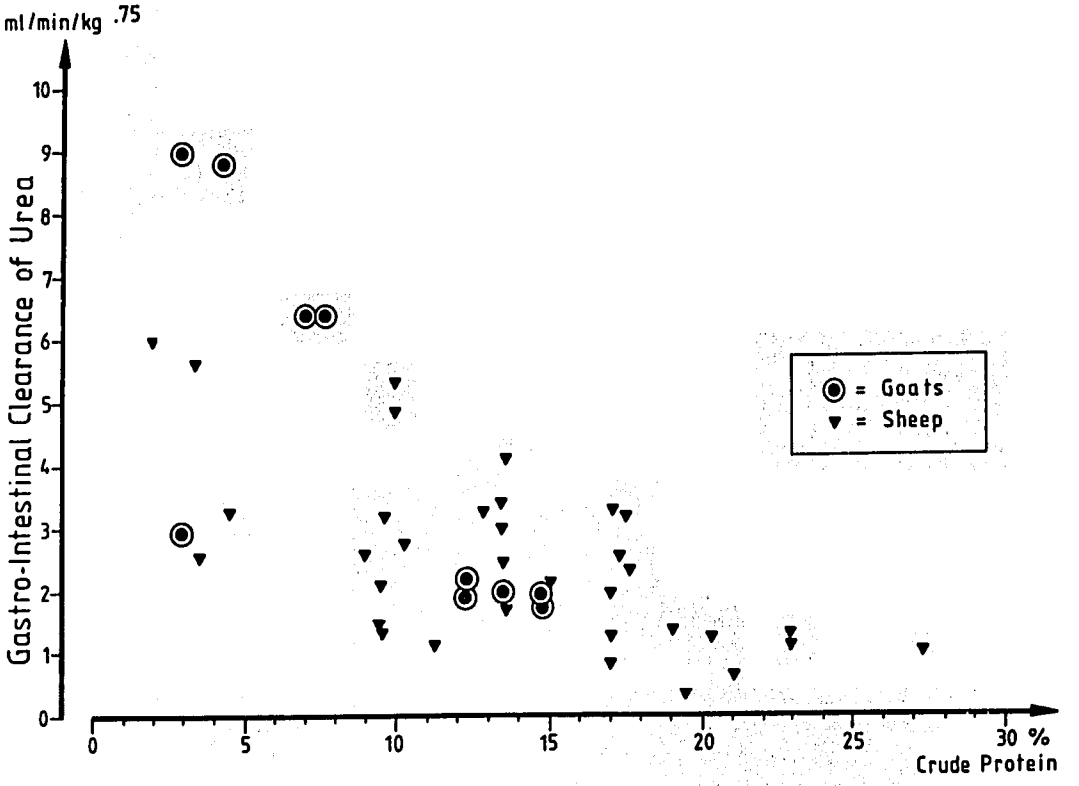

Figure 9. Plot of crude protein content of the diet versus gastrointestinal clearance of urea/kg$^{.75}$ in goats (●) and sheep (▾) (6, 14, 15, 23, 24, 42, 54, 56, 58, 61).

tions. Little is known about these adaptive changes in permeability of the rumen epithelium. It appears unlikely that the responses are mediated by changes of blood flow.

Enzyme activities in the conversion of nitrogenous compounds like arginase, GOT, GPT, and glutaminase have been found in rumen epithelium (21, 48). A transfer of nonessential amino acids (glycine) into the rumen during periods of prolonged starvation also has been suggested (25, 26, 53). Glycine in plasma increased in goats by 100% when feed was withheld (22).

Urea Entry into the Rumen with Saliva

Saliva of goats and sheep contains 10 to 30 mg N/100 ml (63, 79). Of the total salivary N of mixed saliva 60 to 70% was urea N, and salivary urea concentration corresponded to 60% of the urea concentration in plasma (50). Approximately .5 g N passed from blood into the rumen daily through salivation (49, 68, 69, 70, 71, 72). Urea concentration in saliva is not related linearly to urea concentration in plasma particularly during the first phase following food intake (72). The amount of urea N which enters the rumen with saliva can be varied by the flow rate of saliva, changing in sheep from 2 to 27 liters/day (70). Ammonia in rumen concentrations have a depressive effect on salivary flow (59, 73). Sheep fed a forage diet had saliva containing 28 mg N/100 ml, but the urea concentration was only 24% of total N (34). Salivary secretion of urea into the rumen increased from 2.5 to 3.1 mmol/h when the rumen content was gassed with CO_2 (33). Urea influx decreased to 2.3 mmol/h when volatile fatty acids were omitted from saline bathing the washed rumen and increased to 2.9 mmol/h after butyrate was added to the rumen fluid. The portion of urea entering the rumen with saliva is small compared to the transepithelial flow of urea. With ^{14}C labeled urea in goats it

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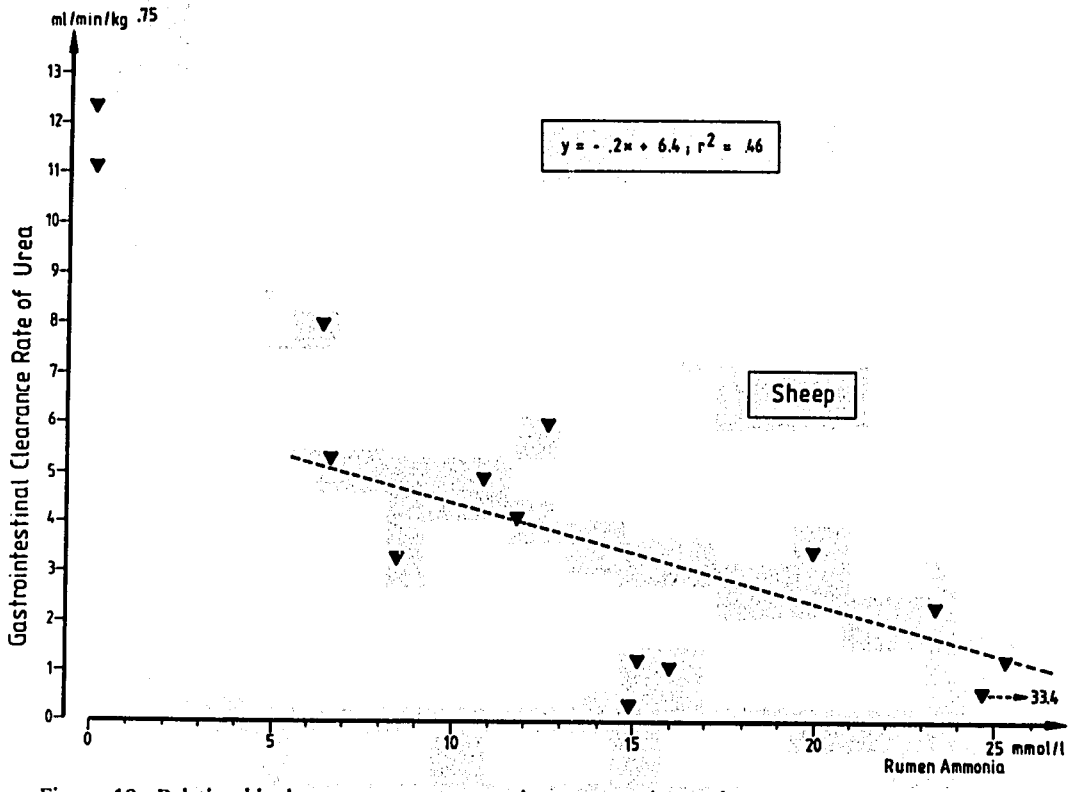

Figure 10. Relationship between rumen ammonia concentration and gastrointestinal clearance of urea. (15, 56, 61).

was estimated that 5 to 10% of the urea degraded in the body returned to the rumen with saliva flow (8, 19). Estimated urea entry into the washed rumen of sheep was 5.2 mmol/h, but only 5.8% of this amount was in saliva (38). Rumen ammonia rose faster in saline filled into the washed rumen when saliva was not allowed to enter the rumen compared to undisturbed salivary secretion (25, 53). Thus, N entry with saliva constitutes only a small fraction of total endogenous nitrogen entry into the rumen. Salivary entry of urea appears related more closely to urea concentration in plasma than does urea passage across the rumen epithelium. Several observations, however, indicate a regulatory mechanism which is sensitive to changes of dietary conditions.

Physiological Significance of Urea Degradation

Urea degradation might constitute merely an inevitable loss of plasma urea due to gastrointestinal urease. Degradation of urea may predominate in those segments of intestines where it cannot be utilized, thus contributing to increased nitrogen recycling. This possibility has been considered (57, 58). In studies with urea labeled with ^{14}C or ^{15}N, the endogenous degradation of urea was not of great physiological importance to sheep fed 800 g of alfalfa/day. Two-thirds of the urea entry (i.e., 13.4 g N/day) were excreted with urine, and one-third (7.0 g N/day) was degraded in the body. Only 17% of the latter (i.e., 1.2 g N/day) entered the rumen, which indicates that the remaining fraction (83%) probably was hydrolyzed in other segments of the gastrointestinal tract where it may not be utilized for net synthesis of microbial protein. This was supported by demonstrating extensive fluxes of urea from blood to cecum and colon.

Evaluation of Urea Degradation by N Balance Studies of the Reticulorumen

Net influx of N and utilization has been

demonstrated with reentrant cannulae at the proximal duodenum or cannulae placed in the abomasum together with the use of suitable markers. Net loss from the reticulorumen was 4.3 N/day when a high protein diet was fed, but net gain was 2.6 g N/day at the duodenal site when animals were kept at the low protein diet (35). In other studies the daily N output was 18% lower than the uptake (34.4 g N/day) when animals were kept on a high protein alfalfa diet but was 14% higher than intake (5.6 g N/day) when a low protein hay diet was offered (36). Thus, an increasing proportion of that part of urea which is degraded in the body is reutilized in the rumen when the crude protein content of the diet is reduced (1, 15). Additions of readily digestible carbohydrates (e.g., saccharose) to the forestomach exaggerate endogenous N entry into the rumen (61). There is net utilization of N in the forestomach from endogenous sources when the crude protein content of the diet is below 12 to 14%. Increasing losses of N may occur at higher crude protein (46).

Assessment of N Utilization from Degraded Urea

Utilization of N from degraded urea in the body has been demonstrated (83). Animals were adapted to a protein-free saccharose-starch diet with urea as the N source. Urea then was omitted gradually from the diet and replaced stepwise by a continuous intravenous infusion of urea to compensate for reduction of N intake. Under these conditions of an N-free diet all the N received from an intravenous infusion of urea, animals could be maintained at constant weight for several weeks. Potthast et al. (60) reported that 27 to 34% of urea degraded in the body entered the rumen when 400 g/day dried grass were fed daily to sheep. This percentage increased to 72% when 300 g of saccharose were added to the diet.

In goats, the extent of urea degradation in various segments of the gastrointestinal tract was determined (12). Changing from a hay diet to a high energy, low protein diet (sugar beet pulp plus straw), diminished the transfer of urea into the colon by approximately 50%, which was related linearly to the drop of urea concentration in plasma. Urea entry from blood into the total digestive system increased, however, four times from 6.3 to 25.2 mmol/h indicating plasma urea preferentially had entered those segments of the digestive system in which N could be utilized.

Thus, with low protein diets the transfer of plasma urea is directed preferentially to the reticulorumen rather than to other parts of the digestive system. The unique ability of ruminants and probably some other mammals (10) to make use of endogenous N waste products to meet maintainance requirements provides great advantages to these species under conditions of limited supplies of feed N. Quantities of N available to wild ruminants during dry seasons sometimes may be limited. Little advantage can be expected from the ability for endogenous recycling of N under conditions where N intake is high enough to meet N requirements of the microbial populations. This is normally the case in high producing domestic ruminants.

FACTORS OF REGULATION OF RENAL UREA EXCRETION

The kidney also possesses specific mechanisms in addition to the gastrointestinal tract to modify excretion or retention of urea according to metabolic needs of the animal. These form an integral part of the regulatory control of urea metabolism in the goat. Renal excretion of urea is enhanced when N consumption is sufficient and may be reduced when the availability of dietary N is limited. This in turn includes improved reutilization of urea. An inverse relationship in goats between renal excretion of urea and urea degradation has been reported (2, 27, 29). Changes of renal excretion of urea depend on dietary factors with no basic differences in renal responses between the three ruminant species (22).

Response of Renal Urea Excretion to Dietary Factors

A lag period of renal response appears much longer than the time necessary to initiate permeability changes of the rumen epithelium (22). Decreases of urea N contents in relation to the total urinary N after feeding low protein diets can be marked. When a diet of 17.3% crude protein is fed, 82% of the urinary N is present as urea N, but only 33% of the total N in urine is urea N when the diet contains 2% crude protein (54). Alterations of excretory

functions of the kidneys with changes in crude protein contents of diets are in Figure 11. Feeding low protein diets to goats lowers renal urea clearance to less than .5 ml/min per $kg^{.75}$. Conversely, feeding high protein diets causes 5- to 10-fold elevation of renal clearance of urea (up to 3.5 ml/min per $kg^{.75}$) (42).

The quantity of urea which is excreted by the kidneys may be influenced by three factors: 1) changes of urea concentration in plasma and corresponding changes of filtered urea loads, 2) changes of the glomerular filtration rates, and 3) changes of tubular resorption of urea.

Variations of the urea concentration in plasma alters renal excretion of urea when urea clearance remains constant. This requires no specific renal mechanisms to modify urea excretion. Indeed, changes of urea concentration in plasma are the principal factors to regulate renal urea excretion over a range of dietary conditions (9). From estimates from the urea/creatinine clearance ratios under various dietary conditions it was concluded that urea excretion was approximately 50% of the filtered load of urea and was related linearly to urea concentration in plasma (15, 66, 74, 77, 78). The data show that the rate of glomerular filtration remains unaffected when diets from 8 to 20% crude protein are offered. This implies that the amount of urea reabsorbed in the tubules increases with increased urea concentrations in plasma and that the percentages of filtered loads of urea reabsorbed remain constant. Specific mechanisms of the kidneys for saving urea from being excreted with urine, however, are considered when nitrogen intake is lowered further and when N supply to the animal remains inadequate for several months. Conclusive evidence from goats that the glomerular filtration rate drops under such conditions has yet to be presented. Results from llamas fed poor quality straw ad lib or hay at 40% of ad lib for several months indicate that the rate of glomerular filtration decreases under such conditions (11). Tubular reabsorption increased up to 90% of the filtered load in sheep resulting in marked reductions of renal N excretion (64, 65). An appreciable increase in tubular reabsorption of urea to more than 90% during lower rates of urinary flow also was reported (15, 66). These adaptive changes in renal urea handling probably are mediated by changes in tubular permeability to urea. The adaptive changes in the gastrointestinal tract

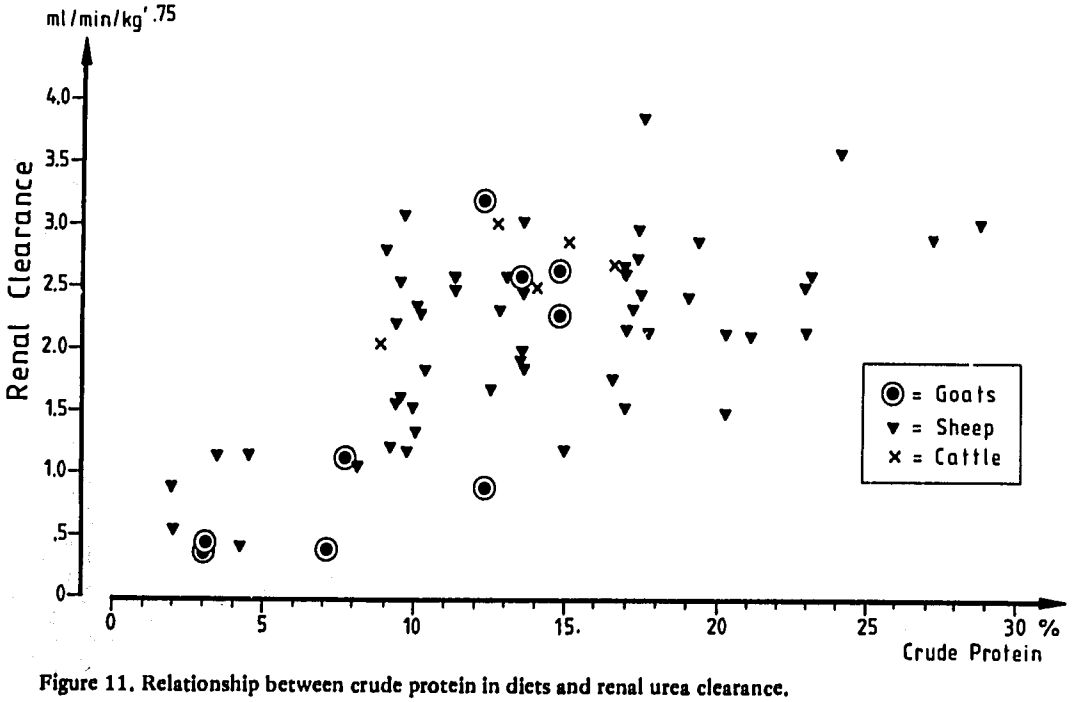

Figure 11. Relationship between crude protein in diets and renal urea clearance.

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and in kidneys have synergistic effects on controlling the amount of urea which either is degraded in the body or excreted. Both mechanisms, sensitive to dietary changes, provide effective means to improve the surviving potential of ruminants under conditions with inadequate supplies of N. Metabolic factors in urea handling of kidneys are understood poorly, but it may be suggested from the lag period of several months that functional changes in the kidneys are associated with morphological changes also.

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Mineral Nutrition of Goats[1,2]

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ABSTRACT

World literature on mineral nutrition of dairy goats was reviewed for the first time. No daily requirements of minerals for goats under different production conditions have been found. Cows, sheep, and goats differ in milk, blood, and tissue contents of minerals. Goats milking between .8 and 2.0 kg/day were in positive calcium and phosphorus balance when receiving between 7.7 and 21.6 g calcium oxide and 6.6 to 13.5 g phosphorus oxide in the feed daily and when sources of vitamin D were provided. Supplies of 238 mg magnesium per day were too small for normal milk production. A concentration of 1.74 g sodium per kilogram feed dry matter allowed normal milk production and growth of goats while .31 g sodium/kg dry matter did not. Dietary supplies of .03% ferrous iron produced normal ruminal epithelial color while .003% did not. Copper deficiencies can develop in the presence of cadmium and sulfur pollution. Zinc supplied at 6 to 7 ppm per day to growing males and milking females produced deficiency symptoms, and a minimum of 10 ppm is necessary for normal functions. Zinc deficiency produced changed sex ratios in favor of female twins. Goats fed 5 ppm manganese daily developed signs of deficiences including changed sex ratios in favor of male twins.

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INTRODUCTION

Research on mineral metabolism of goats has been often not to determine requirements of goats but to use them as a less expensive model in place of cows (88). T. W. Perry in a recent review (123) asked, "Does anyone know what the requirements are?" referring to trace minerals in general. A Cornell Extension bulletin (152) on mineral and vitamin requirements of farm livestock mentions neither goats nor their needs. Guidelines of the National Research Council (NRC) on standards for large domestic laboratory animals, cattle, sheep, and goats (109), suggest that requirements for goats can be estimated from recommendations for dairy cattle (48, 106) or by consulting other publications (33, 137). The feeding of goats for milk, meat, and mohair production has not been discussed in definitive textbooks on animal nutrition either. Yet, there are more than 400 million goats around the world kept for the production of milk, meat, and fiber (47, 58). Even in North America there are more than 3 million head, 20 goats for every 1,000 persons in the United States. In Central America there are 124 goats, in South America 146, in Asia 114, and in Africa 335 goats per 1,000 inhabitants (76). Worldwide these goats produced more than 4.5 million tons of milk and 1.2 million tons of meat for human consumption (47), not even mentioning the production and importance of mohair and goat leather. This indicates the economic potential and financial advantage which the furthering of knowledge in proper nutrition of goats could have.

A recent survey of the mineral content of Pennsylvania forages showed that they were all below NRC recommended allowances for dairy and beef cattle in phosphorus, sodium, zinc, and borderline in magnesium (161). Likewise, in studies around the world many soil and plant conditions have been reported with forages being deficient, imbalanced, or containing toxic excesses of many nutritionally important minerals (38, 56, 59, 94, 122). Goats, however,

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when allowed access to browse, supplement their diets and needs with shrubs and tree leaves, which are often much higher in mineral contents than the forages more commonly used for cattle and sheep (61), but these have been studied little in relation to nutrition of goats (82).

There are 7 elements (106) recognized generally besides nitrogen, oxygen, carbon, and hydrogen as the major essential minerals for livestock: Ca, Mg, Na, K, P, S, and Cl. In addition, there are 10 trace elements considered essential for livestock: Fe, I, Cu, Zn, Mn, Co, Mo, Se, Cr, and F, while 7 others are possibly essential: Ni, Sn, V, Si, Ba, Br, Sr. There are 9 other minerals in animal tissues without any demonstrated important function: Al, B, Ge, Cd, As, Pb, Hg, Ru, and Nb. More than 170 papers during the last 75 yr (1 to 178) have been published worldwide on mineral metabolism in goats with the following number of papers indicating distribution of areas of interest and emphasis:

General–54, Ca–24, Mg–5, Na and Cl–14, K–4, P–9, S–4, Fe–9, I–20, Cu–3, Zn–10, Mn–6, Co–2, Mo–1, Ni–2, Mg, Pb, Sr, Po, Pl, Se–11.

Hennig et al. (73) discussed recent evidence for including Ni among the possible essential elements for goats and pointed out difficulties in trying to establish proof of essentiality of Ni and other trace elements including Cr, V, Si, F, Sn, As, Pb, and Cd.

This review is intended to highlight mineral nutrition research in goats as far as publications could be obtained. Some of the older publications are now classics in the world literature of animal nutrition.

Compositions of goat milk are in Table 1 (94, 99, 119). Components varied depending on breed of goats, stage of lactation, milk yield, type of feed, season of year, fraction of milk, mastitis condition, etc. To assume from dairy cattle data what may apply to goats is a rough estimate at best. Cow and goat milks differ in kinds and amounts of several constituents, which is also indicated by the lower freezing point depression for goat's milk (2, 5, 20, 24, 31, 41, 42, 49, 50, 52, 57, 65, 66, 70, 81, 84, 91, 96, 101, 102, 126, 129, 134, 138, 151, 153, 160, 164, 168, 169, 170).

In Table 2 are comparisons of the mineral

TABLE 1. Ranges of published compositions of goat milk and comparison with cows' milk.[a]

	Goats		Cows
Total solids	11.3	– 15.1%	lower
Milk fat	3.0	– 5.5%	same
Total protein	2.9	– 4.6%	lower
Lactose	3.8	– 5.1%	same
Energy	70	– 86 cal/100 ml	lower
Citric acid	131	– 171 mg/100 ml	higher
Ash	.55	– .92 g/100 ml	lower
Calcium	114	– 163 mg/100 ml	lower
Sodium	35	– 42 mg/100 ml	higher
Potassium	165	– 228 mg/100 ml	lower
Magnesium	13	– 36 mg/100 ml	lower
Phosphorus	84	– 122 mg/100 ml	lower
Chlorine	105	– 259 mg/100 ml	lower
Iron	.01	– .07 mg/100 ml	higher
Copper	.02	– .06 mg/100 ml	same
Manganese	.007	– .009 mg/100 ml	lower
Sulfur	3	– 37 mg/100 ml	higher
Zinc	.002	– .4 mg/100 ml	higher
Molybdenum	traces (1.2[illegible] μg/100 ml)		higher
Iodine	variable (8–30 μg/100 ml)		lower
Freezing point depression	-.58	– -.61 C	higher
pH	6.33	– 6.52	higher

[a]References (2, 94, 99, 119).

TABLE 2. Comparison of ruminant milk ash contents (%).[a]

Mineral in the ash of milk	Goat	Sheep	Cow
Sodium	7.1	9.3	5.8
Potassium	20.7	14.1	27.4
Calcium	22.4	30.4	23.4
Magnesium	1.7	1.5	2.3
Phosphorus	23.6	22.2	21.6
Chlorine	19.5	22.5	19.5

[a]Reference (94).

content in ash of milk of goats, cows, and ewes, and differences between the three ruminant species are indicated (94). Composition of goat blood differs also from that of cow and sheep blood (Table 3) (94). Changes in blood composition before, during, and after parturition of does, ewes, and cows are in Table 4 for calcium, phosphorus, magnesium, and glucose (19). Blood calcium and phosphorus are depressed on the day of parturition while magnesium and glucose are elevated in goats which is similar to cows but different from ewes. Goat kids have higher calcium and phosphorus in blood than their dams. Blood of kids, lambs, and calves is more similar to each other than that of cows, ewes, and does.

Metabolism of Minerals

Calcium (3, 4, 8, 18, 19, 30, 34, 45, 46, 51, 62, 63, 64, 69, 74, 77, 92, 97, 98, 100, 157, 158, 178). One of the now classic studies on mineral utilization was by G. Fingerling at the University of Hohenheim (Germany) during the early years of this century (Table 5) (45). He showed that if lactating goats did not receive the necessary amounts of calcium and phosphorus in their diets, they would compensate by drawing from body stores of these elements without initially affecting milk yield and milk composition. As the calcium deficiency and negative balance continued for weeks, yield of milk decreased. The apparent digestibility of calcium, however, increased from 14.7 to 52.9%. As soon as feed intake of calcium was restored to normal, digestibility of Ca dropped again. The goats replenished their body calcium stores, and milk production rose again. Changes in milk composition were not observed.

In other classic studies at the University of Wisconsin, Madison, it was discovered that the knowledge of calcium contents in feeds for goats was insufficient for proper feeding, but that it was important to know certain facilitating or inhibiting factors which were responsible for the absorption and utilization of minerals, specifically calcium (Table 6) (63, 64, 69). Under the stress of milk secretion and calcium excretion in the milk, negative calcium balances resulted which were alleviated when animals were fed green plants, cod liver oil, or were allowed to be irradiated, which led to the discovery of the essential significance of vitamin D. Further discussion of these interesting papers, found in most chemical libraries, must be reserved for another publication on vitamin metabolism in goats.

Other minerals also may interact with calcium metabolism, but Mn deficiency showed no significant changes in calcium utilization (Table 7) (9). A sidenote in this study was that bones have different calcium contents, but some also appear to differ between males and females in calcium contents.

Experiments with ligated intestinal loops in anaesthetized goats and ^{47}Ca injections (51) showed that intestinal calcium transport is enhanced by carbohydrates and by low luminal concentrations of sodium. Calcium and sodium transports may be independent, and an active Ca transport is involved. Calcium absorption occurred principally in the duodenum, to a small extent in the jejunum, and least in the lower ilium. Calcium absorption was not affected by ouabain, by the absence of sodium,

TABLE 3. Composition of goat blood (g/kg).[a]

Mineral	Whole blood	Red cells	Serum
Sodium	2.66	1.56	3.21
Potassium	.33	.56	.20
Calcium	.97	...	.87
Magnesium	.025	.025	.025
Iron	.382	1.10	...
Phosphorus	.173	.340	.103
Chloride	2.92	1.48	3.69
pH	7.65		

[a]Reference (94).

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TABLE 4. Comparison of ruminant blood contents (mg/100 ml) at parturition and birth.[a]

Mineral	Goats: Doe Day −6	Goats: Doe 0	Goats: Doe +6	Sheep: Ewe −7	Sheep: Ewe 0	Sheep: Ewe +7	Cattle: Cow −10	Cattle: Cow 0	Cattle: Cow +7
Calcium	8.36	7.93	8.35	9.71	9.43	9.57	9.35	8.27	9.51
Phosphorus	8.40	5.01	6.62	3.40	3.82	4.94	5.41	4.42	5.33
Magnesium	2.59	3.13	2.48	1.98	1.92	1.91	2.21	2.53	2.10
Glucose	.56	1.49	.56	.56	.58	.59	.64	.88	.62
	Kid Day 0	Kid +3	Kid +6	Lamb 0	Lamb +7		Calf 0	Calf +3	Calf +7
Calcium	10.63	10.88	10.60	11.25	11.99		11.20	11.36	10.83
Phosphorus	6.57	8.36	8.10	6.94	9.47		7.41	7.37	7.54
Magnesium	2.10	1.92	2.10	1.91	1.78		2.09	1.96	2.07
Glucose	1.56	1.16	1.10	1.04	1.06		.74	1.07	.88

[a]Reference (19).

hypertonicity, heparin, or chondroitin sulphate. Sodium alginate, which depresses calcium and strontium absorption, changed the ratio of calcium to strontium by binding preferentially strontium, which has definite practical implications.

Phosphorus (23, 28, 29, 37, 40, 83, 86, 113, 116). In other, now classic studies of phosphorus utilization (Table 8), Fingerling showed that general conclusions for calcium-deficient diets applied also to phosphorus (45). Goats were able to sustain milk production from body reserves for several weeks of negative P balances. During phosphorus deficiencies where P intake

TABLE 5. Utilization of feed calcium by goats.[a]

Trial period (2 weeks)	CaO fed per day per goat	Apparent CaO digestibility (feed-feces)	CaO metabolized (urine + milk ÷ feed)	Milk yield per day per goat	CaO utilized for milk	Cao retention or loss
	(g)	(%)	(%)	(g)	(%)	(%)
Goat # 1						
I	21.577	14.7	13.5	1958	11.2	+ 1.2
II	2.729	52.9	101.9	1682	81.3	−50.1
III	2.729	52.3	85.4	1185	66.0	−33.1
IV	2.729	46.0	73.1	752	52.6	−27.0
V	11.845	33.7	16.0	754	12.0	+17.7
VI	16.337	15.6	10.9	774	8.5	+ 4.6
VII	21.466	8.3	8.8	804	6.5	− .5
Goat # 2						
VIII	7.730	33.9	30.9	1011	25.6	+ 2.9
IX	2.732	44.9	91.2	982	71.9	−46.3
X	2.732	37.8	83.7	804	59.2	−45.9
XI	2.732	40.4	79.2	735	57.3	−38.7
XII	7.754	76.8	31.1	988	23.0	+45.7
XIII	7.773	63.2	30.0	929	22.5	+33.2

[a]Reference (45).

TABLE 6. Influences on the apparent assimilation of feed calcium in goats.[a]

Feeding periods (third or last of several weeks)		Goat	CaO intake (week)	CaO in feces (week)	CaO in urine (week)	CaO in milk (week)	CaO balance (week)
		(No.)	(g)				
I	no supplement	1	43.1	49.3	.45	6.0	-12.6
		2	43.2	51.7	.30	6.9	-15.7
		3	43.6	52.1	.17	8.4	-17.0
		4	40.0	37.0	2.00	10.2	- 9.2
II	+40 ml cod liver oil, non-saponified fraction	1	44.7	52.1	.41	6.7	-14.5
		2	43.6	55.6	.13	7.8	-19.9
III	+80 ml cod liver oil, nonsaponified fraction	1	44.7	60.2	.13	9.6	-25.2
		3	43.6	61.1	.15	7.1	-24.7
IV	+80 ml cod liver oil, nonsaponified fraction in 15 ml corn oil	1	45.3	37.8	1.14	8.7	- 2.4
		1	45.3	40.0	1.19	7.3	- 3.2
		3	44.1	30.1	.79	6.4	+ 6.7
		3	44.1	33.9	.36	6.3	+ 3.4
V	+40 ml cod liver oil, nonsaponified fraction in 15 ml corn oil	2	38.7	31.6	.41	5.4	+ 1.3
VI	+5 ml cod liver oil	4	37.7	34.3	.21	...	+ 3.2
VII	+ animal irradiation	...	89.7	55.0	1.47	16.4	+16.9

[a]References (63, 64, 69).

was one-fifth of normal for 2 mo, production of milk dropped to about 40%. Supplementation with P and Ca back to 13 g P_2O_5 and 20 g CaO daily raised milk yields by 10% in 2 wk and by 15 to 25% in 4 wk while diets had remained isocaloric and isonitrogenous.

When six sources of phosphorus supplementation were tested, their digestibilities were relatively high (Table 9) and differed no more between sources of phosphorus than between animals (46).

Differences between calcium and phosphorus metabolism in goats have also been studied (4). Estrogen (estradiol) treatment significantly reduced concentration of inorganic phosphate in plasma of goats whereas plasma calcium did not change (4). This helps explain the role of estrogenic steroids on parturient paresis (milk fever). Estrogen which was high in the periparturient goat did depress appetite, feed intake, intestinal absorption, and skeletal phosphate turnover which produced hypophosphatemia with or without concurrent hypocalcemia.

A model (Figure 1) for the proposed P metabolism in goats is given in relation to estrogen effects. It is based on assumptions of goats being dry, open, estrogen treated, and in a normal state of calcium metabolism. Effects

TABLE 7. Calcium contents of bones in male and female normal and manganese deficient goats (g/kg DM).[a]

	Ribs		Carpal bones	
	$\bar{x}$	SE	$\bar{x}$	SE
Males	169	29	144	36
Females	180	27	148	25
Normal diet	174	23	146	40
Mn deficient diet	168	12	146	25

[a]Reference (9).

TABLE 8. Utilization of feed phosphorus by goats.[a]

Trial period	P_2O_5 fed per day per goat	Apparent P_2O_5 digestibility (feed-feces)	P_2O_5 metabolized (urine + milk) ÷ feed)	Milk yield per day per goat	P_2O_5 utilized for milk	P_2O_5 retention or loss
	(g)	(%)	(%)	(g)	(%)	(%)
Goat # 1						
I	13.468	27.3	25.8	1958	25.6	+ 1.5
II	2.639	41.2	121.6	1682	120.5	-80.4
III	2.639	35.4	105.9	1185	104.2	-70.6
IV	2.639	36.1	79.0	752	77.5	-42.9
V	13.271	44.0	15.7	754	15.2	+28.3
VI	13.271	21.7	15.0	774	14.8	+ 6.6
VII	13.468	16.9	15.3	804	15.0	+ 1.6
Goat # 2						
VIII	6.622	42.3	39.4	1011	38.8	+ 2.9
IX	2.642	26.6	96.9	982	95.5	-70.0
X	2.642	24.7	88.2	804	87.0	-63.5
XI	2.642	28.0	84.7	735	83.7	-56.7
XII	6.622	68.9	38.4	988	37.9	+30.5
XIII	6.622	62.3	36.7	929	36.3	+25.5

[a]Reference (45).

upon feed intake resulting from estrogens may signal further animal responses. If estrogen is elevated and phosphorus declines, the parathyroid will act by stimulating or depressing the other homeostatic mechanisms of the stressed goat. Sexual dimorphisms also have been found for phosphorus contents of different organs (Table 10) (9), e.g., phosphorus contents were lower in female heart muscles and pancreas than in those of males.

Magnesium (130, 131, 132, 159, 167). Tolerance time of blood magnesium, i.e., time required after Mg loading to return to normal, decreased in goats fed extra potassium; this also means increased cellular uptake and retention of magnesium since urinary excretion was lowered and endogenous fecal excretion was expected to be depressed (79). Magnesium concentration in blood plasma was not changed by potassium feeding in goats, although this had been reported by workers for sheep (79).

TABLE 9. Comparison of apparent digestibilities (%) of different sources of feed phosphorus in goats.[a]

Phosphorus supplement	Goat 1	Goat 2
Casein 1	86.68	92.10
Casein 2	87.45	91.59
Phytin	97.61	96.00
Lecithin	84.30	84.97
Nuclein	88.54	...
Sodium nucleate	90.18	...
Disodium phosphate	86.65	93.81

[a]Reference (46).

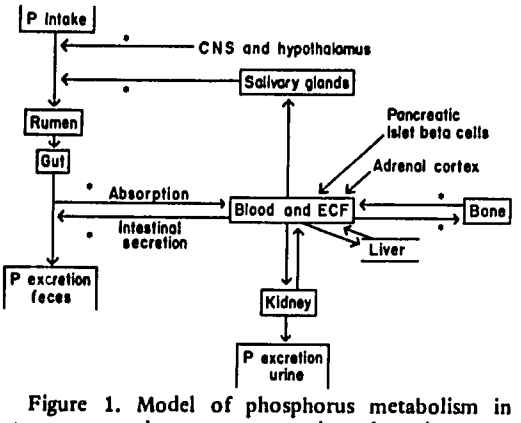

Figure 1. Model of phosphorus metabolism in estrogen treated nonpregnant and nonlactating goats where * marks possible sites of estrogen action (4).

TABLE 10. Phosphorus contents of organs in male and female goats (g/kg DM).[a]

Organ	Male		Female	
	$\bar{x}$	SE	$\bar{x}$	SE
Liver	10.2	2.1	9.4	2.9
Kidneys	10.0	1.8	9.9	1.7
Spleen	12.4	2.5	12.0	2.4
Lungs	9.2	1.8	9.0	2.0
Heart	9.3	2.1	7.6	1.3
Muscle	7.8	1.0	7.7	1.2
Ribs	81	15	85	14
Carpal bones	67	12	69	10
Testicles–ovaries	8.5	2.4	8.2	1.0
Brain	14.6	1.7	15.1	1.4
Spinemarrow	14.7	1.7	14.0	1.8
Pancreas	13.0	2.9	8.5	2.6
Aorta	2.4	.7	2.1	.5
Hair, ppm	360	84	341	101

[a]Reference (9).

Intravenous magnesium loading decreased blood calcium in goats; treatments to cure hypomagnesemia should contain both magnesium and calcium so as not to confound a tetany problem.

During underfeeding of magnesium (238 mg Mg per day to 2-yr-old goats for 11 days), milk yield and urinary excretion decreased markedly, and total magnesium output was reduced (132). While magnesium contents of milk did not change, urine contents first decreased, later increased with low volume, and those of blood plasma increased approximately 10% (132).

Sodium and Chloride (6, 7, 16, 17, 32, 43, 44, 114, 115, 120, 121, 124, 141, 143). Insufficiency of sodium in the diet led to loss of appetite and weight, reduced urine volume, and cessation of lactation in goats (16). Excessive sodium shortage led to diarrhea, muscle trembling, and death. Restoration of sodium supply restored many of the animals to normal. Despite severe deficiencies in blood serum and milk, there were no changes of contents of sodium, potassium, chloride, and osmotic pressure. However, urine became hypertonic.

Estrus and estrogen affected sodium, potassium, and chloride contents of milk, lowering potassium and lactose and raising chloride and sodium, which is similar to colostrum (120).

In studies by Schellner (143), control goats received 1.74 g Na/kg feed dry matter while those on a Na-deficient diet received only .31 g (Table 11). Effects were many, including reduced growth and feed intake, lower milk production, higher feed cost per unit weight gain, higher fat contents of milk, less sodium in the milk total solids, and less sodium in body organs and hair. Hair analyses were variable, and reproductive performance was not impaired.

Feeding ammonium chloride to goats (77) produced acidosis which was supposed to 1) force more excretion of sodium and water from edema cases, 2) increase Ca absorption from the intestines, 3) make a greater calcium pool available in cases of milk fever, and 4) increase solubility of renal stones in urinary calculi because of a more acidic urine. However, feed intake was reduced to the point of even complete refusal which casts doubt on the usefulness of ammonium chloride treatment. Increases of N, Ca, Mg, Cl, Sr, Zn, and pH were significant in urine of goats while concentrations of these elements and pH of feces and milk remained unchanged. The higher urinary Ca was explained by the acidotic state which decreased tubular resorption of calcium ions.

Different ratios of Na to K in purified diets were studied in preruminant kids (165). Ratios ranged from .56 to 1.41, but there were no significant differences in weight gains and nitrogen retention.

Iron (22, 60, 86, 95, 107, 133, 142, 156,

143

TABLE 11. Influence of feed sodium supply on goats.[a]

Item	Normal diet	Na deficient diet
Growing kids		
Daily feed intake, g	591	556
Daily gain, g	89	71
Liver, Na content in DM, ppm	3358	2891
Hair, Na content in DM, ppm	1833	1132*
Milking goats		
Daily feed intake, kg	1.245	.726*
Daily milk yield, kg	1.677	1.148*
Milk fat, %, 1-56th day	3.32	4.18
Milk fat, %, June 17	2.59	2.67
Milk fat, %, June 22	2.33	3.49
Milk fat, %, June 28	2.17	3.27
Colostrum solids, %	22.70	20.00
Milk solids, %, 14th day	10.80	12.70
Milk solids, %, 28th day	11.20	12.00
Colostrum ash in DM, %	3.43	4.55
Milk ash in DM, %, 14th day	6.43	5.98
Milk ash in DM, %, 56th day	7.04	7.42
Colostrum Na in DM, ppm	1654	1505**
Milk Na in DM, ppm, 14th day	2657	2234**
Milk Na in DM, ppm, 56th day	3185	2638**
Hair, Na content in DM, ppm	334	304

[a]Reference (143).

*P<.05.

**P<.01.

173). Hemoglobin, ferritin-hemosiderin, and myoglobin are the quantitatively most important iron compounds of the body (107). Iron contents of body vary with age and sex and depend on supply at birth, nursing, rate of growth, and reproductive requirements in females. Iron deficiencies supposedly are rare in farm animals except in rapidly growing young, during internal parasite infection, after blood losses or extended milk feeding periods. Hemoglobin accounts for approximately three-quarters of body iron, but hemoglobin concentration in goats may fluctuate markedly because one-third of the red cell mass can be held temporarily in the spleen (86).

Blood transferrins have the physiological role of iron transport (107). Other iron-containing compounds are myoglobin in muscle, cytochromes in mitochondria and cellular membranes, metalloflavoproteins, NAD, enzymes, catalase, peroxidase, dehydrogenases, iron storage protein, ferritin, hemosiderin, enzymes requiring iron as cofactor, aconitase, microsomal lipid peroxidase, and hydroxylation of proline and lysine in protocollagen.

The amount of dietary iron absorbed depends on the intestinal mucosa, gastric acid secretion, and gastrointestinal motility (107). Alkalinization precipitates dietary iron and makes it unavailable for absorption; phytate sequesters iron molecules and makes iron less available; inorganic phosphate, calcium, oxalates, carbonates, tannin, clay, and soil depress iron utilization. However, ascorbic acid can enhance iron absorption. All this indicates that availability of iron may be just as important as iron content of the diet. Grasses, legumes, and oil meals may have iron contents between 100 and 300 mg/kg, limestone and dicalcium phosphate sometimes more than 500 mg/kg, and cereal grains between 30 and 60 mg/kg. Iron deficiencies should not be a problem in farm animals, but this has not been studied in goats (107).

Iron metabolism is interrelated with that of other metal ions. Iron stores in the body may

lower or inhibit absorption of manganese, cobalt, cadmium, and lead. Acute iron toxicity from nonmedical sources is unlikely because of the large doses needed to produce poisoning. Chronic exposure to iron dust can be confounded with effects of fluorides (107). Excess iron in feed or water can lower feed intake, weight gains, and milk production (106).

Duodenum is the major site of iron absorption (22) because abomasal contents at pH 3, alkaline intestinal juice, bile, and pancreatic juice are mixed such as to provide the best conditions for solubility of Fe. An in vitro method using duodenal, intestinal, abomasal, or ruminal juice was developed and correlated with the in vivo results in goats for estimating uptake of radionuclides including ^{59}Fe deposited on forages and secreted into goat milk. For purposes of using this method of other radionuclides, the gastrointestinal fluids consistent with the site of major absorption of those radionuclides must be used.

Among minerals, iron was most important in meat type kids for color formation of rumen epithelium (60). Dietary supplies of .03% ferrous iron produced desirable color; .003% did not. There was some relationship to potassium and sodium in the ration. Tissue iron contents were not directly related to rumen epithelium color (60). Iron contents of goat milk are supposedly stable and not influenced by feeding ferrous sulphate (94). An important report by Lintzel and Radeff (95) apparently has been read little. They found that newborn goat kids have low iron reserves in the liver and hemoglobin and receive little in the milk from nursing. This distinguishes goats from cows and most other farm animals.

Iodine (1, 2, 26, 27, 36, 39, 50, 75, 85, 89, 90, 112, 127, 128, 135, 162, 166, 174, 175, 176, 177). Contents in the thyroid are goat 2.8 g/kg, cow 4.8 g/kg, and sheep .82 to 3.2 g/kg (89). Normal iodine content of goat blood is about .012 mg/100 cm^3 (12 gamma). Feeding 180 mg potassium iodide per day resulted in a 100-fold increase in the milk of goats from 10 to 30 gamma per liter daily to more than 1000 gamma; 7.5 mg of KI increased milk contents to 300 to 680 gamma. Cows had normally 40 gamma of iodine in milk, and feeding 76.45 mg KI increased iodine 20 times in the milk of cows.

Six times more iodine appeared in goat milk at environmental temperatures of 33 C than at 5 C (90). Four days after dosing, the thyroid loss was still twice as rapid at 33 C as that for goats at 5 C. Recoveries of an oral dose of ^{125}I at 33 C were 16.8% in milk, 52.5% in urine, and 9.8% in feces compared to 5 C where recoveries were 2.6%, 71.2%, and 18.1%, respectively (90). An explanation would be that at 33 C, less iodide is being used for thyroxine production while the iodide concentrating mechanism continues in the mammary gland. High temperatures made more iodide available, made the mammary gland more efficient in clearing blood of iodide, and influenced the size of body iodine pool.

On the practical side, high temperatures can result in greater than predicted amounts of radioactive iodine appearing in the milk after contamination of pastures and feedstuff. Large variations in iodine of milk will result from changes of ambient temperatures.

Goats show much higher concentrations of radioiodine in milk than cows under similar conditions (89). Goat mammary glands are efficient iodine "traps" and excrete as much as 94% of daily ^{131}I doses vs. only 2.2% for cows. At the same time the thyroid of goats had the equivalent of 250% of a daily dose while cows had only 79%. Radioiodine in plasma was ten times higher in goats than in cows, and the data were more variable between individual goats. Perchlorate, high iodide, and fluoroborate anions abolished the concentration gradient of iodine from plasma to milk. Thiourea reduced the transfer of iodide to milk also but less effectively than these anions. Chlorothiazid increased urinary excretion of radioiodine and decreased levels in milk.

Copper (71, 136, 155). Deficiencies developed in young goats even when copper supplies seemed adequate but where industrial emissions were high in cadmium and sulphur. Symptoms included skeletal damages in the front legs, reduced weight gain, and reduced copper contents of brains to 45% of normal (Tables 12, 13) (9). Other organs also had lower Cu contents including liver, blood serum, hair, testes, and heart. Cadmium and sulphur are considered metabolically antagonistic to copper. Cadmium acts by blocking the protein necessary for copper absorption, thus causing low contents of copper in liver (71). Ceruloplasmin (copper oxidase) activity was studied in serum of

TABLE 12. Zinc and copper contents of organs in goats (ppm in DM).[a]

Organ	Zn		Cu	
	$\bar{x}$	SE	$\bar{x}$	SE
Liver	177	99	8.9	3.5
Kidney	122	36	11.2	2.5
Spleen	83	23	5.2	2.0
Lungs	67	20	9.1	3.3
Heart	85	31	14.7	4.1
Muscle	199	49	3.4	1.5
Brain	50	16	12.1	3.7
Spine marrow	47	34	8.4	4.7
Ribs	69	13	6.7	3.0
Carpal bones	54	15	6.0	2.5
Testicles	63	10	6.7	3.0
Ovaries	57	21	11.0	6.5
Pancreas	127	98	6.4	4.6
Aorta	56	22	3.7	1.6
Hair	134	22	5.6	1.3

[a]Reference (9).

different animals (155). Average units per .1 ml serum were for goats 70 ± 37, sheep 84 ± 32, cows 69 ± 14, calves 32 ± 19, camels 25 ± 10, and laying hens 30 ± 7.

Zinc (55, 93, 104, 108, 110, 111, 118, 144, 147, 154). It is not known whether sheep are more resistant to zinc deficiency than cattle, but apparently they require less than the 8 ppm Zn for normal growth needed by calves (108). Goats, 9-mo-old males, developed deficiencies on a diet of 4 ppm in 5 wk (111). Adult female goats on a diet of 6 to 7 ppm did not develop signs of zinc deficiency until they were lactating. Milk production was not affected, but zinc content of milk was reduced by 50% (55).

Male kids raised on 6 to 7 ppm Zn in the diet were severely stunted, but females were not affected. In a survey of 150 Greek goats, 2% had symptoms of severe zinc deficiency (118).

Deficiency symptoms in goats are similar to cattle (111): parakeratosis, increased bacteria in the mouth, stiffness of joints with swelling of feet and horny overgrowth, excessive salivation, smaller testicles, and no libido.

Normally, little zinc is available to the body except from that ingested in the diet. Zinc must be supplied continuously (108) although some catabolism of muscle, bone, and skin and decreased excretion can make more zinc available to the body.

The suggested requirement for dairy cows per day is 40 ppm Zn. Zinc intake adequate for pregnant goats resulted in severe deficiencies during their lactation (55), indicating that lactation increases zinc requirements.

Beef cow requirements are 10 to 30 ppm Zn per day (108). Availability of zinc differs with diets in monogastrics, but research in ruminants indicates that they also may respond with different Zn absorption depending on feed composition, e.g., when fed soybean oil meal, barley, or other feeds high in phytate or calcium (108).

The extent and frequency of zinc deficiencies in goats is largely unknown. A specific screening test for Zn has not been developed, and the marginal status may have such non-

TABLE 13. Copper contents in organs of young goats (ppm).[a]

Feeding regime	Liver	Heart	Carcass	Hair
Normal	86.0	11.6	4.8	8.3
Copper deficient	3.3	7.0	3.9	6.1
Cadmium supplementation	5.1	6.0	3.3	5.1

[a]Reference (71).

specific symptoms as reduced feed intake and lower rate of growth. Content of blood plasma is reduced in severe deficiencies but not in marginal cases. Hair analyses indicate a long-time zinc status and were correlated with zinc in plasma in some studies (55, 108, 111, 144) (Table 14, 15). However, hair contents can be confounded with reduced hair growth in zinc deficiencies (108). Urinary zinc is used in human studies of zinc status but has not been studied much in animals, goats in particular. Studies with zinc-dependent enzymes have been largely inconclusive, although zinc requirements for the same enzyme need not be the same in different animal species.

Zinc deficiencies interfere with the growth and function of reproductive male and female organs, but most studies were with animals bearing litters. Normally, high concentrations of zinc are in the prostate, semen, and epididymis, but sperm motility appeared to be not affected by zinc status. Libido of male goats has been subnormal when zinc supply was subnormal (111).

Daily zinc supplies are required by all species since little is stored in the body in a readily available form (108). Zinc may interfere with iron and copper metabolism; thus, animals with high zinc intakes should be watched for signs of anemia.

Zinc is not a highly toxic element, but toxic effects of high zinc on pastures downwind from smelter sources have been reported in cattle and sheep (108). Around 1000 ppm zinc was toxic for sheep as indicated by gastrointestinal distress and diarrhea. Lactating cows tolerated 1300 ppm zinc for 6 wk with no adverse effects on health, milk production, and contents. However, cellulose digestion by rumen bacteria in vitro was reduced by zinc concentrations of 10 to 20 mg/ml.

No daily requirements for zinc for goats have been established, but from the discussed direct and indirect evidence lactation, sex, age, and feed composition are factors to be considered. A minimum of 10 mg Zn/kg feed dry matter per day (or 10 ppm) seems indicated.

Zinc excretion appeared 12 h after an oral dose of ^{65}Zn and peaked after 36 h (154). The major route of excretion was in feces (88%) while excretion in urine and secretion into milk was approximately equal and low. Milk contents were related to oral dosage. Normal zinc in goat milk is low for human nutritional needs, just as those of Fe, Cu, and Mg.

Zinc-deficient diets (6 to 7 ppm vs. 80 ppm) resulted in weight loss in lactating goats and reduced feed consumption (55). Half of the

TABLE 14. Influence of feed zinc supply on goats.[a]

Item	Normal diet	Zn deficient diet
Milking does		
Colostrum Zn in DM, ppm	59.8	42.0
Milk Zn in DM, ppm, 14th day	32.8	24.0
Milk Zn in DM, ppm, 28th day	37.2	15.8
Milk Zn in DM, ppm, 56th day	19.0	10.0**
Liver Zn in DM, ppm	158	135
Kidney Zn in DM, ppm	87	78
Hair Zn in DM, ppm	179	103*
Kids of above does		
Liver Zn in DM, ppm	239	128**
Kidney Zn in DM, ppm	101	84
Femur Zn in DM, ppm	112	84*
Carcass Zn in DM, ppm	69	60
Hair Zn in DM, ppm	143	123

[a]Reference (55).

*P<.05.

**P<.01.

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TABLE 15. Influence of feed manganese and zinc supply on goats.[a]

Item	Normal diet	Mn + Zn deficient diet	Mn deficient diet	Zn deficient diet
Mn content				
Colostrum Mn in DM, ppm	1.13	.35**	.63**	.77
Milk Mn in DM, ppm, 14th day	1.27	.78**	.85**	1.27
Milk Mn in DM, ppm, 28th day	1.03	.80**	.86**	1.00
Milk Mn in DM, ppm, 56th day	1.63	.83**	.90**	1.22
Hair Mn in DM, ppm, July 15	.91	1.18	1.29	1.20
Hair Mn in DM, ppm, Oct. 15	1.70	.79*	.96*	1.29
Hair Mn in DM, ppm, Jan. 15	2.39	.88*	1.10*	3.05
Hair Mn in DM, ppm, April 15	3.42	1.02*	1.34*	3.19
Hair of kids, Mn in DM, ppm	1.4	1.0	1.2	1.4
Carcass of kids, Mn in DM, ppm	2.5	1.7	1.8	2.0
Zn content				
Colostrum Zn in DM, ppm	41	31*	46	28*
Milk Zn in DM, ppm, 14th day	31	25*	36	21*
Milk Zn in DM, ppm, 28th day	18	13*	16	11*
Milk Zn in DM, ppm, 56th day	17	14*	24	12*
Hair Zn in DM, ppm, July 15	115	119	118	123
Hair Zn in DM, ppm, Oct. 15	103	103	116	109
Hair Zn in DM, ppm, Jan. 15	114	109	123	101*
Hair Zn in DM, ppm, April 15	118	102*	118	92*
Hair of kids, Zn in DM, ppm	100	85**	112	65**
Carcass of kids, Zn in DM, ppm	72	67*	79	64*

[a]Reference (144).

*P<.05.

**P<.01.

zinc-deficient goats died in the 3rd mo of lactation. Zinc contents of milk were depressed. Milk production was reduced slightly while milk fat and protein contents were not affected. Reproduction in females was not affected except for delayed first estrus. Length of gestation, birth, and birth weights were not affected either.

Male kids showed dwarfism. Half-year-olds weighed 18 kg vs. 32 kg for normals (52). A sexual dimorphism for zinc requirements was reported. Libido was absent and testes and scrotum were underdeveloped; semen qualities and quantities were not affected adversely by Zn deficiency. Deleterious effects on testicles were reversible with Zn supplementation.

Zinc deficient goats had fewer male twins than normal and showed nervous behavior. Milk contained less zinc in deficient does. They refused feed intake, walked uncoordinated, had tetanus-like conditions, cried and bleated often, had coarse and twisted hair, and 2- to 3-month-old-kids were losing hair (Table 14). Zinc contents in liver, femur, carcass, and hair of kids from Zn-deficient does were reduced significantly, which means that Zn-deficient does cannot mobilize zinc sufficiently to cover needs of fetuses and milk.

Manganese (9, 10, 12, 14, 54, 72, 144). Goats fed 20 ppm manganese over 12 mo had normal conception rates but lower Mn contents in milk (144). Manganese-deficient goats had normal Zn contents in milk (Table 15). Manganese deficient animals lay down a lot, could not walk well, and had deformations on the forelegs but not on the hindlegs. They kidded normal young and had normal amounts of milk. Hair analyses were significant indicators of chronic deficiencies of Mn, but Mn contents in goat hair were lower than in cattle hair.

In a study (10) over 38 mo with 20 goats on 5.5 ppm Mn daily in the 1st yr but 1.9 ppm Mn in the 2nd yr (controls received 90 ppm Mn), estrus of goats was mostly silent, bucks were

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less active, ovulation was normal, conceptions reduced, abortions high around 36% at 12 to 15th wk, birth weights were lower, and 53% more male kids were born, but less kids were weaned because of death.

In another study (9) with 64 goats over 3 yr, males had lower Mn contents in lungs and ribs (Table 16, 17). Manganese deficiency resulted in significantly lower Mn in femur, liver, kidneys, spleen, heart, ribs, spine marrow, and hair, but not in the reproductive organs, brain, pancreas, or lungs. Ash contents of all organs, P, Zn, and Cu contents of all organs, and Ca contents of bones or milk showed no changes or effects.

Manganese metabolism was affected by Ca and P supplies (14). An excess supply of P worsened utilization of Mn. Only 3.3% Mn was absorbed. Ninety-six hours after an intraruminal dosage of ^{54}Mn in $MnNH_4PO_4$, .5% was excreted in urine while more than 95% was excreted in the feces. Manganese was incorporated principally into the liver, specifically the gall, followed by skeleton, muscle, blood, kidney, hair, skin, spleen, brain, and lungs. No difference in absorption was noted between $MnNH_4PO_4$ and $MnSO_4$.

Others (11, 13, 15, 21, 25, 35, 67, 68, 73, 78, 79, 80, 103, 117, 125, 140, 145, 146, 148, 149, 150, 163, 171, 172). Nickel has been found in the enzyme urease. Ammonia liberation in the rumen was reduced when Ni was low in the liquor, and reduced growth of goats has been reported (73).

TABLE 16. Manganese contents of organs in male and female goats (ppm in DM).[a]

Organ	Male $\bar{x}$	Male SE	Female $\bar{x}$	Female SE
Liver	13.2	12.7	9.9	9.5
Kidney	4.1	1.6	4.2	2.5
Spleen	3.3	1.6	3.8	1.9
Lungs	2.0	1.2	3.0	1.4
Heart	2.0	.9	1.8	1.1
Muscle	1.7	.8	1.6	.8
Ribs	6.8	2.0	9.0	4.1
Carpal bones	6.3	3.2	6.9	2.6
Brain	3.6	1.2	3.8	1.3
Spine marrow	2.8	1.6	2.3	1.3
Pancreas	6.2	3.9	5.6	2.9
Aorta	1.9	1.1	2.3	2.2
Hair	2.4	1.7	2.9	2.5

[a]Reference (9).

TABLE 17. Influence of feed manganese supply on organ contents in goats (ppm in DM).[a]

Organ	Normal diet	Mn deficient diet
Liver	11.5	3.7**
Kidney	4.4	2.6**
Spleen	3.8	2.3*
Lungs, female	3.0	2.7
Lungs, male	2.0	1.8
Heart	2.1	1.1**
Muscle	1.7	1.6
Ribs, female	9.0	4.9*
Ribs, male	6.8	4.9*
Carpal bones	6.8	6.1
Brain	3.8	3.0
Spine marrow	2.8	1.5**
Ovaries	4.3	2.7
Testicles	2.9	2.9
Pancreas	5.8	5.4
Aorta	2.2	1.8
Hair	2.9	1.5*

[a]Reference (9).

*$P<.05$.

**$P<.01$.

Sulphur supplementation (2 g daily) with or without urea was studied for 17 wk, but growth of goat kids showed no significant effects (25). Calcium, phosphorus, and nitrogen utilization was not affected in adult goat bucks (171) and blood and white cell counts and hemoglobin showed no changes (172).

Speculation is directed to chromium, vanadium, silicon, fluorine, tin, and arsenic for some function in growth and reproduction, but little work has been on these elements with large animals, specifically goats (73).

Some elements have interesting effects, so far little considered in goat research, e.g., lithium in modifying behavior (139).

The nonessential and undesirable elements also have been investigated little in the goat although their presence due to effluents, pollution, landfill, etc. is of increasing interest and potential hazard.

Intraruminal injections of 203-methyl mercuric chloride showed activities 2 h after dosing in blood with a peak at 32 h (148).

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Urine excretion amounted to 1.4% and fecal excretion to 31%, which was similar in goats and cows. The Hg content (.28%) was low in goat milk; none was in cow milk 24 h after dosing. Tissue concentrations of Hg were high in liver, kidney, and muscle but low in fat. Liver retained 6.6% of the dose and the adrenals only .01%. The percentage of the mercury dose recovered was 97.9.

Clearance of radionuclides with or without vermiculite in the feed of goats was different for cesium but not for strontium (67). Goats fed vermiculite (10% in the concentrate ration) excreted 83% of the oral dose of radioactive cesium, .3% in milk, 1.7% in urine, and 64.6% in feces, while goats without vermiculite feeding excreted only 62%, 2.3% in milk, 11.2% in urine, and 26.6% in feces.

In a massive Russian study (117) of 189 cows, 175 sheep, 98 goats, 207 pigs, and 490 chickens radioactive strontium was absorbed almost 100% in growing goats but only 10 to 12% in mature goats. The greater the calcium content of the diet the lower was absorption of ^{90}Sr. Accumulation was principally in the skeleton. Among animal species, the coefficient of accumulation differed in decreasing order: cows, sheep, goats, and pigs. Effective half-life of ^{90}Sr was 600 days in cows, 300 days in sheep, and 450 days in pigs. Milk content changed with calcium content of the diet. When 80 g calcium were fed daily, secretion into milk was not more than .15% of the ^{90}Sr intake; but in a Ca deficient diet, secretion of radioactive strontium was increased 5- to 10-fold.

This review would be much longer if all references were treated in detail. A discussion of highlights was intended instead, with the complete bibliography for further studies. The bibliography includes old and foreign publications of little perusal in the English literature so far. This review should stimulate a wider knowledge of more precise feeding requirements of minerals for goats under various production conditions. A tentative summary interpretation of data in this review is given in the abstract for the guidance of practical goat management.

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Desert Conditions and Goat Milk Production

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ABSTRACT

Adaptation of the small Black Bedouin goat breed to arid desert conditions is discussed. They are watered only once in 2 to 4 days which increases their foraging range greatly. During water deprivation for 4 days, they lose 25 to 30% of body weight from reduction of total body water and blood plasma volume. Nevertheless, these goats are relatively high milk producers. Daily yields of over 2 kg have been recorded for animals weighing only 15 to 25 kg. Milk composition is similar to that of other goat breeds. Yearlings have usually only single kids, but twinning occurs about 50% of the time in older does. Birth weights of single kids are about 2 kg with twins slightly lighter. Growth rates of kids have exceeded those of other goat breeds. Milk production efficiencies have exceeded 33% of energy consumed.

WATER ECONOMY AND METABOLISM OF BLACK BEDOUIN GOATS

A breed of small black goats (15 to 25 kg bodyweight) is herded by Bedouins inhabiting the Negev desert of Israel and the Eastern Sinai. This breed occupies a unique ecological niche and was first described 34 yr ago by Epstein (9) in the area of Hejaz, where, he believed, they had thrived since the dawn of history. They are of considerable interest to the development of dairy farming in arid regions.

Their food resources are meager and water holes widely spaced (20). Under such conditions the ability of a ruminant to withstand water deprivation becomes a major factor in determining stocking rates and efficiency (22).

In normal Bedouin husbandry the goats are watered only once every 2 to 4 days, even in the middle of summer. This has been the object of several studies (6, 7, 23, 24, 25). Following drinking, their total body water (HTO space) amounted to over 76% of their body weight, and their blood plasma (EB space) to 68% of body weight (Figure 1). During 4 days of water deprivation, the goats lost 25 to 30% of their body weight, total body water was reduced to 69% of body weight, and blood plasma was reduced to 57% of body weight, but the animals continued to eat normally. Upon visiting a water point, the Bedouin goats seemed to "store" water that could be utilized during the following days of grazing in the barren desert. When arriving at a water point 4 days later, after continuous grazing, the goats replenished all water previously lost. The goats drank, within 2 min, volumes of water to 30 to 45% of their dehydrated body weight which amounts to a vital process of rapid rehydration (7, 23, 24).

In addition to the capacity to withstand prolonged water deprivation, Bedouin goats also appear to have relatively low daily calorie demands for maintenance per unit metabolic weight according to determinations by Shkolnik et al. (23) and Silanikov et al. (25).

Even in the extreme desert, this combination allows a relatively high stocking rate, which is determined by the number of animals, their combined body mass, their ability to graze distances away from a water point, and their nutrient needs. Thus, 90 Bedouin goats (1350 kg total body mass) can be herded successfully 2 days away from water points, where only one fat-tail Awassi sheep (50 kg) or 1.5 Black Mediterranean goats (75 kg) would be able to live (23, 24) because of more frequent watering needs.

The body weight of lactating Bedouin goats usually exceeds that of the same animals not lactating (19, 25). Gain of weight by lactating goats represented enlargement of water space

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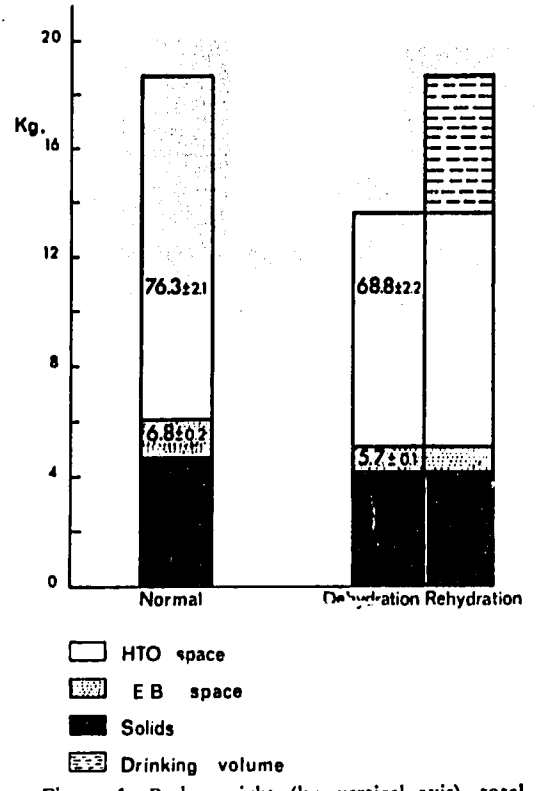

Figure 1. Body weight (kg, vertical axis), total body water (HTO space), and plasma EB volume (Evans Blue space) in 10 normally watered Bedouin goats after dehydration and immediately following rehydration (6).

(HTO) with body solids remaining unchanged (Figure 2).

Lactating goats deprived of drinking water lost water at a higher rate than nonlactating goats (23) (Figure 3). After 4 days without water, loss of HTO space in lactating Black Bedouin goats was 33%, whereas nonlactating goats took 10 days for similar losses (19) (Table 1). Nevertheless, even after 4 days of water deprivation the HTO and EB spaces in the lactating goats were above mammalian normals. Apparently, enlarged water "storage" enables this ruminant to forage freely in the desert at distances of 2 walking days from water sources.

Considerable significance is attributed to the ability of desert mammals for maintaining plasma volume, although there is great loss of water from other compartments (4, 16). This does not seem to pertain to Black Bedouin goats and Somali donkeys (18). Four days of

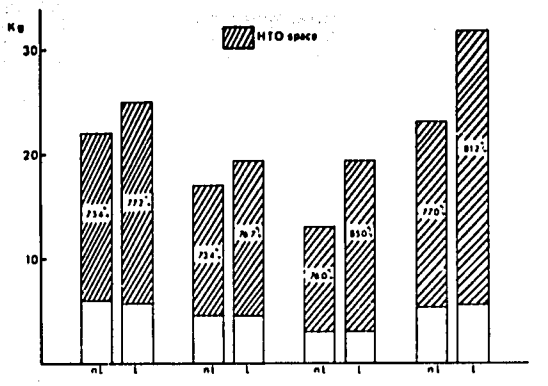

Figure 2. Body weight (kg, vertical axis) and HTO space as percent of body weight in four Bedouin goats before (NL) and during lactation (L) (19).

water deprivation dropped the HTO space in the lactating goat to 66.4% of initial space and the EB space to 68.6%. Ratios of equalization of changes in both water spaces indicate that

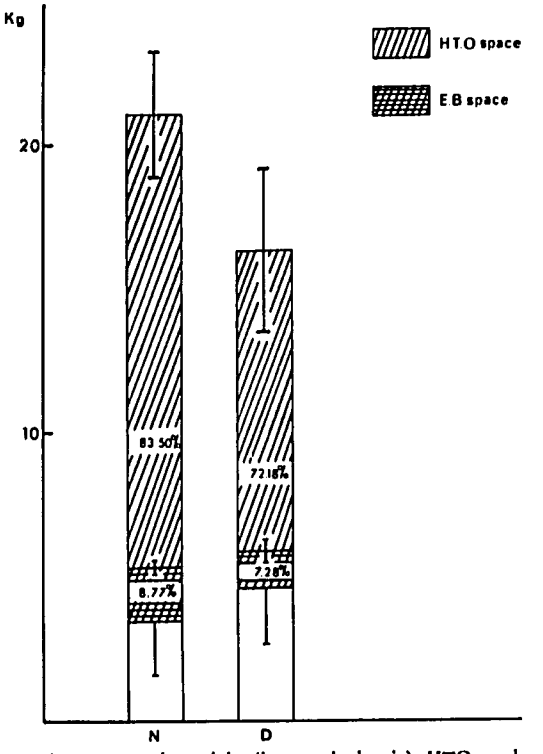

Figure 3. Body weight (kg, vertical axis), HTO, and EB space (means ± SD) in lactating goats (N = 4) watered daily (N) and following 4 days of water deprivation (D) (19).

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TABLE 1. Turnover of water in lactating and nonlactating black Bedouin goats.

Animals	Body weight (kg)	(SD)	Water turnover (ml/kg body weight per day)	(SD)	Half-life t .5
Lactating (n = 5)	21.26	3.09	210.10	28.88	6
Nonlactating (n = 5)	18.57	3.62	86.77	6.47	3

gain and loss of fluids were evenly distributed over all body compartments, thereby buffering their osmotic effects.

The extra burden of milk production is reflected in the high rate of water turnover (Table 1; 19), which in lactating Bedouin goats amounted to over twice the rate in nonlactating goats. In lactating sheep and camels increase was only 44% (16, 17). The high rates of water turnover in lactating Black Bedouin goats actually should make them highly dependent on frequent visits to water holes, which is not the case (24, 25).

The grazing strategy of Bedouin exploits the capacity of their black desert goats to graze far away from water holes. A Bedouin camp rarely is close to a water point but rather is often 5 to 8 km away. Lactating goats, after suckling their kids, graze 1 day toward the water point. Following drinking they return in the evening to the camp to nurse their kids again. The next day grazing will be in the opposite direction to the water hole. This stragegy enables Bedouins to increase the grazing area of their goats. The high milk yield of Bedouin desert goats is imperative for survival of their kids, although it defies the natural need of does in the desert to conserve water.

MILK YIELD OF DESERT GOATS

The apparent high capacity for milk production by Bedouin goats was studied also in our laboratory (19). Nine female goats, born and raised in our laboratory, gave birth at the age of 1 yr before reaching full adult weight. Only single kids were born to the yearling goats. In 29 females 2 to 7 yr old, a 44.4% delivery of twins was recorded. Females older than 7 yr were not studied. Birth weight of kids averaged 1.82 ± .34 kg, which is about 10% of their mother's weight. With twins the weight of the litter was 17.5% of their mother's weight. Growth rates of kids varied from 134 ± 13 g/day in 11 single kids of 2 to 7-yr-old does to 113 ± 13 g/day for 9 single kids from yearling

TABLE 2. Yield and composition of goat milk during the peak month of lactation.

Breed	Body weight (kg)	Yield of milk (g/kg body weight/day)	Total solids	Milk fat	Total protein	Lactose	Reference
			(%)				
Swiss Saanen	50	70	11.55	2.81	2.17	3.50	(11)
Black Mediterranean	50	70	13.16	3.36	2.59	3.29	(3)
African Dwarf	26.5	79	18.70	6.90	3.91	6.30	(1)
Black Bedouin	23.1	86.3	14.53	3.68	2.79	3.74	(19)

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TABLE 3. Milk yield during 4-mo lactation in Black Bedouin goats.

Age of goat (yr)	N	Body weight		Months of lactation 1st (g/day)		2nd		3rd		4th	
		$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
1	4	17.75	2.33	953	280	1083	272	1003	144	831	281
2	4	21.35	1.66	1561	183	1553	255	1309	289	957	218
3–7	8	21.69	2.42	1640	217	1682	282	1409	256	1267	364

mothers to 105 ± 12 g/day for 14 twin kids of 2 to 7-yr-old does.

Highest milk yields were at the age of 3 yr. Peak yields were recorded in the 2nd mo (Table 3). Two goats milked for 10 mo. The highest yield of one of the goats (S_{27}) was 2,200 ± 60 g/day (Table 4). Composition of the milk was measured by standard methods (2) (Table 5). Highest milk contents were 14.4% solids, 5.5% fat, 3.5% protein, and 5% lactose (Table 5). In Table 6 are osmotic and ionic concentrations. Milk composition of the Black Bedouin goat was similar to that of other dairy goats (8, 11, 21).

According to body size relationships (15), approximately 880 ml of milk could be expected from Black Bedouin goats, but the volume in our studies was over twice that. Furthermore, goats in our studies were at best only of average producing ability since the Bedouins were reluctant to part with their best goats. Yield of milk per kilogram body weight equaled that of the larger Swiss Saanen and Black Mediterranean goats, both of which have been selected during ages of domestication for high milk production (Table 2). Bedouin goats produced more milk than the African dwarf goat, a breed of similar body size and equally indigenous to marginal lands (1). They exceeded the relative yields of Awassi fat-tail sheep native to our area (3) and of reasonably producing dairy cows per unit metabolic weight (10).

The birth weights of kids born single agree with those expected from the size of does (14). However, the birth weight of Black Bedouin goat twins was 3.68 kg compared to 2.16 kg expected. As 44% twins were born, litter weights averaged 128% of expected. The young doubled their birth weight in 15 to 17 days, a period shorter than that for meat producing sheep in East Mediterranean countries (12). The rate of weight gain (105 to 134 g/day) in kids exceeded other breeds of goats indigenous to tropical marginal lands (13, 26).

TABLE 4. Daily yield of milk and consumption of feed during the second month of lactation in Black Bedouin goats.

Goat	Body weight (kg)		Milk yield (kg/day)		Feed consumed: Alfalfa hay (kg DM)		Concentrate (kg DM)		Total (kcal)[a]	
			$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	
S_8	22.7		1.830	.030	.350	.095	.951	.051	5877	
S_9	24.8		2.120	.094	.690	.094	.908	.111	7247	
S_{10}	19.7		1.820	.093	.371	.074	.969	.047	6054	
S_{27}	25.0		2.200	.060	.255	.040	1.105	.100	6565	
Mean ± SD	23.1	2.5	1.993	.196	.417	.189	.983	.085	6434	614

[a]Caloric content of alfalfa hay 4.5963 kcal/g DM; caloric content of concentrate 4.4880 kcal/g DM.

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TABLE 5. Milk composition during 4 mo of lactation for Black Bedouin goats aged 3 to 7 yr.[a]

Month of lactation	Total solids		Milk fat		Total protein		Lactose		Ash	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
1	12.42	1.17	4.25	.91	3.16	.27	4.28	.24	.74	.02
	(11.10–13.90)		(3.10–5.50)		(2.72–3.39)		(4.05–4.67)		(.71–.75)	
2	12.58	1.40	4.27	.88	3.23	.30	4.33	.58	.75	.02
	(10.98–14.38)		(3.37–5.33)		(2.75–3.54)		(3.43–4.98)		(.71–.77)	
3	12.11	1.30	4.04	.85	3.21	.34	4.11	.31	.75	.02
	(10.66–13.73)		(3.10–5.13)		(2.73–3.58)		(3.64–4.48)		(.71–.76)	
4	11.94	1.20	3.83	.99	3.08	.35	4.30	.20	.74	.02
	(10.40–13.62)		(2.94–5.45)		(2.65–3.41)		(4.07–4.58)		(.71–.77)	

[a]Range in parentheses.

TABLE 6. Osmolar and electrolyte concentration of the milk of Black Bedouin goats.[a]

Month of lactation	mOsm/kg milk		Na mg/liter		K mg/liter		Cl mg/liter		Ca mg/liter	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
1	293.85	2.64	25.34	4.56	49.63	5.88	45.57	4.43	40.85	10.83
	(290.17–296.67)		(21.00–32.00)		(41.00–55.50)		(39.67–51.83)		(29.17–58.33)	
2	296.88	6.63	30.07	1.92	51.37	3.11	44.87	4.18	41.85	9.92
	(291.00–306.71)		(28.67–31.33)		(46.67–54.67)		(38.67–18.83)		(29.10–55.83)	
3	294.41	3.65	26.62	2.45	50.79	4.89	51.20	3.91	39.72	10.14
	(291.00–295.29)		(24.00–29.33)		(47.00–59.13)		(50.00–54.67)		(27.67–51.67)	
4	300.98	3.35	22.97	2.89	56.50	4.31	51.40	5.81	52.37	3.31
	(297.17–305.67)		(19.50–27.17)		(49.00–59.50)		(43.17–59.17)		(48.50–57.67)	

[a]Range in parentheses.

According to Brody (5), "dairy merit" is the biological efficiency of milk production measured by the percentage of total digestible energy consumed which is converted into fat corrected milk energy. Milk energy produced daily by our highest milking Bedouin goats was 1,558 kcal. The digestibility of the feed energy consumed by our goats was 72% (25) which amounted to 4,633 kcal per day (Table 4). Thus, dairy merit was 33.6%, and represented a superior dairy animal.

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Milk Production in Goats Compared to Buffalo and Cattle in Humid Tropics[1]

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ABSTRACT

Dairy goats are important for the supply of high quality proteins in milk through conversion of feed from non-competitive sources. Significance of milk production in less developed countries is growing. Goats are the third ranking source of milk, but these countries produce approximately 52% of the world production of goat milk. Given are gross composition of goat milk for breeds in the tropics, comparisons with milk from buffalo and cows, size of fat globules, amino acid composition of casein, nitrogen distribution of normal milk, fatty acid composition, mineral and vitamin contents. Intakes of dry matter as percent of adult body weight for tropical, imported, and European breeds were 3.3, 3.6, and 4.6%. Milk yields were 280, 577, and 1,476 kg for lactation lengths of 199, 221, and 455 days. Efficiency of milk production is dependent on high milk yields. Efficiency of protein production in milk of goats compared to meat is discussed. Development of milk production from goats by small farmers in the tropics can complement commercialized milk production from buffalo and cows and is important for alleviation of undernutrition and malnutrition.

INTRODUCTION

Production of food energy and protein from dairy cattle systems is more efficient than from beef producing systems (2, 35, 37). In humid tropics, three types of animals are important for milk production, goats, buffalo, and cattle. Each is valued differently in different locations. Goats and cattle are important in Africa and parts of Southeast Asia, whereas in India and Pakistan buffalo are outstanding in milk production. Buffalo and cattle have been the subject of much research and development but goats less. With buffalo and cattle, commercial milk production is common, but milk production from goats is essentially an uncommercialized, subsistence enterprise. Also, in most parts of the tropics, the value of goats for milk production is secondary to meat production. Unlike the temperate regions, milk production from goats in the tropics is a small farm enterprise aimed at meeting the needs of the peasant and his family.

The contribution by goats to world milk production is in Table 1. Within the LDC (less-developed countries) goat milk ranks third after cow and buffalo milk with about 5% of the total (26). The LDC produced about 52% of the total world production of goat milk. In terms of world production of all milk, goats produced 1.5%. The bulk of buffalo milk is produced in the Southeast Asian region, India, and Pakistan and sheep milk in the Near East. Goat milk is produced in all regions of Iran, Iraq, Syria, Africa, the Near East, and Southeast Asia. South America is least important for production of goat milk. In Southeast Asia goat milk is produced mainly in India and Bangladesh. Nevertheless, the contribution by goats to the total meat supply is usually more important than milk production (Table 2).

COMPOSITION OF MILK OF GOATS, BUFFALO, AND COWS

Table 3 presents gross composition of goat milk for indigenous tropical and European breeds in the tropics. A comparison between composition of goat milk with that from buffalo and cows is in Table 4. Total solids, protein, ash, and lactose contents of goat milk appear to be higher than in cow milk. Buffalo

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TABLE 1. Contribution of goats to milk production in the world (26).

Region	Milk production[a]	Goat milk	Buffalo milk	Cow milk	Sheep milk	Goat milk vs. total
	(tons 10^3)					(%)
Africa	12,429	1,271	1,188	9,412	558	10.2
Central America	9,024	229	...	8,795	...	2.5
South America	23,923	126	...	23,765	32	.5
Near East	8,392	1,119	326	5,047	1,900	13.3
Southeast Asia	12,572	663	8,204	3,660	45	5.3
Production from LDC[b]	66,340	3,408	9,718	50,679	2,535	5.1
World production	450,343	6,548	27,435	409,092	7,268	1.5

[a]From buffalo + cows + goats + sheep.

[b]Less-developed countries.

milk has the highest content of total solids, solids-not-fat, and fat.

Although gross composition of goat milk is similar to cow milk, there are differences, especially in extent of utilization and appearance of milk precursors from the diet (40). A greater proportion of calcium in milk may be derived from the diet in goats compared to cows (42). Higher metabolic rates, related to their smaller body size (4), are reflected in larger amounts of feed consumed and milk produced per unit of body weight (51). However, diameters of milk fat globules differ significantly between species (Table 5). The range of size of milk fat globules is the same in cows and goats (1 to 10 μm diameter), but contents of smaller globules are more in goats. Up to 4.5 μm diameter, the percentage distribution of fat globules was 85.7% in sheep, 82.7% in goats, 62.4% in cows, and 40.9% in buffalo milk. Nutritionally, the high concentration of small fat globules is an advantage, but for butter making, milk fat of goat milk is more difficult to separate than that of cow or buffalo.

Goat milk has a larger amount of nonprotein nitrogen than cow milk (52). Goat milk casein has a lower content of arginine, isoleucine, and valine compared to casein of cow milk but is richer in histidine, aspartic acid, and tyrosine (Table 6). Casein of buffalo milk is less in arginine, lysine, threonine, and valine compared to cows. The nitrogen distribution in colostrum and whole milk of Jamnapari goats is is Table 7.

Fatty acids in goat milk in comparison to buffalo and cow milk are in Table 8. Goat milk has a relatively higher content of C6:0, C8:0, C10:0, C12:0, and C14:0. Cow milk has a higher content of C16:0, C18:0, C18:1, and C18:2. Buffalo milk is high in C16:0 but is lower in C18:1. The saturated fatty acids in goat milk fat comprise about 67% of the total weight of fatty acids.

Mineral information for goat milk is limited (13, 20, 54, 59). Contents of Na and K appear to be higher in goat than in buffalo milk but are comparable to cow milk. Mineral contents in the milk of West African dwarf goats, Red Sokoto, and Saanen goats were reported from Nigeria (49) (Table 9). Considerable variation is related to stage of lactation.

Vitamin contents in goat, buffalo, and cow milk (Table 10) indicate that vitamin A, nico-

TABLE 2. Relative importance of goats to meat and milk production in the South East Asian region (20).

Country	% Total production	
	Meat[a]	Milk[a]
Afganistan	13.7	5.2
Bangladesh	15.1	28.0
India	47.6	2.3
Iran	17.4	10.3
Malaysia	9.1	...
Nepal	25.6	4.3
Pakistan	23.9	3.6
Philippines	4.2	...
Sri Lanka	4.3	3.0

[a]Includes buffalo, cattle, goats, and sheep.

TABLE 3. Gross composition of milk of dairy goats in the tropics.

Breed	Location	Total solids	Fat	Protein	Solids-not-fat	Ash	Lactose	Reference
		(%)						
Tropical								
Barbari	India	13.35	3.88	3.89	9.47	.82	4.76	(59)
Beetal	India	13.67	4.43	3.38	9.23	...	...	(69)
Boer	South Africa	15.71	5.65	3.05	10.06	.89	6.12	(71)
Jamnapari	India	14.24	4.60	4.01	9.64	.84	4.79	(59)
Malabar	India	12.35	4.96	3.89	7.39	.83	4.11	(20)
Red Sokoto	Nigeria	15.85	5.32	4.74	10.53	.78	4.77	(48)
European								
Anglo-Nubian	West Indies	12.20	4.10	3.31	8.10	.79	4.10	(13)
British Alpine	West Indies	11.50	3.40	2.89	11.00	.78	4.40	(13)
Saanen	Nigeria	12.25	3.34	3.04	8.91	.75	4.56	(48)

tinic acid, choline, and inositol are higher in goat milk than in cow milk, but vitamin B_6 and ascorbic acid (vitamin C) contents are lower. Characteristic of goat milk, and unlike cow and buffalo milk, is the absence of carotenoid pigments and precursors of vitamin A (41). The riboflavin and pantothenic acid contents of goat milk are higher than in buffalo milk (25, 52).

In general, the most important contribution of goat milk to human nutrition is that of proteins and minerals. The 32 g protein supply of 1 liter goat milk represents 70% of daily requirements (46 g) of a lactating or pregnant peasant mother and is adequate for the daily needs of a child up to 11 yr of age. The Ca supply of 1.7 g/liter is adequate to meet daily requirements also.

TABLE 4. Composition of milk from goats, buffalo, and cattle in the tropics.

Constituent	Goat[a]	Murrah buffalo	Indian cow
Total solids (%)	13.9	18.7	13.5
Fat (%)	4.8	6.5	4.8
Protein (%)	3.7	3.7	2.8
Solids-not-fat (%)	9.1	9.7	8.1
Ash (%)	.85	.86	.74
Lactose (%)	5.0	4.8	4.6

[a]Indian, Nigerian, and South African.

DRY MATTER INTAKE BY GOATS

Capacity for dry matter intake (DMI) by goats is a determinant of productivity. It is influenced by temperature, feed, ratio of roughage to concentrate, stage of lactation, and health. A greater proportion of DMI is used for milk production in goats than in cows or buffalo (5, 20). The DMI as percentage of live weight in goats is approximately 3%. With Kambing Katjang goats, valued for meat production in Malaysia, DMI between 2.2 to 2.8% of live weight has been reported (11, 18). Variation in DMI due to breeds and environments is summarized in Table 11.

TABLE 5. Frequency distribution of average size fat globules in milk of goats, buffalo, cows, and sheep (27).

Diameter	Goat	Cow	Buffalo	Sheep
(μm)	(%)			
1.5	28.4	10.7	7.9	28.7
3.0	34.7	32.6	16.6	39.7
4.5	19.7	22.1	16.4	17.3
6.0	11.7	17.9	20.3	12.1
7.5	4.4	12.2	20.9	2.0
9.0	1.0	3.1	10.5	.2
10.5	.2	1.4	1.7	...
12.0	...	.1	2.0	.1
13.5	...	...	.4	...
15.0	...	...	.3	...
16.5	...	...	...	...
18.5	...	...	.1	...
Average	3.49	4.55	5.92	3.30

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TABLE 6. Amino acid composition of caseins from goats, buffalo, and cows (g/100 g casein) (32, 34, 52).

Amino acid	Goat	Buffalo	Cow
Alanine	3.6	2.4	3.4
Arginine	2.1	2.8	4.1
Aspartic acid	27.3	7.4	7.4
Cystine/cysteine	.4	...	.4
Glycine	2.1	8.6	2.1
Glutamic acid	20.3	...	23.2
Histidine	5.0	1.6	3.2
Isoleucine	4.3	13.6	6.6
Leucine	9.1	...	10.0
Lysine	3.5	7.6	8.1
Methionine	6.0	2.0	3.2
Phenylalanine	14.6	4.5	5.4
Proline	...	...	11.8
Serine	5.2	...	6.6
Threonine	5.7	3.7	4.3
Tyrosine	4.8	4.2	5.8
Tryptophan	1.3	1.5	1.3
Valine	5.7	5.6	7.5

Maekenzie (44) recommends DMI of 5 to 7% for dairy goats. Dry matter intake on the basis of metabolic body size (kilograms bodyweight $^{.75}$ ($W^{.75}$)) is a better comparative measure (4), and accordingly, Table 11 presents means of 79.6, 88.0, and 106.1 g/$W^{.75}$ for tropical, introduced, and European breeds of goats.

High milk yields are consistent with high DMI. Average dairy goats in the tropics do not match the performance of goats in temperate zones. Imported dairy breeds must be provided with adequate rations to assure high lactation yields in the tropics. Reduced performance by imported dairy goats in the tropics is caused also by ambient temperatures that depress DMI and productivity. Nevertheless, dairy goats have relatively higher DMI than lactating buffalo and cows (70). In practical diets for milking goats, especially imported breeds, more DMI must be allowed than for milking buffalo or cows.

MILK PRODUCTION BY GOATS, BUFFALO, AND COWS

Lactation milk yields of tropical dairy goats in the Asian region have been reviewed (Tables 12, 13) (20, 21, 23, 61) and range widely. Milk yields and lactation lengths were least for tropical and highest for breeds in temperate regions. Dairy goats introduced into the tropics were intermediate. In Guadeloupe, imported Saanen goats produced less milk yield than the same breed in France (7).

There has been little selection among the few recognized dairy goat breeds in the tropics. This is reflected in the paucity of information on selection for improvement and the absence of prominent dairy breeds in the humid tropics. A few dairy goat breeds are indentifiable, but they are few compared to the large number of meat breeds and crossbred types. There is limited demonstrable information on the impact of selection on performance, and there is definite need for selection and breed improvement programs for tropical dairy goat breeds.

Inadequate nutrition is by far the most important factor responsible for low productivity of dairy goats, for example, in the Caribbean (7, 13) and in Nigeria (48). Lower fat contents have been attributed to reduced DMI and high temperatures (13, 48). Significance of adequate nutrition was demonstrated in feeding trials in India (Table 13) (59). On small farms, opportunities for stimulating higher yields through improved nutrition and management are enormous.

Problems of continuing concern are animal health and diseases. Mortality of kids and adults is high. In Bangladesh, for example, mortality was 82% in kids and in 48% in adults. Of the causes, 36 to 44% of the deaths were due to respiratory diseases and 25 to 44% due to gastrointestinal parasites (1). In Sri Lanka, kid mortality from 2340 pregnancies was 28% (56);

TABLE 7. Nitrogen distribution in colostrum and normal milk of Jamnapari goats (67).

Constituent	Colostrum[a]	Normal milk[b]
Total N (%)	1.467	.749
Protein N (%)	1.384	.745
Casein (%)	.627	.534
Whey protein (%)	.758	.172
Lactalbumin (%)	.701	.121
Lactoglobulin (%)	.814	.051
Nonprotein nitrogen (%)	.081	.044
Casein number	47.0	71.2

[a]Mean of 6 consecutive milkings.

[b]Mean of 4-mo lactation.

TABLE 8. Fatty acid composition of goat, buffalo, and cow milk fat.

Species	C4:0	C6:0	C8:0	C10:0	C12:0	C14:0	C16:0	C16:1	C18:0	C18:1	C18:2	Reference
	(Percentage by weight)											
Goat	2.6	2.9	2.7	8.4	3.3	10.3	24.6	2.2	12.5	28.5	2.2	(33)
Buffalo	3.9	1.6	.8	1.6	2.1	10.8	33.0	...	11.0	24.5	...	(10)
Cow	3.3	1.6	1.3	3.0	3.1	9.5	26.5	2.3	14.6	29.8	2.5	(33)

pleuropneumonia and intestinal parasites were the main causes. In the West Indies, internal parasites and infectious agalactic diseases have been identified as major problems with Alpine goats (7). Poor condition of goats due to poor nutrition is also a major problem. Metabolic diseases occur in lactating goats. Goats are intermediate between sheep and cows in susceptibility to ketosis (65).

An aspect related to lactation milk yield and efficiency is persistency and lactation curve of goats as compared to buffalo and cattle. Goats have relatively flat lactation curves, and peak milk yields are reached between the 8th and 12th wk of lactation (38, 50, 53, 55, 64). By comparison, cows have a maximum daily milk production at about the 4th to 6th wk of lactation (31). The lactation curve of buffalo appears to resemble that of the cow. This implies that goats are more persistent milkers. In Beetal goats lactation yield and body weight are correlated .3 (53). For local, Nubian x local, and Anglo-Nubian x local crossbred goats in Malaysia, correlation coefficients (r) ranged from .59 to .93 (23). Figure 1 demonstrates typical curves for lactation milk yield of goats, buffalo, and cows. Relatively high milk yields in goats are from mammary glands and volumes of secretory tissues comprising a relatively greater proportion of the body than in cows and buffalo.

For cows yield of milk proteins is more important than production of meat proteins, because efficiency of feed conversion to milk

TABLE 9. Mineral contents in milk of West African Dwarf, Red Sokoto, and Saanen goats (49).

Mineral	Stage of lactation	West African Dwarf	Red Sokoto	Saanen
Ca	Early	145.8	90.7	112.0
(mg/100g)	Mid	157.4	153.2	102.0
	Late	126.2	141.8	90.7
P	Early	66.1	42.1	132.0
(mg/100g)	Mid	62.2	62.2	158.0
	Late	59.9	59.9	134.0
Mg	Early	18.5	13.4	13.3
(ng/100g)	Mid	16.4	14.2	15.8
	Late	14.3	15.1	13.4
Zn	Early	772	846	1,036
(μg/100g)	Mid	755	737	818
	Late	934	...	796
Fe	Early	10,418	8,417	8,820
(μg/100g)	Mid	10,667	9,254	7,620
	Late	9,108	...	10,610
Mn	Early	421	429	490
(μg/100g)	Mid	440	421	470
	Late	375	...	470
Cu	Early	458	463	491
(μg/100g)	Mid	485	440	470
	Late	491	...	470

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TABLE 10. Vitamin contents in the milk of goats, buffalo, and cows (25, 52).

Vitamin	Goat	Buffalo	Cow
Vitamin A[a]	2074	1669	1560
Vitamin D	23.7	...	...
Thiamine	.40	.50	.44
Riboflavin	1.84	1.07	1.75
Nicotinic acid	1.87	1.71	.94
Vitamin B_6	.07	.25	.64
Pantothenic acid	3.44	1.50	3.46
Biotin	.039	.13	.031
Folic acid	.0024	.51	.0028
Vitamin B_1	.0006	.0004	.0043
Ascorbic acid	15	25.4	21.1
Choline	150	...	121
Inositol	210	...	110

[a]Vitamin A as IU/liter; all others as mg/liter.

proteins is superior (2, 35, 69). Table 14 shows that the yield of proteins from indigenous goats is approximately 7 times and for European goats about 39 times that from meat goats. Based on four kiddings or lactations, Table 14 also shows the important life-time production of milk proteins. Table 15 presents examples of protein input and output in several locations and efficiency of protein conversion. There is a tendency toward higher yield of protein and efficiency in temperate countries such as Australia. The pattern of protein production is consistent with the pattern of milk yield for the three categories of goats (Table 12).

ASPECTS OF INCREASING MILK PRODUCTION

In most situations, temperate and tropical, purchased concentrates are fed to ensure adequate DMI and milk production. The crude protein input in these concentrates is usually from oilseeds (e.g. oilmeals from peanuts, soybeans, and coconuts), which constitute the most expensive ingredient in the diet. Given current knowledge of nonprotein nitrogen (NPN) utilization by the ruminant, about 70 to 75% of the total crude protein intake can be replaced by cheaper NPN sources like urea or biuret in developing countries. This has the effect of not only reducing the cost of feeding, but also, substantially increasing the amount and quality of proteins in milk. The utilization of urea has the effect of upgrading protein quality from unbalanced dietary sources to produce high quality milk proteins for human consumption. The efficiency of protein con-

TABLE 11. Dry matter intake (DMI) of adult dairy goats in different environments.

Breed	Location	DMI as % live weight	DMI/$W^{.75}$	Reference
Tropics				
Indigenous breeds				
Barbari	India	3.4–4.2	76.0– 94.0	(66)
Beetal	India	3.1	81.2	(70)
Jamnapari	India	3.1	67.3	(46)
Jamnapari	India	2.7–3.4	68.3– 86.0	(66)
Jamnapari	India	3.0	65.1	(63)
Unknown	Pakistan	3.8–3.9	83.7– 85.9	(36)
Introduced breeds				
Anglo-Nubian	Trinidad	4.5–4.9	113.1–123.2	(12)
British Alpine	Trinidad	4.8–5.0	114.6–119.4	(12)
British Alpine	Trinidad	2.2–3.0	52.8– 72.0	(9)
British Alpine	Trinidad	2.5–3.8	61.2– 87.6	(14)
French Alpine	Guadeloupe	2.5–3.1	55.1– 68.3	(3)
Alpine	India	2.9	77.2	(70)
Alpine X Beetal	India	3.2	84.0	(70)
Temperate zones				
Alpine	Norway	3.2	70.4	(51)
Saanen	Australia	4.4	115.9	(57)
Saanen	France	4.0	88.1	(59)

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TABLE 12. Lactation milk yields of tropical dairy goats in the Asian region (20)[1].

Breed	Location	Milk yield	Lactation length	Butterfat
		(kg)	(days)	(%)
Beetal	India	200.1	208	5.2
Barbari	India	118.0	183	3.9
Jamnapari	India	182.0	168	4.5
Beetal	Pakistan	146.8	186	4.9
Barbari	Pakistan	100.0	100	4.1
Bikaneri	Pakistan	75.0	100	5.1
Chopper	Pakistan	75.0	105	5.2
Dera Deen Panah	Pakistan	204.5	130	4.9
Damani	Pakistan	106.8	105	...
Kamori	Pakistan	227.3	120	4.7
Malabar	India	180.6	180	5.1

[1] European breeds in the tropics: 143–1011 kg, 106–336 days; European breeds in temperate zones: 245–2707 kg, 180–730 days.

version is then higher than in Table 15. A recent study in India demonstrated that urea or biuret are valuable for goat feeding (68). With a 50% substitution of total digestible protein by urea or biuret to goats over 150 days, there were no significant differences in 4% fat-corrected milk yield and milk composition.

In Nigeria, two sources of nitrogen (urea and peanut oilmeal) were fed to West African Dwarf goats (47). The urea-fed goats tended to grow faster than those fed peanut oilmeal diets. That NPN sources substituted for as much as 50% of dietary nitrogen, which resulted in about 25 g of high quality proteins (Table 15), indicates the value of NPN in the diet of lactating goats. Similarly, in many countries use can be made of poultry litter (a by-product), which is a source of NPN, with a concurrent reduced cost of feeding.

Agro-industrial by-products are abundant, varied, and constitute an important source of feed ingredients in humid tropics. In many parts of Asia, for example, this is a consequence of the emphasis on tree cropping. Recently, the

TABLE 13. Effects of nutrition on lactation milk yields of two dairy breeds of goats (Barbari and Jamnapari) in India (59).

Lactation number	Barbari			Jamnapari		
	(MH)[a]	(LL)[b]	Difference	(HH)[c]	(LL)[b]	Difference
	(liters)		(%)	(liters)		(%)
1	101.0	27.8	263.3	153.7	44.0	249.3
2	129.7	30.3	328.1	196.0	58.4	235.6
3	100.4	21.7	362.7	131.8	45.2	191.6
4	106.8	...	...	128.0	...	...
5	109.2	...	...	...	...	...
Mean	110.4	26.6	315.0	160.5	49.2	226.2

[a]Medium-high plane of nutrition.

[b]Low-low plane of nutrition.

[c]High-high plane of nutrition.

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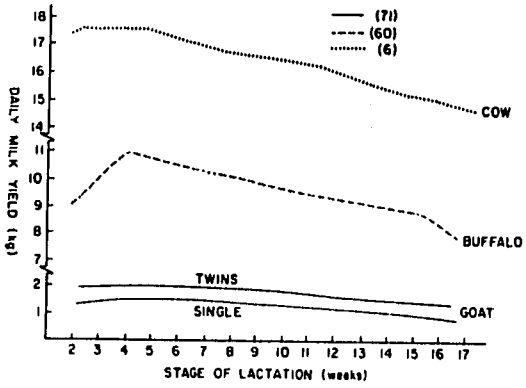

Figure 1. Lactation curve in the goat compared with lactation curves in the buffalo and the cow.

value of tree by-products for feeding farm animals in the South East Asian region has been reviewed (24).

The extent of the availability of these by-products is indicated in Tables 16 and 17. Major by-products can form the base in a feeding system, but minor ingredients supplement the diet. The division is by no means absolute as some by-products like oil cake meals can be classified into either category. A high proportion of these by-products are wasted currently. They represent potentially important components of the diet of goats. The potential for increased efficiency in utilization of complex fibrous carbohydrates is enormous, and their use is favored because of the efficiency of digestion of fiber by goats (19).

A strategy for increasing the efficiency of nutritional management of goats calls for the following (22): a) a compilation of feeds and their composition; b) information on the feeding value of new sources of forage such as ipil-ipil (*L. latisiliqua* (L)), sesbania (*S. grandiflora*) and cassava (*M. esculenta* Crantz); c) development of appropriate management regimens which include comparisons of grazing and stall feeding systems (little, for example, is known about the value of tree leaves in stall feeding systems); and d) definition of production systems that can demonstrate high production, and their profitability.

A primary consideration in favor of goats is their small size and value within small farmer systems (22). Small farmers are essentially crop-oriented subsistence farmers with incomes close to poverty. They may possess cattle or buffalo (not more than one or two head), but most possess goats or sheep.

Main advantages of goats are supplementary

TABLE 14. Milk and protein production from goats.

Characteristics	Dairy goats: Temperate zones	Dairy goats: Tropics	Meat goats: Tropics
Annual production (Per animal)			
Average milk yield/lactation (kg)	1,480	280[a]	
Average yield of milk proteins (kg)	54.8	10.4[a]	1.4[b]
Lifetime production (Per animal)			
Total yield from 4 lactations (kg)	6,000	1,100[a]	
Yield of proteins (kg)	222.0	40.7[a]	8.3
Annual production (Per ha)			
Average milk yield/ha (kg)		5,970[c]	
Average yield of milk proteins/ha (kg)		220.9[c]	
Average milk yield/ha (kg)		11,120[d]	
Average yield of milk proteins/ha (kg)		411.4[d]	

[a]Indigenous dairy goats in the tropics.

[b]Based on a litter size of 2, dressed carcass weight of 5 kg and 16% protein content in boneless meat.

[c]Indigenous goats, based on 14 tons dry matter yield of good quality Guinea grass (*Panicum maximum*), an annual dry matter requirement of 660 kg and average lactation milk yield 280 kg; liveweight is 45 kg.

[d]European goats in the tropics, fed Guinea grass and producing an average of 580 kg per lactation; average live weight is 50 kg.

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TABLE 15. Protein input-output and efficiency of protein conversion in dairy goats.

Breed	Location	Input	Output	Efficiency[a]	Reference
		(g/day)	(g/day)	(%)	
British Alpine	West Indies	267.4	56.7	21.2	(13)
Anglo-Nubian		235.2	45.6	19.4	
Anglo Nubian X local crossbreds	Malaysia	250.2	59.3	23.7	(16)
Alpine	India	260.2	49.4	19	(70)
Beetal		205.5	32.9	16	
Alpine X Beetal crossbreds		260.2	49.4	20	
Beetal	India	216.6	23.6	10.9	(68)
		112.1[b]	25.5	22.7	
		106.4[b]	24.9	23.4	
Saanen	Australia	278.6	72.2	25.9	(57)
Saanen		311.6	91.6	29.4	

[a]Calculated according to $E = \frac{\text{Protein in milk}}{\text{Protein in feed}} \times 100\%$.

[b]Excludes 50% contribution from urea and biuret, respectively.

TABLE 16. Major agro-industrial by-product feeds from tree and field crops, with extraction rates in Asia and the Far East (17).

Crop	By-product feed name	Approximate extraction rate (%)[a]
Tree Crops		
Cocoa (*Theobroma cacao*)	Cocoa bean waste	5–10
	Cocoa husk	70
Coconut (*Cocos nucifera* L.)	Coconut meal	35–40
Oil palm (*Elais guineensis*)	Oil palm sludge (dry)	2
	Palm press fibre	12
	Palm kernel meal	2
Rubber (*Hevea brasiliensis*)	Rubber seed meal	55–60
Sago (*Metroxylon sago*)	Sago refuse	55
Field Crops		
Cassava (*Manihot esculenta* Crantz)	Cassava waste	55–59
Castor (*Ricinus communis* L.)	Castor meal	45–50
Cotton (*Gossypium* spp.)	Cotton seed meal	40–45
Corn (*Zea mays*)	Corn bran	8–10
	Corn germ meal	16–18
	Corn stover	70–75
Rice (*Oryza sativa*)	Broken rice	4–5
	Rice bran	10
	Rice husk	15–17
	Rice straw	100[b]
Sugarcane (*Saccharum officinarum*)	Bagasse	12–15
	Green tops	15–20
	Molasses	3–4
Wheat (*Triticum aestivum* L.)	Wheat straw	100[b]

[a]Extraction rate is defined as % by-product produced.

[b]Implies equivalent weight to the yield of grains.

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TABLE 17. Minor by-product feeds from various sources, with extraction rates in Asia and the Far East (24).

Crop	By-product feed name	Approximate extraction rate (%)
Plants		
Cassava (*Manihot esculenta* Crantz)	Cassava leaves	6–8
Dhupa (*Vateria indica*)	Dhupa meal	70–73
Peanut (*Arachis hypogaea*)	Peanut vines (stems & leaves)	41–57
	Peanut meal	53–37
Guar (*Cyampsis psoraloides* DC)	Guar meal	70–80
Kakan (*Salvadoza oleoides*)	Kakan meal	55–58
Karaj (*Pohogomia pinnata*)	Karaj meal	55–60
Kakum (*Garcinia indica chois*)	Kakum meal	40–42
Kusum (*Schleichara oleosa*)	Kusum meal	67–70
Mahura (*Madhuka indica*)	Mahua meal	35–40
Mango (*Mangifera indica*)	Mango kernel	50–55
Nahor (*Mesua ferrea* Lin.)	Nahor meal	60–62
Neem (*Azadirachta indica*)	Neem meal	45–50
Oak (*Quercus dilatata*)	Oak meal	60–62
Pineapple (*Annanas comosus*)	Pineapple waste	60–80
Pisa (*Actindaphne hooberi*)	Pisa meal	40–42
Sal (*Shorea robusta* Gaerth)	Sal seed meal	35–40
Sesame (*Sesamum indicum* L.)	Sesame cake	60
Soybean (*Glycine soya*)	Soybean	70–75
Sweet potatoes (*Ipomoea batatas*)	Sweet potato vines (stems & leaves)	24–35
Tamarind (*Tamarindus indica*)	Tamarind seed hulls	30–35
Animals		
Poultry	Poultry litter (dry)	26.0[a]
Ruminants	Blood meal	.6[c]
	Meat and bone meal (dry)	25–30[b]
	Rumen contents (wet)	.8[c]

[a]Based on a daily faecal production of 100 g/adult bird.

[b]Of the weight of wet offals.

[c]Of the live weight.

income and low risk. Their value is as a renewable resource supplying important proteins to the human diet. Large ruminants require more labor, more feed, and care. Goats invariably are cared for by women and children and require only limited resources. During periods of feed shortage, managing a few, smaller sized animals (goats) is less difficult.

Concerning the utilization of feed resources, there is little controlled feeding throughout the tropics. On small farms, the goat's value lies in converting agro-industrial by-products to meat and milk. Given that extensive uncontrolled management of goats is common (21) and that by-product feeds, e.g. the fibrous materials are mainly waste products, goats are performing a valuable function in converting these materials to meat and milk.

With cows in the tropics, many heifers do not produce their first calf and first milk before 3 to 4 yr of age (69). The situation is even later in buffalo. By comparison, goat does begin to produce milk at 1 yr of age after only 5 mo of pregnancy (23).

In most LDC, milk production is from cattle and less from buffalo. Dairy development in the modern context is confined to promotion of cattle, and in India and Pakistan, to buffalo as well (29).

Under these circumstances, the dairy goat as a logical animal and an important resource for small farm agriculture should be recognized to fit the system and to perform a useful role in the supply of high quality animal proteins. Unlike the dairy cow or buffalo, dairy goats are more suited for uncommercialized, small farm agricultural systems in the supply of a small but consistent supply of milk. Dairy goat develop-

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ment on small farms is an important complement of large dairy development of buffalo and cattle. However, there is currently little attention to development of goats for milk production.

The complementarity of dairy goats with large commercialized milk production from buffalo or cattle and the economic possibilities of goats for commercial dairying in the tropics merit more attention and research.

The success of such a development strategy will necessitate improved managerial efficiency, of which improved feeding and disease management are particularly important, including wider use of NPN and more effective utilization of agro-industrial by-products.

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Relationship Between Body Conformation and Production in Dairy Goats[1]

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ABSTRACT

Type appraisal is important in goat breeding, but few data on relationships between body conformation and milk production are available. About 20 to 30% of the variation of milk yield is explained by variation of body weight. The relationship is closest if weight is taken shortly after kidding. Udder volume increases linearly between milkings and is related with milk yield, which depends on empty udder weight and secretion per kilogram mammary tissue. Milk yield may be assessed by visual appraisal of udder size. Multiple regressions of milk yield on body measurements have positive relationships with body weight, skeletal size, abdominal volume, and udder volume but negative relationships with weight of body fat and muscles. This indicates that increased body weight favors milk yield only if it is due to scale while it reduces milk yield if due to fat and muscle mass. These relationships would disfavor increasing meat production from dairy goats, but due to a marked sex dimorphism male kids may be used for fattening. Multiple regressions also indicate that early maturing goats tend to produce less milk in their first lactations. About 70% of the variation of first milk production is explained by the common variation of body characteristics and growth rate. Heterozygous polled goats or those with wattles are more prolific than horned animals or without wattles. There is a need for better understanding of body characteristics having importance for adaptability and resistance to adverse environmental conditions.

INTRODUCTION

Body conformation is used in dairy goats as an aid toward selection. Different from cattle, formal breeding and selection plans for goats based on modern genetic theory through organized herd testing programs or governmentally supported associations are operated in very few countries only, e.g., France (41) and to some extent Norway (45). The majority of breeding stock is selected on individual appraisal where evaluation of physical appearance plays a major role.

In most countries milk recording is limited to relatively small numbers of goats. This is in part due to the high cost of milk recording in goats (17). As long as the procedure applied is the same as in cattle, cost per animal will be higher than in cattle due to the smaller size of operations and thus much higher per unit cost of milk produced. Proposals have been made for simplifying milk recording in goats without losing too much accuracy (5) and in 1978 have been accepted in principle by the International Committee for the Productivity in Milk Animals (ICRPMA).

Since genetic merit of breeding animals is not assessed by more exact methods, the question has not been raised in dairy goats as to whether consideration of physical conformation in addition to production data may increase selection response or reduce it. In Europe in particular, most breeds of dairy cattle are bred for both milk and meat. To a considerable extent, appraisal of dairy cattle is geared towards beef production of both surplus cows and young bulls. This aspect has not received attention in goats since kids traditionally are slaughtered at a young age. The result is a marked uniformity of type of most goat breeds. Similarly, there has been little selection for increasing growth rate. Considering the diffi-

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culties brought about by such selection in other species, Shelton (50) may be right in presuming that "goats appear to have benefited from man's neglect in respect to fertility in that as a species they no doubt have the highest reproduction rate of competing ruminant species".

Apart from the use of body conformation as a selection aid, dairy goats sometimes are judged and bred almost exclusively on conformation and for the sake of type and beauty proper. In some countries and at some time the show ring took much more importance than production recording. All breed societies have their breed standards. The requirements for a perfect doe read much the same in most of these. Dairy characteristics are postulated as in dairy cattle. A typical description may read like this: "Because goats are dairy animals, they must have dairy characteristics. Check to see that the doe has a feminine head, thin neck, sharp withers, well-defined spine or backbone and hips, thin thighs, and rather fine bones. The skin should be thin and fine over the ribs. Look for a wide spring of rib and roomy barrel. This will help you to know how much feed she can eat. The constitution, or physical nature, is an important item shown by the depth and width of the chest. It's important to look at the udder, too. It should be large when full of milk and very much smaller when empty". A large udder does not always mean a high milk yield (28). While few breeders will challenge these requirements from a practical point of view, there is little scientific evidence to support the presumption that animals with a body conformation according to these standards produce more milk and produce it more economically than others.

This paper is to report scientific research to analyze relationships between body conformation and milk production in dairy goats. However, a thorough search of the literature reveals that the number of publications on the subject is small.

Size

One of the principal characteristics of goats as dairy animals is their small size in comparison with cattle. Mature does of dairy breeds weigh between 30 and 80 kg. There is, however, considerable variation of size within breeds, and this receives major attention. The results of a number of investigations on phenotypic relationships between body weight and production are in Table 1. As in dairy cattle, space for

TABLE 1. Phenotypic relationships between body weight and milk production in goats.

Record	Time of measurement	b	r^2	n	Reference
Yearly production, kg milk	after kidding	4.76	.23	104	(11)
Yearly production, kg milk	...	9.6	...	160	(29)
Yearly production, kg milk	1 May	7.68	.14	549	(43)
Yearly production, kg milk	1 May	...	.16	5795	(44)
Lactation yield, kg milk	7 months of age	...	.27	...	(41)
Yearly production, kg fat	1 May	.48	.27	549	(43)
8 months lactation, kg FCM	31 days postpartum	.91	.32	318	(34)
200 day lactation, kg FCM	after kidding	5.889	.33	120	(21)
200 day lactation, kg FCM	5 weeks postpartum	9.946	.28	120	(21)
35 days kg FCM	5 weeks postpartum	1.74	.29	108	(8)
70 days	10 weeks postpartum	1.764	.12	139	(8)
140 days	20 weeks postpartum	3.099	.17	141	(8)

a large rumen volume and a large udder volume is considered important in dairy goats. To some extent size and growth rate are observed as a prerequisite for economical utilization of surplus kids. In dairy cows, body size and economic efficiency do not seem closely related. Relationships are dependent on the feeding regime because the contribution of milk yield to income over feed costs is large (33). Likewise, Brody et al. (3) and Ormiston et al. (34) have concluded that gross energetic efficiency in the dairy goat is independent of body weight. With high milk production at the beginning of lactation, goats are not able to consume without adverse effects the quantities of concentrates needed to supply the required energy. They draw on their body fat stores (32). This appears to be a natural mechanism, particularly marked in goats, for sustained high production on increasing forage capacity, and improved efficiency of forage utilization is an important breeding goal along with direct selection for lactation milk yield. Since feed intake capacity – physical and behavioral – is difficult to assess directly, size traditionally is an indicator. In 79 goats of an experimental herd, Schaedlich (47) took linear body measurements during wk 5 and 10 of the first lactation. Measurements were width of abdomen, depth of abdomen, loin length, front length, and body weight. The accuracy of measurements was assessed by the intraclass correlation (r_I) of repeated measurements by one and by two persons; r_I fell between .91 and .97. Correlations between measurement and milk produced up to the day of measurement in wk 10 are in Table 2. Correlations were not close, in general, and no single measurement was closer related to fat-corrected milk (FCM) than body weight.

TABLE 2. Correlation coefficients between body measurements and milk yield.[a]

		FCM	F	L	W	A
Front length	(F)	.03				
Loin length	(L)	.26	.27			
Width of abdomen	(W)	.25	.22	.13		
Depth of abdomen	(A)	.27	.44	.43	.62	
Body weight	(Wt)	.36	.54	.35	.59	.69

[a]79 goats, 10th wk of lactation (47).

Multiple regressions of FCM on all four linear measurements did not significantly increase r^2 over any simple regression. Introducing body measurements as additional variables in a regression equation of FCM on body weight did increase r^2 from .13 to .2, but this increase was not significant.

Steine (52) in an investigation with 22,038 records of Norwegian goats found that a multiple regression equation of milk production on body weight taken in June and month of kidding had a partial regression coefficient of 1.25 ± .29.

Lampeter (21) in 198 German Alpines during lactations one to five compared the regression of 200 day FCM yield on body weight taken immediately after kidding and 5 weeks postpartum. The relation was closer with weight after kidding. Weight was highest in the fifth lactation. Simple regressions within lactations were not significant. The coefficients of regression of one of the two feed groups are recorded in Table 3. All regression coefficients differ significantly from zero, but in the multiple regression of FCM on weight and age, age is not significant and its inclusion does not increase r^2 significantly. Lampeter concluded that while weight and age are confounded partially, the primary influence on milk production is that of weight and not of age independent of weight. In 5795 records of goats weighing between 20 and 70 kg around the 1st of May, i.e., during about the 3rd to 4th mo of lactation, Rønningen (44) analyzed the relative importance of age and weight sources of variation of milk yield. He found that age had a predominant influence as estimated by the reduction of the error variance through a second degree regression of milk and fat production on weight or age. Error mean squares of milk production were reduced by 32.6% and 6.5% through age and weight, respectively. He concluded that the common influences of weight and age on milk and fat production were 5.7%, 26.9%, .5%, and 23.4%, respectively. The difference between these findings and those of Lampeter may be largely explained by the different points in lactation where goats were weighed. Gall (8) found that weight loss in the beginning of lactation was recuperated between the 2nd and 4th mo of lactation. Therefore, different relations will be expected if weights are taken immediately postpartum or at a later stage of lactation.

TABLE 3. Coefficients of regression of 200 day FCM yield on age and body weight.[a]

a	b_A	b_W	r^2
225.95	.0780	.....	.16
31.05	.....	5.8892	.33
26.38	−.0049	6.1361	.33

[a]120 goats (21).

Results have been similar in some investigations with cattle; in others weight and age had about the same influence or conversely age had more influence than weight (33).

Gall (9) investigated relationships between paunch girth, external body volume, and volume and contents of reticulorumen in animals fed to their ingestive capacity. Results in Table 4 indicate a fairly close relationship. The time needed for clearing rumen contents by rumination is dependent on body size in goats as in sheep and cattle (56). The r^2 of a third degree polynomial of rumination time on body weight was .78.

From these investigations body weight and size of the abdomen, in particular, are indicators of forage capacity of the goat.

Udder

As Shelton (50) has pointed out, even in a modern Herd Improvement Program with milk recording and artificial insemination, the visual evaluation of the udder should receive some attention. Most breed standards require a large, well attached udder with well-marked teats of a certain shape and size. Udder attachment is of particular importance in grazing goats. W... udder attachment with the tendency for pendulous udders may be a limiting factor for dairy goats in range pastures with thorny brush and cacti. In some breeds the prevalence of such udders is a major weakness.

TABLE 4. Coefficients of correlation between external body measurements and rumen volume (n) (9).

	Rumen volume	Rumen contents: Fresh matter	Rumen contents: Dry matter
Paunch girth	...	.87 (64)	.52 (64)
Abdomen volume	.98 (40)	.65 (20)	...

The size of the cisterns of both gland and teat in relation to the volume of secretory tissue seems to be greater in the goat than in the cow although this characteristic is not well established. As a consequence for milking practice, more milk is available for milking in the cisterns before oxytocin action for initiating milking. However, this peculiarity seems to favor the extension of the sinus walls, giving rise to broken teats and bottle shaped udders. During an extended milking interval of up to 19 h, milk secretion continued and udder volume increased linearly (19), but lactation milk production was reduced to about 50% by milking once a day only (30).

Horak (18) evaluated the udder shape of 588 Czechoslovakian polled Saanen goats and took linear measurements. He classified udders as round, egg-shaped, pendulous, or flat in 72.6, 24.7, 2.0 and .7% of the goats, respectively. Teat forms were funnel shaped, cylindrical, bottle-shaped, or bulbous in 50.0, 38.4, 8.2, and 3.4% of the goats. Milk yield was correlated with length .41, width .20, and circumference .43 of the udder, teat length .21, teat circumference .22, and teat ground clearance −.97. Does with round and egg-shaped udders had about the same milk yield (second 300-day lactation) of 1092 kg, but does with pendulous udders produced more milk (1119 kg).

Das et al. (4) took 12 udder measurements in 30 Barbari and 30 Bengal goats. Correlations of these measurements with milk yield on the day of measurement were positive (.46 to .80) in the Barbari breed and similar (.37 to .86) in the Bengal breed. Multiple correlations with daily milk yield were .74 and .69 for Barbari and Black Bengal goats.

Junge (19) investigated relationships between size of udder and milk production. He measured 74 German Alpine goats during the 5th, 10th, and 20th wk of their first and third lactations. Eighteen goats were measured in wk 8 and sacrificed. The volume of separated udder was measured directly by water displacement and compared with the volume measured by three methods on the live animal; namely, water displacement, a cast modeled by a wire mesh, and a combination of three linear

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measurements. Accuracy of the measurements was checked by consecutive repetitions. Intraclass correlations of these were .99, .98, and .83 to .96, respectively. Correlations between measurements of the isolated udder and milk yield are in Table 5. Correlations between part-lactation production up to the day of measurement in the 20th wk of lactation and udder volume measured on the live animal directly or calculated from linear measurements were .85 and .83, respectively. Udder volume increased linearly with time between milkings, and the decrease of udder volume after milking corresponded well with the volume of milk removed.

Due to the close correlation between daily milk yield and lactation milk yield, correlations between these and volume of the milk filled udder are to a considerable degree spurious. However, empty udder volume was more closely related with part lactation yield (r = .55) than with milk yield on day of measurement (r = .49). Gall et al. (14) sacrificed 64 goats in wk 10 of their first lactations and found a correlation of .73 between empty udder weight and 10-wk milk energy yield (Table 12). From his investigations on relations between udder size and milk yield in Saanen and Welsh goats (a nondairy breed), Linzell (23) concluded that production per kilogram mammary gland is the same in both breeds and that the Saanen produce more milk because they have larger udders.

TABLE 5. Correlations between measurements of the isolated udder and milk production in 18 German Alpine goats sacrificed during wk 8 of lactation and 19 h after last milking (19).

Measurement	Quantity of milk present in the udder	Daily milk yield	Part lactation milk yield up to day of slaughter
Volume of milk filled udder	.72	.70	.72
Volume of empty udder	.37	.49	.55
Volume difference	.80	.51	.49

From relationships between udder conformation and milk production, the visible and measurable size of the udder largely reflects the milk secretion capacity, although weak udder attachment and extended teat sinuses may lead to erroneous estimates. We have calculated the rank correlation coefficient for 200-day FCM yield within our experimental herd for one single recording of daily milk yield in wk 8 of lactation or maximum daily yield at .88 and .90, respectively (9). The praxis of gauging the productive capacity of a goat from visual udder appraisal is rather well based. This would imply consideration of age, stage of lactation, and interval from last milking as well as lactation length, i.e., persistency, and of feeding and management practices for ranking between herds.

Multiple Relations

The animal organism is dependent for its functions upon appropriate body conformation, which – always inadequately – is described by a number of individual traits. Since these traits, being part of a whole, are more or less closely interrelated, multiple relationships between physical traits and production should yield more information about the type of animal most useful for economic production. To analyze body characteristics that are related with biological efficiency of milk production, a series of experiments at the University of Munich between 1960 and 1969 was with German Alpine goats.

The relationship between milk production, body weight, abdominal volume, skeletal measurements, and udder volume was studied first in 130 live goats during their first to third lactations and at three stages of these lactations, 5, 10, and 20 wk postpartum (8). All individual traits were positively related with milk production. The coefficient of determination (r^2) of the multiple regression of milk produced on body measurements varied between .47 and .56 (Table 6), increasing with the inclusion of additional variables. The standard partial regression coefficient of milk yield on body weight became negative when volume of udder and abdomen and skeletal measurements were held constant, indicating that higher body weight within groups of animals, uniform for these traits, affected milk production negatively (Table 7).

TABLE 6. Change of variance due to regression for including several measurements in 139 German Alpine goats in the 10th wk of lactation (8).

Regression of FCM yield on[a]	r^2	F for increase of s_y^2
U	.46	....
U + W	.48	4.89*
U + W + V	.51	8.85**
U + W + V + E	.54	6.97**
U + W + V + E + S	.55	4.59*

[a]U = udder volume; W = body weight; V = abdominal volume; S = front length; E = age. FCM = 1.30 + .0649 U + 4.55 V − 2.74 W − .00798 E + 5.18 S.

*$P<.05$.

**$P<.01$.

Later in these investigations, the muscle mass of the body, first determined directly by carcass dissection and then by indirect estimation from forearm muscle volume, was studied (12). Within multiple regressions of FCM on body weight, skeletal measurements, and volumes of abdomen and udder, the indicators for muscle mass had a negative coefficient (Table 8). The standard partial regression coefficient of FCM on muscle mass was negative indicating that any positive relation between milk production and muscle mass, as in Table 12, was due to body size being related to both milk production and muscle mass. The negative coefficients indicate that between animals of the same body conformation those carrying more muscles tend to produce less milk.

These findings led to the hypothesis that those body measurements that favor the size of tissues having a bearing on milk producing capacity, such as rumen and udder volume, were positively related with milk production whereas the volume of tissues that does not have importance for milk production was negatively correlated. Therefore, body fat was determined also. We did not succeed in accurately estimating body fat on the live animal (16) so these investigations were confined to goats sacrificed after a short lactation. Enz (6) had analyzed relationships between part lactation data and total milk yield and found that the latter may be estimated from a 10-wk lactation period (Table 9). Furthermore, we found that total body fat could be estimated by the quantity of abdominal fat and total muscle weight by forearm muscle weight (Tables 10 and 11) (13). Coefficients of correlation between milk energy yield and body measurements are in Table 12; multiple regression equations of milk yield on body measurements are in Table 13. Coefficients for body fat in the equations are negative as are those for muscle weight.

TABLE 7. Change of the partial regression coefficients for additional independent variables.[a]

	b	b'
b_{FW}	1.764	.3570
$b_{FW \cdot V}$	.451	.0912
$b_{FW \cdot V, U}$	−.212	−.4283
$b_{FW \cdot V, U, S}$	−2.829	−.5724

[a]Data and symbols as Table 6; F = FCM.

TABLE 8. Change of the standard partial regression coefficient for additional independent variables (12).[a]

	b'
b_{FM}	.2671
$b_{FM, U}$	−.0187
$b_{FM, UW}$	−.1146
$b_{FM, UWV}$	−.1153
$b_{FM, UWVM}$	−.1672

[a]Symbols as in Table 6; M = muscle volume, A = forearm length. FCM = 11.75 + .0524 U + 2.8370 A − .1150 M − 2.4057 S + .5862 W + .4649 V; r^2 = .59.

TABLE 9. Relationships within one herd between part lactations and lactation yield in FCM (6).

Feeding group	n	r^2 for lactation yield and part lactations of 35 days	70 days	100 days	140 days
1	80	.69	.74	.85	.96
2	98	.66	.77	.89	.97

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TABLE 10. Coefficients of simple correlations between measurement data of 32 goats.[a]

		W Live-weight	A	M	D	M_{tot}	F	F_{anat}	F_{chem}
Forearm length	A	.60							
Forearm muscle weight	M	.66	.66						
Diaphragm-weight	D	.81	.44	.76					
Muscles of the carcass side	M_{tot}	.77	.75	.80	.77				
Abdominal fat	F	.47	.44	.47	.63	.68			
Anatomically separable fat	F_{anat}	.46	.46	.48	.67	.69	.97		
Extracted fat	F_{chem}	.66	.57	.56	.63	.73	.77	.76	
Total body fat	F_{tot}	.54	.52	.53	.67	.74	.97	.98	.87

[a]Correlations with diaphragms are of 11 of these goats only (13).

These results are in accordance with the supposition that relationships between milk production and body conformation, at least in part, reflect energetic relationships. The amount of energy that the animal utilizes to produce milk depends upon the amount of energy ingested and the amount used for other body functions. However, to produce milk out of the available energy, the animal needs further characteristics, such as an appropriate udder volume. Since these investigations do not delineate cause and effect, no conclusion can be drawn from the results as to whether some goats produce more milk because they have large udders or whether they develop large udders because they are stimulated to produce more milk by other factors. Nor can it be said whether animals deposit fat because they only produce limited amounts of milk or whether they produce only limited amounts of milk because they tend to deposit fat.

Growth Rate

One explanation why relationships between body weight and milk production in dairy goats are not consistent may be that a certain weight may represent different stages of development in animals of different growth rhythm. In growing ruminants there seems to be a general relationship between the type of growth and mature size; rapidly growing animals tend to become large at mature size and animals maturing early (i.e., depositing fat at a young age and thus decreasing in growth rate) tend to become smaller at maturity. Size of animal per se does not appear to be a decisive factor in efficiency of production (33). However, select-

TABLE 11. Coefficients of multiple regression equations of total body fat and muscle weight of the carcass side to their components (32 goats).[a]

Dependent variable	Absolute term	Independent variables						
		F_{anat}	F	D	M	W	A	r^2
Total body fat	522.3	1.303						.96
Total body fat	437.8		1.771					.94
Muscles of carcass side	539.4			33.22				.60
Muscles of carcass side	1643.0				21.34			.65
Muscles of carcass side	340.8				10.33	65.05	13.95	.79

[a]Equation [3] is of 11 of these goats only; symbols as in Table 10.

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TABLE 12. Coefficients of simple correlations between milk yield and body characteristics (n = 64) (14).

Item		Cal	W	P	A	L	U	R	DM	M	D	F	T
Calorific value of milk	Cal	1.00											
Liveweight	W	.32	1.00										
Abdominal circumference	P	.33	.81	1.00									
Forearm length	A	.32	.70	.32	1.00								
Loin length	L	.23	.66	.35	.69	1.00							
Udder weight	U	.73	.66	.47	.60	.45	1.00						
Rumen contents	R	.33	.65	.87	.14	.20	.34	1.00					
Dry matter in rumen	DM	.35	.36	.52	.06	−.04	.27	.56	1.00				
Forearm muscle weight	M	.18	.76	.45	.72	.50	.57	.26	.23	1.00			
Diaphragm weight	D	.23	.86	.61	.72	.64	.65	.39	.15	.75	1.00		
Abdominal fat	F	−.11	.60	.24	.55	.51	.36	−.07	−.17	.61	.63	1.00	
Weight of thorax organs	T	.04	.71	.35	.66	.54	.54	.09	.04	.75	.78	.76	1.00

ing for animals with growth curves which combine fattening ability and growth on high roughage diets, animals with large mature size may be the solution for simultaneously enhancing economic milk production and for efficient use of surplus young animals for meat production. Sex dimorphism with high growth rate of males may be a distinct advantage.

We tried to analyze the weight development of goats up to the beginning of their first lactation and relate it to the following milk production. Sixty-four German Alpines were weighed weekly until first kidding at about 13 mo of age. We tried various ways to describe the growth curve and found the method described by Taylor and Fitzhugh (55) particularly useful, although we had to assume a uniform mature weight for all animals. The method defines certain degrees of maturity (u) as the fraction of body weight of the final weight at the time (t). Seven degrees of maturity were fixed for the 64 goats and the age (t_u) determined at which they were reached. The mean time taken to mature (ln t_u) was used to describe the growth rhythm. Goats were sacrificed after a 10-wk lactation and udder volume, rumen content dry matter, and muscle and fat weights were determined. Body muscle and body fat were estimated from forearm muscle weight and abdominal fat, because of simplicity of the procedure and the close relationships between parts and whole in earlier investigations (Table 10) (13). Multiple regression equations of milk energy on body measurements and growth are in Table 14. In combination with udder volume, ln t_u does not contribute significantly to a reduction of deviations from regression. However, if udder volume is left out, the contribution of ln t_u becomes significant. While r^2 is lower in his equation, it is still appreciable. The positive regression coefficient on ln t_u indicates that late maturing animals with a flat growth curve and, thus, high t_u tend to produce more milk. Ricordeau et al. (39) reported genetic correlations between growth from 3 to 7 mo of age and subsequent milk production during the first 100 days and lactation yield of −.14 and .04 which, however, were not significant statistically.

Our results agree with what is known about the importance of growth rhythm in dairy cattle. It follows that the late maturing animal reaching higher mature weight had the better disposition for milk production. It would mean, however, that acceptable carcasses would be expected at higher weight only which would explain the dissatisfactory results of Fehr et al. (7).

Meat Production

As in other dairy animals, meat produced in a herd of dairy goats originates from cull females and from surplus kids. No attempt is being made in dairy breeds to enhance the salvage value of goats by increasing fleshiness as is done in some dual purpose dairy cattle. The investigations by Gall et al. (14) discussed above indicate that this would tend to affect milk production negatively. Little attention generally is paid to the meat producing qualities of young kids for slaughter. These animals are being slaughtered at a young age of about 2 to

TABLE 13. Coefficients of multiple regression equations of milk produced (in calories) on body measurements (64 goats) (14).[a]

Absolute term	Udder volume	Abdominal fat	Forearm muscle	Diaphragm	Rumen contents	Abdominal circumference	Loin length	Thoracic organs	r^2
	Independent variables								
44,025	90.11	....	−326.67[a]	....	....	....	....	....	.61
	14.91		141.20						
			13.34						
20,785	89.13	−12.22	−149.47	....	5.67	....	....	....	.70
	15.22	6.33	175.00		10.16				
		32.65	1.65		.99				
8,467	88.99	−13.51	−137.61	....	....	178.10	....	....	.70
	15.56	5.80	171.70			430.87			
		32.65	1.65			.54			
2,168	88.53	−14.85	−134.97	....	....	....	799.54	....	.71
	15.33	6.07	167.85				1,234.44		
		32.65	1.65				1.34		
−10,710	91.91	−14.23	....	146.13	....	....	1,183.00	....	.71
	16.10	6.04		138.40			1,319.00		
		32.65		1.92			2.64		
26,688	94.23	− 8.96						−56.19	.72
	14.50	7.02						40.82	
		5.57						33.96	

[a]The numbers above are the regression coefficients, below are standard deviations and F-values for inclusion of that variable. Table values are about 7 and 4 at 1% and 5% *P*, respectively.

5 wk and about 6 to 12 kg liveweight (7). It commonly is accepted that they have thin and shallow carcasses. There is, however, some interest in carrying kids to a heavier weight to utilize this resource (7). These authors fed kids on a high concentrate diet up to a liveweight of 32 kg. They found that width and depth of the carcass increased more rapidly than length; carcasses became rounder and more compact. The proportions of bone and muscle in the carcass were about 68 and 23%, respectively. These high percentages are due to a low fat content of 5 to 7%. Carcasses were lacking subcutaneous fat to an extent that storage and commercial presentation were affected. To some extent this low fat cover may have been due to insufficiencies in feeding in this experiment so that the results should not be generalized.

Dairy breeds exhibit a considerable sex dimorphism, adult males weighing 20 to 25 kg more than females (1). This difference is reflected in higher birth weights of male kids and higher average daily weight gains (9, 7). With a view to meat production as a side line to milk production, this dimorphism should be maintained. There are other goat breeds, such as the Maradi goat, in which male weights do not exceed greatly those of females (42).

Coat

Color patterns are distinctive of breeds and continuously selected for, but there is no indication of relationships with production. With goats grazing on extensive ranges there is a preference by goatherders for white animals which are detected easier.

There are short-haired breeds like the Saanen, Alpine, or the Spanish dairy breeds; and there are breeds with long hair like the Poitevine or some of the Toggenburg strains. Long hair occurring along the back and the rear

TABLE 14. Coefficients of multiple regression equations of milk produced (in calories) on body measurements and growth parameter.[a]

Absolute term	Udder volume	Forearm muscle	Abdominal fat	Rumen contents	Growth parameter	r^2
4368	86.6	−127	−14.4**	....	8631	.704
−62346	...	....	−11.04**	10.9*	44.8**	.307

[a]64 goats slaughtered during the 10th wk of their 1st lactation (11).

sides of the legs are discriminated against in the short-haired breeds although no relationship with productivity has been reported. Mackenzie (26) asserted that long, coarse, and dense hair-cover will be useful for animals fed intensively in cool climate. These animals eat little fiber, and their rumen fermentation yields less heat while animals grazing on range and feeding on high fiber plants were producing sufficient internal heat not to need protection from dense hair cover.

Heat Tolerance

Among the dairy breeds, Nubians have the reputation for heat tolerance. This, in part, may be a presumption because of their origin in a country of hot summer climates. It may be deduced, also, from their physical appearance with long legs, long ears, fine coat, and skin. The breed is preferred for breed improvement in tropical countries. However, from experience in Mexico (31) and Venezuela (15) no striking superiority of Nubians over Saanen and Alpine is evident. No systematic investigations of body characteristics related to heat tolerance have been published. Laor (22) reported that introduction of the Appenzell, a long-haired breed, in Israel failed completely. Experiences with Toggenburgs, which are partly long haired, are controversial. Reproductive performance in Venezuela was below the Saanen and Alpine breeds both as purebreds and as crossbreds with Criollo. Milk production, however, was higher than that of Nubians and Alpines but still below the Saanen (15). However, in climate chamber trials, Toggenburgs carrying long hair coat did better in hot and in cold exposures than Saanen and short-haired German Alpines (2).

Legs and Feet

Healthy and well formed extremities should be a prerequisite for adequate milk production, especially in grazing animals. While corresponding descriptions are part of all breed standards, there are no investigations available on relationships of deficiencies with milk production. Swollen joints, the carpal joint in particular, are a widespread ailment in goats especially in confined dairy animals. A genetic component seems to be involved in its etiology (53), but no relationships with milk production have been analyzed.

Wattles

These "appendices colli" occur in most goat breeds. They are located somewhere between the ear and the bottom of the neck but in the majority of animals at the upper third of the neck. They vary in size; single, unilateral wattles occur (49). Wattles are due to a simple dominant autosomal gene (*W*) (36). Wattles are not considered in judging dairy goats. This does not cause concern among breeders since wattles do not have any apparent function and may be removed easily without scarring. However, *WW* or *Ww* appear to be 13% more prolific than *ww* does (36). Polled does with wattles are 25.6% more prolific than the average, but there are wide differences between herds in this superiority.

Horns and Polled Goats

While both sexes of most goat breeds are horned, polled are widespread. Some goat keepers find horns useful handles of the animal, but others find them a nuisance especially in males and during the mating season. In horned goats, rank order is established firmly, and low ranking animals avoid fighting with dominating

individuals, but fights are repeated and fierce also in polled goats (46). Thus, it is understandable that breeders have selected for polled. Shelton (50) recently has summarized the state of knowledge about this trait. The dominant allele for polled (*P*) has a pleiotropic effect, restricted to homozygous individuals, which interferes with development of sexual organs. Accordingly, a breeding program should avoid homozygous individuals. Ricordeau (38) has demonstrated that the shape of the skull in the region of the os parietale and the form of the poll are different in *PP* and *Pp* animals. While the poll of the homozygote is rounded and well separated, in 2- to 3-yr-old heterozygotes the polls form like beans arrayed on a V pointed forward and having scurfs 2 to 3 cm in length (38). A detection of homozygotes by physical examination should be possible, and a breeding program can be followed with only heterozygous polled animals, reducing the frequency of horned and potentially intersex animals to 25% but taking advantage of polled for animal handling, of the higher fertility of *Pp* females (37, 51), and higher birthweights of their progeny (40).

Horns serve a thermoregulatory function, especially for the neighboring brain (54). Polled goats would be at a disadvantage in this respect as well as in maintaining their place in the herd rank order. However, no experiments have tested this and considered the presence or absence of horns in relation to production.

Male Goats

Adult males within a herd function to sire and to transmit genetic potential. The genetic transmitting ability is estimated from the production of his ancestors or his progeny. Individually, they are judged for their body conformation which, transmitted to their progeny, should enable these to produce efficiently. However, no investigations are available relating body conformation of bucks with milk production of their daughters. Mason (27) was very skeptical of this approach and assumed that it might be easier to measure the milk yield transmitted by a male than to estimate his merit from physical appearance.

A visible body characteristic of importance to male fertility is the size and shape of the testes. Podany (35) measured in 52 goats of the Czechoslovakian polled Saanen breed the size of the testes. He assumed that the range of ±2 standard deviation from the mean should be the limits required for registration. However, he gave no indication whether a relationship between testes size and breeding performance was established.

Loeliger (25) gave minimal testes measurements for German goat breeds. He stressed, however, that impaired fertility cannot be assumed unless confirmed by a microscopic sperm examination. Bucks infertile due to hypoplastic testes were smaller than their full sibs (24, 48). While bucks infertile due to epidydimal obstruction were larger and heavier than normal bucks, this difference was not statistically significant and was partially attributed to effects of feeding (24).

An alleged early indicator of normal sexual development used by practical goat breeders is the size of the penis as estimated by the distance between the navel and the praeputial orifice. Kaemmerer (20) measured this distance in animals uplifted on their hind feet with fully extended abdominal wall. He could not find a relationship of wide distance with impotence, but all the bucks with hypoplastic testes had distances of more than 6 cm.

CONCLUSIONS

With no large-scale type classification programs in goats, there are no extensive data available for statistical analysis of relations between type and production. By the same token, breeders and geneticists need not worry about any genetic waste that may result from undue importance being attached to type evaluation. There is, however, reason for concern with the rising demand for breeding stock by developing countries to be used for upgrading local breeds. These animals may not produce up to expectations if not originating from populations continuously selected for productivity and economically important traits.

While practical breeders have firm ideas about the physical conformation of good producers, there is not sufficient experimental evidence to support all of these ideas. However, the goat is no exception from other livestock. On the contrary, the goat has benefited from its role as an experimental animal. A number of experiments which contribute to our knowledge of relations between type and production

in goats have been initiated with objectives other than improving goat production. However, it is surprising to see how uniform some breeds of goats may be which are not subject to any kind of selective breeding. If well managed and fed to their productivity, they may not be exceeded always by improved but also unadapted breeds. Body characteristics that have a bearing on adaptation to adverse environmental conditions and utilization of coarse feeds need to be investigated. A more intimate knowledge of the manifold interrelations of body conformation with production would enhance the utility of dairy goats as a model of a lactating ruminant.

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Call for Papers for the 1981 Annual Meeting of The American Dairy Science Association

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The 76th Annual Meeting of the American Dairy Science Association will be held at Louisiana State University, Baton Rouge, June 28–July 1, 1981. All members of the Association are encouraged to present papers. Abstracts must be received by division or section chairman *no later than* March 1. Abstracts of papers for student competition should be accompanied by a letter of intent.

Type the abstract on the form supplied by the ADSA Executive Secretary according to directions on the form; submit original and one copy to the chairman of the division or section. Follow style and abbreviations of the Journal; refer to abstracts published in the May 1975 Journal for guidance. Indicate clearly in the title the nature of the research and in the abstract objectives, design, and major results. Make the data meaningful with brief essential statistics. Papers must have sufficient substance to justify presentation, but the author(s) should also exercise care not to try to present too much factual material for the audience to comprehend. Only 12 minutes are allotted to develop and communicate the ideas to the audience. If critical data are to be fully exposed, only one, two, or possibly three major points can be developed fully. Presentation of material in 12 minutes that is of such scope as to require 30 minutes for its full revelation is a disservice to the audience. More attention should be given to providing an opportunity for discussion and questions following paper presentations.

Abstracts of research accepted for publication by a scientific journal before the annual meeting are not acceptable. The Program Committee favors the general policy that a person present only one paper. If the total number of papers submitted by the membership is too great to include in the program, the Committee will assign some papers to be read by title only. Stimulating the highest quality of applied and fundamental research is the goal of the Committee. Mathematical and statistical units should be rechecked to avoid costly corrections in final printing. Careful experimental design and interpretation of results are necessary prerequisities. Compliance with the instructions for preparation of abstracts will simplify tasks of the Program Committee and of the Editors' offices.

Careful editing of abstracts before submission is essential.

Mimeographed copies (200) of pertinent details and data are desirable for distribution at the time of presentation. Projected material, such as 2 × 2 slides, should include large lettering for easy reading.

Names and addresses of the chairman to whom abstracts should be sent are given below. If acknowledgment of the receipt of the abstract is not received by March 15, the appropriate chairman should be contacted.

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