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Department of Crop Production in the Tropics and Subtropics

Master thesis

Diet quality and feed intake of traditionally raised goats in oasis systems of the Jabal Akhdar mountains, Oman

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asl …………………... above the sea level

CA …………………... crude ash

CL …………………… crude lipids

CP …………………… crude protein

d .... digestibility

DM ……………………dry matter

DOM ………………… digestibility of dry matter

$DOM_{calc.}$ ………………digestibility of dry matter calculated from $N_{fec.}$

FM .... fresh matter

Gb …………………… gas production

HFT ………………….. Hohenheimer Futterwert Test

IOM ………………….. intake of organic matter

LW …………………… life weight of animals

ME …………………… metabolizable energy

MW …………………... metabolic weight of animals

N ……………………... nitrogen

n ……………………… number

NC ……………………nutrient component

N_{fec} …………………... faecal nitrogen

NDF ………………….. neutral detergent fiber

OM …………………… organic matter

P ……………………… phosphorus

P_{fec} ……………………. faecal phosphorus

PEG ………………….. polyethylene glycol

SD ……………………. standard deviation

Introduction

The Sultanate of Oman

Geography and population

The Sultanate of Oman is located in the southeastern part of the Arabian Peninsula, and is covering about 309 500 km^2 with a coastline of 1700 km length (FAO 2004). The country borders the United Arab Emirates in the North-West, the Kingdom of Saudi Arabia in the West and the Republic of Yemen in the South-West (Figure 1).

The country can be divided into three major physiographic regions:

- The coastal plain comprises areas with an average elevation above sea level (asl) between zero and 500 m. The most important areas are the Batinah Plain in the North, which is an important agricultural area, and the Salalah Plain in the South.
- Mountains cover about 15% of the country, reaching an altitude of > 2000 m in the northern Hajar range, particularly in the highest part, the Jabal Akhdar mountains peaking at > 3000 m asl. The Dhofar mountains in the extreme South of the country reach altitudes of 1000 - 2000 m.
- The inland region between the coastal line and the northern and southern mountains consists of several desertic plains with an elevation of less than 500 m.

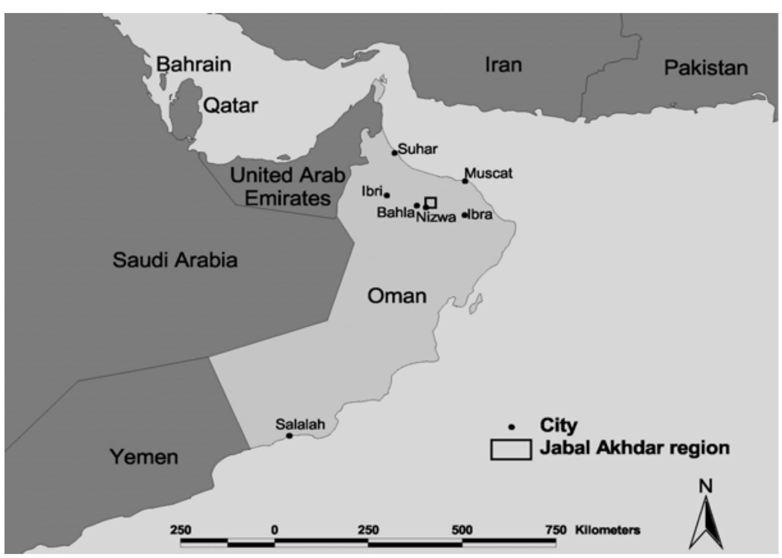

Fig. 1: Map of the Sultanate of Oman.

According to FAO (2004), Oman's total population was 2.77 million inhabitants in the years 1998-2002, of which about 24% lived in rural areas. The population density has increased from 2 inhabitants km^{-2} in the 1960s to almost 9 inhabitants km^{-2} at the end of the 1990s. Especially major cities such as the capital Muscat and the nearby city of Matrah are densely populated, while the desert regions are poorly inhabited. The agricultural and fishery sector is employing about 37% of the country's total labor force but contributes only 3.3% to the country's Gross Domestic Product (GDP).

Climate

The climate of Oman is extremely hot and dry with the exception of the southern region of Dhofar, which receives summer monsoon rains. The annual mean daily temperatures vary between 18 – 29 °C. The hottest months of the year are June and July, the mildest month is January.

Occasional rains can occur across the whole year, except for the period between September and November, when there is practically no rainfall in the country. Rainfall is also distributed unequally across the country. The Hajar and Dhofar mountains yearly receive between 100 mm and 300 mm of rainfall and the coastal areas about 100 mm a^{-1}, while in the inland desert region the precipitation does not exceed 20 mm a^{-1} (FAO, 2002). The mean potential evapotranspiration exceeds 2000 mm a^{-1} (Nagieb at al., 2004).

Due to its elevation of > 2000 m asl, the climate of the Jabal Akhdar mountain range differs from the climate of other regions in Oman. The temperatures in the summer (May – September) reach 25 – 27 °C and drop down to 15 – 17 °C during the rest of the year (October – April) (www.tutiempo.net/en/Climate). The average temperature throughout the year ranged between 19 - 21 °C in last 10 years, which makes this region cooler than other parts of Oman. The potentially high rainfall of 300 mm a^{-1} which fluctuates among years (Figure 2), is opposed to a high evapotranspiration in this area (2800 mm a^{-1}), which reduces the effective rainfall to a value of only 45 mm a^{-1}. Due to low atmospheric saturation, air humidity during the summer months is only 30%. (Tariq Moosa Al-Zidjali, 1995).

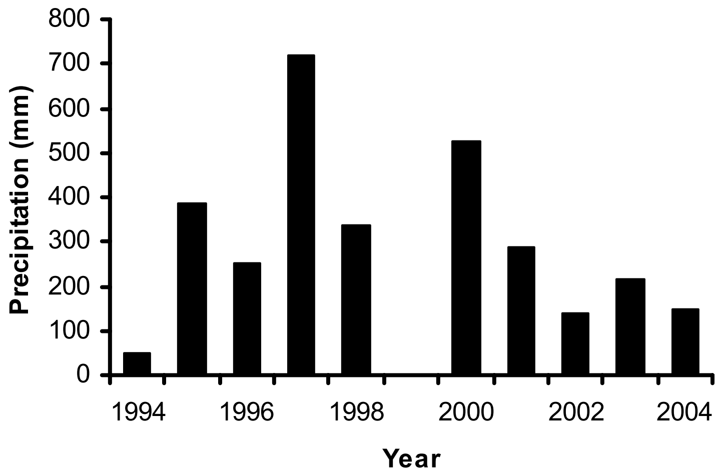

Fig. 2: Mean annual precipitation in the Jabal Akhdar range. Meteorological Station Saiq (N 23°4', E 57°39'). Source: www.tutiempo.net/en/Climate

The Hajar mountains consist of different types of rock with varying infiltration and storage properties. The porous, often incident, limestone has a particularly large storage capacity and enables water to easily infiltrate from the catchments area. Typically above the impermeable bedrock under the limestone massif a water table builds and surfaces in a spring. The water is channeled to oases situated below the spring to meet the demands of the inhabitants' for daily life and irrigated agriculture (Mortimer at al.; 1993 Luedeling, 2004).

Agriculture

The prevailing hot dry climate of Oman is the most limiting factor for agriculture. According to FAO (2004), between 1998 and 2002 only 81 000 ha of land were cultivated with annual (47%) and permanent crops (53%). Under the climatic conditions of Oman, more than 75% of the cultivated area is irrigated year-round.

Over centuries, a traditional method of irrigation has been developed. The falaj system (plural: "aflaj") includes the source of water, which can be a spring or the upper reaches from flowing wadis, and a system of conveying channels that lead the water to the place of use. There are different types of falaj systems from very deep or shallow underground ones to the open above-ground systems bringing the water directly to the fields (Nagieb et al., 2004). Of all households practicing irrigated agriculture, 39% are depending on falaj systems, 47% collect their water from wells, 14% have access to both sources and only 6% use sprinklers or other modern irrigation techniques (FAO, 2002).

The main crop grown in Oman is the date palm (*Phoenix dactylifera* L.), complemented by fodder crops such as alfalfa (*Medicago sativa* L.), fruit trees such as citrus (*Citrus spp*.), banana (*Musa spp*.) and mango (*Mangifera indica* L.), vegetables such as potato (*Solanum tuberosum* L.), tomato (*Lycopersicon esculentum* Mill.), garlic (*Allium sativum* L.) and onion (*Allium cepa* L.) and cereals such as barley (*Hoerdeum vulgare* L. s. l.), wheat (*Triticum aestivum* L s. l., *Triticum durum*, Desf.), sorghum (*Sorghum bicolour* Moench s. l.) and maize (*Zea mays* L.) are grown (FAO, 2002).

Oman's animal husbandry is determined by the natural conditions and cultural and religious influences. In the year 2004 there were 1.8 Million of ruminants in Oman, of which 56% were goats, 20% sheep, 18% cattle and 6% camels. The discovery of the oil resources, mining and exporting to international markets has brought a lot of changes to the entire society. In the animal production sector, this resulted in a decrease of the flock size and in a high dependency on meat imports (Zaibet, 1994). Meanwhile the situation of the livestock production sector is changing. During the past 40 years, an increase in numbers of goats and sheep has been recorded (Figure 3) and the import of goat meat has declined (FAO STAT, 2004).

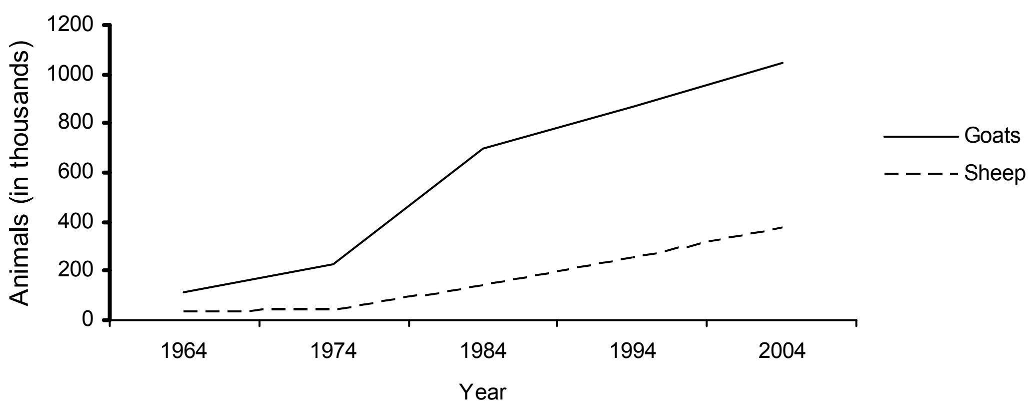

Fig. 3: Evolution of the Omani goat and sheep herds (in thousands of heads) during 1964 – 2004. Source: FAO STAT, 2004.

The government is supporting livestock production in intensive systems with modern technologies such as vaccination stations and others, in order to improve fertility, decrease death rates and increase growth rates. Artificial insemination was implemented to improve the local cattle breeds. The aim is to increase the local meat production and through that reduce the dependency on imports of red meat (www.nizwa.net).

Nevertheless, in many parts of Oman, livestock husbandry remains traditional. Especially goats are raised under traditional management systems in the marginal areas of the country, due to their ability to adapt to harsh environments. Their highly selective grazing behavior and their effective digestive system enable them to survive in arid areas where often food quality is low and forage is not continuously available. Due to their low body mass and low metabolic requirements, indigenous breeds of goats can minimize their requirements for metabolizable energy and water when necessary (Silanikove, 2000).

Goats and goat management systems in Oman

Traditionally small ruminants play an indispensable role in the lives of farmers. They supply red meat for important religious feasts during the year. The livestock keepers also benefit from their milk and skins. In the year 2004, a production of 81 400 Millions tons goat milk accounted for more than 78% of the country's total milk production. The rest was provided by cow milk (FAO, 2004). The fact that butter, ghee and cheese are mainly produced from cow or sheep milk obscures the importance of goat milk, which is mostly consumed unprocessed.

The domestic goats of the Middle East originate from *Capra ibex* (Steele, 1996). In Oman three main goat breeds are found: Dhofari, Batinah and Jabal Akhdar, which contribute 40%, 55% and 5% to Oman's total goat population. ***Dhofari goats*** are found in the Dhofar mountains in the South. They are small (20-25 kg live weight of adult male), have a small elongated head, a long neck, thin legs, short ears and horns and short hair. They appear in various colors but the most common is pure white. The ***Batinah breed*** is found in the coastal plains north of the capital Muscat. The body is long, the legs are thin. Most males and females carry twisted horns and medium dropping ears. Their long rough hair coat is black and brown in color with white markings on the face, legs and tail. The average weight of an adult male is usually between 35 and 45 kg. The ***Jabal Akhdar goats*** are primarily raised on the slopes of Jabal Akhdar range. They look similar to Batinah breed but are bigger in size, adult males reaching 40 - 55 kg of live weight (Zaibet et al., 2004).

Zabiet et al. (2003) are listing five traditional goat management systems in Oman: transhumance, settled villages, small-scale farms, Shawawi and the hill rearing systems. ***Transhumance*** is practiced in the desert areas, where Bedouins move seasonally with their mixed flocks of goats, sheep and camels to areas where more favorable conditions ensure the availability of water and fodder for their stocks.

Small-scale farms and settled villages are not typical for a particular part of Oman but can be found all over the country. Herds of 10 - 100 animals partially graze on the rangelands or on mountainous pastures surrounding the settlements. Additional fodder is usually given at the homesteads, such as Rhodes-grass hay (*Chloris gayana* Kunth), alfalfa, cereal grains, dates and kitchen leftovers. Small farms are mostly oriented towards crop production; the fields are traditionally irrigated with falaj channel systems or depend on water from deep wells.

Shawawi are semi-nomads with large flocks of up to 200 animals. They graze their livestock on the foothills of mountains and also feed some additional supplements in the stable, such as dates, alfalfa and Rhodes-grass.

The ***Hill rearing*** system is typical for the Dhofar and the Jabal Akhdar mountains, where even larger flocks are kept by farmers, counting up to 300 heads. In a study conducted in 40 villages of the Jabal Akhdar mountains region it was found that more than 60% of farmers keep flocks with less than 40 animals whereas 20% had more than 60 animals. Traditionally, farmers kept animals for their own consumption, for special needs of the family during religious and social events and to honor important guests. The income generated from marketing of animals has increased with increasing size of the flock. The farmers stated that construction and maintenance of animal houses, purchase of feedstuffs and the transport of animals to the market are the main costs occurring in animal production (Zaibet et al., 2004).

Methods to estimate feed intake of free-ranging ruminants

One of the most important factors influencing the development of an animal, its well-being and productivity, is the amount and quality of fodder ingested and the extend of digestion. Exact data are needed to determine if the quantitative feed intake and the quality of the fodder meet the nutrient requirements for maintenance, growth and reproduction of the animal.

Various methods have been developed to estimate the quantitative feed intake, the qualitative diet composition and the foraging behaviour of animals under different types of management. The advantages and disadvantages of some of these methods when applied to free-ranging ruminants are summarized in the following chapter.

Short term intake

Animals are partially or continuously grazing on a broad range of vegetation communities, from sown monocultures to diverse natural mixtures of plant species. During the grazing time, the animal can choose its feed. According to Gordon (1995), a series of short-term decisions are made by the animal on which plants or which parts of plants to select, and how long to search for new feed between bites. Long-term decisions concern the length of the time spent grazing, the feeding stations, the distance between grazing sites, drinking places and shelter. However, vegetation structure (species, diversity) and land use patterns also affect the foraging behaviour.

During foraging, animals take a series of bites of different size. The combination of bite size and the short-term rate of biting are defined by Gordon (1995) as the short-term intake rate with mg DM s^{-1} or g DM min^{-1} as units. During the day the animal spends a certain period of time on grazing. This time, when multiplied with the intake rate, gives in the long-term intake rate and it is expressed in kg DM d^{-1}. Data on intake rate reflect the influence of resource distribution and the sward structure as well as between-animal variation in intake.

The short-term intake can be estimated either directly on the pasture or in arenas where representative plant material is offered to the animal. For this, three approaches can be used. The first one is based on **observing the grazing animal**. During visual observation of the bites, the observer mimics their bite size and simulates this by handplucking of the same parts and amounts of the vegetation which are consumed by the animal at that moment. The observer has to be able to identify plants on the pasture and has to note carefully what species and plant parts are grazed. Animals should be tame and the presence of the observer should not influence their normal grazing behaviour; therefore this technique is not recommended for intake estimations in wild animals. This method is very time consuming, it is impossible to observe animals' grazing during the night without infrared observing technology and the results of this method are biased towards plants, which are easy to observe. Also inter-observer differences in estimating the size of the bite can be a source of experimental error. On the other hand this method might be very accurate in cases where animals are browsing and where grazed plants are spaced widely apart.

A second method to estimate the short-term intake rate is to measure **short-term changes in life weight** (LW) before and after grazing. Periods of 1 hour or 1000 bites are usually used. For the weighing, very accurate scales are needed and it is necessary to correct LW changes for faecal, urinary and respiratory weight losses. This method might be very accurate when used in tame animals (the animal must stand still on the scale for a time long enough to take the measurement) and when high precision scales are available.

The third technique assumes a strong correlation between the number of boluses swallowed during the grazing period and the quantitative intake of herbage (Gordon, 1995). Intake can therefore be determined by **measuring the change in geometry of the oesophagus or the pressure or conductance on an oesophageal cannulae** as the food is passing down the oesophagus. The main assumption is that the boluses are of a constant size during the whole period of grazing. This method requires surgical implants into animals to record the number of boluses swallowed.

The most accurate technique to determine intake rate consists in **collecting extrusa samples** from oesophageally fistulated animals for a determined period of time and the simultaneous recording of the animal's bite rate. The disadvantages of this method are welfare problems which might be caused by the oesophageal fistulation.

Long term intake

Information on the long-term intake, which describes the amount of fodder ingested over a longer period of the time can be gained simply by **multiplying the results of short-term intake** experiments by the time which the animal spent grazing during the day. This approach is not very precise due to two factors. First it is leading to an overestimation of the long-term intake because animals are kept without fodder for a period of time prior to the experiments of short-term intake determination and secondly the rate of short-term intake changes during time and it is difficult to estimate a valid daily average from individual grazing periods observed during the day.

Gordon (1995) mentions two types of long-term intake measurements: pasture-based and animal-based methods. **The pasture-based techniques** comprise measurements that are based on the depletion of offered forage. The feed dry mater intake is calculated as the difference between pre-grazing and post-grazing herbage mass. This approach can lead to under- and overestimations of herbage intake. If the measurements before and after grazing are taken with a certain time delay (1-2 days), the calculated intake will be underestimated due to the growth of the pasture. In case of further consumption by other species or trampling of the vegetation, the intake will be overestimated. It is possible to reduce these error sources by correction measurements taken from exclosures installed on the pasture. This technique is mainly used in high-yielding pastures that are intensively grazed for a short period of time. Since it is not possible to determine between-animals differences in intake, this method is suited to estimate the intake of whole groups of animals (Macoon, 2003).

Animal-based techniques are more accurate and rely on measurements of the faecal output (F) and digestibility of the diet (d). Intake is estimated as:

$$I = \frac{F}{(1-d)}$$

The total amount of faeces excreted by an animal can be collected using collection bags. These must be emptied according to amount of faeces produced (e. g. twice a day in goats and sheep). Mixing of faeces with urine should be avoided, and collection bags can be equipped with a gauze bottom to allow urine to drain in female goats and sheep. In cattle, this is not recommended because the urine would wash out part of the already very moist faeces. Another possibility to separate urine from faeces is the use of a plastic tube attached to the vulval area, but the easiest is to choose male animals, where urea and faeces naturally do not mix. Animals should be trained to wear the collection bags to avoid behavioural changes during the sampling period. The approach is very laborious and the normal grazing behavior of animals might be disturbed by carrying and frequent emptying of collection bags.

Therefore methods have been developed to estimate the faecal output using **concentrations of indigestible orally dosed marker in faeces**. According to Kotb and Luckey (1972) faecal markers should ideally "be inert with no toxic, physiological or psychological effects, be neither absorbed nor metabolized within the alimentary tract and therefore be completely recovered from either raw or processed food; mix intimately with the usual food and remain uniformly distributed in the digesta; have no influence on the alimentary secretion, digestion, absorption or excretion; have no influence on the microflora of the alimentary tract, and be precisely and quantitatively measured". Some of the substances that are used as faecal markers are described below.

External markers are added to the fodder whereas internal markers are endogenous to the feedstuff. They might be given to the animal either in one or two doses per day, they can be dosed continuously using slow release capsules or incorporated directly in the fodder of animals. Using the external marker technique the faecal output is calculated as follows:

$$F = \frac{M_d}{M_f} * R$$

where M_d presents the daily dose of the marker, M_f the concentration of the marker in faeces and R is the recovery rate of the marker in faeces (Lippke, 2002).

One of the most frequently used external markers is **chromium sesquioxide** (Cr_2O_3). The recovery rate of Cr_2O_3 is assumed to be almost 100% (Kotb and Luckey, 1972), while Titgemeyer criticizes that the recovery rate of Cr_2O_3 strongly varies among animals. Since Cr_2O_3 is moving through the digestive tract independently of undigested particles, the faecal Cr_2O_3 concentration varies strongly during the day. More frequent dosing (up to six times per day) decreases the diurnal variation but Lippke (2002) considers this as impractical in any situation. This problem can be overcome by using controlled release devices that supply Cr_2O_3 slowly over a longer period of time.

Titgemeyer (2001) **titanium dioxide** (TiO_2) as a possible alternative to Cr_2O_3. TiO_2 is insoluble in water and diluted acids and can be added legally to the feedstuff as a color additive. Plants do not take up this substance into their tissues. According to experiments carried out by Titgemeyer (2001) the recoveries of TiO_2 were between 90 and 95% for cattle but not significantly different from 100%.

Another group of substances which could be possibly used as external markers are rare earth elements. Lanthanum, cerium, neodymium, samarium, europium, dysprosium, erbium and ytterbium fulfill the necessary characteristics of being indigestible and not absorbed by animals. The technique involves binding the rare earth elements to plant material. This can be done either by spraying the material or by soaking the plant particles in a solution. The ability to bind to plant particles varies among the group; ytterbium tends to have the strongest binding capacity. Nevertheless, during *in vitro* experiments dissociation of ytterbium from the plant particles occurred, but the re-association to unmarked feeds was found to be very low and it was suggested that the dissociated marker is mostly transported by the liquid fraction of the digesta (D'Mello, 2000). Lippke (2002) prefers a single dose technique for rare earth elements in comparison to Cr_2O_3.

Internal markers are substances indigenous to the feedstuff being consumed by the animal. They have the advantage of being cheap and can be used in experiments with wild or free ranging animals, where the administration of external markers might be complicated or would disturb the grazing behaviour of animals. Unfortunately there are some problems with respect to analytical methods and with recovery rates. Internal markers include for example lignin, odd-chain n-alkanes, indigestible neutral detergent fiber (INDF) and indigestible acid detergent fiber (IADF), insoluble ash, 2.6-diaminopimelic acid (DAPA), D-alanine and nucleic acids.

Lignin is present commonly in plant cell walls of mature plants. Animals do not posses any enzyme which would enable them to digest lignin. This fact makes indigestible lignin a possible internal marker. Due to the complex structure of lignin with different chemical properties, which may vary among different plants and even among different parts of the same plant, D'Mello (2000) states that the recoveries of lignin in faeces are low and inconsistent.

Long-chain n-alkanes can serve as both external and internal faecal markers (Lippke, 2002). Odd-chain alkanes with a carbon chain length from 21 to 35 naturally occur in high concentrations as waxes in the cuticules of all plants in high concentrations, whereas concentrations of even-chained alkanes are very low. This allows to use the latter as dosed external markers, whereas odd-chain alkanes can be used as internal markers. In most plant species C_{29}, C_{31} and C_{33} are the predominant n-alkanes present, but their concentrations vary between plant species. The recovery of plant and dosed n-alkanes in sheep is incomplete (Mayes, 1986), but increases with increasing chain length, but the recovery of odd- and even-chain alkanes of adjacent length is similar. The dry matter intake can be calculated from the dose of the even-chain n-alkane and the concentrations of odd- and even-chain n-alkanes estimated in the diet and the faeces (Mayes, 1986; Gordon 1995).

McMeniman (1997) presents the three basic principles for this technique. The first is that the recovery of the pair of n-alkanes must be similar. This was proved for ruminants but for example not for horses. In these cases preliminary experiments on recovery rates must be conducted. The second principle is to ensure that the concentration of dosed marker in faeces is constant. This is achieved by dosing capsules with the marker twice daily for one week before sampling starts or using slow release capsules during the experiment. Thirdly, the concentration of n-alkanes in the diet must be known. When animals are grazing on pasture, the concentration of n-alkanes in different plant species composing the diet must be established.

Digestibility

To calculate the long-term intake of ruminants not only measured or estimated total faecal output must be known but also digestibility of the ingested feedstuffs. The digestibility is defined as the proportion of feed which is consumed by the animal and not excreted. The digestibility coefficient is usually expressed as a percentage. Several techniques were developed to estimate the digestibility of feeds.

The basic principle of the ***in vivo* trials** is giving a known amount of investigated food to the animal and measuring the total output of faeces. Due to the between-animal variability in digestive ability more than one animal must be involved in these experiments. The fodder is given to the animal for about one week before the collection of faeces begins. This preliminary period assures cleaning the digestive tract off previously ingested feedstuffs. Food intake and faecal excretion are recorded for a period of 10 – 14 days. The longer the experimental period, the more accurate are the obtained results (Close and Menke et al., 1986).

The second method is measuring the ***in sacco*** **disappearance** of feed. Samples of oesophageal extrusa or feed are placed in small polyester or nylon bags and are incubated in the rumen. The disappearance of organic matter is determined. In each run samples of known *in vivo* digestibility are included and the organic matter digestibility of each examined sample is corrected by the difference between *in vivo* and *in sacco* digestibility of the known sample. This method is assumed to be very accurate (McMeniman, 1997).

The most commonly used technique is the ***in vitro*** **two-stage technique** described by Tilly and Terry in 1963. The first stage where samples are incubated with buffered rumen fluid is followed by digestion in a pepsin solution. The rumen liquor is taken from a rumen cannulated animal being fed a good quality maintenance diet and not fasting longer than 16 hours. Because there might be organic matter already presented in the liquor, blanks with only buffer and rumen liquor are taken through the procedure and the values of blanks are subtracted from the values of samples. There are also 3 samples of known *in vivo* digestibilities incubated in each run. They are chosen to be slightly lower, higher and similar to the expected digestibilities of the examined samples. The relationship between their known *in vivo* digestibility and obtained *in vitro* results is used to calculate a correction factor for the new samples if necessary (McMeniman, 1997).

Sample incubation with buffered ruminal fluid is the basis for another technique using the **production of gas** during the process of microbial fermentation. Samples are fermented in syringes and the volume of produced gases CO_2 and CH_4 is directly measured in the syringes. In case of gas production exceeding the volume of the syringe, the gas volume is read and recorded and the scale line is set down to a certain point of the scale, that is recorded and in the end the total gas volume is summed up.

This process can be repeated for a certain period of time or as long as gas is produced or. Similar to the previously described method, blanks of rumen fluid and standard samples of known gas production are incubated simultaneously with the examined samples. If the measured standard values are ± 10% from the average for the particular standard, the ruminal fluid is proclaimed as normal and can be used for experiments. Results are corrected by the factor calculated as average standard volume divided by run standard volume. When the obtained standard results are out of the 90-110% interval, the ruminal fluid is supposed to be of 'abnormal' composition and data from these runs can not be used. The disadvantage of this technique is that, due to the fact that the results are depending on the actual air pressure, it might be difficult to compare data from different laboratories, unless air pressure is measured and reported with the data. This technique was developed at the Institute for Animal Nutrition at the University of Hohenheim in Germany and it is known as Hohenheimer Futterwerttest (Close and Menke et al., 1986).

Feed digestibility can also be estimated by using internal **markers** or by adding external markers to the feedstuffs (D'Mello, 2000). The advantage of this method is that no total faecal collection is needed but randomly taken samples of faeces are sufficient, which saves a lot of time, labor and costs. When using markers, the calculation of feeddigestibility (d) is as follows:

$$d = 1 - \frac{M_h}{M_f}$$

where M_h is the marker concentration in herbage and M_f the marker concentration in faeces. For cases of incomplete but constant faecal recovery of the marker, the equation has to be corrected by the recovery. The above equation can be modified do calculate the digestibility of a certain nutrient component (NC):

$$d = 1 - \frac{M_h}{M_f} * \frac{N_f}{N_h}$$

where M_h is the marker concentration in herbage, M_f the marker concentration in faeces, N_h the concentration of the NC in the herbage and N_f concentration of NC in the faeces.

Diet digestibility can be also derived from the **faecal nitrogen concentration**. There exists a relationship between the digestibility of DM of the feedstuffs and the concentration of nitrogen in faeces (Lukas et al., 2005). The metabolic faecal nitrogen excretion increases with increasing digestibility of digested fodder. Because the relationship is depending on the species composition of the pasture, the time of the year when the pasture is grazed, the level of intake and the internal parasite infection of the animal, it might be necessary to define the exact relationship between the digestibility of available feedstuffs and faecal N excretion for an individual pasture in a particular experiment.

As presented, there are various methods to determine the intake of grazing animals, all using different aspects of feeding behaviour and feed digestion and resulting in a broad scale of results. There does not exist a “best” method. Common for all methods used to estimate feed intake is the necessity of minimal influence on the foraging activity of the animals. In any case a disturbed feeding process will lead to biased results. It is very important to be aware of the conditions of the research area and the behavioural characteristics of the animals under study. The objectives of the research and the available facilities will also influence the choice of a set of appropriate methods to achieve the desired results. Sources of possible errors should be known and tried to be minimized.

Study objectives

This study aimed at analyzing the quality of feed available to goats and the contribution of goat husbandry to the nutrient fluxes in the traditional hill rearing system of the Jabal Akhdar range in Oman. Particular attention was paid to the quantification of the energy intake through the different feeds compared to the energy requirements of goats and to the estimation of the ration between internal and external inputs in the current feeding systems.

Hereby, specific goals were to:

- determine the quantitative contribution of pasture vegetation to the daily feed intake of goats;
- examine the quality of feeding stuffs offered at the homestead and of wild plants ingested on the mountain pastures;
- determine the quantity and quality of the faeces excreted by goats, to characterize its value as organic fertilizer for the crops cultivated by the local farmers.

Materials and methods

Site description

The study area was located in the central Jabal Akhdar mountains of northern Oman. It comprised three ancient oasis settlements in a watershed ranging from the rainfall catchments area of the Saïq plateau with A Ayn/Sheragia (sister oases) (plateau fringe; 23.07° N, 57.66° E; 1720-1860m asl) over Al Qasha (mid altitude cliff; 23.06° N, 57.67° E; ~1500 m asl) to Masirat (cliff bottom; 23.05° N, 57.67° E; 1090-1180 m asl (Figure 4. and 5.).

Total terrassed cropping area was estimated at about 10 ha for Al Ayn/Sheragia, at 3 ha for Al Qasha and at 5 ha for Masirat. Given a total annual precipitation of around 200 mm at all three sites, year-round agricultural production on the Irragric Anthrosols depends on irrigation whereby large seasonal differences exist in the amount of fallow land. Walnut (*Junglans regia* L.), pomegranate (*Punica granatum* L.), alfalfa (*Medicago sativa* L.), wheat (*Triticum ssp*.) and barley (*Hordeum vulgare* L.) dominate at Al Ayn/Sheragia; pomegranate, lemon (*Citrus ssp*.), banana (*Musa ssp*.) alfalfa and barley at Al Qasha, and date palm (*Phoenix dactylifera* L.), alfalfa, citrus, maize (*Zea mays* L.), sorghum (*Sorghum bicolor* Moench s. l.), barley, oat (*Avena sativa* L.), garlic (*Allium sativum* L.) and onion (*Allium cepa* L.) at Masirat.

The irrigation systems consist of many centuries-old Ani Aflaj systems that channel the water from springs to fields sized 5-100 m^2. The often silt-stone rocks have very little fracture porosity and act as an aquifuge, whereas the often overlaying carbonates are highly fractured and karstic which allows the groundwater to be stored and to migrate over long distances (Weier, personal communication; Nagieb et al., 2004; Luedeling et al., 2005).

Depending on the farmer's wealth, flocks of 5 - 20 or more goats are kept. The amount of feed offered to the individual animal depends on its sex, age and physiological stage. Lactating females and males fattened for slaughter at the next religious feast receive higher amounts of green feed and concentrate than the rest of the flock and are often fed individually, while the other goats are fed in groups.

Rainfall in Jabal Akhdar was very low in 1994 – 2004 (except for the 1997 and 2000; Figure 1.). From December 2004 to March 2005 over 200 mm rainfall was recorded at Saiq meteorological station (www.tutiempo.net). This rainfall has certainly affected the amount of vegetation on the pasture available for grazing.

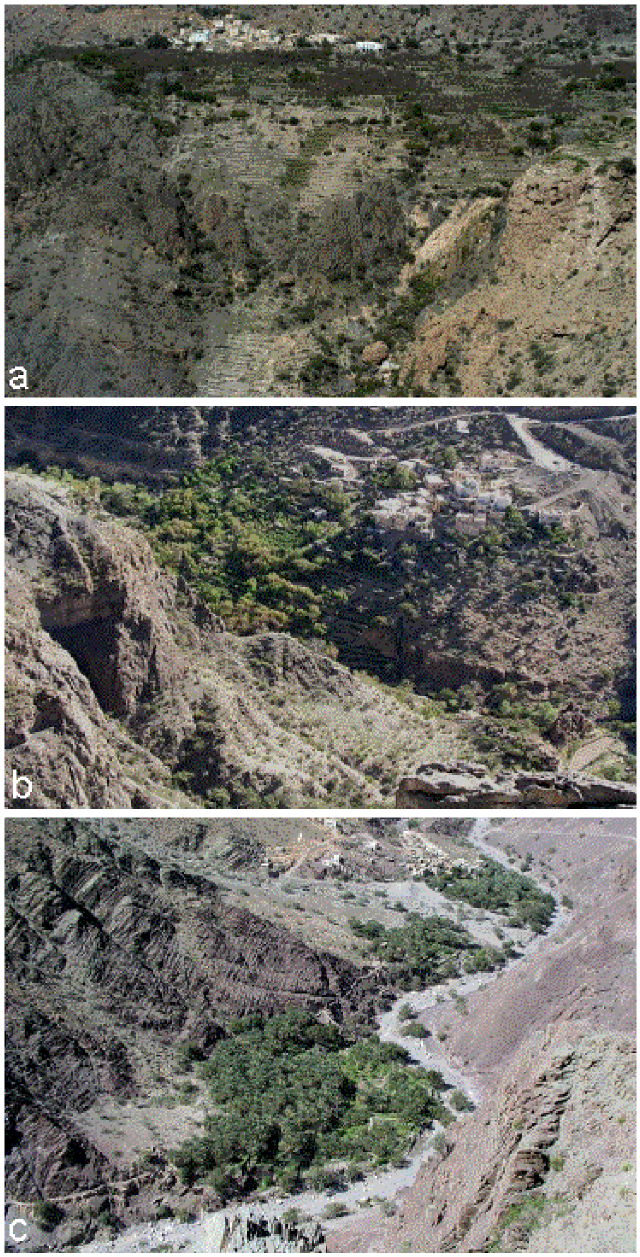

Fig. 4: Oases of Al Ayn/Sheragia (a), Al Qasha (b) and Masirat (c) in the central Jabal Akhdar mountains of the Al Hajar range in northern Oman

Experimental animals and their management

In every village 8 males goats were chosen as follows:

Al Qasha from 2 farmers, 5 and 3 animals

Masirat from 4 farmers, 2 animals from each

Sheragia from 3 farmers, 2/3/3 animals

One animal in Masirat did not regularly return from the pasture to the oasis after grazing and was therefore excluded from the experiment. The experimental animals were weighed once at the beginning of the experimental period.

Table 1: Live weight of experimental animals in kg

Oasis	Sheragia	Al Qasha	Masirat
Mean	27	32	27
SD	6	7	6
Min.	19	24	19
Max.	36	43	36

In the villages of Al Qasha and Sheragia, goats were fed at the homestead in the morning and evening, while they were fed only in the evening in the village of Masirat. In the stable, every experimental animal was attached with a rope and fed individually.

After the morning feeding in Al Qasha and Sheragia, all goats of the village were gathered into one herd and conducted by a herdsman onto the mountain pasture areas, from where they returned in the afternoon. In Masirat, a free grazing management was practiced. The village goats were conducted to the mountain pastures by young girls and then left to graze on their own. In the course of the afternoon, the individual goats or small groups of 2 - 5 animals kept returning to the village from around 11 a.m. to 5 p.m. During the daily time on the pasture, the plant selection of grazing goats was observed on 4 days during the 7-day experimental period in each oasis. Samples of the grazed plant species were collected by the observer, weighed fresh, air dried and weighed again.

After the evening return to their homesteads, all experimental goats were offered green fodder such as alfalfa, but also barley, maize or oats, all harvested in the milk or dough stage of the grain and in some cases weeds. In addition supplements such as dried fish, dates, wheat meal, bread, barley grain and leftovers from the kitchen were offered to the animals.

The green feed and the supplements were weighed individually on portable battery driven scale (accuracy 2 g, range 0 – 5000 g) before they were offered to the animal; a sample was kept of each feed. After the end of the meal, the leftovers were weighed and samples kept for analysis (see below). Leftovers of supplement mixtures were separated into their individual components (e.g., dates and fish) and these were weighed individually. Because of the high variability in diet composition and difficulties in collection and further analysis, no samples of leftovers from meals (boiled rice, chicken bones and orange peels) were taken for analysis. The amounts of feed offered and refused were weighed as described above. All samples of roughage and some supplement feeds (cereal grains, dates, bread) offered at the homestead were weighed fresh, filled in cotton bags and air-dried at ambient temperature. Samples of fish were deep-frozen after determination of fresh weight.

Application of the Titan dioxide marker

The application of the TiO_2 marker started 4 days ahead of the experimental period, in order to establish a constant concentration of the marker in the digestive tract of the animal. The application continued until day 7 of the experimental period. One gelatine capsule containing 3 g (+/- 0.03 g), of TiO_2 was applied orally every evening prior to offering the supplement feed (Figure 6). In case of incomplete swallowing or regurgitation of part of the marker, one additional capsule containing 1 g TiO_2 (+/- 0.03 g), was administered. The exact amount of applied marker was noted, and it was tried to estimate eventual losses as precisely as possible.

Fig. 5: Oral application of marker capsules

Collection of faeces

During the animals' night rest at the homestead, faeces were collected in faecal bags fitted to the experimental animals after the evening feeding (Figure 6.) and emptied in the morning before the goats went out for grazing. Samples of faeces from each animal were taken every day and were deep-frozen after the fresh weight had been determined in the field (portable battery driven scale, accuracy 2 g, range 0 – 5000 g). After the 7-day sampling period, aliquots of the faeces collected on days 1-2, 3-5 and 6-7 were pooled as outlined in Table 2. An additional sample of pooled faecal aliquots of days 1-7 was constituted to determine the air-dry weight.

Table 2: Schema for pooling faecal samples; numbers indicate sampling day

Animal #	Sheragia	Al Qasha	Masirat
1	1-2; 3-5; 7	1-2; 3-5; 6-7	
2	1-2; 3-5; 6-7	1-2; 3-5; 6-7	1; 2-3; 4-5; 6-7
3	1-2; 3-5; 6-7	1-2; 3-5; 6-7	1; 2-3; 4-5; 6-7
4	1; 2-3; 4-5; 6	1-2; 3-5; 6-7	1; 2-3; 4-5; 6-7
5	1-2; 3-5; 6-7	1-2; 3-5; 6-7	1-2; 3-5; 6-7
6	1-2; 3-5; 6-7	1-2; 3-5; 6-7	1-2; 3-5; 6-7
7	1; 2; 3; 4; 5; 6; 7	1-2; 3-5; 6-7	1-3; 4-5; 6-7
8	1; 2-3; 5	1-2; 3-5; 6-7	1-3; 4-5; 6-7

Fig. 6: Fitting faecal bags to the experimental animal

Sample analysis

Fodder samples

All samples of fodder, supplement feeds and pasture plants were analyzed for their **dry matter** (DM) and **organic matter** (OM) concentration using standard procedures (Naumann et al., 1983). First they were dried in a force draft oven at 50°C for 2 hours to eliminate the moisture, which might have been taken up by air-dried samples during storing and transport. Consequently, samples were ground to pass a 1 mm mesh screen and dried at 105° C over night to determine DM.

Samples of fish and dates were treated differently. Fish samples were first autoclaved for 20 min at of 120°C, pre-froze at -38°C over night and than freeze-dried in vacuum until the pressure dropped to 0.009 m Bar (about 4 days). After freeze drying, samples were ground using a small kitchen mill to avoid losses of the material. Flesh of dates was also freeze-dried and pulverized manually in liquid N_2. Of the freeze-dried material, 2 g (± 0.5 g) were weighed for the determination of the residual water concentration by drying at 105° C over night.

The samples dried at 105° C were burned in a muffle furnace at 550° C for 5.5 hours. The ash was weighed and OM was calculated.

From the ash, a solution for the **determination of phosphorus** was prepared by washing the ash from the dish into a 100 ml flask using 20 ml HCl (32%). The mixture was left over night and the following day filled up to 100 ml with distilled water and filtrated through an ash-less BLUE RIBBON filter paper (Gericke and Kurmies, 1952). This P solution was stored in the fridge. To measure the P-concentration in the solution, 10 ml thereof were taken. After adding 15 ml of ammonium molybdat vanadat, the flasks were filled with distilled water up to 100 ml and a color reaction (yellow) was observed. The absorption was measured by a spectrophotometer (U-2000, Spectrophotometer, Hitachi, Tokyo, Japan) at a wave length of 460 nm.

Nitrogen content was measured by gas analyzer (FP-328 Leco LECO INSTRUMENTE GmbH, 1993, Mőnchengladbach, Germany). The technique is based on burning the sample (0.030g ± 0.005) and measuring the pressure being developed by produced NO_x gases. Two measurements were taken from each sample and the average was calculated. In the case of dates, three measurements were taken because of a higher heterogeneity of the samples that was caused by the problematical grinding process of date flesh with its high sugar concentration.

Crude protein (CP) was calculated by multiplying the nitrogen concentration of these samples by the factor 6.25 (Close and Menke, 1986).

The **digestibility of OM** was estimated by the Hohenheim gas test (**HFT,** Hohenheimer Futterwert Test); (Close and Menke, 1986). Three times 0,200g (± 0,05g) samples were weighted, inserted onto the bottom of 100 ml glass syringes and stored at 39°C over night. Before morning feeding, 1 liter of the rumen liquor was taken from each of two rumen fistulated cows. Buffered solution of the rumen liquor was prepared (see the Appendix Nr 1.) under continuous CO_2-flushing. The buffered rumen liquor was filled (30 ml) into each syringe and the initial volume (sample plus liquor and eventually air bubles) was noted. Syringes were incubated in a water bath at of 39°C for 24 hours. During the first 8 hours syringes were shaken hourly. After 24 hours, the produced amount of gas was read from the syringes and recorded (Figure 7). If the production of gas exceeded the capacity of the syringe (gas volume reaching about 80 ml after 8 hours of incubation), the exact volume of produced gas was noted and the scale line was set back to 40 ml. Each sample was incubated twice during two subsequent days. In each run there were 6 blancs and at least 3 standards incubated. The blanc values were subtracted and the correction factor was calculated for the standard to be used for the correction of the gas production of samples.

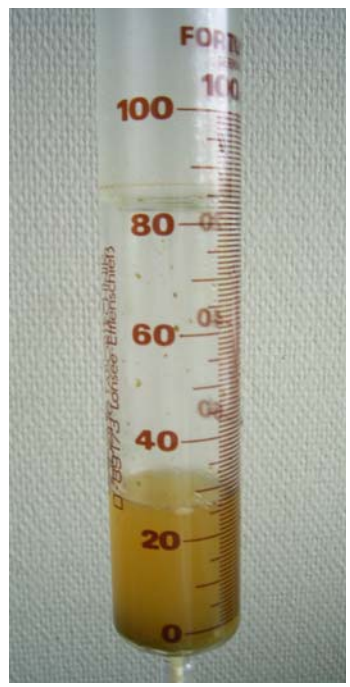

Fig. 7: A syringe with an incubated sample after 24 hours.

The gas production of the samples was calculated as follows:

$$Gb = \frac{V_{24} - V_0 - Gb_b * 200 * F_H}{W}$$

where:

Gb = gas production in ml after incubation of 200 mg material for 24 hours

V_{24} = position of the piston after 24 hours of incubation

V_0 = initial position of the piston at the beginning of the incubation

Gb_b = mean gas production from blancs

F_H = correction coefficient $F_H = 49.61 * GB_S^{-1}$

GB_S = mean gas production of the standard

W = weight of the tested sample in mg DM

The average value of gas production from both days (6 replicates per sample) was taken to calculate the digestibility of organic matter (DOM %) as follows:

$$DOM = 14.88 + 0.889\ Gb + 0.045\ CP + 0.065\ CA$$

where:

Gb = mean gas production of the sample (ml)

CP = crude protein content (g kg^{-1} DM)

CA = crude ash content (g kg^{-1} DM)

The content of metabolizable energy (ME, MJ kg^{-1} DM) was calculated as follows:

$$ME = 1.242 + 0.146\ Gb + 0.007\ CP + 0.0224\ CL$$

where:

Gb = mean gas production of the sample (ml)

CP = crude protein content (g kg^{-1} DM)

CL = crude lipids content (g kg^{-1} DM)

The crude lipids content were not measured but taken from a feed composition table (Close and Menke, 1986).

Samples of the dried fish were excluded from the gas test as this was developed to examine digestibility of plant-based feeds. DOM and ME of fish were taken from the table of Close and Menke (1986).

Based on the HFT results, 16 samples with a gas production ≤ 30 ml were examined for **content of tannins using the polyethylene glycol (PEG) method** (Makkar and Becker, 1996). PEG is building inert complexes with tannins, deactivates them and reduces the negative effect of tannins on the digestibility of the plant material. In each run, six syringes per sample (0.350 g, ± 0.02 g) were incubated, three of them without and three with PEG addition (0.750 g, ± 0.02 g). The buffer capacity was high (Appendix Nr 2.) and 30 ml of buffered rumen fluid were used for the incubation. Blancs and the standard were run together with samples. The experiment was repeated twice with the same samples. A marked difference in gas production between the sample when incubated with and without PEG, indicated that the low gas production was caused by tannins contained in the sample.

To determine the content of cellulose, hemi-cellulose and lignin in selected samples of roughages offered at the homestead and of pasture plants, the concentration of **neutral detergent fiber (NDF)** was determined by the standard method of Van Soest modified by Tecator (1978). One gram of sample was boiled for 1 hour with neutral detergent solution, filtered, washed with acetone, sucked dry and dried at 105° C over night. After weighing, samples were burned in the muffle furnace at 550°C and weighed again.

Faecal samples

From the fresh (frozen) faeces, a representative sample was taken, smashed and the concentrations of **DM, OM, nitrogen and phosphorus** were established as described for plant material.

In all frozen samples of faeces, the **concentration of TiO_2** was estimated following the approach of the Department of Animal Nutrition, University of Kiel, Germany. To 2 g (± 0,05 g) (exact weight was recorded and used for calculation) DM of faeces sample, 10 g K_2SO_4, 4 ml of 10% $CuSO_4$ and 50 ml of H_2SO_4 (96%) were added. The mixture was boiled until a pure light green color was obtained (about 5-6 hours). After cooling down, particles of samples on the walls of the boiling glasses were washed down with distilled water and further boiling occured until the whole content was clear (about 2-3 hours). After cooling down, the content was poured into a 500 ml flask, filled up to 500 ml with distilled water and filtrated. The prepared solution was stored at room temperature.

To measure the TiO_2 concentration, two times 10 ml of this solution were placed into two flasks and 1 ml of mixture I. was added to one of the flasks. To establish the own coloring of the solution, 1 ml of the mixture II. was added to the second flask. The mixtures were prepared as described in Appendix Nr. 3. Both flasks were properly shaken. After at least 30 min., the extinction of light (405 nm) was measured with the spectrophotometer UVIKON 930 (Kontron Instrumenst, Neufahrn, Germany) against water.

Calculation of organic matter intake by goats

The total intake of organic matter of goats was calculated according to Gordon (1995) using the formula

$$IOM = \frac{F_{OM}}{1 - DOM}$$

where:

IOM = intake of organic matter (g d^{-1})

F_{OM} = total faecal organic matter (g d^{-1})

DOM = digestibility of total organic matter ingested by the animal

As faeces were collected only during the night, total faecal excretion was not measured but calculated from the marker using the following formula (Lippke, 2002):

$$F_T = \frac{M_D}{M_{conc}} * R$$

where:

F_T = total faecal output (kg DM d^{-1})

M_D = applied marker dose (g d^{-1}), average marker dose for the experimental period

M_{conc} = marker concentration in faeces (g kg^{-1} DM d^{-1}), weighted average of concentrations of marker in pooled faecal samples

R = recovery of the TiO_2 marker in the faeces, R = 0.93 (Titgemeyer et al., 2001)

The overall digestibility (DOM) was calculated from the equation of Lukas et al. (2005).

$$DOM = 79.76 – 107.7 * e^{(-0.01515 * CP)}$$

where:

CP = crude protein content of faeces (g kg^{-1} OM)

The organic matter intake of fodder ingested by the animals at the homestead was calculated by subtracting the weight of the refused fodder from the initially offered amount. The daily organic matter intake from the stable was subtracted from the calculated total intake of OM in order to obtain the proportion of organic matter intake coming from the pastures.

Statistical analysis

All results were tested for normal distribution of residuals using the Kolmogorov-Smirnov test. If data were not normally distributed, functions $y = x^2$, $y = x^{1.5}$, $y = x^{0.5}$ or $y = \log x$ were used for transformation. The fodder quality parameters were compared with *post hoc* Multiple comparisons for observed means using the Tuckey test with location and feed type as fixed factors. For the digestibility calculated from faecal CP, for faeces quality and quantity and for organic matter intake, the location was the fixed factor in the Tuckey test. All statistical analyses were performed with SPSS 12.0 for Windows.

Results

Fodder quality

The fodder ingested by the goats can be divided into three types: pasture plants, green fodder cultivated by the farmer and supplements. The green cultivated fodder included alfalfa, barley, maize, oats and olive leaves. Dates, fish, bread, wheat meal, barley grain and leftovers from meals were fed as supplements. The pasture plants preferentially consumed by the animals were determined botanically (Table 3).

Organic matter (OM)

The organic matter content of the animal feeds did not vary significantly among the feed types and villages (Table 3.). The average OM content of pasture plants was 892 g kg^{-1} DM (SD 53.6). The mean of the different feed supplement was with 891 g kg^{-1} DM (SD 115.2) almost similar. The mean OM content of cultivated green fodder was with 868 g kg^{-1} DM (SD 21.5) slightly lower compared to the other two fodder types.

Table 3: Organic matter content (OM, g kg^{-1} DM) in feeds of three villages in the Jabal Akhdar mountains of Oman. (Means and (SD)). Values with different letters in rows (a, b) and columns (α, β) differ at P ≤ 0.05.

Village	Feed type					
	Pasture plants		Green fodder		Supplements	
Sheragia	888 a;α	(61.5)	869 a;α	(27.8)	930 a;α	(96.3)
Al Qasha	891 a;α	(52.7)			856 a;α	(119.8)
Masirat	901 a;α	(39.9)	869 a;α	(22.0)	888 a;α	(128.3)

Digestibility of organic matter (DOM)

There were no between-oasis differences in the digestibility of organic matter for each of the three types of feeds (Table 4.) but the DOM of the different feed types differed significantly with means of 560 g DOM kg^{-1} OM (SD 113.4) for the pasture plants, 680 g DOM kg^{-1} OM (SD 33.2) for the cultivated green and 807 g DOM kg^{-1} OM (SD 79.5) for the supplements.

Table 4: Digestibility of organic matter (DOM, g kg^{-1} OM) in feeds of three villages in the Jabal Akhdar mountains of Oman. (Means and (SD)). Values with different letters in rows (a, b) and columns (α, β) differ at P ≤ 0.05.

Village	Feed type					
	Pasture plants		Green fodder		Supplements	
Sheragia	561 a;α	(95.2)	656 ab;α	(27.6)	785 b;α	(88.0)
Al Qasha	565 a;α	(109.4)			800 b;α	(76.7)
Masirat	545 a;α	(156.3)	703 b;α	(39.4)	831 c;α	(79.0)

Metabolizable energy (ME)

The metabolizable energy content was significantly different for the different feed types. For pasture plants, ME was much lower than for green forage and supplements (Table 5.). The mean value of ME of pasture plants was 5.6 MJ kg^{-1}OM and the cultivated green forage and supplements reached 10.7 and 10.5 MJ kg^{-1} OM, respectively. There were no between-villages differences in the ME content for all three types of feeds.

Table 5: Metabolizable energy (ME, MJ kg^{-1} OM) in feeds of three villages in the Jabal Akhdar mountains of Oman. (Means and (SD)). Values with different letters in rows (a, b) and columns (α, β) differ at P ≤ 0.05.

Village	Feed type					
	Pasture plants		Green fodder		Supplements	
Sheragia	5.7 a;α	(1.34)	10.8 b;α	(1.02)	10.9 b;α	(1.50)
Al Qasha	5.7 a;α	(1.44)			9.9 b;α	(0.28)
Masirat	5.4 a;α	(1.62)	10.6 b;α	(1.78)	10.7 b;α	(1.46)

Nitrogen content

For green fodder and supplements, the nitrogen concentration did not differ significantly between the three oases, but the N content in pasture plants in Sheragia was significantly lower than in the other two villages (Table 6.). The N content in feeds supplements ranged between 3.8 and 97.3 g kg^{-1} OM. Although the average N content in supplement was higher (38.3 g kg^{-1} OM, SD 36.00) than that of the pasture plants (17.3

g kg^{-1} OM, SD 3.05) and cultivated fodder (mean 17.5 g kg^{-1} OM, SD 0.71), they were not significantly different from each other.

Table 6: Nitrogen content (N, g kg^{-1} OM) in feeds of three villages in the Jabal Akhdar mountains of Oman. (Means and (SD)). Values with different letters in rows (a, b) and columns (α, β) differ at P ≤ 0.05.

Village	Feed type					
	Pasture plants		Green fodder		Supplements	
Sheragia	14 a;β	(5.1)	18 a;α	(4.6)	32 a;α	(31.6)
Al Qasha	18 a;α	(6.7)			47 a;α	(41.1)
Masirat	20 a;α	(7.6)	17 a;α	(6.0)	35 a;α	(36.7)

Phosphorus content

The average P concentration of pasture plants in Sheragia was significantly lower than in the other two villages, while there were no between-oasis differences in P content in the other two feed types. The P content of feed supplements In Al Qasha and Sheragia was significantly higher than that of the pasture plants, while in Masirat, there were no differences in P concentration among all three feed types (Table 7.).

Table 7: Phosphorus content (P, g kg^{-1} OM) in feeds of three villages in the Jabal Akhdar mountains of Oman. (Means and (SD)). Values with different letters in rows (a, b) and columns (α, β) differ at P ≤ 0.05.

Village	Feed type					
	Pasture plants		Green fodder		Supplements	
Sheragia	1.0 a;β	(0.44)	2.6 ab;α	(1.16)	5.6 b;α	(5.69)
Al Qasha	1.6 a;α	(0.67)			6.9 b;α	(5.38)
Masirat	1.8 a;α	(0.97)	3.5 a;α	(1.00)	4.6 a;α	(4.20)

Neutral detergent fiber (NDF)

The average NDF concentration of cultivated forages was significantly higher (454 g kg^{-1} OM, SD 76.0) than of pasture plants (346 g kg^{-1} OM, SD 137.9). The NDF concentrations of both feed types did not vary among the oases (Table 8.).

Table 8: Phosphorus content (P, g kg^{-1} OM) in feeds of three villages in the Jabal Akhdar mountains of Oman. (Means and (SD)). Values with different letters in rows (a, b) and columns (α, β) differ at $P \leq 0.05$.

Village	Feed type			
	Pasture plants		Green fodder	
Sheragia	342 a;α	(129.7)	451 b;α	(59.1)
Al Qasha	301 α	(75.9)		
Masirat	397 a;α	(155.1)	457 b;α	(85.1)

Digestible OM of pasture plants ranged from 334 to 731 g kg^{-1} OM, with a metabolizable energy content of 3.1 to 8.9 MJ kg^{-1} OM, nitrogen concentration from 6 to 38 g kg^{-1} OM, phosphorus concentration from 0.4 to 3.2 g kg^{-1} OM and neutral detergent fiber concentration from 183 to 657 g kg^{-1} OM (Table 9.).

Table 9: Proximate composition of individual pasture plants grazed by goats on the Jabal Akhdar range, Oman (n = number of samples)

Plant name	**n**	**OM**	**ME**	**DOM**	**N**	**P**	**NDF**
		g kg^{-1} DM	**MJ kg^{-1}OM**		**g kg^{-1} OM**		
Acacia gerardii	5	857	6.8	624	26.0	1.4	324
Aizoon canariense	1	722	5.5	621	19.8	3.2	
Aristida adscensionis	1	905	7.4	605	10.2	0.9	
Boerhavia diffusa	1	841	8.0	706	24.8	2.3	
Capparis cartilaginea	1	689	7.1	731	13.5	0.4	
Capparis spinoza	1	908	8.1	674	29.5	1.5	
Cymbopogon commutatus	2	905	5.3	478	11.7	1.0	645
Cynodon dactylon	2	814	6.6	612	10.5		
Dichanthium annulatum	4	906	6.5	525	13.0	0.7	
Dodonea viscosa	2	945	4.9	425	12.6	1.2	
Dyerophytum indicum	3	935	3.2	352	23.7		
Eragrostis spec.	1	856	7.9	677	17.0	1.5	
Euphorbia larica	1	931	4.2	383	6.7	0.6	521
Fagonia bruguieri	1	890	6.6	581	19.8	0.8	
Ficus cordata subsp. salicifolia	2	941	6.1	522	22.8	2.8	
Helianthemum lippii	1	935	6.2	519	14.9	0.9	
Helichrysum makranicum	2	915	8.9	701	19.4	1.3	

*Herniaria spec.**	1	885	8.3	677	19.9	2.0	
Euryops arabicus	1	890	8.1	644	8.8	1.5	
Labiatae	1	887	6.8	612	29.8		
Sideroxylon masctense	4	916	7.6	626	22.6	1.1	263
Moringa peregrina, (leaf)	1	927	3.1	334	14.4	0.8	
Moringa peregrina, (pod)	1	958	3.9	345	5.7		657
Nerium mascatense	1	821	3.7	451	15.4	0.9	
Notoceras bicorne	1	883	7.2	635	28.8	2.8	
Ochradenus arabicus	1	950	5.5	457	8.1		
Olea europea subsp. cuspidata	1	945	6.3	513	14.0	1.2	415
Paracaryum intermedium	2	843	7.2	646	21.2		
Plantago amplexicaules	1	875	7.5	644	16.8	2.3	
Pteropyrum scoparium	1	928	3.2	336	13.0	1.2	481
Solanum incanum	2	876	5.6	556	38.3	3.1	405
Spergularia spec.	1	840	7.2	649	20.9	3.0	
Taverniera glabra	1	923	7.3	604	24.3		
Tetrapogon villosus	2	894	7.5	613	15.8	1.0	
Tribulus terrestris	1	995	7.6	590	30.9	1.3	
Trigonella stellata	1	880	5.6	556	35.2		
Juniperus excelsa subsp. polycrpa	1	939	5.4	450	5.6	0.6	
Ziziphus hadjarensis	1	916	6.2	547	24.8	1.4	183
Ziziphus spina christi	3	886	5.7	525	17.3	1.2	588

(OM – organic matter, DOM – digestibility of organic matter, ME – metabolizable energy, N – nitrogen, P – phosphorus, NDF – neutral detergent fiber, SD – standard deviation)

* *H. hirsuta or mascatense*

Polyethylene glycol bioassay

From 16 samples tested for their concentration of tannins, 10 samples reacted positively on the addition of PEG by markedly increasing the gas production during 24 h of incubation *in vitro* (Table 10).

Table 10: Effect of the addition of polyethylene glycol (PEG) on the gas production from samples of individual Jabal Akhdar pasture plants when incubated in vitro.

Plant name	Gas production increase with PEG (%)
Acacia gerardii	57
Aizoon canariense	0
Cymbopogon commutatus	0
Dodonea viscosa	204
Dyerophytum indicum	168
Euphorbia larica	83
Ficus cordata subsp. salicifolia	119
Juniperus excelsa Subs.. polycarpus	29
Moringa peregrina, leaf	131
Moringa peregrina, pod	0
Ochradenus arabicus	0
Olea europea	0
Pteropyrum scoparium	185
Solanum incanum	0
Trigonella stellata	29
Ziziphus spina christi	66

The cultivated forage and supplements were of higher quality than pasture plants. The OM digestibility, metabolizable energy and P concentration of both these feed types was significantly higher ($P \leq 0.05$) than that of pasture plants. N content in supplements was higher than in pasture plants and cultivated forage (Table 11.).

Table 11: Quality of fodder species fed at the homestead of crop-livestock farmers in the Jabal Akhdar region of Oman. (n = number of samples, means and standard deviations)

Name	n	OM (g kg^{-1} DM)		ME (MJ kg^{-1} OM)		DOM (g kg^{-1} OM)		N		P		NDF	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Alfalfa	3	880	11.1	13.2	1.09	675	35.8	22.7	4.02	1.89	0.81	332	54.5
Barley prebloom	2	853	10.4	7.0	1.57	760	5.1	21.4	0.00	5.12	0.35	422	0.0
Maize milk stage	2	906	1.1	11.9	0.41	727	38.3	10.5	1.64	3.66	0	517	1.3
Oats prebloom	7	861	14.1	12.0	1.31	674	32.9	15.4	4.37	3.17	0.39	495	45.1
Weeds from fields	2	906	46.4	7.0	2.35	581	185.5	24.0	0.00	0.58	0	623	0.0
Olive leaves	2	938	9.0	5.5	0.17	492	89.7	11.9	2.90	0.85	0.1	305	57.7
Barley grain	2	976	0.2	12.0	0.56	838	0.0	16.5	1.67	3.04	0.1		
Wheat meal	3	943	5.9	10.0	0.53	751	43.3	24.5	0.59	9.25	0.27		
Bread	5	930	5.7	13.2	0.58	918	0.3	22.5	9.46	1.25	0.03		
Dates fruits	9	971	11.5	10.1	0.34	716	20.5	4.5	0.56	0.78	0.1		
Fish	10	739	33.0	10.0	0.44			85.3	7.80	10.9	1.86		

(OM – organic matter, DOM – digestibility of organic matter, ME – metabolizable energy, N – nitrogen, P – phosphorus, NDF – neutral detergent fiber, SD – standard deviation)

Digestibility of organic matter calculated from faecal CP content

The organic matter digestibility of the overall diet ingested by the goats varied at $P \leq 0.05$ between the three oases (Figure 8). The average DOM_{calc} in Sheragia was 5% lower than the average calculated for Masirat, which was the highest DOM_{calc} of fodder digested by the experimental animals.

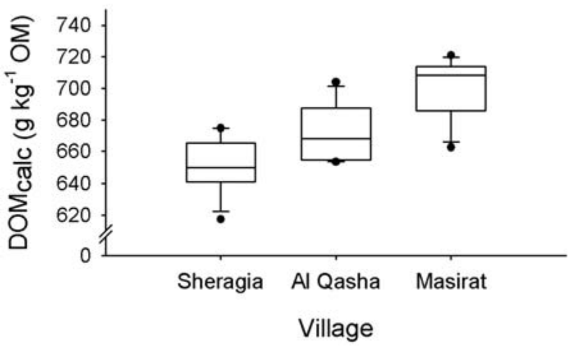

Fig. 8: Overall diet digestibility (DOM, g kg^{-1} OM) ingested by goats in three villages of the Jabal Akhdar mountains, Oman. (The boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers lines above and below the box indicate the 90th and 10th percentiles and the points are outlying data.)

Feed intake

The type of forages and the quantity of the offered fodder varied not only between farmers but also between individual days during the sampling period.

The total IOM (g OM kg$^{-0.75}$d^{-1}) of the animals in Al Qasha (82 g, SD 8.1) was significantly higher ($P \leq 0.05$) than of goats in Masirat (69 g, SD 20.0) and in Sheragia (62 g, SD 18.1). IOM of goats in Masirat and in Sheragia were not significantly different but values nevertheless differed by 12% (Figure 9.).

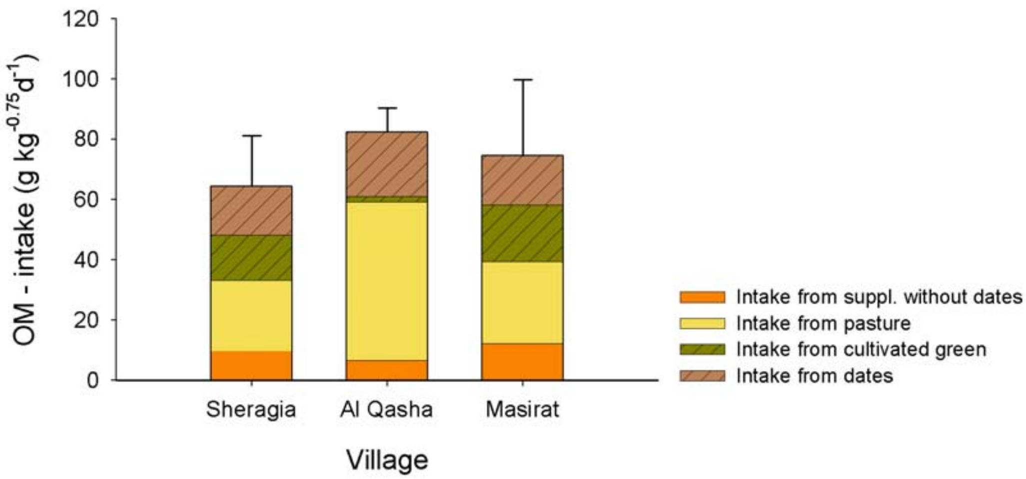

Fig. 9: Organic matter (OM) intake (g kg$^{-0.75}$d^{-1}) from external (pasture plants and supplements others than dates) and internal (cultivated forage and dates) sources of feed in three villages in the Jabal Akhdar mountains, Oman. Patterned units represent internal sources, non-patterned are external sources. Colored units represent means of intake of different types of feed. Standard deviation of the total intake of OM.

The quantity of supplements offered to the goats in the three oases was not significantly different ($P \leq 0.05$). Nevertheless, there were some clear differences in the composition of supplement feeds given to the animals. The supplement feeds in Al Qasha mainly comprised dates, fish and wheat meal. Dates presented almost 70% of the supplements (almost 300 g OM kg$^{-0.75}$ day^{-1}), 26% came from the wheat meal and only 4% were contributed by fish. In Masirat and Sheragia, the supplement composition varied more. Dates and fish were complemented by bread and in some cases by boiled rice and else kitchen leftovers or barley grain. The amount of dates fed in these oases was lower in comparison to Al Qasha, about 200 g kg$^{-0.75}$d^{-1}. On the other hand, IOM of fish was twice as high as in Al Qasha (20 g kg$^{-0,75}$d^{-1}), namely 44 and 48 g kg$^{-0.75}$ d^{-1} in Masirat and Sheragia, respectively. Bread was regularly offered to most of the goats during the 7-day experimental period and the average daily intake reached 44 g OM kg$^{-0.75}$ in Masirat and 48 g OM kg$^{-0.75}$ in Sheragia.

The cultivated green fodder was fed fresh and unprocessed. In Al Qasha, five goats were regularly fed with prebloom barley (average 38 g OM kg$^{-0.75}$ d^{-1}), the other three experimental animals were not fed green cultivated fodder at all. In Masirat and Sheragia, the cultivated green fodder was of significantly higher importance ($P \leq 0.05$) and presented 27% and 24% of the total intake of OM, respectively.

The intake of OM from the pasture varied between the three oases. In Al Qasha it represented a large portion of the total intake (64%) and was significantly higher ($P \leq 0.05$) than the values obtained for Masirat and Sheragia. In these two villages, the pasture vegetation contributed 38% to the total intake.

The different feedstuffs are of either internal or external origin. Internal feedstuffs originate from within the oasis, namely green forage cultivated by the farmer or obtained from another farmer in the oasis. Internal fodder also includes dates, which mostly originate from within the oasis. The other supplements (fish, wheat meal, bread and rice) are brought to the oasis from outside. Together with pasture vegetation, these are representing external sources of nutrients.

While OM intake in Masirat and Sheragia originated almost evenly from external and internal sources, in Al Qasha the intake from pasture and supplements other than dates presented 72% of total OM intake.

Origin of nutrients

The contribution of different sources of feedstuffs to the total intake of major nutrients varied between the three oases (Figure 10). In Al Qasha, pasture plants contributed on average 70% (967 mg N $kg^{-0.75}d^{-1}$, SD 241) to the total N intake. In Masirat and Sheragia, the intake of N from supplements was slightly higher than N – intake from pasture vegetation, with supplement N - contribution being 40% (562 mg N $kg^{-0.75}$ d^{-1}, SD 245) and 42% (mean 537 mg N $kg^{-0.75}d^{-1}$, SD 346), respectively.

The proportional contribution of N intake from pasture and cultivated forage reflected their contribution to the OM intake. On the other hand, OM intake of supplements other than dates accounted for only 17% of total OM intake in Masirat and 15% in Sheragia, but contributed 36% to the total N intake. The contribution of dates to total N intake did not exceed 7% at either site.

Fig. 10: Nitrogen (N) intake (mg kg$^{-0.75}$d^{-1}) from external (pasture plants and supplements others than dates) and internal (cultivated forage and dates) sources of feed in three villages in the Jabal Akhdar mountains, Oman. Patterned units represent internal sources, non-patterned are external sources. Colored units represent means of intake of different types of feed. Standard deviation of the total intake of OM.

The situation was different for P, where the intake of fish played an important role. Supplements contributed 48%, 46% and 51% to the total P intake (mean 166 mg kg$^{-0.75}$d^{-1}, SD 41) in Al Qasha, Masirat and Sheragia. In Al Qasha, a similar contribution (47%) came from the pasture plants (80 mg kg$^{-0.75}$d^{-1}, SD 20).

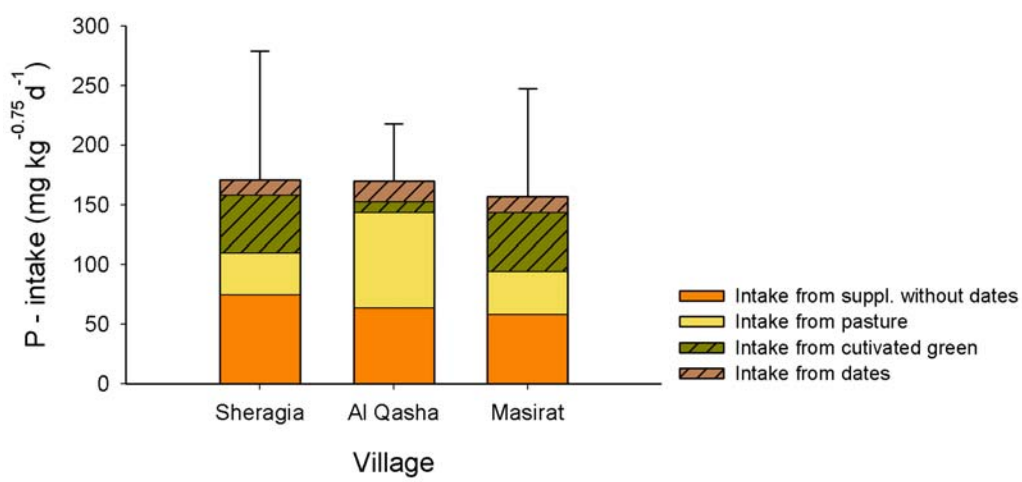

Fig. 11: Phosphorus (P) intake (mg kg$^{-0.75}$d^{-1}) from external (pasture plants and supplements others than dates) and internal (cultivated forage and dates) sources of feed in three villages in the Jabal Akhdar mountains, Oman. Patterned units represent internal sources, non-patterned are external sources. Colored units represent means of intake of different types of feed. Standard deviation of the total intake of OM.

The contribution of external supplements to nutritional intake was higher for P than for N. This is due to the fact that the phosphorus-richest supplements, namely fish and wheat meal, belong to this group. In Sheragia, 44% of total P intake originated from the external supplements. In Al Qasha and Masirat they contributed 38% to P intake. Nevertheless, in Masirat and Sheragia cultivated forages contributed 32% and 28 % to total P intake.

The importance of different sources to the metabolizable energy (ME) intake differed among the three oases (Figure 12.). Supplement feeds, especially dates, bread and wheat meal contributed between 268 and 311 kJ $kg^{-0.75}d^{-1}$ to the daily energy intake in the three oases. Dates contributed 34%, 24% and 30% to the total ME intake in Al Qasha, Masirat and Sheragia. In Masirat, dates together with cultivated forage contributed 68 % to the total ME intake. In Sheragia, 51% of ME intake originated from internal sources, while in Al Qasha 64 % of ME intake originated from external sources, namely from pasture (54%) and purchased supplements (10%).

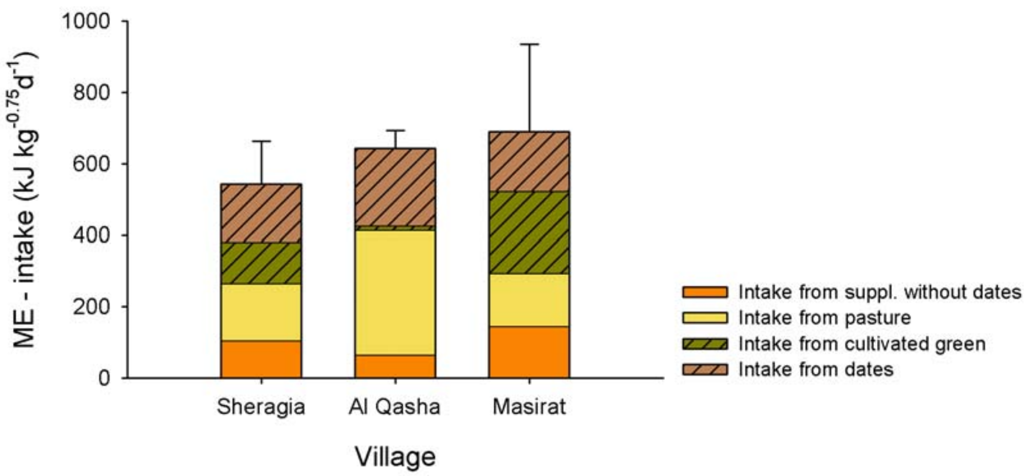

Fig. 12: Metabolizable energy (ME) intake (kJ $kg^{-0.75}d^{-1}$) from external (pasture plants and supplements others than dates) and internal (cultivated forage and dates) sources of feed in three villages in the Jabal Akhdar mountains, Oman. Patterned units represent internal sources, non-patterned are external sources. Colored units represent means of intake of different types of feed. Standard deviation of the total intake of OM.

Quality and quantity of faeces

The faecal N concentration (N_{fec}) varied for the individual animals, but was nevertheless significantly different ($P \leq 0.05$) between the three oases (Figure 13.). The lowest average N_{fec} values were obtained in Sheragia (21 g kg^{-1} OM, SD 2.0), followed by those from Al Qasha (23 g kg^{-1} OM, SD 1.9) and Masirat (26 g kg^{-1} OM, SD 2.1).

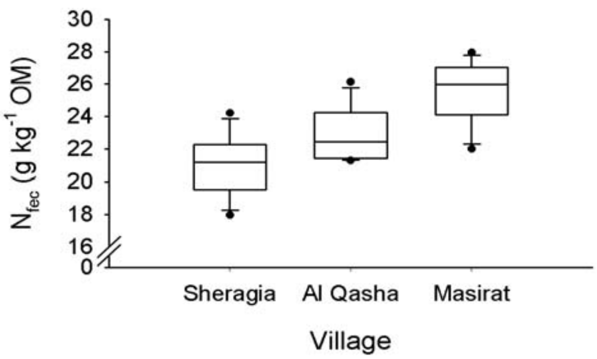

Fig. 13: Faecal nitrogen concentration in faeces (N_{fec}) (g kg^{-1} OM) excreted by goats kept in three villages in the Jabal Akhdar mountains, Oman. (The box plot description in Fig.8)

Differences in the concentration of phosphorus (Figure 14.) in the faeces of animals were not significant between the three oases ($P \leq 0.05$). A big variation was observed in Al Qasha (5.9 g kg^{-1} OM, SD 1.9), where animals 1, 2 and 3 which belonged to one farmer had lower P_{fec} contents than the other five animals belonging to the other farmer. The differences in P_{fec} resulted from different feeding practices. The mean values of P_{fec} in Masirat and Sheragia were 4.8 g kg^{-1} OM (SD 1.6) and 4.3 g kg^{-1} OM (SD 1.3).

Fig. 14: Faecal phosphorus concentration in faeces (P_{fec}) (g kg^{-1} OM) excreted by goats kept in three villages in the Jabal Akhdar mountains, Oman. (The box plot description in Fig.8)

The total amount of the faeces excreted (Table 12.) was significantly higher ($P \leq 0.05$) in Al Qasha (26.8 g OM $kg^{-0.75}d^{-1}$, SD 2.72), than in Masirat and Sheragia (20.8 g OM $kg^{-0.75}d^{-1}$, SD 5.82 and 21.2 g OM $kg^{-0.75}d^{-1}$, SD 5.80). Faecal organic matter excretion was 33% (Sheragia), 33% (Al Qasha) and 27% (Masirat) and of total intake of OM (Figure 15.).

Table 12: Faecal OM, N and P excretion of goats in three villages in the Jabal Akhdar mountains of Oman. (n = number of goats, means and SD).

Village	n	OM_{fec}		N_{fec}		P_{fec}	
				($g\ kg^{-0.75}d^{-1}$)			
		mean	SD	mean	SD	mean	SD
Sheragia	8	21.2	5.80	10.2	6.02	1.8	0.57
Al Qasha	8	26.8	2.72	16.6	3.04	4.3	1.58
Masirat	7	20.8	5.82	11.6	6.08	2.2	1.36

OM_{fec} – faecal OM, N_{fec} – faecal N, P_{fec} – faecal P

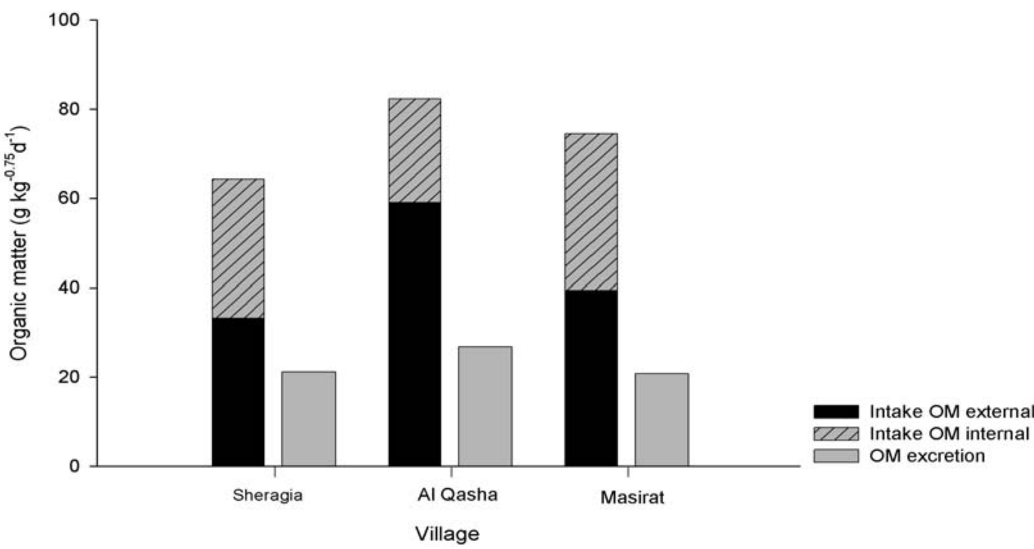

Fig. 15: Intake of OM from internal and external sources and OM excretion of goats in three villages of the Jabal Akhdar mountains, Oman. Patterned units represent internal sources of intake.

The nitrogen excretion by goats did not vary much between the three oases. In Sheragia, Al Qasha and Masirat, 0.45, 0.61 and 0.53 g N $kg^{-0.75}$ were excreted daily in the faeces (Figure 16.), which presented 35% (Sheragia), 44% (Al Qasha) and 38% (Masirat) and of total nitrogen intake.

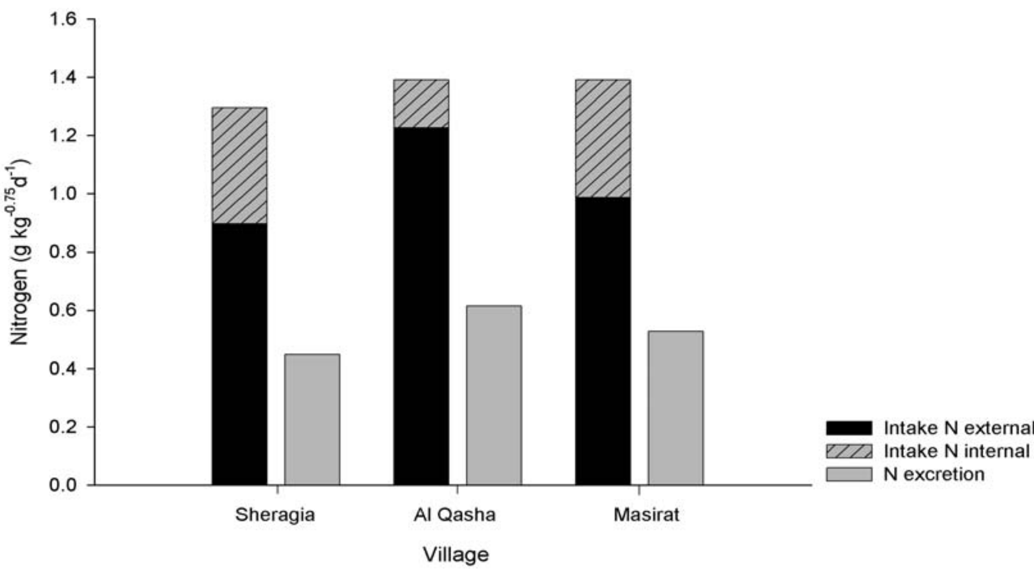

Fig. 16: Intake of N from internal and external sources and N excretion of goats in three villages of the Jabal Akhdar mountains, Oman. Patterned units represent internal sources of intake.

In Al Qasha, the P excretion in faeces was 93 % of the ingested P. In Masirat and Sheragia, 63 % and 50 % of ingested P were excreted (Figure 17).

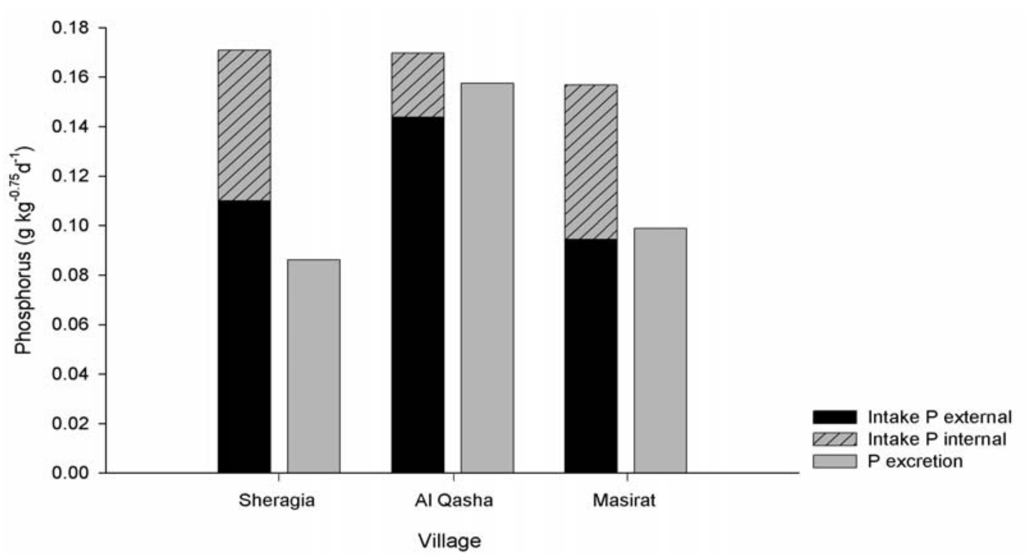

Fig. 17: Intake of P from internal and external sources and P excretion of goats in three villages of the Jabal Akhdar mountains, Oman. Patterned units represent internal sources of intake.

Discussion

Fodder quality and feed intake

The environmental conditions of the mountain oases of the Jabal Akhdar range are characterized by a dry and hot climate. These oasis systems have developed and adapted to these conditions over centuries (Nagieb et al., 2004). Goats are traditionally kept under extensive management, characterized by keeping animals at the homesteads over night and allowing them to graze and browse on the mountainous pastures during daytime. This way of keeping animal also determines the feeding practices. The total daily intake is composed of fodder supplied by the farmer at the homestead and by freely selected plant species or different parts of the pasture plants during the day grazing period.

The pasture vegetation was composed mainly of shrubs and various herbaceous plant species. The digestibility of the pasture plants ranged between 334 and 731 g DOM kg^{-1} OM and was lower in than the average digestibility of the cultivated green fodder (648 g DOM kg^{-1} OM). Factors being responsible for that are the higher content of cell wall constituents, a high extent of lignification and the presence of secondary compounds such as tannins and saponins. Their content increases during the growth cycle of a plant and is highest in mature plants or plant parts, respectively. (Van Soest, 1982).

The addition of polyethylene glycol (PEG) to the 16 plant samples with the lowest *in vitro* digestibility increased the gas production of 10 samples by 30% - 200%. From this it can be concluded that the low digestibility of these plant species was caused by high content of tannins (Van Soest, 1982). The metabolizable energy content of pasture plants was only half of the ME of the grown forage. Despite this, the voluntary OM intake on pasture presented a high proportion of the total daily intake. The local breed of goats seems to be well adapted to the harsh environmental conditions. Goats are excellent selectors of the less fiber containing and less lignified plant parts and the longer mean retention time of digesta in the rumen assures better digestive efficiency (Silanikove, 2000). In this experiment, the ME content was calculated from results of the HFT gas test, where cow rumen fluid was used for the incubation of the samples. Goats are able to partially decrease the anti-nutritional effects of tannins through different mechanisms (Gall, 2001). Because the *in vitro* approach can simulate the real digestion of the pasture plants by goats only to a certain extend, it is possible that the real ME content available to the animals was slightly higher than the one resulting from our calculations.

A proportional difference between the intake of organic matter from pasture, cultivated forage and supplements existed between the three oases. The total OM intake was similar to the values reported by Alcaide et al. (1997) from an experiment with grazing goats and sheep on low quality pastures in Southern Spain, where the IOM was 68.3 g $kg^{-0.75}$ d^{-1} and 40.9 g $kg^{-0.75}$ d^{-1} for goats and sheep, respectively. In our case, IOM was even higher in Al Qasha (82 g $kg^{-0.75}d^{-1}$). This seems to be due to an almost doubled intake from the pasture in comparison to Sheragia and Masirat, which was probably caused by the fact that green forage was not fed at the homestead. The high portion of intake from pasture vegetation in Al Qasha in comparison to the other two oases might also be explained by the fact that the grazing area of Al Qasha as related to the number of grazing animals was relatively large in comparison to the pastures of Masirat and Sheragia, where the density of goats was much higher.

Differences in intake might be also explained by different management practices in the three oases. In Masirat goats are freely grazing and the time spent on the pasture is not fixed. Some individuals even reduced the grazing time to few hours per day. In contrast, the daily pasture time of goats in Al Qasha and Sheragia is under the control of a herdsman and the longer time spent on the pasture apparently plays a role for the intake of pasture plants.

The digestibility and metabolizable energy content of the collected pasture plants did not vary much between the oases and the altitude difference apparently did not have a remarkable effect on these qualitative parameters of the grazed vegetation. Nevertheless, the N and P concentration in pasture plants in Sheragia was significantly lower than that of pasture plants in lower situated villages. From this it can be concluded that the elevation had an effect on the N and P concentration in pasture vegetation.

The main constraint in the Omani Jabal Akhdar mountains is the lack of available water. Wild plants growing in extremely arid areas are well adapted to the harsh conditions through various mechanisms. One of them is the ability to react immediately to any amount of moisture by growing, flowering and seeding. Their vegetation period is short and intensive (Schmidt, 1969). Since 2002 the annual precipitation at Saiq hardly exceeded 200 mm and until November 2004 little rainfall occurred. The dry period was followed by 4 months, during which 200 mm of rainfall were recorded (www.tutiempo.net). The abundant rainfall resulted in a boost of vegetation on the mountainous pastures, especially in annual grasses and dicots and through that lead to increased fodder availability.

The fact that a considerable portion of OM was ingested on the pasture was reflected by the fact that farmers in Al Qasha did not see the need to feed large amounts of cultivated roughages at the homesteads to meet their animals' nutrient requirements. Only neglectable amounts of cultivated green forage were offered to goats by one of the two farmers after the evening return from the pasture, and often goats did not ingest the entire amount of offered forage.

The most constant part of the goats' diet among the oases and also among different farmers seemed to be the supplements. In all three oases the amount of supplements daily given to the animal varied closely between 26-28 g OM $kg^{-0.75}d^{-1}$. Nevertheless, the proportional share of different supplements and the nutrients derived from them, varied among oases. Fish and dates were fed by all farmers in the three oases. Mahgoub et al. (2005) examined the quality of sun-dried sardines fed to Omani sheep. They found that the nutritive value of these fish was quite high: the protein concentration averaged at 650 g kg^{-1} DM which is in the range of values reported for the commercial fish meal. The fat content of the local sardines was higher (40 g kg^{-1}, not stated if in DM or OM) than of extracted fish meal (0.9 - 13 g kg^{-1}). In the experiment, diets containing different amounts of dried sardines as main source of protein instead of soybean meal were fed to goats. The highest weight gain occurred when 50 g kg^{-1} LW d^{-1} of sardines (not stated if DM or OM) were fed. Diets containing more than 200 g kg^{-1} LW of sardines had a negative impact on total feed intake. Fish samples collected in the present study contained on average less crude protein (534 g kg^{-1} OM) but were the CP-richest among all supplements given. The negative effect of high amounts of fish included in the diet on the intake as stated by Mahgoub et al. (2005) does hardly apply to the present study as the average ration did not exceed 50 g kg LW d^{-1} of sardines.

According to Elhag and Elkhanjari (1992), dates are a good complementary feed to the fish. In feeding experiments with calves and goats, date-fish based diets were fed and in both cases dates seemed to be an effective and beneficial supplement. For calves, the fish-date based diet was more palatable than a fish-barley diet, nevertheless the daily weight gain was not higher. Goats were fed date by-products (leaves and stones) and fish; as a control the conventional pelleted roughage component in growing/finishing ruminant diets was used. The results showed that in the combination with fish, dates and their by-products are sufficient, effective and cheaply available supplements. In the present case, the fish was combined with date fruits of a high nutritive value (the metabolizable energy of fed dates averaged 13.17 MJ kg^{-1} OM and their digestibility exceeded 90 %) then that of stones or leaves. In the recent study, the N and P concentration values of fish showed that these can supply effectively protein and phosphorus and highly digestible dates fed to animals contribute considerably to the ME intake. Therefore, the conclusion of Elhag and Elkhanjari (1992) on the positive impact of fish-date based diets certainly applies to this study as well.

The overall metabolizable energy (ME) intake of the goats originated from the ME intake of fodder given to the animals in the stable (exactly calculated) and ME intake from pasture plants (calculated from the mean value of ME of pasture plants). The mean values of ME intake for Sheragia, Al Qasha and Masirat were 554, 648 and 734 kJ $kg^{-0.75}d^{-1}$. Maintenance requirements of goats for ME range between 401 and 443 kJ $kg^{-0.75}d^{-1}$ (Lachica at al., 2003). In addition to maintenance, metabolizable energy for activity must be supplied, especially when animals are grazing on sparsely vegetated or mountainous pasture with long travel distances and great altitude differences to be overcome. Lachica et al. (2003) estimated average maintenance requirements of goats at 422 kJ ME $kg^{-0.75}d^{-1}$ and energy costs of walking at 3.4 J $kg^{-0.75}km^{-1}$. Per day, goats on average walked 17, 12 and 13 km, in Sheragia, Masirat and Al Qasha. (Schlecht et al., forthcoming). This would demand on average 0.05 kJ ME $kg^{-0.75}d^{-1}$ in addition to the maintenance requirements. Although exact information on the age of the experimental animals is lacking, from their body weight (min. 19 kg, max. 43 kg, mean 29 kg, with live weight of an adult Jabal Akhdar goat exceeding 40 kg; Zaibet et al., 2004) it was concluded that most of the experimental animals were still young and growing. Growth necessitates additional energy; the requirement for 1 g of gain for goats are 30 kJ ME (National Academy of Science, 1981). After covering the energy requirements of goats for maintenance, about 130 – 310 kJ ME $kg^{-0.75}d^{-1}$ remains and can be used for growth and gaining weight. This is adequate to 4 – 10 g $kg^{-0.75}$ daily weight increase. Mahgoub et al. (2005) reported a weight gain of 128 g kg LW daily in bucks of Jabal Akhdar breed kept for meat production. From the estimated ME intake by goats in the three oases it can be concluded that the ME supply is sufficient to cover requirements for maintenance and locomotion and also provide some energy for growth and weight gain. Nevertheless, this does not suffice to fulfill the fattening potential of the animals.

Origin of nutrients

The different sources of feed vary in their importance as far as their contribution to the total intake of different nutrients is concerned. The high nitrogen intake from the pasture (70 % of total N intake) in Al Qasha reflects the general high intake of organic matter (65 % of the total OM intake) from the pasture vegetation. As in Masirat and Sheragia proportionally more fish was fed and green forage was supplied at the homestead, the N intake of these elevated the total nitrogen intake to the same level as in Al Qasha. On the other hand, because the pasture vegetation was not very rich in phosphorus, its importance was less as far as P supply is concerned. The main source of P were supplements, and especially fish, which supplied about half of the total P intake in all three oases. Similar results were obtained for the intake of ME, where supplements also supplied almost half of the total ME intake, although the main source in this case were the dates. The contribution of cultivated forages to the nutrient intake in general was slightly higher in Masirat than in the other two oases: represented 24% of total N, 31% of total P and 33% of total ME intake. The intake of N, P and ME from supplements plus pasture vegetation covered about 82%, 79% and 81% of the total intake of these nutrients across the three oases.

The intake of OM and nutrients was compared on the basis of internal and external sources of feed (Figures 9. – 12.). External and internal OM intake were well-balanced in Masirat and Sheragia, while in Al Qasha, the external sources presented 70 % of the total intake due to the high intake from pasture. Nitrogen mostly originated from external resources in all three oases and only about 24% were supplied by fodder grown in the oases. For P intake, green forage played an important role in Masirat and Sheragia, where the internal sources of feeds supplied 40% and 36% of the total P intake. In Al Qasha, where green forage was hardly fed, the internal feed sources contributed only 15% to the total P intake.

The only parameter where the internal and external feeds equally contributed to the intake was the metabolizable energy. Across the three oases, internal feedstuffs contributed about 52% to the total ME intake, mostly due to the high ME content of the dates.

These results indicate that the external sources contributed more than a half of the total intake of nutrients ingested by goats and it can be concluded that the pasture vegetation as well as the imported feed supplements contribute considerably to the goats' nutrition in the mountainous oases and must be considered in the context of oasis agriculture.

As outlined before, this study was conducted only on male individuals. There were two major reasons for this choice: firstly the collection of faeces by collection bags, which is more problematic with females, and secondly because of the apparently different management of males and females due to preferences of the local population. The role of female animals is the reproduction of the herd and the supply of some milk whereas the bucks are kept for meat production. They are used either for auto consumption, to honor guests or they are sold for the traditional Islamic feasts (Zaibet et al., 2004). These different production goals are quite clearly reflected in the feeding strategies of farmers. In all three oases, bucks obtained evidently more fodder at the homesteads than does and farmers were intentionally fattening the males. The fattening of bucks is also reasonable because they grow more rapidly and have a better carcass composition than does and castrated males (Mahgoub et al., 2004).

Faeces quality and quantity

In the agro-pastoral oasis systems of Northern Oman, animal faeces play an important role in the complex nutrients fluxes. The nutrients are channeled along different pathways within the oases and between oases and their external environment. Through the yields of field crops and palm trees nutrients flow to households and stables; animals receive nutrients from the households in the form of kitchen leftovers and bring in some nutrients from the outside mountainous pastures. On the other hand, produced milk and meet is consumed by the farmers, manure from stables and ash from households is applied on the fields and to palm trees which in addition are fertilized by human excreta. Beyond this, the selling of crop products and livestock and purchase of food-stuffs, animal feeds and chemical fertilizers constitute nutrients that are exchanged with other settlements (Nagieb, 2004) or external markets.

The N and P concentrations of goats' faeces measured in this experiment were higher than that reported for the oases of Balad Seet and Maqta in Northern Oman (Buerkert et al., 2005). At 6 g P kg^{-1} DM was slightly higher than in Balad Seet and Maqta (5 g kg^{-1} DM), at an overall average of 27.5 g kg^{-1} DM faecal N concentration was 50% higher than the 18 g kg^{-1} reported by Buerkert et al. (2005). This might in part be due to high concentrations of tannins in some pasture plants, but also reflects the oases' connections to the outside economy by purchasing N-rich fish as supplement feed for goats. However, the final quality of manure brought to the fields is also affected by other factors, such as the way and the duration of storing the manure; transport and application practices can also lead to losses of nutrients. Simple sun-drying of fresh faeces in this experiment did not cause any nitrogen losses, but further investigation on the manure management in these three oases will be necessary in order to define the nutrients pathways and their balances and losses under different fertilizing practices and certain environmental conditions.

Although the nutrient concentration of the manure was very high, the direct profit for the farmer of this organic fertilizer is limited. Goats excreted 27, 21 and 21 g $kg^{-0.75}d^{-1}$ of faecal OM in Al-Qasha, Masirat and Sheragia. According to Schlecht et al. (1997), the faecal excretion is almost equally distributed across a 24 hour period. As goats are staying in the mountains during the day time, return to the oasis in the afternoon and stay at the homestead over night, it may be assumed that only about half of the faeces is available to the farmer as manure to apply on his fields. For a farmer having for example 15 goats (LW average 29 kg) with the above-mentioned faecal excretion annually 780 kg faecal OM would be available as organic fertilizer for his fields. At average faecal N concentration of 23 g kg^{-1} OM and faecal P concentration of 5.0 g kg^{-1} OM, this would supply 18 kg N and 4 kg P to the farmer's fields. The sizes of fields and the quantitative application of manure in the three oases are subject of further studies. Buerkert et al. (2005) reported an annual input of N of 100 - 500 kg ha^{-1} on 55 % of the fields and 1-90 kg P on 46 % of the fields in the oasis of Balad Sheet. In the three oases studied here, it would not be possible to reach these inputs by applying animal manure only, chemical fertilizer inputs would also be needed.

When comparing the external and internal sources of N and P intake to the faecal excretion of N and P outside and inside the oasis (Figures 16 and 17.) it can be seen that a larger portion of nutrients originates from external sources. As only half of nutrients excreted by goat are lost and half stay in the oasis, it can be concluded that even organic fertilization of oasis cropland depends on an import of N and P from outside the oases.

Conclusions

From the results of this study on goat keeping in mountainous oases of the Omani Jabal Akhdar range, it can be concluded that the animal husbandry system appears to be overall well adapted to the environmental conditions. As far as the feeding practices are concerned, the grazing on the natural pastures outside the oases is combined with feeding high quality supplements and cultivated forages.

The potential of the local Jabal Akhdar breed for meat production and its adaptation to the harsh and dry environment assures a positive basis for animal husbandry in these oases. The overall metabolizable energy intake by goats in the oases seems to be high enough to cover the animals' requirements for maintenance, locomotion in the mountainous terrain and growth.

A higher portion of nutrients taken in by goat was coming from external sources such as purchased fish, wheat meal and pasture vegetation. Especially the purchase of high quality supplement feed shows a certain dependence of oasis animal feeding on external inputs. In this study, the contribution of the pasture vegetation to the intake of organic matter and nutrients by goats is considerably high as it contributed in average 47% of total N intake, 30% of total P intake and 35% of total ME intake by goats. Nutrients ingested by animals are in part recycled to cropland through the application of animal manure. Due to the important portion of external nutrients in goat feeding, organic manuring of cropland indirectly also depends to considerable part on these external nutrients.

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Summary

This experiment was conducted to investigate the contribution of pasture vegetation to the total intake of goats and the contribution of goats keeping to nutrient fluxes in traditional systems of three mountainous oases at different elevation (1800, 1500 and 1100 m asl.) in northern Oman. Eight male goats were chosen from at least two different farmers in each oasis. Titan dioxid was used as an external marker to establish the total intake of the grazing animals.

The quality parameters of the feedstuffs (digestibility of OM, ME) did not vary much between the oases, but they reflected different nutritional characteristics of various feedstuffs. Nutrients N and P concentration in pasture plants was the lower in the higher situated oasis of Sheragia.

The intake of organic matter from pasture varied among animals in the range between 23 and 78 % of the total daily intake. The highest contribution of pasture vegetation was observed in Al Qasha, probably caused by lower density of goats on the pastures than in the other two oases.

The intake of nitrogen and phosphorus (mg $kg^{-0.75}$ d^{-1}) by goats was similar in the different oases in contrast to the intake of metabolizable energy (kJ $kg^{-0.75}$ d^{-1}), which was slightly lower in Sheragia. Nevertheless the proportional contribution of different fodder sources to the total intake of nutrients varied among oases. In Al Qasha, a large part of N (70 %), P (47 %) and ME (54 %) originated from the pasture. In general, the pasture vegetation contributed considerably to the total intake of organic matter and nutrients, which indicates high importance of goats' grazing. The total daily intake of ME covers sufficiently the energy requirements of goats.

In general the nutrients taken in by the animals (and partially excreted at the homestead and used as a manure on the farmers fields) came from outside of the oasis (pasture, bought supplements) and even when considering lost of nutrients in faeces excreted during the grazing time on the pastures, a considerable import of nutrients in the oases can be stated.

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Appendix

Appendix 1: The chemical composition of buffered rumen fluid for HFT

Hohenheim Gastest medium

		Components		Final	conc.	amount	unit
		HFT buffer		15.873	%	523.81	ml
		Macrominerals		15.873	%	523.81	ml
		Microminerals		0.0159	%	0.5238	ml
0.4	%	Reszurine		0.0079	%	0.6548	ml
		dH2O				1150.5	ml
		Sodium sulfite		0.1984	mg/ml	654.76	mg
6	N	NaOH		0.0013	N	0.6984	ml
		Rumen fluid				1100	ml
		total volume	# of syr.	100		3300	ml
			Volume / syringe	30	ml		
			Buffer capacity	low			

HFT buffer

Components	MW	final	conc.	amount	unit
Ammonium bicarbonate	79.06	0.0506	M	8	g
Natrium bicarbonate	84.01	0.4166	M	70	g
ddH2O				2000	ml
total volume				2000	ml

Macrominerals

Components	MW	final	conc.	amount	unit
diNatrium Hydrogen Phosphate	142	0.0401	M	11.4	g
Postassium diHydrogen Phosphate	136.09	0.0456	M	12.4	g
Magnesium Sulfate 7xH2O	246.48	0.0024		1.2	g
total volume	make up to with dH2O			2000	ml

Microminerals

Components	MW	final	conc.	amount	unit
Calcium Cloride	147.02	0.4489	M	6600	mg

2xH2O					
Mangan Chloride 4xH2O	197.91	0.2526	M	5000	mg
Cobald chloride 6xH2O	237.93	0.021	M	500	mg
Ferric triChloride 6xH2O	270.3	0.148	M	4000	mg
total volume	make up to with dH2O			100	ml

Resazurine (0.4% w/v)

Components	final	conc.	amount	unit
Resazurine	0.4	%	400	mg
total volume			100	ml

NaOH (6N)

Components	MW	final	conc.	amount	unit
NaOH	40	6	N	7.2	g
total volume	make up to with dH2O			30	ml

Appendix 2: The chemical composition of buffered rumen fluid for PEG assay

Hohenheim Gastest medium

		Components	MW	Final	conc.	amount	unit
		HFT buffer		16	%	1143	ml
		Macrominerals		16	%	571	ml
		Microminerals		0.016	%	0.571	ml
0.4	%	Reszurine		0.008	%	0.714	ml
		dH2O				684	ml
		Sodium sulfite		0.1984	mg/ml	714	mg
6	N	NaOH		0.00126984	N	0.762	ml
		Rumen fluid				1200	ml
		total volume	# of syr.	110		3600	ml
			Volume / syringe	30	ml		
			Buffer capacity	high			

Individual components were prepared as in Appendix 1.

Appendix 3: Spectrophotometrical determination of TiO_2

Mixture I.

Component	Conc. (%)	Amount (ml)
H_2O_2	35	40
H_3PO_4	85	120
H_2SO_4	96	200
H_2O	destilled	360

Mixture II.

Component	Conc. (%)	Amount (ml)
H_3PO_4	85	120
H_2SO_4	96	200
H_2O	destilled	400