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Master thesis

Nutritional and ecological aspects of goat husbandry in mountain oases of the Al-Jabal-al-Akhdar, Northern Oman

by

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Witzenhausen, July 2006

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Abbreviations

CA	Crude ash
Ca	Calcium
CL	Crude lipids
CP	Crude protein
DM	Dry matter
DOM	Digestible organic matter
FDM	Faecal dry matter
FOM	Faecal organic matter
Gb	Gas production (from German: Gasbildung)
GDP	Gross domestic product
HFT	Hohenheim Gas Test (German: Hohenheimer Futterwerttest)
IME	Intake of metabolizable energy
IN	Intake of nitrogen
IOM	Intake of organic matter
IP	Intake of phosphorus
LW	Liveweight in kg
m asl	Meters above sea level
ME	Metabolizable energy
n	Number
N	Nitrogen
n.d.	Not determined
NDF	Neutral Detergent Fiber
n.s.	Not significant
OM	Organic matter
P	Phosphorus
SD	Standard deviation

Acknowledgements

I want to thank Prof. Dr. Eva Schlecht and Prof. Dr. Andreas Buerkert for the opportunity to participate in the project on “Transformation processes in the mountain oases of northern Oman” and to gather such formative experiences. I very much appreciated the support, the inspiring discussions and their confidence in me.

I also want to express my gratitude to Eva Wiegard, Claudia Thieme, Burkhard Heiligtag, Christiane Jatsch and Herrmann Baumgaertner for the technical assistance and patience during the sample analyses and thank Prof. Dr. Annette Patzelt for the determination of the plant species as well as Beate Fromowitz for her friendly advice in the data analyses.

I am very grateful for the experiences during the stay in Oman, owing to the hearty cooperation of the farmers and the employees of the agricultural center as well as Dr. Maher Nagieb and Eike Luedeling. I very much appreciated their encouragements.

My gratitude is also directed towards my mother Barbara Torbeck-Dickhoefer, my sister Ursula Dickhoefer and Luke Watkiss for patience, understanding and endless support.

Affirmation

I declare that the master thesis “Nutritional and ecological aspects of goat husbandry in the mountain oases of the Al-Jabal-al-Akhdar, Oman” has been written only by the undersigned and without any assistance from third parties.

Furthermore, I confirm that no sources have been used in the preparation of this thesis other than those indicated in the thesis itself.

Witzenhausen, July 5th 2006

Uta Dickhoefer

1 Introduction

The traditional strategies of farmers to balance environmental conditions in arid and semi-arid landscapes have since long raised the interest of researchers. A low and variable rainfall typical for these areas also characterizes the Sultanate of Oman and agricultural activities in the mountain areas are additionally constrained by low temperatures during the winter months and a very dissected relief. The agro-pastoral systems of the Al-Jabal-al-Akhdar mountain mountains in northern Oman combine irrigated crop cultivation on terraces and livestock husbandry and have been adapted to these environments over centuries.

However, the country has undergone significant economic, political and social changes in the past four decades, which also affect the agricultural systems in the mountain oases. Therefore, the DFG-funded research project on "Transformation processes in the mountain oases of northern Oman" conducted by the Department of Organic Plant Production and Agroecosystems Research in the Tropics and Subtropics and the Department of Animal Husbandry in the Tropics and Subtropics* of the University of Kassel aims to describe these systems and their functioning. In the last years, research focused on crop cultivation, while the role of livestock within these systems remains to be analyzed.

The objectives of the present study therefore were:

- to determine the main characteristics of livestock husbandry in the mountain oases of the Al-Jabal-al-Akhdar mountains;
- to clarify the linkages between the livestock and the other components of the agro-pastoral system;
- to analyze the management strategies that balance the varying environmental conditions;
- to identify the problems in livestock husbandry that are related to the current transformation processes in these oases.

2 Study location

2.1 The Sultanate of Oman

The Sultanate of Oman is located in the southeastern part of the Arabian Peninsula (21° N 57° E) surrounded by the Persian Gulf and the Gulf of Oman in the north and the Arabian Sea in the east. In the west and southwest, the country borders the United Emirates, Saudi Arabia and Yemen Republic. Oman`s capital city is Muscat, while other important, but smaller cities are Ibri, Nizwa and Salalah (Figure 2.1).

Figure 2.1. Map of the Sultanate of Oman and study location (Oman Maps, Perry Castaneda Map Collection, University of Texas Library, USA; www.lib.utexas.edu)

The country's total surface area of 309,500 km^2 (WDI, 2006) is divided into the coastal plains in the north (Batinah) and the south (Salalah Plains), the internal plains, frequently referred to as Rub' al Khali ("Empty Quarter"), as well as the mountain regions, which account for about 15% of the total land area (FAO, 2006).

The Al-Jabal-al Akhdar mountains stretch from the northwest to the southeast of the country reaching elevations of 2980 m (Jabal Shams; FAO, 2006). The mountain body is mainly composed of limestone and dissected by deep valleys. The karstic character allows the fast infiltration of the rainwater and is responsible for the mountain`s freshwater storage capacity, while the location and flow of springs determined the foundation and survival of human settlements in this environment (Luedeling et al., 2004).

Since the beginning of the leadership of Sultan Qaboos in 1970, the country has undergone significant economic and social changes favored by an increasing exploitation and export of oil and natural gas. The country's gross domestic product (GDP) increased by an annual 3% to 24.3 billion US$ in 2004, while the annual per capita income rose to 9,070 US$ (WDI, 2006). The mountain regions benefited from these developments in form of an improvement and expansion of the road network, infrastructure, such as schools, telephones and extension services, the establishment of groundwater wells ameliorating the water supply, and the building of dams to reduce water runoff and increase infiltration. However, currently about 75% of the 2.57 million Omanis concentrate in urban areas, such as Muscat and Salalah (WRI, 2006), while rural districts are less densely populated. Furthermore, the rapid increase in the urban population and a rather slow growth in the rural areas indicate a strong migration of people towards urban areas.

According to the FAO classification, the Sultanate of Oman is located in the agro-ecological zone of the warm arid and semi-arid tropics. However, the climate within the country varies significantly.

While most of the country receives less than 100 mm of rainfall per year and even less than 25 mm in the internal plains (FAO, 2005), while the precipitation in the mountain areas of Salalah and the Al-Jabal-al-Akdhar is substantially higher. In the latter area, the annual rainfall of 316 mm at Sayq, an average annual temperature of 17.8 °C and a reduced evaporation enhance the availability of freshwater for domestic and agricultural consumption. However, the climate in the mountain regions is characterized by a high inter- and intraannual variability, arid conditions throughout most of the year and low temperatures of 9 to 11 °C during the winter months (Figure 2.2).

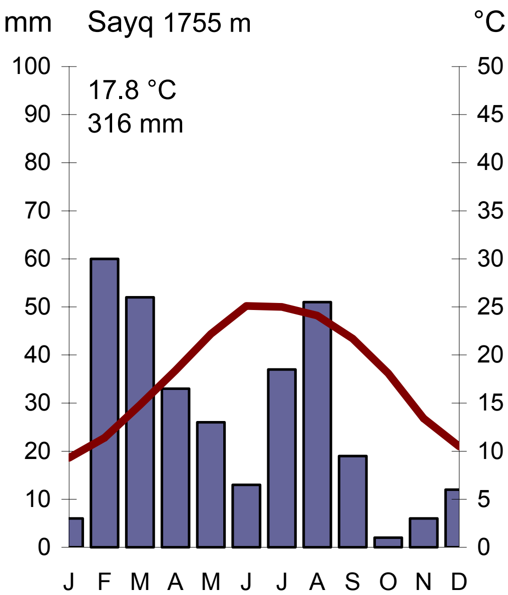

Figure 2.2. Climate diagram of Sayq, Al-Jabal-al-Akhdar mountains (www.klimadiagramme.de)

Overall, agriculture in Oman is largely constrained by water scarcity and depends on irrigation. Of the country's surface area, 0.3% are arable and permanently cropped land and 0.2% are irrigated (FAO, 2006). Deep ground water wells and desalinization plants help to promote agriculture in the coastal plains of the Batinah region, where most of the country's agriculture is concentrated. Main agricultural crops are dates, citrus fruits and tobacco, and the increasing number of livestock includes goats, sheep, cattle, camels and poultry. Given the importance of the oil industry for Oman's economy, agriculture generates only about 3.7% of the total GDP, but still employs 360,000 people, representing 34% of the total labor force (FAO, 2006).

2.2 The agricultural systems of the Al-Jabal-al-Akhdar mountains

The agriculture in the mountain regions of the Sultanate of Oman is characterized by agro-pastoral systems that combine crop cultivation with livestock husbandry. In the valley bottoms or in extensive terrace systems on the mountain slopes, crops are cultivated on rather small plots that belong to different farmers of the villages. The date palm (*Phoenix dactylifera* L.) is an important perennial crop grown at lower elevations, while it is replaced by pomegranate (*Punica granatum L.*) in oases of higher altitude. Other perennial crops are bananas (*Musa* ssp.), various citrus and other fruit and nut trees, but also roses (*Rosa* ssp.). Annual crops are partially grown under the cover of the trees and include wheat (*Triticum* ssp.), sorghum (*Sorghum bicolor* Moench s.L.), barley (*Hordeum vulgare* L.s.L.) and oat (*Avena sativa* L.) as the main cereals as well as vegetables, such as garlic (*Allium sativum* L.), onion (*Allium ceta* L.) or carrot (*Daucus* ssp.). Additionally, several fodder crops for animals are cultivated, including maize (*Zea mays* L.) and alfalfa (*Medicago sativa* L.).

Figure 2.3. Terrace system of Al 'Ayn and Ash Sharayjah on the Al-Jabal-al-Akhdar mountains (October 2005)

Despite the higher rainfall, crop cultivation in the mountain regions depends on the irrigation by the Aflaj system (Aflaj: plural of falaj). This is a traditional irrigation system practiced on the Arabian Peninsula, but also in other parts of Asia and Africa. It allows to access water either from perennial flow in surface gravels of mountain valleys (wadis), from sub-surface sources by the means of tunnels or from natural springs on the mountain slopes (Wilkinson, 1977). The system is based on gravity flow and channels lead the water downhill to the settlements and their adjacent cultivated areas. Within the gardens, the main channel splits into several branches, conveying the irrigation water to the different terraces and the single fields. The distribution follows complex principles of shareholding and is rotational according to certain time schedules for the irrigation of individual plots. Where the falaj flow is highly variable, additional water might be collected in cisterns and the government has recently established additional wells to ameliorate the water availability (Anonymous, 1995).

The area cultivated and the crops grown change throughout the year, depending on the potential evapotranspiration and the amount of water available to plants. In times of low falaj flow, preference is given to the irrigation of the palm groves, while farmers cultivate additional terraces and grow annual crops with higher water demand in the winter months when temperatures are low and more water for irrigation is available. Crop cultivation is mainly for subsistence and only surplus is sold on local markets. However, dates and various other fruits, such as pomegranate and lime, can play a more important role as a source of income.

The goat *(Caprus hircus)* is the main domestic animal in the villages of the Al-Jabal-al-Akhdar mountains, where most farmers keep less than 40 goats (Zaibet et al., 2004). Depending on the household additionally sheep *(Ovis aries)*, cattle *(Bos* ssp.*)*, chickens *(Gallus domesticus)* or rabbits *(Oryctolagus cuniculus)* are kept to produce meat, milk and eggs and traditionally to sell fiber. The animals graze on common rangeland during the day and are locked in the barn over night, where supplement feeds such as dates, fish as well as cultivated green fodder are offered. The animal manure is the main source of nutrients and organic matter in crop production. Thus, farmers collect the faeces excreted over night and apply them to the fields.

3 Materials and methods

3.1 Study sites

The present study was carried out in the three villages Masayrat ar Ruwajah (23.05° N, 57.67° E; 1070 m asl; further referred to as Masayrat), Qasha' (23.06° N, 57.67° E; 1700 m asl) and Ash Sharayjah (23.07° N, 57.66° E, 1980 m asl) in the central Al-Jabal-al-Akhdar mountain mountains during the months of October until December 2005 (Figure 3.1). The villages are located within a distance of 10 km of Sayq Qattanah, as the central settlement of the Al-Jabal-al-Akhdar mountains.

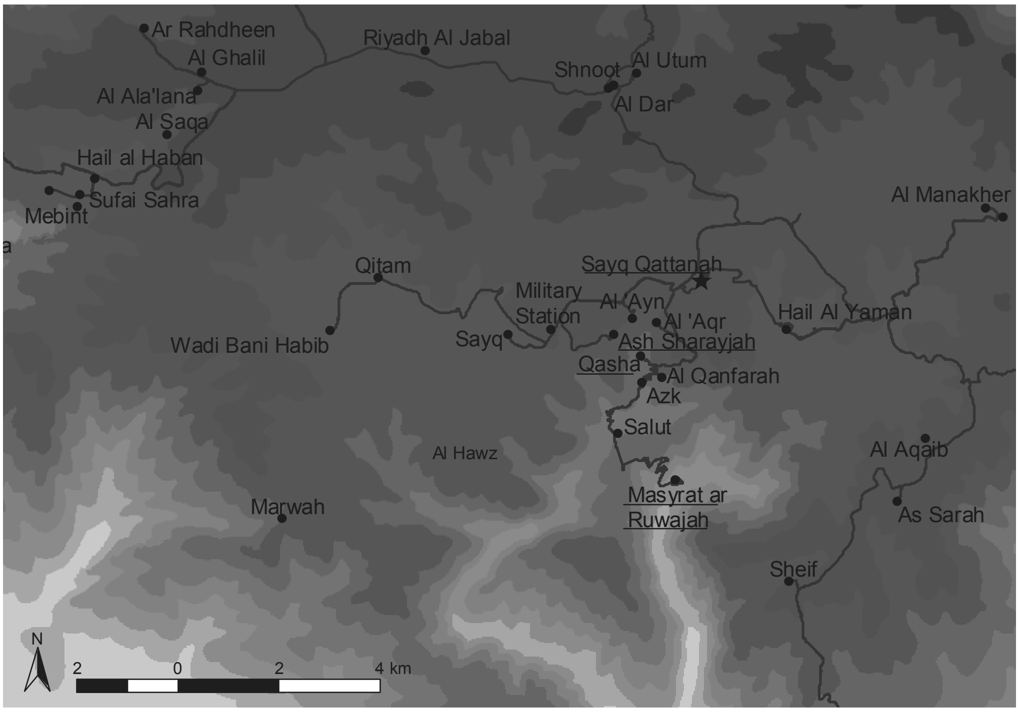

Figure 3.1. Study villages of the Al-Jabal-al-Akhdar mountains, Oman

3.2 Data collection

Interviews with livestock keepers

To gather qualitative and quantitative information about the goat management and in particular of the breeding, health and nutrition of the goats, three farmers in Masayrat and Ash Sharayjah and two farmers in Qasha' were interviewed using detailed formal questionnaires. Questions concerning the sale and purchase of animals, fodder and manure were asked to cover some important economic aspects related to the livestock husbandry.

An additional point of interest was the grazing practice and, if possible, maps were used to identify major grazing areas. However, some of the older farmers had problems to read the maps, so that oral descriptions were necessary. In Ash Sharayjah, one of the herders hired by the livestock keepers was asked about his herding routine as well as about the vegetation of the pastures, and discussions with the employees of the Agricultural Center of Sayq Qattanah were organized to clarify specific aspects concerning the health care of the animals.

Determination of feed intake

To estimate the total intake of fodder by the animals and to determine the important fodder sources, the external marker titanium dioxide (TiO_2) was used during an experimental period of seven days per village. Eight male goats of the cooperating farmers in Qasha' and Masayrat and six animals in Ash Sharayjah were chosen. However, one animal in Ash Sharayjah died during the study period. The animals were weighed twice and the average liveweight was determined (Table 3.1).

Table 3.1. Liveweight (kg) of study animals in three villages of the Al-Jabal-al-Akhdar mountains, Oman

Village	Masayrat	Qasha'	Ash Sharayjah
n	8	8	5
Mean	26	34	36
Max.	28	62	51
Min.	22	22	23

Starting four days prior to the experimental period, each animal orally received one capsule with 3g ± 0.03 of TiO_2 per day during the evening feeding at the homestead. If a capsule was destroyed or spat out by the goats, marker losses were estimated and additional capsules of either 3 g or 1 g of the marker were administered to assure an intake of approximately 3 g TiO_2 per animal per day. The total marker intake per animal per day was recorded.
During the experimental period, the animals were fitted with faecal collection bags in the evening to collect the faeces excreted over night (see appendix). The animals were tied at the homestead to avoid the loss of the bags and fed individually. The following morning, the collected faeces were weighed and samples taken for each animal. The samples were frozen and pooled at the end of the experimental period, as described in Table 3.2. Additionally, material was taken from the samples collected for each goat to form one pool per animal, which was dried at ambient temperature in the shade to determine the air-dry weight.

Table 3.2. Pooling of fresh faecal samples

	Masayrat	Qasha'	Ash Sharayjah
Animal		days	
1	1-2; 3-4; 5-6	2-3; 4-5; 6; 7	1-2; 3-5; 6-7
2	2; 3-4; 5	2-3; 4-5; 6-7	
3	1-2; 3-5; 6-7	2-3; 4-5; 6; 7	1-2; 3-5; 6-7
4	1; 7	1-2; 3-5; 6-7	1-2; 3-5; 6-7
5	1; 3; 5-6; 7	1-2; 3+5; 6-7	1; 2-3; 4; 5-6; 7-8
6	1; 3-5; 6-7	2-3; 4-5; 6-7	1; 2; 4-6; 7-8
7	1; 2; 4-5; 7	1-2; 3-5; 6-7	
8	1-2; 3-5; 6-7	1-2; 3-5; 6-7	

The fodder offered by the farmers during the experiment included fresh maize, alfalfa and grass hay as cultivated feeds, collected fodder, such as tree foliage and weeds from the fields, as well as supplements, including dates, fish, barley grain, wheat meal and meal rests. The quantity of the different feeds offered to the animals each day as well as the amount of fodder refused were weighed to calculate the approximate intake of the different feeds per animal and day. The components of supplement mixtures offered were weighed separately on three days during the experimental period and an average ratio was calculated. Samples of the green fodder offered at the homestead were taken each day and their air-dry weight determined. Samples of supplement feeds were taken from each farmer on three different days and pooled per each feed type and farmer at the end of the experimental period. Additionally, a sample of unboiled rice was taken. Daily access of the goats to the pasture areas was necessary to determine the fodder intake during grazing.

Grazing behavior of goats and pasture vegetation

To gain insight into the plant selection of goats on the pastures of the Al-Jabal-al-Akhdar mountains, grazing observations were carried out during four days per village. The observer followed the herd during the daily grazing period. In Masayrat, this period lasted between 4-6 hours, whereas the goats of Ash Sharayjah and Qasha' spent 8-10 hours on the pasture. Every three minutes, the observer recorded the number of animals feeding on the shrub and tree strata or the ground vegetation and individual plant species grazed by the goats were noted if possible. The average time goats spent feeding on the different plants allowed to identify the animals` preferred fodder plants during grazing. Samples of important pasture species were taken and their air-dry weight determined. Additionally, the botanical composition of the vegetation and the biomass offered by the ground vegetation were analyzed on the plateau near Sayq and the Al Hawz plateau 1.5 km southwest of Ash Sharayjah. The latter was regarded as sort of an enclosure, where goat grazing was strongly limited given the poor accessibility of this solitary plateau.

In eight different plots of 10 x 10 m^2 on the Sayq plateau, six plots of 20 x 20 m^2 in the wadis of the Sayq plateau and in five plots of 4 x 4 m^2 in the enclosure area, the ground cover of the different plant species was estimated using cover classes defined by Braun-Blanquet (1964). The plant species were determined according to Jongbloed et al. (2003) and at the herbarium of the Sultan Qaboos University. Prof. Dr. Annette Patzelt of the University's Biology Department helped to identify critical species. Within the plots, the biomass production of the grass and herb strata was determined by collecting plant material from 31 areas of 1 m^2 on the Sayq plateau, 23 areas in the wadis and twelve 1 m^2 areas on the Al Hawz plateau, comprising low, medium and highly vegetated areas. The air-dry weight of samples was determined and two pools formed for each location for further quality analyses. Additionally, the herbaceous cover of the Sayq plateau was determined with one transect walk on the plateau area and one through the wadis. Every ten meters, the proportion of bare, low, medium and highly covered ground was estimated. The biomass production of the ground vegetation was calculated using the stratified ground cover and the average biomass production.

3.3 Quality analysis of the feed samples

Samples of fodder plants, supplement feeds and pasture plants were analyzed to determine the concentration of dry matter (DM) and organic matter (OM) as well as of phosphorus (P) and nitrogen (N). Before grinding to pass a 1mm screen, all samples were dried in a forced drought oven at 60°C for one to two hours to eliminate the moisture that they might have been taken up during transport and storage. Rice, date fruits and fish samples were treated differently. The rice sample was boiled first and then dried at 60°C over night. Fish and date pulp were freeze-dried with liquid N_2 before they were ground.

To determine **dry matter (DM) and organic matter (OM)** of the different feed samples, duplicates of 2 g (± 0.5 g) were weighed, dried over night at 105°C, and weighed again. Subsequently, the samples were burned in a muffle furnace at 550°C for 5 hours. Remaining ash was weighed and organic matter content of the samples calculated.

For the determination of the **phosphorus (P) concentration**, the ash was washed into 100 ml flasks using 20 ml of HCl (32%). After leaving the ash-acid mixture over night, the flasks were filled to 100 ml with distilled water the following day. The solution was filtered using a Blue-Ribbon filter paper. Subsequently, 10 ml of the filtered solution were filled in a 100 ml flask, 15 ml of ammonium molybdat vanadat added and the flasks filled to 100 ml with distilled water. The P concentration in the solution was measured with a spectrophotometer at a wavelength of 460 nm.

The **nitrogen (N) concentration** of the feed samples was determined with a gas analyzer (FP-328, LECO), which burns the sample (0.03 g ± 0.005 g) at 950°C and measures the pressure of produced gases (NO_x). The N concentration of each sample was measured twice and the crude protein (CP) concentration calculated using the average N concentration of protein (factor 6.25).

Additionally, the **Neutral Detergent Fiber (NDF) concentration** of the feed samples was determined. The feed samples, including green fodder and pasture plants as well as barley grain and bread, were weighed (0.5 g ± 0.1 g) in duplicate. 100 ml of the neutral detergent solution, 2 ml of decahydronaphtalin and 0.5 g natrium sulfit were added and the mixture boiled for one hour, filtered and the flask washed out twice with hot distilled water followed by acetone. Subsequently, the remaining sample material was dried at 105°C over night, weighed again and the NDF concentration in the feed samples was calculated.

The concentration of **digestible organic matter (DOM)** of animal feed and pasture plants was determined by the Hohenheim gas test (HFT). This *in vitro* method is based on the measurement of gas (methane and carbon dioxide) produced during incubation of the samples in rumen fluid, and was developed to determine the digestibility of fodder plants. Therefore, fish samples were not analyzed.
The measurements were taken with three replicates per feed sample and repeated on two different days. Additionally, three hay samples with a standard gas production of 49.61 ml as well as six blanks were prepared to capture the daily differences in the composition and activity of the rumen liquor. 200 mg ± 0.02 mg of the grounded sample material was weighed into glass syringes. The pistons were greased and inserted to make the syringes airtight. The syringes were stored over night in an oven at 39°C.
The following day, rumen fluid was taken from two fistulated cows before the morning feeding. A reagent solution was prepared, including the rumen fluid as well as macro- and microminerals (see appendix). 30 ml of the reagent was filled into each syringe and the starting volume noted. The mixture was incubated for 24 hours in a water bath at 39°C. In the first six hours, the syringes were shaken hourly. If the volume exceeded 60 ml after seven hours, it was noted and the syringes reset to 40 ml. The following morning, the final volume was read, and the total gas production per sample calculated as follows (adapted after Close and Menke, 1986).

$$Gb = \frac{(V_{24}-V_0-Gb_0)*200*F_H}{W}$$

where:

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

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

V_0 = position of the piston at the beginning of incubation

Gb_0 = mean gas production in 24 hours of rumen liquor without sample (blank)

F_H = correction factor with FH= $49.61*(Gb_S-Gb_0)^{-1}$

Gb_S = mean gas production of standard feed mixture after 24 hours

W = weight of the tested sample in mg dry matter

Using the average gas production from both incubation days, the concentration of digestible organic matter was calculated (after Close and Menke, 1986).

$$DOM = 14.88 + 0.889*Gb + 0.0045*CP + 0.065*CA$$

where:

DOM = digestible organic matter concentration in %

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

CP = crude protein concentration of the sample in g kg^{-1} DM

CA = crude ash concentration of the sample in g kg^{-1} DM

Based on the results of the Hohenheim gas test, the metabolizable energy (ME) concentration was also calculated (after Close and Menke, 1986).

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

where:

ME = concentration of metabolizable energy in MJ kg^{-1} DM

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

CP = crude protein concentration of the sample in g kg^{-1} DM

CL = crude lipid concentration of the sample in g kg^{-1} DM taken from feed composition tables in Close and Menke (1986)

3.4 Quality analysis of faecal samples

The pooled and air-dried faecal samples were ground to pass a 1 mm screen and used to determine the dry matter, OM and P concentration as described for the feed samples. The frozen faecal samples were ground with a mortar and pestle and the N concentration determined with a gas analyzer (see above). Then, samples were dried over night at 105°C and DM concentration calculated.

The concentration of TiO_2 was determined, following a method developed by the Department of Animal Nutrition of the University of Kiel, Germany. For this, 2 g of the dried, grounded material were weighed into a flask, the exact weight noted and 50 ml of H_2SO_4 (96%) added. The resulting mixture was heated slowly to 90°C for about 30 minutes and then cooled down. 10 g of K_2SO_4 and 4 ml of $CuSO_4$ were added, and the mixture again heated slowly and boiled for 3-4 hours until it obtained a green color. Then it was cooled down again, poured into 500 ml flasks and filled up to 500 ml with distilled water. The solution was then filtered using a Blue Ribbon filter paper.

The concentration of TiO_2 was measured with a spectophotometer (UVIKON 930, Kontron Instruments, Neufahrn, Germany). Two mixtures were prepared for the following steps (see appendix). While mixture I contained hydrogenperoxide, which reacts with the TiO_2 and results in a yellow color, mixture II was used to measure the coloring of the solution itself (blank). In each of the two flasks, 10 ml of the filtered solution were filled. 1 ml of mixture I was added to one, 1 ml of mixture II to the other flask. The solutions were shaken and left to rest for at least half an hour.
The concentration of TiO_2 was measured based on the absorption of yellow light with the spectophotometer at a wavelength of 405 nm and was calculated as follows.

$$TiO_2\ (\text{mg g}^{-1}\ \text{FDM}) = \frac{EK/ES*0.4*50}{W}$$

where:

EK = extinction of the sample corrected by the extinction of the blank

ES = extinction of the standard corrected by the extinction of the blank

W = weight of the tested sample in g dry matter

3.5 Calculation of the organic matter intake

The formula of Gordon (1995), based on the total faecal OM excretion (FOM; g d^{-1}) and digestibility (DOM; g kg^{-1}), was used to calculate the total organic matter intake (IOM; g d^{-1}).

$$IOM = \frac{FOM}{1 - DOM}$$

The total amount of faeces excreted was calculated based on the concentration of the marker TiO_2 in the faecal samples, using the formula of Lippke (2002).

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

where:

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

M_D = applied marker dose (g d^{-1})

M_{conc} = marker concentration in faeces (g kg^{-1} DM d^{-1})

R = recovery of the marker (%)

The weighted average of the values for the 7-day experimental period were used for the applied marker dose per animal and day as well as the marker concentration in the faeces. According to Titgemeyer et al. (2001), the recovery rate of TiO_2, when used as a faecal marker in ruminants, is 93%.

The formula by Lukas et al. (2005), which is based on the crude protein concentration in the faeces, was used to calculate the average organic matter digestibility of the animals` diets. This approach was also applied by Predotova (2005) in her MSc thesis.

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

where:

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

To calculate the intake from the pasture, the intake of organic matter in the stable was subtracted from the total organic matter intake calculated.

3.6 Statistical analysis

The qualitative and quantitative data provided by the interviews was categorized whenever appropriate. Since only eight farmers were interviewed, absolute numbers are presented instead of percentages. Results of the marker study were tested for normal distribution using the Kolmogorov-Smirnov test and, if necessary, transformed with $y = x^2$, $y = x^{1.5}$, $y = \lg x$, $y = \sqrt{x}$ and $y = 1/\sqrt{x}$. Statistical tests were carried out with the SPSS 12.0 software for Windows. To compare the data and determine significant differences between goats of the three villages or goats under different management practices ($P \leq 0.05$), the Tukey test was applied. Simple linear regression analysis was used to identify significant correlations between different variables and to determine the effects of fodder intake and quality as well as diet composition on the intake and excretion of organic matter and nutrients.

4 Results

4.1 Herd management

The eight families of the interviewed farmers had between five and ten (n=5) and even more than ten family members (n=3). In every household, several members were involved in the livestock husbandry. Besides the farmer himself, this included the women (n=7) and the children (n=4) of the households. Besides livestock, all farmers owned fields for crop production and in seven households at least one member had an additional income from outside the farm. This included income from employments in the military station near Sayq Qattanah as well as positions as bus drivers or teachers and pension payments.

All farmers have kept goats in the past, however, only five farmers thought that one of their children would take over the livestock husbandry in the future. The main reasons for keeping animals were the production of meat (n=5) and the additional income (n=4). Three farmers regarded milk and manure as important outcomes of goat husbandry (Table 4.1).
The average herd size per household was 25 goats (SD 15.2), ranging from two farmers in Ash Sharayjah with only nine animals to one farmer with 50 goats in Qasha'. Only two households also had cattle and chickens.

Table 4.1. Main reasons of eight farmers in three villages of the Al-Jabal-al-Akhdar mountains, Oman, for keeping livestock

Reason	Farmers (n)
Meat production	5
Source of income	4
Manure	3
Milk	3
Love of the animals	3
Tradition	2
Part of the system	2

The herd size of four farmers has been decreasing over the past 15 years, while the others maintained (n=2) or even increased their stock numbers (n=2). All farmers stated that herd size changes throughout the year due to the reproduction cycle of the goats, the kidding times lasting from October to December as well as in the early summer months and the sales of animals mainly during Eid celebrations. Only one farmer adjusts the herd size to the available fodder on the pasture. While in neighboring villages, such as Hail al Haban and Al 'Aqr (Figure 2.1), goats of the Dhofari breed are kept, herds of the interviewed farmers included only animals of the Al-Jabal-al-Akhdar breed.

The goats are mainly kept for meat production. Seven farmers sell animals for slaughtering at the Souq in Nizwa (n=7) or to people coming directly to the farm (n=2). All farmers slaughter animals for their own consumption, especially when visitors are expected, and consume the extra milk that the goats produce during their lactation period (n=8).

Five or less animals are sold per year (n=5), while only two farmers sell more than five animals. Additionally, all farmers slaughter less than five animals for their own consumption and four 1 - 3 animals per year. Animals are also sold when money is needed (n=5). According to one farmer current prices (October 2005) for slaughter animals vary between 70 OR* for female and up to 200 OR for male goats.

Depending on the herd size, between five and ten goat kids are born per year (n=5), while only one farmer reported less than five and one even more than ten kids. Breeding is done randomly, since bucks and does freely grazed together on the pasture. Only two farmers use breeding pens with a group of selected does. Breeding bucks are born and raised in the herd (n=5). However, since all goats of a village graze on pasture, breeding with bucks of neighboring farmers is also possible (n=8). Although only one farmer in Qasha' mentioned that bucks from other villages run in the herd, male animals from Al 'Ayn and Sayq Qattanah were joining the herd of Ash Sharayjah during the grazing observations. None of the households purchases breeding bucks from outside the area. Furthermore, one farmer in Ash Sharayjah mentioned that breeding was done more professional in the past, when several farmers together bought and exchanged breeding bucks.
Health and fitness are important criteria for the selection of animals by farmers (n=6), while only two farmers consider the fast growth of the animal. Three farmers mentioned the physical appearance, such as the body condition or the color of the hair, as important reasons for the sale or the slaughtering of an animal. Selected does might be kept up to an age of seven to ten years, while bucks are usually sold at the age of 2-3 years.

Abscesses caused by *Corynebacterium pyogenes* (n=7) and the respiratory disease due to *Mycobacterium mycoides* (n=6) are the most prominent health problems in the goat herds (Table 4.2). Farmers (n=7) use the medical assistance provided by the agricultural center in Sayq Qattanah and additionally isolate sick animals from the herd (n=6). Only one farmer treats his animals exclusively by himself and is also the only one who does not participate in the annual vaccinations for rabies, foot and mouth disease and enterotoxaemia. Only two farmers stated that they regularly use remedies for parasites provided by the agricultural centre.

Table 4.2. Health problems in goat herds of the Al-Jabal-al-Akhdar mountains, Oman, as perceived by eight farmers

Health problem	Farmers (n)
Abscesses	7
Pneumonia	6
Claw problems	4
Diarrhea	3
External parasites	3
Infertility/ Abortion	3
Internal parasites	2
Malnutrition	2
Malformation in kids	1
None	1

* 1OR = 2.02 €

All farmers offer purchased feed as well as fodder from their own fields as grazing supplements. While in Ash Sharayjah and Qasha', dates are bought at the Souq in Nizwa, the farmers in Masayrat rarely buy dates and mainly use fruits from their own palms (n=3). Cultivated green fodder includes maize (*Zea mays* L.), alfalfa (*Medicago sativa* L.) and barley (*Hordeum vulgare* L.). Additionally, leaves from trees (*Olea europaea* ssp. *cuspitata, Ziziphus spina-christi*) and weeds collected in the garden are fed (n=4). Supplement feeds offered to the animals are dates and fish (n=8), but also wheat meal (n=3) and barley grain (n=4). Three farmers also pointed out that they offer meal left overs, such as bread, rice, vegetables or fruits to their animals. Pregnant and lactating does and sometimes male animals for slaughter get more fodder than the rest of the herd (n=8).

Animal fodder offered at the homestead changes throughout the seasons (n=6). While supplement feeds such as dates and fish do not change (n=2) or only when prices are high (n=1), the green fodder varies according to season (n=4). During times of higher precipitation more alfalfa is grown (n=2) and more weeds from the garden are offered (n=1), while during drier or colder periods maize is cultivated (n=2) and more fodder is collected from trees (n=1). One farmer in Qasha' stated explicitely to feed less if there is more rain and consequently more fodder available on the pasture.

Animal manure collected over night is used to fertilize the terraces (n=8). While farmers interviewed in Masayrat and Qasha' obtained enough manure from their own livestock, the three farmers in Ash Sharayjah additionally bought 40, 50 and even 100 bags (5 kg) of manure per year from livestock keepers in Hail al Haban for 1 OR per bag.

4.2 Fodder quality and intake

Fodder quality

Organic matter concentration of the fodder offered at the homestead varied between 782 g kg^{-1} DM in fish and 976 g kg^{-1} DM in dates (Table 4.3). Other supplements also had a high concentration of digestible organic matter (799 g kg^{-1} OM) and of metabolizable energy (11.7 MJ kg^{-1} OM), especially in comparison to collected fodder with only 500 g DOM kg^{-1} OM and 5.8 MJ ME kg^{-1} OM.

Table 4.3. Quality of different feeds offered to goats in three villages of the Al-Jabal-al-Akhdar mountains

		OM		ME		DOM	
		g kg^{-1} DM		MJ kg^{-1}OM		g kg^{-1} OM	
Feed type	n	Mean	SD	Mean	SD	Mean	SD
Cultivated green fodder	8	875	16.5	7.0	0.6	639	43.3
Collected fodder	8	914	48.3	5.8	1.15	500	91.4
Dates	6	976	4.8	10.9	0.23	754	12.5
Fish	3	782	9.4				
Other supplements*	4	971	21.5	11.7	1.54	799	70.1
Pasture plants	17	892	62.1	5.4	1.31	490	113.5

* barley grain, bread, rice and wheat meal

The leaves collected from *Ziziphus spina-christi* and *Olea europea* ssp. *cuspidata* had a low concentration of digestible organic matter of 498 g and 381 g kg^{-1} OM and a low concentration of metabolizable energy of 6.2 MJ and 4.5 MJ kg^{-1} OM. Supplements, such as bread and rice, and especially dates showed a high digestibility (799 g DOM and 754 g DOM kg^{-1} OM), combined with very high concentration of metabolizable energy (11.7 MJ and 10.9 MJ kg^{-1} OM). However, N and P concentrations in dates with 4 g N and 0.7 g P kg^{-1} OM were rather low. In contrast, nutrient concentrations in fish were much higher (135 g N and 21.0 g P kg^{-1} OM; Table 4.4).

Table 4.4. Quality of different feeds offered to goats at the homestead in three villages of the Al-Jabal-al-Akhdar mountains, Oman

		OM ($g\ kg^{-1}$ DM)		ME ($MJ\ kg^{-1}$ OM)		DOM ($g\ kg^{-1}$ OM)		N ($g\ kg^{-1}$ OM)		P ($g\ kg^{-1}$ OM)		NDF ($g\ kg^{-1}$ OM)	
Feed	n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Alfalfa*	2	865	6.7	7.6	0.14	660	1.3	33	0.2	3.2	0.28	473	16.2
Maize (milk stage)*	5	873	13.6	7.4	0.68	646	37.8	19	3.2	4.3	0.59	679	33.0
Grass hay (purchased)	1	905		6.7		560		16		1.3		857	
Dates	6	976	4.8	10.9	0.23	754	12.5	4	0.3	0.7	0.10		
Fish	3	782	9.4					135	8.1	21.0	1.77		
Barley grain	1	976		11.9		803		17		2.6		485	
Wheat meal	1	941		9.5		701		27		11.1		549	
Bread	1	975		12.8		866		19		1.7			
Rice	1	992		12.6		824		13		0.8			
Weeds*	2	839	19.0	6.0	0.09	587	15.2	19	1.6	2.9	0.97	702	95.1
Acacia gerardii (pods)	1	948		7.5		564		27		2.0			
Olea europea ssp. *cuspidata***	2	936	7.4	4.5	0.25	381	23.4	15	0.5	1.5	0.15	425	11.6
*Ziziphus spina-christi***	3	939	18.5	6.2	1.00	498	42.2	19	1.0	0.8	0.66	410	72.9

* harvested green; ** leaves green

In comparison to the fodder plants offered at the homestead, plants collected from pasture had a lower concentration of digestible organic matter and metabolizable energy, ranging from 360 g DOM kg^{-1} OM and 3.2 MJ ME kg^{-1} OM in *Pteropyrum scoparium*, a shrub on the pastures in Masayrat, up to 684 g DOM kg^{-1} OM and 6.8 MJ ME kg^{-1} OM in young plants of *Ficus cordata* ssp. *salicifolia* (Table 4.5)

Table 4.5. Quality of pasture plants (one sample per plant) selected by grazing goats on the Al-Jabal-al-Akhdar mountains, Oman

Plant species	OM	ME	DOM	N	P	NDF
	g kg^{-1} DM	MJ kg^{-1} OM	g kg^{-1} OM			
Acacia gerardii (leaves)	919	5.0	435	16	0.6	460
Acacia gerardii (pods)	942	7.1	543	26	1.6	495
Capparis spinosa	892	5.9	519	22	0.7	489
Dodonea viscosa	943	4.6	382	14	0.7	359
Euryops arabicus	897	6.6	561	10	0.7	311
Ficus cordata ssp. *salicifolia*	773	5.3	617	22	n.d.	n.d.
F. cordata ssp. *salicifolia juv.*	812	6.8	684	26	2.6	371
Olea europaea ssp. *cuspidata*	904	3.9	372	9	0.6	350
Potamogeton nodosus	764	5.0	604	48	5.1	n.d.
Pteropyrum scoparium	867	3.2	360	10	1.0	579
Saccharum ravennae	957	4.7	371	5	0.4	883
Sideroxylon mascatense	943	5.5	443	16	0.4	483
Tavernia glabra	842	6.1	589	27	1.8	398
Unidentified wooden species*	956	3.6	305	10	0.6	597
Ziziphus hadjarensis	935	5.5	558	12	1.0	568
Ziziphus spina-christi	881	6.3	450	8	0.5	512

* found in the wadis of the Sayq plateau, possibly related to the date palm *(Phoenix* ssp.*)*; n.d. not determined

The overall diet digestibility derived from the crude protein concentration in the faeces varied between 706 g kg^{-1} OM (SD 16.4) in Ash Sharayjah and 720 g kg^{-1} OM (SD 20.9) in Masayrat. These values are higher than the digestibility obtained by the HFT tests for the pasture plants and for the fodder offered at the homestead and point to the positive influence of dates and other supplements, such as wheat meal, barley grain or rice, on the overall diet digestibility.

The average NDF concentration of the selected pasture plants of 490 g kg^{-1} OM (SD 150.3) was similar to the concentration of the collected leaves offered at the homestead (425 g kg^{-1} OM; SD 15.7) as well as of alfalfa (473 g kg^{-1} OM; SD 16.2), while the NDF concentration of maize (679 g kg^{-1} OM; SD 33.0) and especially of grass hay (857 g kg^{-1} OM) were higher. The latter was purchased at the Souq in Nizwa and, according to the salesmen, was grown in the Batinah plains. It showed a high proportion of grass stalks, which explains the high NDF concentration.

Fodder intake

Total organic matter intake per metabolic body mass ($kg^{-0.75}$) did not differ significantly between the goats of the three villages (P>0.05) with an average minimum of 88 g $kg^{-0.75}$ d^{-1} in Masayrat and an average maximum of 107 g $kg^{-0.75}$ d^{-1} in Qasha' (Table 4.6). The high standard deviation of 20.6 in the latter oasis was the result of the diverging body weight of the animals (Table 3.1) and the related differences in total OM intake.

The same applied to the average N and P intake of 1.13 g - 1.44 g N $kg^{-0.75}$ d^{-1} and 104 mg - 133 mg P kg^{-075} d^{-1}. While total organic matter intake was higher in Ash Sharayjah than in Masayrat, it was the opposite for the N and P intake. However, these differences were not significant (P>0.05).

Table 4.6. Total organic matter (IOM), nitrogen (IN) and phosphorus (IP) intake of goats in three villages of the Al-Jabal-al-Akhdar mountains, Oman (per $kg^{-0.75}$ d^{-1})

		I OM (g)		IN (g)		IP (mg)	
Village	n	Mean	SD	Mean	SD	Mean	SD
Masayrat	8	88	16.7	1.17	0.27	113	33.1
Qasha'	8	107	20.6	1.44	0.76	133	103.5
Ash Sharayjah	5	95	16.6	1.13	0.23	104	32.6

The fodder offered at the homestead accounted for 53%, 44% and 29% of the total OM intake in Ash Sharayjah, Masayrat and Qasha'. At 31 g $kg^{-0.75}$ d^{-1}, OM intake from fodder in Qasha' was significantly lower than in Ash Sharayjah (51 g OM $kg^{-0.75}$ d^{-1}; P≤0.05). However, there was not only a difference in the quantity offered at the homestead, but also in the diet composition (Figure 4.1). Dates were the most important supplement feed in Qasha' (26.3 g OM $kg^{-0.75}$ d^{-1}), accounting for 83% of the total organic matter intake at the homestead, whereas in Masayrat, they only contributed to 48% to the fodder intake at the homestead (18.0 g OM $kg^{-0.75}$ d^{-1}, P≤0.05). Although, organic matter intake from dates was highest in Ash Sharayjah (32.9 g OM $kg^{-0.75}$ d^{-1}), the differences to Qasha' and Masayrat were not significant due to the varying feeding practices of three farmers (P>0.05).

In Qasha', farmers did not offer collected fodder, such as tree foliage or weeds from the garden, and only 1.6 g OM $kg^{-0.75}$ d^{-1} of hay were taken up by the animals. In contrast, leaves and seeds from *Ziziphus spina-christi, Olea europea* ssp. *cuspidata* and *Acacia gerardii* as well as *Achyranthes aspera*, a weed found in the gardens, summed up to 10.3 g $kg^{-0.75}$ OM intake per day. Together with the intake of cultivated maize (5.4 g OM $kg^{-0.75}$ d^{-1}), the collected fodder accounted for 17% of the total OM intake in Ash Sharayjah. In contrast thereto, an intake of 11.1 g OM $kg^{-0.75}$ d^{-1} of supplement feeds other than date represented almost 13% of the total OM intake in Masayrat and was therefore significantly higher than in the other two oases (P≤0.05).

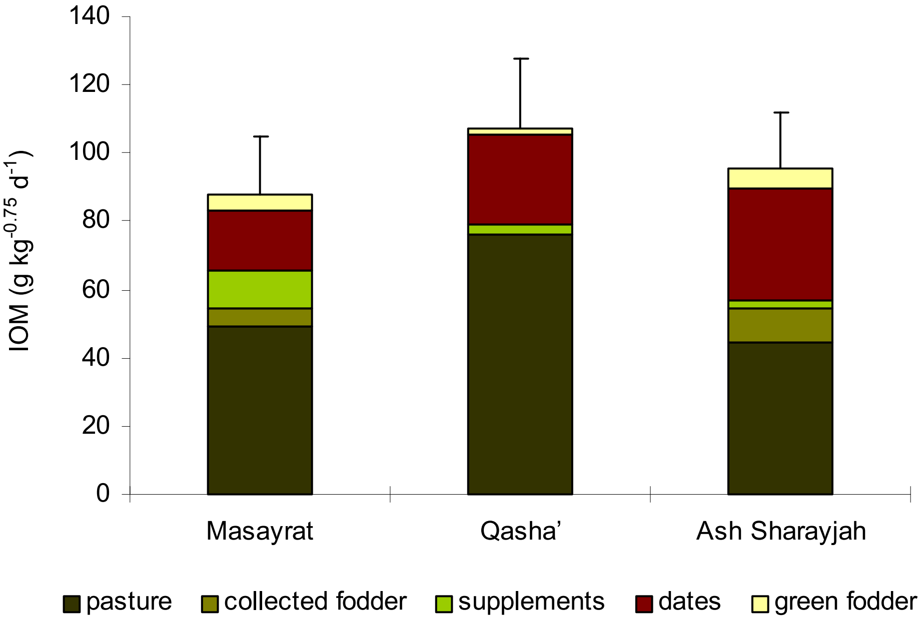

Figure 4.1. Organic matter intake (IOM) of goats in three villages of the Al-Jabal-al-Akhdar mountains, Oman, by feed type (g kg$^{-0.75}$ d^{-1})

The pastures were an important source of organic matter and nitrogen in all three oases. While in Masayrat 56% of the total OM intake originated from pasture (50 g kg$^{-0.75}$ d^{-1}; SD 18.0), the organic matter intake during grazing in Qasha' of 76 g kg$^{-0.75}$ d^{-1} (SD 24.2) accounted for even 71% of the total OM intake. This was significantly higher than the intake in Ash Sharayjah of 44 g OM kg$^{-0.75}$ d^{-1} (SD 13.9; $P \leq 0.05$), representing only 47% of the total OM intake. Furthermore, the OM and nutrient intake on pasture varied between different animals. While heavier animals were not offered significantly more fodder at the homestead ($P > 0.05$), they showed a higher intake on pasture ($r = 0.77$), which led to an increased total OM intake ($r = 0.85$; Figure 4.2).

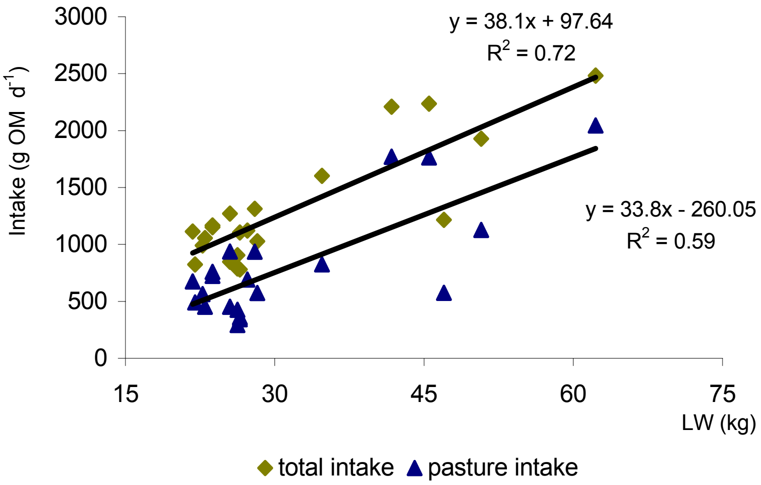

Figure 4.2. Linear regression between the liveweight (kg) and total and pasture OM intake of goats in three villages of the Al-Jabal-al-Akhdar mountains, Oman

No differences in the OM intake during grazing were observed for animals that were herded or not herded as well as those that were fed once or twice a day (P>0.05). Thus, the grazing practice as well as feeding time did not seem to influence the intake of the animals on pasture. However, the intake during grazing was negatively influenced by an increasing intake at the homestead (r=-0.62), and especially goats that were offered more green fodder, including both cultivated plants and collected feeds, ingested less forage during grazing on pasture (r=-0.68).

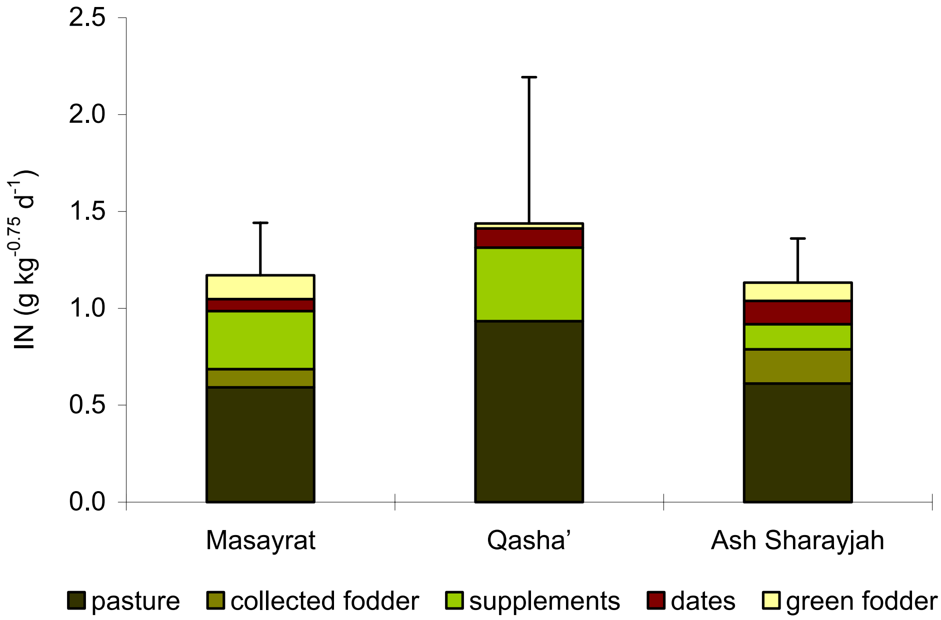

Figure 4.3. Nitrogen intake (IN) of goats in three villages of the Al-Jabal-al-Akhdar mountains, Oman, by feed type (g kg$^{-0.75}$ d^{-1})

The pasture vegetation also supplied 51% - 65% of the total N intake, being significantly higher in Qasha' with 0.9 g N kg$^{-0.75}$ d^{-1} than in Masayrat, where only 0.6 g N kg$^{-0.75}$ d^{-1} originated from the surrounding rangeland (P≤0.05; Figure 4.3). Additionally, supplements other than dates were an important source of nitrogen in the two oases with 0.3 g N kg$^{-0.75}$ d^{-1} in Masayrat and 0.4 g N kg$^{-0.75}$ d^{-1} in Qasha'. In particular, the proportion of fish in the diet was positively correlated with the total N intake (r=0.66; P≤0.05). Collected and cultivated fodder as well as dates and other supplements contributed almost equally to the total nitrogen intake of animals in Ash Sharayjah.

The forage intake on pastures played a less important role for the animals` phosphorus supply, providing only 21% - 35% of the total P intake per day, while supplement feeds other than dates contributed 23% - 51% to the daily P intake (Figure 4.4). The difference was most profound in Qasha', where the P intake from pasture of 46.5 mg $kg^{-0.75}$ d^{-1} was even lower than the P intake from supplements (67.6 mg $kg^{-0.75}$ d^{-1}). Consequently, the P intake from cultivated green fodder was significantly higher in the other two oases with 17 mg P $kg^{-0.75}$ d^{-1} in Masayrat and 25 mg P $kg^{-0.75}$ d^{-1} in Ash Sharayjah ($P \leq 0.05$).

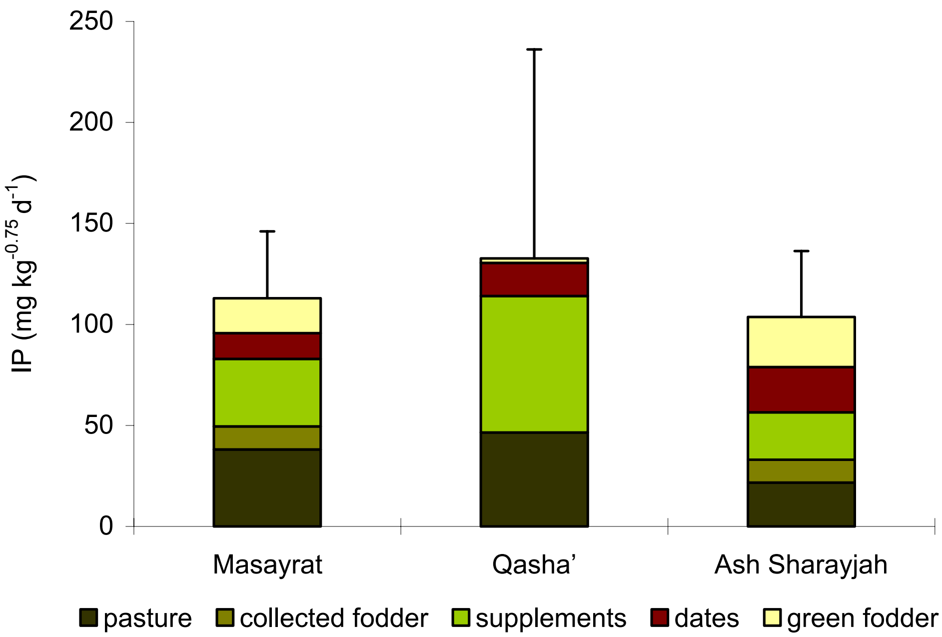

Figure 4.4. Phosphorus intake (IP) of goats in three villages of the Al-Jabal-al-Akhdar mountains, Oman, by feed type (mg $kg^{-0.75}$ d^{-1})

The amount of dates and fish offered to the animals influenced the total nutrient supply as well as the average phosphorus concentration in the fodder. Thus, a higher proportion of dates in the animals` diets led to a significantly lower phosphorus concentration (r=-0.55) and intake (r=-0.59). On the other hand, both parameters increased with the increasing intake of fish (r=0.91; r=0.96). The intake of cultivated fodder and other supplements did not influence the P intake.

In all three villages, the intake of organic matter, N and P from external sources, including purchased fodder, collected tree foliage and pasture plants, was higher than the intake from internal sources, such as cultivated green fodder and weeds from the fields (Table 4.7).

Table 4.7.Total organic matter (IOM), nitrogen (IN) and phosphorus (IP) intake of goats in three villages of the Al-Jabal-al-Akhdar mountains, Oman, by feed source (per kg$^{-0.75}$ d^{-1})

			IOM (g)		IN (g)		IP (mg)	
Village	Source	n	Mean	SD	Mean	SD	Mean	SD
Masayrat	external*	8	68	18.6	1.0	0.23	82	24.8
	internal**	8	20	7.6	0.2	0.09	31	12.6
Qasha'	external	8	107	20.6	1.4	0.75	145	106.9
	internal	8	0	0.0	0.0	0.00	0	0.0
Ash Sharayjah	external	5	90	17.8	1.0	0.17	91	13.4
	internal	5	6	3.5	0.1	0.11	25	25.9

* external= pasture plants, collected tree foliage, purchased fodder (hay, fish, wheat meal, barley grain, meal left over and dates in Qasha' and Ash Sharayjah)
** internal= cultivated fodder, weeds from the fields, dates in Masayrat

The proportion of external feeds of the total organic matter (77%), nitrogen (83%) and phosphorus (75%) intake was lowest in Masayrat. While in Ash Sharayjah external sources provided 94%, 91% and 76% of the total OM, N and P intake, farmers in Qasha' did not offer any fodder from the fields and purchased feeds accounted for even 100% of the animals` diets.

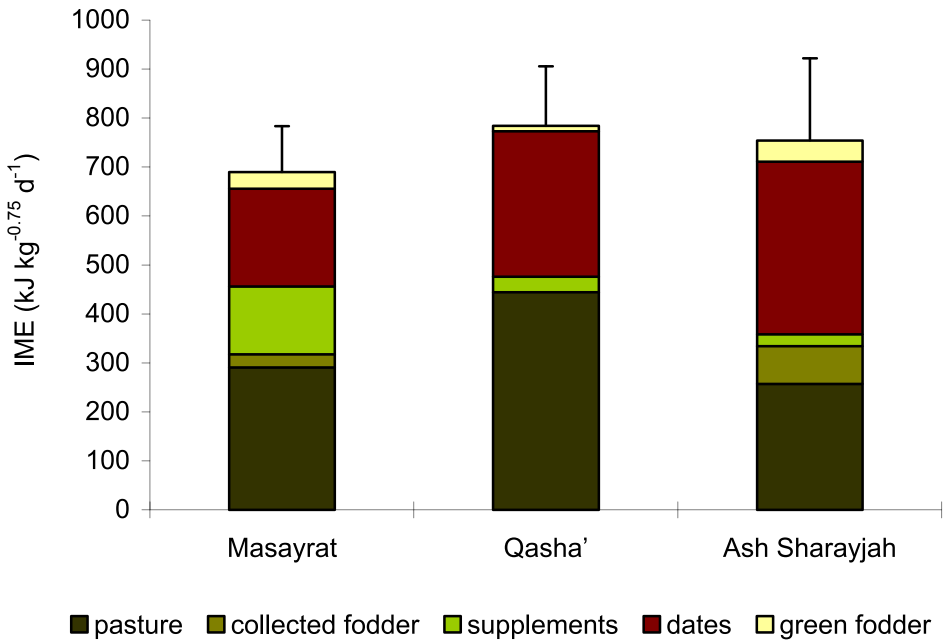

Figure 4.5. Metabolizable energy intake (IME) of goats in three villages of the Al-Jabal-al-Akhdar mountains, Oman (kJ kg$^{-0.75}$ d^{-1})

The average intake of metabolizable energy was 741 kJ $kg^{-0.75}$ d^{-1} (SD 125.3) and was higher in Ash Sharayjah (754 kJ $kg^{-0.75}$ d^{-1}; SD 167.8) and Qasha' (784 kJ $kg^{-0.75}$ d^{-1}; SD 121.5) than in Masayrat (690 kJ $kg^{-0.75}$ d^{-1}; SD 93.6). The pasture intake accounted for 32% to 57% of the daily energy intake. With the exception of Masayrat, where other supplements, and mainly boiled rice, supplied 20% of the ME intake, dates were the main source of energy provided at the homestead, supplying 29% to 47% of the daily energy intake (Figure 4.5).

In Qasha', an average NDF intake of 46.6 g $kg^{-0.75}$ d^{-1} (SD 13.39) was obtained by the animals, of which 97% were provided by the intake on pasture. In contrast thereto, the fodder offered at the homestead accounted for 18% and 28% of the NDF intake in Masayrat (34.0 g $kg^{-0.75}$ d^{-1}; SD 11.09) and Ash Sharayjah (32.5 g NDF $kg^{-0.75}$ d^{-1} (SD 7.80), since the farmers in both villages provided a higher proportion of cultivated and collected fodder to the animals than farmers in Qasha'.

4.3 Quality and excretion of the faeces

Organic matter, nitrogen and phosphorus concentrations of the faeces excreted by goats did not differ significantly between the three villages (P>0.05). The faecal organic matter varied between 846 g and 863 g kg^{-1} DM and the faecal N concentration in Masayrat (27.9 g N kg^{-1} OM) was only slightly higher than in Qasha' and Ash Sharayjah (26.3 g N kg^{-1} OM). However, the P concentration of the faeces was highest in Ash Sharayjah (4.5 g P kg^{-1} OM; Table 4.8).

Table 4.8. Quality of the faeces excreted by goats in three villages of the Al-Jabal-al-Akhdar mountains, Oman

		OM		N		P	
		(g kg^{-1} DM)		(g kg^{-1} OM)			
Village	n	Mean	SD	Mean	SD	Mean	SD
Masayrat	8	846	17.9	27.9	2.75	3.9	0.72
Qasha'	8	853	18.6	26.3	1.17	3.8	0.84
Ash Sharayjah	5	863	13.5	26.3	1.98	4.5	1.70

The amounts of faecal organic matter and nitrogen excreted per unit liveweight (kg^{-1}) were also not significantly different between the three villages (P>0.05). The organic matter excretion varied between 10.4 g (SD 2.80) and 13.2 g kg^{-1} d^{-1} (SD 2.24) in Masayrat and Qasha', while the daily amounts of nitrogen excreted over the faeces were 0.29 g kg^{-1} d^{-1} (SD 0.06) and 0.36 g kg^{-1} d^{-1} (SD 0.04). This was equivalent to 56% and 66% of the total N intake (Figure 4.6).

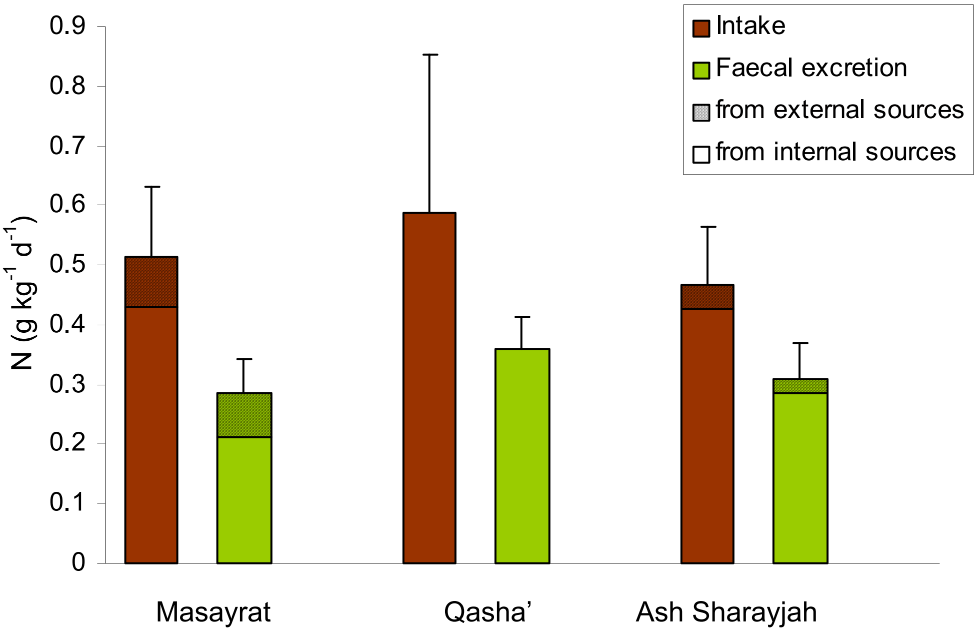

Figure 4.6. Nitrogen intake and excretion of goats in three villages of the Al-Jabal-al-Akhdar mountains, Oman (g kg^{-1} d^{-1})

In contrast, 79% to 95% of the total P intake were excreted over the faeces in Masayrat and Qasha’ (Figure 4.7). The average P excretion in Ash Sharayjah even exceeded the mean intake of phosphorus of the goats, and also in Qasha’ and Masayrat, a negative P balance was obtained for animals of single farmers. Although differences between the villages were not significant (P>0.05), P excretion in Masayrat (39.7 mg kg^{-1} d^{-1}) was about 20% lower than in Qasha’ (49.6 mg kg^{-1} d^{-1}).

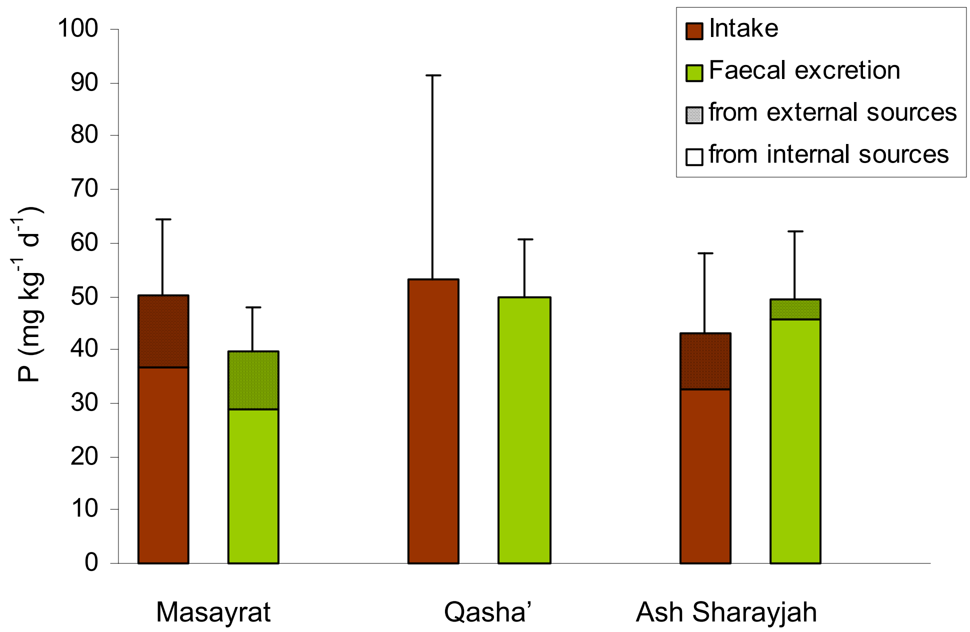

Figure 4.7. Phosphorus intake and excretion of goats in three villages of the Al-Jabal-al-Akhdar mountains, Oman (mg kg^{-1} d^{-1})

A higher intake of organic matter (r=74), especially from pasture and collected fodder (r=0.75), and an increased NDF concentration in the diet resulted in an increasing OM excretion (r=0.55). Although nitrogen concentration in the faeces was lower (r=-0.58), the amount of nitrogen excreted also increased with a higher OM (r=0.71) and NDF intake (r=0.76). In contrast, the average N and P concentration in the fodder did not affect the nutrient excretion or concentrations in the faeces. Similarly, the feeding of fish also did not influence the nutrient concentrations in the faeces and no significant differences were obtained with this respect between animals that were or were not offered fish (P>0.05).

During the study period, an average of 5.0 g kg^{-1} d^{-1} (SD 1.48) of faecal organic matter, 0.13 g kg^{-1} d^{-1} (SD 0.04) of nitrogen and 19.2 mg kg^{-1} d^{-1} (SD 5.05) of phosphorus were collected over night. This represented 42% and 43% of the total excretion and is approximately the amount that can be collected by the farmer for the fertilization of the cultivated fields.

4.4 Pasture vegetation and grazing behavior of goats

Pasture management

Every day, the farmers send out all their goats on pasture with the exception of the very young stock or sick animals. One farmer sometimes keeps goats determined for slaughter at home for a better feeding and consequently a faster growth. The reasons for grazing of the animals are the additional source of fodder (n=6) and the benefits for the health of the goats, such as the direct sunlight, the fresh air and the exercise (n=4). While the animals of only a few farmers graze together in Qasha' and Masayrat, all households of Ash Sharayjah send out their goats in one herd, which is joined by a small number of animals from Al 'Ayn and Sayq Qattanah.

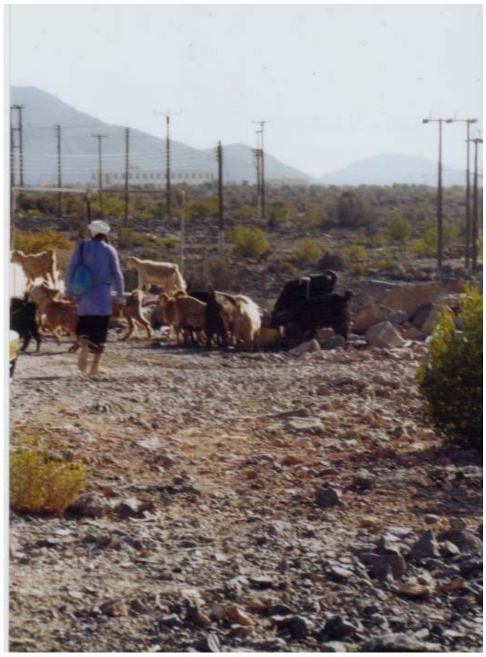

Figure 4.8. The herder from Ash Sharayjah, Al-Jabal-al-Akhdar, Oman, is leading the goats to a watering point

In Ash Sharayjah and Qasha', the goats are herded during grazing (Figure 4.8). While in the past, members of several families accompanied the herd, farmers of Ash Sharayjah hire two herders since 1998. They take weekly turns and receive 9 OR per goat per year and extra payments in case of any incidences out on pasture. In Qasha', the animals of two households are herded during the day by different members of the families. In Masayrat, some households guarded the animals throughout the day in the past, as reported by one farmer. However, since five years, several family members just take the animals out to pasture and leave them to come home by themselves. The main reason for herding the animals is the protection (n=5), since the herders can avoid incidents with wild animals, such as snakes or foxes, help in case of kidding or injury and prevent the loss of animals. Additionally, the herder leads the goats to pastures with more and higher quality fodder (n=3) or prevents conflicts with neighbors or people from other villages (n=2).

Although the access to the grazing land is free, four farmers and the herder stated that arrangements exist between the villages to avoid that animals of different oases graze together on the same pasture. All villages have several pastures, and in Masayrat, separate grazing areas were defined for single households or groups of farmers. The interviewed households use the pastures in the valley and on the hillslopes in the east of the village (Figure 4.9). Other households lead their animals further down the valley or direct them towards the hillslopes in the southeast of the village. Since the animals are not herded and stay fairly close to the oasis in comparison to Ash Sharayjah and Qasha', they already return around midday. However, not all goats are immediately locked up in the stable. Some stay in the close proximity of the village in the afternoon or even browse on trees standing in between the houses.

In Qasha', the two households involved in the study keep their goats in stables in Al Qanfarah. From there, the farmer and the children of one family lead the animals to the pastures in the east of the village. The other household brings the goats to the pastures in the southwest (Figure 4.9), where some animals of Salut join the herd. While the women of this family leave the goats on pasture and return home earlier, the farmer stays with the animals throughout the day. Both families take daily turns in herding the goats.

In Ash Sharayjah, the herders decide about the grazing routine. The pasture in the southwest of the village is only used 2-3 times per year, since it is rather small, while the pastures on the Sayq plateau are grazed on a daily basis (Figure 4.9). The area available for grazing is strongly limited due to the military area and the expanding housing areas of Sayq Qattanah. While goats of Al ʿAyn graze in the western parts of the plateau, the herders of Ash Sharayjah lead the goats further east. However, in the winter, when days are shorter, animals do stay closer to the village.

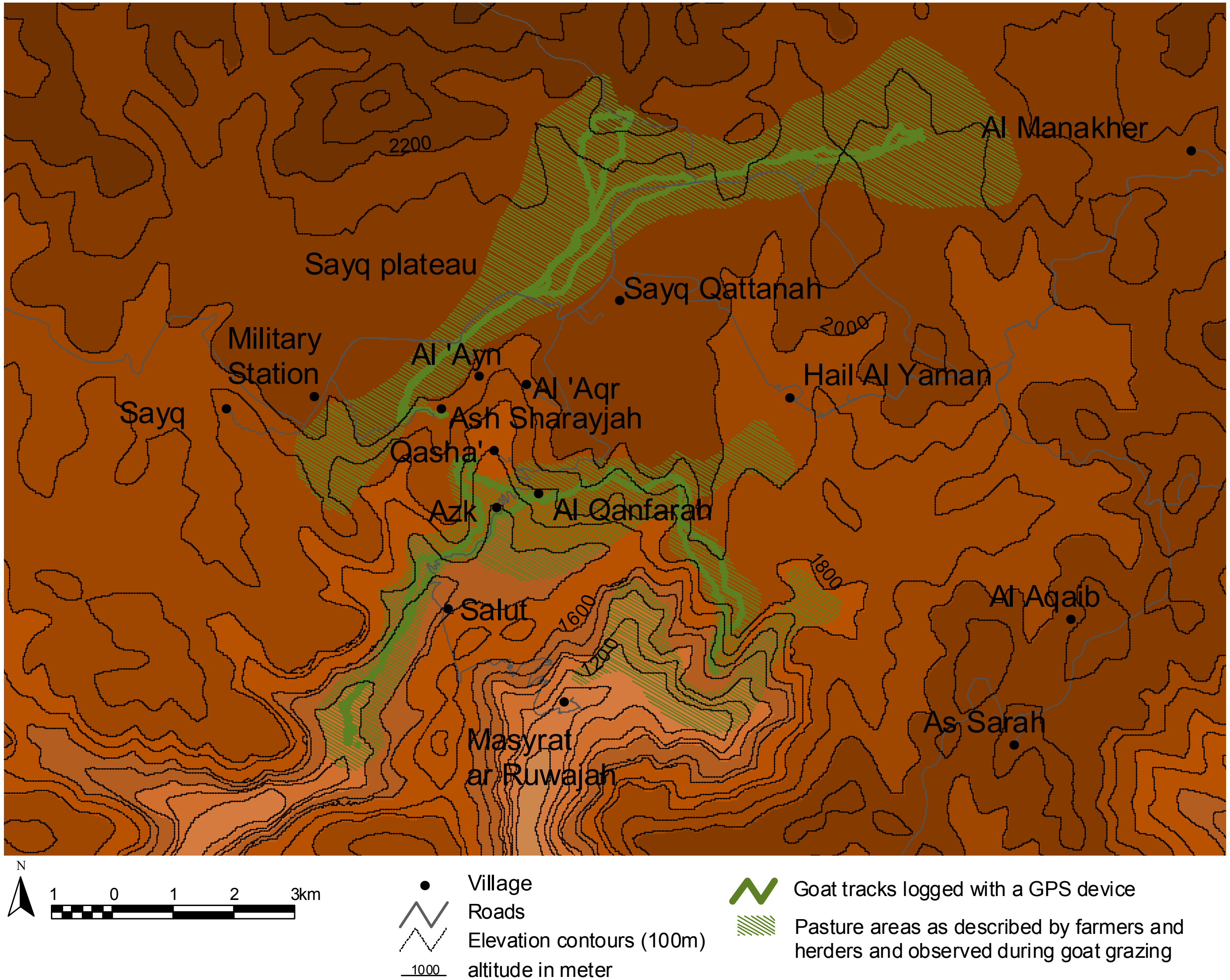

Figure 4.9. GPS tracks and pasture areas in three villages of the Al-Jabal-al-Akhdar mountains, Oman, as described by farmers and herders and as determined during grazing observations (pasture area in Masayrat refers to one group of farmers)

Pasture vegetation

In October 2005, the dominating tree species on the pastures of the Sayq plateau (2000 m asl) were *Juniperus excelsa* ssp. *polycarpos, Olea europea* ssp. *cuspidata* and *Sideroxylon mascatense* (syn. *Reptonia mascatensis*), accompanied by *Dodonea viscosa, Euryops arabicus, Grewia erythraea* and *Sageretia thea,* as the abundant shrubs. In the wadis, *Acacia gerardii, Ziziphus spina-christi* and a so far unidentified wooden species, which is most likely related to the date palm, complemented the shrub and tree strata. The ground vegetation was composed of grass species, such as *Aristida adscensionis, Cenchrus ciliaris*, *Cympopogon spec., Cynodon dactylon* and *Tetrapogon villosus.* The main herbs were *Heliochrysum glumaceum, Salvia aegyptica* and *Teucrium spec..* While the ground vegetation on the plateau areas was sparse (ground cover of 1.5%) and little diverse (n=10 species), plant diversity (n=12 species) and ground cover (4%) in the wadis were higher and therefore represented important grazing areas for the livestock.

The vegetation of the enclosure on the Al Hawz plateau included some of the abundant tree and shrub species identified for the pastures on the Sayq plateau, namely *Sideroxylon mascatense*, *Sageretia thea, Grewia erythraea* and *Dodonea viscosa.* The ground cover of the shrub and tree strata of 7% (SD 3.2) was higher than on the pastures of the Sayq plateau (2%, SD 1.4), whereas the ground cover of trees and shrubs in the wadis near Sayq was highest (42%, SD 17.2). The vegetation of the enclosure was mainly characterized by its ground vegetation (Figure 4.10 a, b). Besides the species described for the Sayq plateau, additional grass and herb species were identified, such as *Enneapogon persicus*, *Fingerhuthia africana*, *Heteropogon contortus, Helianthemum lippii* or *Linum corymbosulum.*

a) b)

Figure 4.10 a,b. The vegetation of the Sayq plateau (intensively grazed; a) and the Al Hawz plateau (no grazing; b) on the Al-Jabal-al-Akhdar mountains, Oman, in October 2005

The weighted average biomass of the vegetated patches on the Al Hawz plateau (753 kg DM ha^{-1}) was significantly higher than the values obtained for the grazed plateau areas (14 kg DM ha^{-1}; Table 4.9) and the wadis (21 kg DM ha^{-1}) near Sayq for October 2005. The N and P concentrations of the biomass samples collected from the grasses and herbs in the enclosure were lower than of the biomass samples of Sayq plateau and wadis. While the NDF concentrations of the biomass samples collected in the enclosure were about 24% higher (814 g NDF kg^{-1} OM, SD 19.6) than of the biomass samples of the Sayq plateau, the digestibility of 479 g DOM kg^{-1} OM (SD 10.7) was about 12% than the values obtained for the biomass samples of the ground vegetation on the Sayq plateau.

*Table 4.9. Ground cover, weighted average biomass production and nutrient concentrations of the ground vegetation on vegetated patches at three locations on the Al-Jabal-al-Akhdar mountains, Oman, in October 2005**

		Ground cover	Herbaceous biomass*	N		P
		%	(kg DM ha^{-1})	(g kg^{-1} OM)		
Location	n			n	Mean	Mean
Sayq plateau**	8	2	14	2	9.4	0.6
Sayq wadis**	6	4	21			
Al Hawz plateau***	5	14	753	2	6.3	0.3

* rainfall of ~300mm in spring 2005
** continuous grazing; samples from wadis (n=23) and plateau (n=31) were pooled into two composite pools for determination of N and P concentrations
*** no grazing; samples for biomass (n=12) were pooled into two composite pools for determination of N and P concentrations

Grazing behavior and plant selection of the goats

During the grazing observations in Qasha' and Masayrat, goats were feeding on grass and herb species as well as dead plant material (leaves, seed pods) for 66% and 60% of the observed feeding time, while in Ash Sharayjah the goats browsed mainly on trees and shrubs (74%). The main fodder shrubs on pasture varied between the different villages (Table 4.10).

Sideroxylon mascatense is an abundant shrub on the Sayq plateau and on the grazing areas of Qasha' and was heavily browsed by the goats. Despite being the most abundant species on the Sayq plateau after *Sideroxylon mascatense*, goats hardly foraged on *Dodonea viscosa*. According to the herder, the animals just eat the young leaves and flowers of the shrub. *Euryops arabicus* and *Daphne mucronata,* two further shrubs identified on the plateau, are poisonous to the animals and therefore not browsed by the goats.

Table 4.10. Feeding time of goats per strata (% of observed feeding time) and plant species (% of feeding time per strata) in three villages of the Al-Jabal-al-Akhdar mountains, Oman

Strata	Plant species	Masayrat	Qasha'	Ash Sharayjah
Shrubs/trees		40	34	74
	Acacia gerardii	11	20	4
	Capparis spinosa	16	0	0
	Pteropyrum scoparium	45	0	0
	Sideroxylon mascatense	1	60	88
Ground vegetation		60	66	26

Pteropyrum scoparium was widespread in the valley of Masayrat and therefore heavily browsed by the goats. The concentrations of digestible organic matter (360 g DOM kg^{-1} OM), nitrogen (10 g N kg^{-1} OM) and phosphorus (1.0 g P kg^{-1} OM) of this shrub species were low (see Table 4.5). On the contrary, nutrient concentrations of *Ficus cordata* ssp. *salicifolia*, a shrub equally abundant in the region of Masayrat, were much higher (26 g N kg^{-1} OM; 2.6 g P kg^{-1} OM). However, only the leaves of young plants were frequently browsed by the animals. *Capparis spinosa* and *Euphorbia larica* were the dominant shrubs on the hillslopes near to Masayrat. While goats frequently fed on *Capparis spinosa*, *Euphorbia larica* contains a milky sap and was therefore avoided by the animals.

Figure 4.11. Goat feeding on Pteropyrum scoparium in the valley near Masayrat, Al-Jabal-al-Akhdar mountains, Oman

Acacia gerardii was found in Masayrat as well as in the wadis at higher elevations. The leguminous tree is typical for the Al-Jabal-al-Akhdar mountains and an important source of fodder for the animals. Especially the seeds were rich in nitrogen (36 g N kg^{-1} OM) and phosphorus (2.3 g P kg^{-1} OM) and herders hit the branches with sticks, so that the seeds would fall on the ground and were available for the goats.

The grasses and herbs grazed by the goats included the abundant species of the Sayq plateau such as *Cympopogon spec., Tetrapogon villosus* and *Teucrium mascatense* and *Salvia aegyptica.* Especially during the grazing under trees, the goats also fed on leaves and seeds shed by *Acacia gerardii* or *Ziziphus spina-christi*. The nutrient concentrations of biomass samples collected from the grass and herb vegetation (9 g N kg^{-1} OM; 0.6 g P kg^{-1} OM) were much lower than the N and P concentrations of the leaves and twigs of *Acacia gerardii, Capparis spinosa and Pteropyrum scoparium* as well as the N concentrations of *Sideroxylon mascatense* (see Table 4.5).

All farmers perceived that pastures have changed over the past. A general decline in the vegetation cover was noticed (n=8), and the herder of Ash Sharayjah also mentioned that grass and herb species have decreased, while the abundance of shrubs, such as *Daphne mucronata* and *Euryops arabicus,* has increased. All farmers link the changes to a constantly decreasing precipitation. While three farmers mentioned that they changed their grazing areas and go further into the wadis, three farmers also stated that they stay out longer with the herds now than in the past.

5 Discussion

5.1 Methodological aspects

Interview techniques

The interviews conducted in the three villages of the Al-Jabal-al-Akhdar mountains were based on open questions, which allowed the farmers to freely explain the different aspects of the livestock husbandry. While other methods such as multiple-choice questionnaires clearly define the scope of a question and therefore allow an easier analysis of the results, the answers obtained during the interview were often not sufficiently precise. The need to translate the questions and answers and the cultural differences imposed additional problems. Furthermore, some farmers had difficulties reading the maps, which were used to identify the grazing areas, and oral descriptions were necessary. However, the advantage of this interview technique was that farmers and the herder were able to include issues, which were previously not considered as well as their personal perceptions about the livestock husbandry of the Al-Jabal-al-Akhdar mountains.

Determination of the feed intake

The total organic matter intake of animals can be calculated based on the faecal excretion and the average diet digestibility. Different methods were developed to determine the total faecal production including the use of indigestible substances as markers. They allow a quantification of the total faecal excretion based on the marker concentration in the faeces and the marker recovery rate. The determination of the marker intake and its recovery rate are difficult, especially if internal markers are used, which are present in the fodder material (Lippke, 2002; McMeniman, 1997). Although the estimation of the marker intake also caused problems in this study, whenever the capsules were destroyed, both parameters are easier to determine for external markers such as titanium dioxide (TiO_2), which is added to the feed.

The overall diet digestibility calculated from the faecal CP concentration was higher than the values obtained for the individual fodder plants by the HFT test. The discrepancy is most likely due to secondary compounds in individual plant species, which inhibit the diet and protein digestibility and therefore increase the concentration of undigested dietary N in the faeces (McSweeney et al., 2001; Powell et al., 1994). As a consequence, the formula of Lukas et al. (2005) would overestimate the digestibility of the animal's diet. This indicates that the total OM intake and subsequently the feed intake on pasture might be lower than the calculated values. Similarly, Lukas et al. (2005) pointed towards the fact that the formula overestimates the intake for fiber rich diets.

To determine the intake of supplement feed at the homestead, the study required that animals were fed individually to determine the. Since farmers usually feed animals in a group (with the exception of sick goats, lactating goats and does in late gravity and sometimes slaughter animals), the intake at the homestead may differ from the normal feeding practices. Additionally, it was observed that some goats in Masayrat fed on weeds and crop residues from the gardens during the day, which could not be included in the fodder intake at the homestead and was therefore attributed to the pasture intake.
However, as pointed out by Lukas et al. (2005), there is a positive relationship between the CP concentration in the faeces and the diet digestibility. Furthermore, the total organic matter intake and the OM intake on pasture as well as the values obtained for the overall diet digestibility did not differ from results of Predotova (2005). Thus, despite the methodological problems, the study methods appear suitable to provide a comprehensive insight in the livestock husbandry, its main characteristics and problems and to estimate the total intake as well as to determine the main fodder sources of animals in these mountain oases.

5.2 Herd management

The beneficial role of livestock and in particular goats in smallholder farming systems of tropical environments is widely accepted (Schiere et al. 2002; Scoones, 1995; Silanikove, 2000). It is due to an increasing diversification of the system and its outcomes as well as the efficient use of additional resources (El Aich et al., 1999). The animals provide meat and milk for the own consumption and livestock can be sold at times when income is needed, stressing its function in financial insurance for the household (Bosman et al., 1997). Additionally, the manure is applied to the fields to replenish organic matter and nutrient concentrations of the soil.

The results of the interviews conducted in November and December 2005 unveiled the substantial role of livestock in the agricultural systems of the Al-Jabal-al-Akhdar mountains. Independent from the herd size, farmers acknowledge the animals as a source of meat and milk as well as income. Furthermore, religious and cultural benefits, such as the slaughter of animals during Eid celebrations and to honor guests, should not be neglected. However, whether sufficient amounts of animal manure are available from the own herd, largely depends on the herd size and the area cultivated. Therefore, the farmers in Ash Sharayjah, which kept less than 15 animals, additionally purchased manure from livestock keepers in Hail al Haban to fertilize their fields.

Goats are the predominant livestock species within the selected villages and farmers only keep animals of the local Al-Jabal-al-Akdhar breed. In comparison to cattle and sheep, goats are known for their mobility and ability to climb, making them especially suitable for this terrain with steep hillslopes and rocky underground. Their feeding behavior and digestive physiology is adapted to the pasture vegetation. Thus, goats have a higher intake than sheep on pasture, select plants or plant parts that have a higher nutritive value and prefer a large proportion of browse in their diet (Molaine Alcaide et al., 1997; Ramirez, 1999), which makes them more independent of seasonal changes in the quantity and quality of the ground vegetation. Furthermore, they show a higher ability to digest fodder that contain secondary compounds or high levels of lignin than other livestock, due to a longer rumen retention time, an adapted rumen microflora and the efficient recycling of nitrogen (Knights et al., 1997). Additional advantages derive from the lower maintenance requirements and the higher fertility in comparison to cattle, as well as low investment costs and therefore capital losses in case an animal dies (Knights et al., 1997; Silanikove, 2000).
In comparison to the Dhofari goat, the Al-Jabal-al-Akdhar breed is characterized by long hair, a higher body height and weight. The breed is therefore well adapted to the local climatic conditions, but also has a good production potential (Maghoub et al., 2005). In the past, the long hair was used for carpets and clothes as well as the sealing and decoration of the rose water bottles, as a typical product of this region. It therefore provided an additional income (Figure 5.1).

a) b)

Figure 5.1 a, b. Goats of the Al-Jabal-al-Akhdar (a) and the Dhofari breed (b); the animal in picture a) is wearing a collar with a GPS device to log the grazing tracks on pasture

However, the breeding is not done selectively (n=6), since farmers only use bucks from their own herd or from neighboring farmers and the mating is random during grazing on pasture. Although farmers look for healthy (n=6) and productive (n=2) animals, the described breeding methods suggest that farmers do not use their potential influence on the overall herd productivity and health. Furthermore, the decreasing herd sizes reported by farmers (n=4) and the lack of import of new breeding stock (n=8) indicate an increasing risk of inbreeding.

Health problems due to bacterial infections are predominant in the livestock herds. Abscesses caused by *Corynebacterium pyogenes* and pleuropneumonia caused by *Mycoplasma mycoides* are present in the herds, promoted by the close contact of the animals and the mixing of the herds on pasture. Although farmers state that they isolate the sick animals (n=6), the lack of space at the homestead and of hygienic conditions represent an evident problem, especially since sick goats cannot be sold for slaughter. The service provided by the agricultural center is used regularly (n=7). However, considering the frequency of diseases and the number of livestock keepers that need to be covered, the health care is still mainly the responsibility of the farmer. Therefore, livestock keepers need to be trained in the appropriate treatment of these contagious diseases to control the further spread and infection of the herds.

5.3 Feeding strategies and feed intake

The feeding of goats in the households involved in the study relies on fodder from external sources. Of the total organic matter intake, 47% - 71% are derived from pasture, and purchased supplements, such as fish, barley grain or wheat meal, account for 45% - 100% of the fodder offered at the homestead. Apart from the payments for the herders in Ash Sharayjah, the costs for these supplement feeds represent the main expense in livestock husbandry. In comparison to the farmers in the other two villages, the farmers in Masayrat offered a significantly higher proportion of fodder from the own fields, since besides cultivated green fodder also dates are harvested from the own palms (23% of the OM intake at the homestead).
One farmer in Ash Sharayjah additionally pointed out that the feeding of dates and fish has increased since road towards the village was build 15 years ago and the easier transportation is possible. But also the constantly decreasing precipitation combined with a reduced cultivation of crops with higher water demands, such as alfalfa (n=2), and the high proportion of the fallow land observed during the study, suggest that the feeding of purchased fodder has increased in the recent past.
However, the diet composition also changes throughout the seasons. Thus, during the spring months, cultivated fodder accounted for 24% and 27% in Ash Sharayjah and Masayrat (Predotova, 2005), while alfalfa and maize represented only 6% of the total OM intake of goats in October and November 2005. Moreover, in Qasha', where only 21 g OM d^{-1} of purchased hay were fed per animal (bodyweight of 30 kg), 487 g OM d^{-1} of prebloom barley were offered in April 2005 (Predotova, 2005). This complies with the seasonality in the feeding reported by farmers (n=6) and the crop rotation systems described for the mountain oases of Oman (Anonymous, 1995).

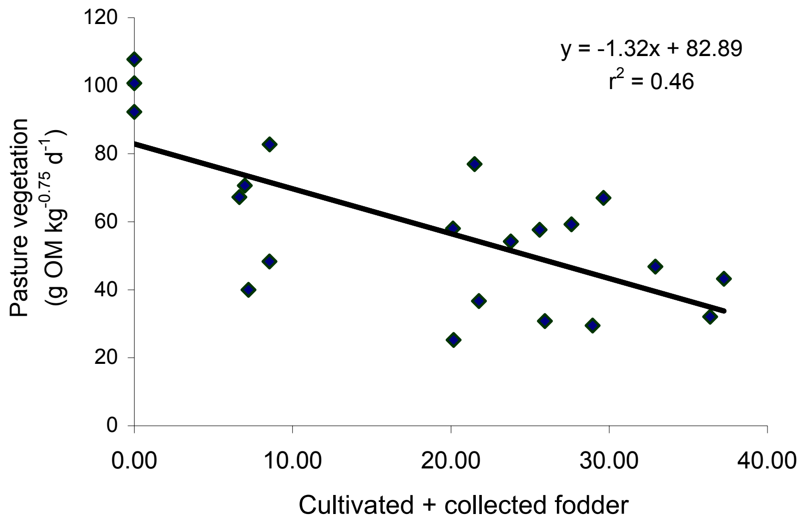

Figure 5.2. Linear regression between the intake of cultivated and collected fodder at the homestead and the OM intake on pasture of goats in three villages of the Al-Jabal-al-Akhdar mountains, Oman

Pasture plants are a substantial part of the diet, providing 47% - 71% of the daily OM intake. The feed intake during grazing was affected by the quantity of fodder offered at the homestead (r=-0.62) and in particular the intake of cultivated and collected fodder (r=-0.68; Figure 5.2). This shows that farmers can influence the grazing behavior of animals by the quantity and the composition of the fodder offered at the homestead.

Predotova (2005) determined the feed intake of goats in the three villages of the Al-Jabal-al-Akhdar during the spring months of 2005. Since the study period was shortly after a heavy rainfall, the available forage biomass on pasture was most likely higher than in October 2005 after a longer dry period. Nevertheless, the OM intake of goats during grazing (44 g – 76 g OM $kg^{-0.75}$ d^{-1}) was higher in October 2005 than in the spring months of the same year (24 g - 53 g OM $kg^{-0.75}$ d^{-1}). The results are contrary to farmers` perceptions and the hypothesis that the decrease in the plant biomass on pasture with the progression of the dry season leads to a decreasing OM intake during grazing. Golding (1985) and McDowell (1985c) stated that the nutrient concentrations and intake of fodder on dry-season pastures are reduced in comparison to the rainy seasons, which leads to significant weight losses of the livestock. Similarly, Fynn et al. (2000) found that supplemental feeding during the dry season was necessary for animals kept in paddocks with high stocking densities and a consequently reduced herbaceous biomass. Hence, the results regarding the intake of goats on pastures of the Al-Jabal-al-Akhdar mountains should be verified before any conclusions can be drawn.

5.4 Energy and nutrient intake versus requirements

Due to the high activity during the grazing on the sparsely vegetated mountain pastures, the daily energy requirements of the goats for body maintenance and locomotion are high. The Natural Resource Council (NRC, 1981) documented energy requirements of goats under these conditions of 1.68 - 3.83 Mcal for a bodyweight of 20 – 60 kg, which is equivalent to 742 - 745 kJ $kg^{-0.75}$ d^{-1}. The average ME intake of the goats in the oases of the Al-Jabal-al-Akhdar mountains of 741 kJ $kg^{-0.75}$ d^{-1} (SD 125.3) was mainly provided by the fodder offered by the farmers (43% - 68%) and covered the energy demands of the animals for maintenance and locomotion. Considering that the study method most likely overestimates the intake of animals, the feed intake of goats appears to be insufficient to provide additional energy for potential growth and production of the animals. However, animals of different breeds are not only adapted to the climatical conditions of their original environment, but also to the fodder quantity and quality available (Knights et al., 1997). Maghoub et al. (2005) showed the high production potential of the Al-Jabal-al-Akhdar breed under feedlot conditions. The productivity of goats of this breed, which adapted to the mountainous climate, should also be studied for the described feeding practices of the farmers in the villages of the Al-Jabal-al-Akhdar mountains.

Proteins are important constituents of the body cells and apart from the animal itself, the microorganisms in the rumen also need protein for their maintenance and activity. Therefore, dietary deficiencies affect the functioning of the whole body and in particular the fodder digestion. Under described conditions, protein requirements of goats for maintenance and activity ranged from 64 g - 146 g CP d^{-1} (NRC, 1981) at a bodyweight of approximately 20 – 60 kg of the study animals. The daily N intake of goats on the Al-Jabal-al-Akhdar of 0.65 g - 2.66 g N kg^{-075} (SD 0.505), equivalent to 46 - 273 g CP, strongly varied between the animals and is partly below the level defined by Milford and Minson (1966) of 70 g CP kg^{-1} DM, when the forage intake of sheep decreases, because the CP demand of the microflora in the rumen is not satisfied. Although sufficient for most of the goats, CP intake might have failed to cover the daily demands of some of the animals, which were not offered any fish.
The absorption of protein in the rumen or the small intestine is largely influenced by the fodder digestibility. The foliage of shrubs and trees represents an important component of the diet of goats in arid and semi-arid environments. Its digestibility can be strongly reduced, due to high lignin concentrations as well as secondary plant compounds, such as tannins (McSweeney et al. 2001). Tannins bind dietary and endogenous proteins and form complexes with carbohydrates or minerals as well as microbial secretions in the rumen. Therefore, they inhibit the overall digestibility of the fodder and reduce the feed intake and availability of energy and nutrients to the animal (Delve et al., 2001; McSweeney et al., 2001).

About 51% - 65% of the daily nitrogen intake of goats was derived from pasture plants with an average N concentration of 18 g N kg^{-1} OM (SD 10.8). The gas production of the tree and shrub species during the incubation of feed samples in rumen fluid (24.4 ml 200 mg^{-1}, SD 9.22) was significantly lower than the gas production of cultivated fodder plants (40.9 ml 200 mg^{-1}, SD 4.82) and supplement feeds (65.2 ml 200 mg^{-1}, SD 6.25; $P \leq 0.05$). Although not significant ($P > 0.05$), values obtained were also 19% lower than for the ground vegetation (30.1 ml 200 mg^{-1}, SD 5.48).

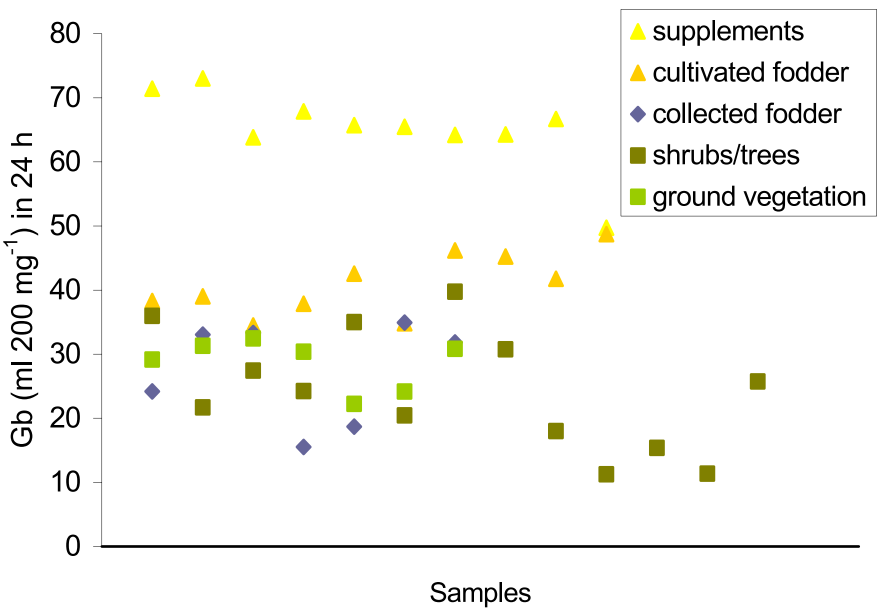

Figure 5.3. Gas production (Gb) of feed samples (200 mg ± 0.02) collected in three villages and pastures of the Al-Jabal-al-Akhdar mountains, Oman, during the incubation in rumen fluid

The significantly lower gas production may indicate the influence of secondary plant compounds in the plant material of the shrub and tree species found on the Al-Jabal-al-Akhdar mountains (Figure 5.3). Predotova (2005) showed that *Ficus cordata* ssp. *salicifolia, Pteropyrum scoparium* and *Ziziphus spina-christi,* important pasture shrubs browsed by the goats, contain polyphenoles that reduce the digestibility of the plant material. Samples of *Acacia gerardii* showed similar results and tannins have been discovered in several other *Acacia* species (Chriyaa et al., 1997; Rubanza et al., 2005). Furthermore, the extremely low digestible organic matter concentrations of *Olea europaea* ssp. *cuspidata, Saccharum ravennae* and the unidentified wooden species found in the wadis of the Sayq plateau, indicate the presence of polyphenoles or other secondary compounds that inhibit the microbial degradations of these forages in the rumen. Consequently, the digestibility of fodder plants ingested on pasture as well as the nutrient availability for the animals might be limited.

The results regarding the ME and CP intake of goats on the Al-Jabal-al-Akdhar mountains stress the insufficient nutrition. Since the pasture plants supply a substantial part of the animals` diet and are characterized by a low digestibility, energy and nutrient concentrations, supplement feeding at the homestead is necessary. The farmers in the study villages offered supplements such as dates, fish, barley grain, wheat meal or rice to the animals that have high ME concentrations of 10.9 MJ and 11.7 MJ kg^{-1} OM and therefore provide 29% - 47% of the daily ME intake. Legumes such as alfalfa or the pods of *Acacia gerardii* and especially fish are beneficial supplements for low protein diets, the latter additionally providing phosphorus. However, the supplemental feeding must be sufficient to balance the seasonal changes in the fodder quality as well as in the nutrient requirements of goats, to maintain the health and productivity of the animals.

In the adult ruminant, P is mainly excreted in the faeces (McDowell, 1985a). The excretion of phosphorus exceeded the intake of individual goats in all three villages. The nutrient balances of the animals were highly correlated with the total P intake, in particular with the proportion of fish in the diet. Therefore goats in Qasha' and Ash Sharayjah, which were not offered any or only small amounts of fish (<2% of the total OM intake), and no other supplements with higher P concentrations, such as barley grain or wheat meal, showed a negative P balances (Figure 5.4).
The average phosphorus concentration in the diet of 0.11% - 0.13% across the villages as well as the daily intake of 104 mg - 133 mg P kg^{-075} were lower than the recommended 0.16% - 0.37% (McDowell, 1985a) and 1.4 g - 3.5 g P (NRC, 1981). The results therefore indicate that phosphorus supply by the available fodder does not meet the animals` requirements.

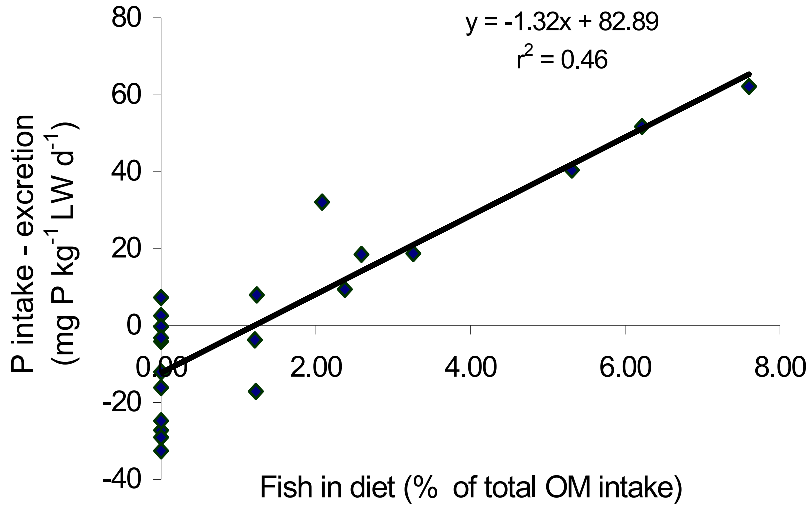

Figure 5.4. Linear regression between the proportion of fish in the diet and the phosphorus balance of goats in three villages of the Al-Jabal-al-Akhdar mountains, Oman

P deficiencies are an important problem in grazing ruminants and linked to the low quality and P concentrations of the diet (McDowell, 1985a). Since pasture plants accounted for 47% - 71% of the total OM intake of goats in the villages of the Al-Jabal-al-Akdhar mountains, P concentrations in the ground vegetation as well as in shrubs and trees largely affect the overall P intake. While *Pteropyrum scoparium*, an important fodder shrub in Masayrat, showed a higher concentration of phosphorus, lower P concentrations were obtained for *Acacia gerardii, Ziziphus spina-christi* and *Sideroxylon mascatense,* the main shrubs browsed by animals in Qasha' and Ash Sharayjah. An exception was *Potamogeton nodosus* (5.1 g P kg^{-1} OM), a water plant found in a dam east of Masayrat, eaten during 0.5 % of the observed grazing time of goats on pasture. Furthermore, the P concentration of the pasture plants (0.4 - 2.6 g kg^{-1} OM) was slightly lower than the values reported by Predotova (2005) for the samples collected in the spring months of 2005 (0.4 g - 3.2 g P kg^{-1} OM). Two factors that majorly influence the P concentrations in plants are the mineral concentrations in the soil as well as the stage of plant maturity (McDowell, 1985b). The shallow, little developed soils on the Al-Jabal-al-Akhdar mountains and the low mineral levels reported for most of the soils of the Middle East as well as the highland pastures in Southern Oman (Cookson, 1996; Zaroug, 1995) indicate a reduced mineral supply for the plants. Since the main flowering period of the important fodder species is from February until May (Jongbloed et al., 2003; Miller et al., 1988), the transport of plant nutrients from the leaves into the seeds after seed formation might additionally explain the low P concentrations of the collected samples as well as the differences to the results of Predotova (2005).

The absorption of phosphorus in the small intestine is strongly influenced by the diet digestibility, which was largely reduced by the low digestible organic matter concentration in the pasture plants (see above). Furthermore, the availability of other minerals and most importantly calcium (Ca) affects the P retention (McDowell, 1985a). Ca:P ratios of 1:1 to 2:1 are recommended in literature, while wider ratios result in a reduced absorption and consequently an increased excretion of P (Karn, 2001). Since Ca:P ratios are wider in mature plants (McDowell, 1985a) and the Ca supply on the Al-Jabal-al-Akhdar mountains is not limited due to the calcareous base material, ratios wider than those recommended can be expected for the pasture plants and Grosser (1988) described strongly decreasing P concentrations in the leaves of *Acacia gerardii* in the mountain areas of Yemen, while Ca concentrations increased with progression from the wet to the dry season.

In contrast to findings in literature, the faecal P concentrations of 3.8 - 4.5 g kg^{-1} FOM were not affected by the P concentration in the diet and did not differ significantly between goats of different farmers or villages. The buffering mechanisms of the ruminant body might offer an explanation. Up to 60% to even 90% of the faecal P are of endogenous origin (Karn, 2001), which is mainly introduced into the digestive tract over the saliva. Since small ruminants produce 6 - 16 l of saliva per day (Kolb, 1971), containing about 260 - 400 mg l^{-1} of P (Orth and Kaufmann, 1966), substantial amounts of P are added to the daily fodder that can even exceed the P intake via the feed. Although the P concentration in the saliva is related to the P intake (McDowell, 1985a), in case of P deficiency, P from the skeleton is mineralized and diffused into the blood system to buffer the concentration in blood and consequently in saliva. In this way, a minimum P level is maintained in the saliva, which might explain that the P concentrations in the faeces were not sensitive to different P intake rates. The combination of the restricted feeding of P rich supplements, the low P concentration in the pasture plants, the reduced absorption and increased faecal excretion of P due to the low fodder quality and digestibility explain the negative P balances obtained for some goats.

P compounds and in particular phosphate are essential for the strength of the skeleton, the energy metabolism (as a main component of ATP and ADP*), but also the functioning of the nervous system and the digestion by supplying P to the rumen microorganisms (Hennig, 1972; Karn, 2001; McDowell, 1985a). P deficiencies therefore affect many body functions and symptoms include the lack of appetite resulting in a retarded growth, apathy and the inability to stand or move coordinately, as well as fertility problems and rickets (Bostedt et al., 1996; Hennig, 1972). Although it might also be caused by other mineral deficiencies, animals lacking phosphorus tend to chew on bones and other objects (McDowell, 1985a). These symptoms comply with the problems reported by the farmers and the behavior of the animals that was noticed during the study and grazing observations. The slightly higher P concentrations in the pasture plants, the consequently higher intake of phosphorus with the fodder and the positive nutrient balances reported by Predotova (2005) suggest that the P deficiencies might be restricted to seasons, when P concentrations of the vegetation are low and the requirements of the animals are high. However, this aspect should be verified through further analysis.

5.5 Nutrient excretion

During the study period, about 42% - 43% of the total amount of faeces excreted was collected over night, equivalent to 5.0 g OM kg^{-1} (SD 1.48), 0.13 g N kg^{-1} (SD 0.04) and 19.2 mg kg^{-1} (SD 5.05) per night, which are available for the fertilization of the fields. The feed intake and diet composition strongly influence the amount and quality of the faeces (Delve et al., 2001; Powell et al., 1994; Romney et al., 1994). Although the present study was not designed to detect the effects of feeding practices on OM and nutrient excretion, some relationships were also shown in the results (Table 5.1). The higher intake of OM and in particular of NDF resulted in a higher OM excretion. Although N concentration in the faeces decreased with a higher OM intake (r=-0.58), the excreted amount of faecal nitrogen increased as a result of the higher OM excretion. The nutrient concentrations in the fodder did not significantly influence the faecal N and P concentrations ($P>0.05$).

*adenosine-tri- and di-phosphate

Table 5.1. Correlation coefficients (r) of linear regressions between the organic matter, nitrogen and phosphorus intake and excretion of goats in three villages of the Al-Jabal-al-Akhdar mountains, Oman

Y= ax+b	Dependent parameters (y)		
	Faecal OM excretion	N excretion*	P excretion*
Independent parameter (x)	(g per animal d^{-1})		
Liveweight (kg)	0.84	0.85	0.76
OM intake (g $kg^{-0.75}$ d^{-1})	0.74	0.71	n.s.
N intake (g $kg^{-0.75}$ d^{-1})	0.76	0.76	n.s.
P intake (g $kg^{-0.75}$ d^{-1})	0.69	0.71	0.58
Pasture intake (% total intake)	0.67	0.66	n.s.
Pasture+Collected fodder (% of total intake)	0.75	0.74	0.55
Fish (% of total intake)	0.67	0.70	0.57
NDF in diet (g kg^{-1} OM)	0.55	0.63	0.54
DOM in diet (g kg^{-1} OM)	-0.66	-0.65	-0.81

n.s. not significant (P> 0.05) ; * in the faeces

The strong correlation between the intake of pasture plants as well as collected leaves and seeds from *Ziziphus spina-christi, Olea europaea* ssp. *cuspidata* and *Acacia gerardii* and the N excretion (r=0.74) is most likely due to the influence of polyphenoles. As mentioned above, tannins form complexes with dietary, endogenous and microbial protein, which results in a higher N excretion via the faeces. Additionally, the feeding of browse foliage increases the proportion of insoluble N in the faeces (Powell et al., 1994). The slow release of tannin-bound nitrogen during mineralization can reduce the N-leaching during irrigation and improves the availability of nutrients for plant growth (Delve et al., 2001). In contrast, the feeding of highly digestible fodder such as dates and other supplements will result in a higher nutrient excretion via the urine. Since the animals in the three villages of the Al-Jabal-al-Akhdar mountains are not corralled on the fields, the nutrients excreted over the urine are lost for cropping.

The results and evidences in literature therefore show that farmers can influence the quantity and quality of faeces available for manuring the fields by the diet composition. However, the feeding of tannin-rich diets decreases the nutrient availability for the animals and therefore reduces their productivity and health. Farmers consider these aspects more important than the production of manure and the latter is also available from livestock keepers in neighboring villages. Therefore, the feeding should primarily be adjusted to meet the requirements of the animals.

The collection and application of the faeces on the fields, but also the herding of the animals are labor intensive and time consuming responsibilities. Consequently in all households, several members of the family are involved in livestock husbandry. While farmers in Masayrat switched to free-grazing and the two households in Qasha' decided to take turns in herding their animals, farmers in Ash Sharayjah have hired herders to guide the animals on pasture. Additionally, the number of goats per household has decreased over the past (n=4). Furthermore, at least one member of the family earns a non-agricultural income (n=7). In combination with the migration of the rural population towards the cities described in the beginning, this shows that off-farm labor and income is also becoming more important for the people living in relatively remote mountain oases.

5.6 Pasture vegetation and grazing behavior of goats

Pasture vegetation

In October 2005, trees and shrubs such as *Olea europea* ssp. *cuspidata, Sideroxylon mascatense, Dodonea viscosa* and *Sageretia thea* dominated the vegetation of the Sayq plateau. The ground vegetation included *Cympopogon spec., Heliochrysum glumaceum, Teucrium spec.* and *Tetrapogon villosus.* These species are characteristic for the *Reptonia-Olea* woodlands described by Mandaville (1977) for the Al-Jabal-al-Akhdar mountains at 1350-2300 m asl (*Oleetum-Reptonietum* by Sankary, 1980; Kuerschner, 1998). Additionally, *Juniperus excelsa* ssp. *polycarpos, Euryops arabicus, Daphne mucronata* and *Salvia aegyptica* indicate the transition to the *Juniperus* woodlands, which represent the natural vegetation of the mountain ranges in Saudi Arabia and Oman above 2300 m asl (*Juniperueto-Euryopsietum* by Sankary 1980; Kuerschner, 1998).
In contrast thereto, *Acacia gerardii* is typical for the shrublands in elevations below 2200 m asl. Since the tree prefers deeper, alluvial soils (Miller et al., 1988), it was found in the wadis of the Sayq plateau as well as the pastures of Qasha' and Masayrat. In the valleys below 1350 m asl, the *Euphorbia larica* community with *Euphorbia larica, Dyerophytum indicum, Capparis spinosa* and *Ficus cordata* ssp. *salicifolia* as well as the *Pteropyrum-Nerium* shrublands with *Pteropyrum scoparium, Nerium mascatense* and *Moringa peregrina,* dominate the vegetation (*Acacieto-Euphorbietum*; Sankary, 1980; Kuerschner, 1998).

Pasture management

In all three villages, the goats had daily access to the pasture. However, the grazing practice and time as well as the main fodder plants varied between the villages. All villages have defined grazing territories in agreement with neighboring villages. In Masayrat, different grazing areas were determined for certain groups of farmers. Therefore, goats graze on the same pastures every day.

Even in Ash Sharayjah and Qasha', where the grazing of the different pastures alternates, the same areas are used every 2-3 days. While in Masayrat, goats were grazing freely and returned to the homestead at noon, a hired herder or members of the households in Ash Sharayjah and Qasha' guided the animals during the day. Although the study was not laid out to clearly identify the effects of the grazing practice on the feeding behavior, no significant differences were obtained in the OM, N or P intake on pasture for herded and free-grazing animals. This is in contrast to the perceptions of farmers, that the herder can direct the animals to better grazing areas and therefore enhance their fodder and nutrient intake. However, Scoones (1995) showed the ability of grazing livestock to exploit heterogeneous landscapes and therefore to adapt to seasonal changes in the fodder availability on pasture.

The N and P concentrations of the leaves and twigs of *Acacia gerardii, Sideroxylon mascatense* and *Pteropyrum scoparium* were higher than of the ground vegetation of the pastures on the Al-Jabal-al-Akhdar mountains. The high proportion of browse foliage in the diet can therefore increase the N and P intake of goats during grazing (Ramirez et al., 1999) and might additionally explain the lacking effect of the herding practice on the forage and nutrient intake on pasture. Consequently, the protection of the animals and the avoidance of conflicts with other farmers and villages seem to be the predominant reasons for herding the animals. In Masayrat, where pastures are distant from other villages and the cultivated areas are fenced off, the herding of the goats during grazing is not essential. However, in Ash Sharayjah and Qasha', it is necessary to avoid the mixing of different herds on pasture, to keep the animals out of the gardens and to protect the goats from the traffic whenever they cross the roads.

Grazing behavior of goats

The abundant tree and shrub species as well as the frequent herbs and grasses of the ground vegetation were the main plants grazed by goats. Although the goats in Masayrat mostly fed on grasses, herbs, dry leaves or seeds on the ground, *Pteropyrum scoparium*, *Capparis spinosa* and the young plants of *Ficus cordata* ssp. *salicifolia* were also important fodder shrubs. In contrast, shrubs and trees, and in particular *Sideroxylon mascatense,* were the main forage plants of goats on the pastures in Ash Sharayjah and Qasha'.

The foliage of *Olea europea* ssp. *cuspidata,* as the second characteristic species of the *Reptonia*-*Olea* woodlands at 1350 – 2000 m asl, is collected by the farmers and fed to the animals at the homestead. Although less frequently browsed by goats than *Sideroxylon mascatense*, it therefore still represents an important fodder plant, especially during the dry seasons (Miller et al., 1988).
Besides *Teucrium spec.*, which is attractive to the livestock due to aromatic compounds (Miller et al. 1988), the perennial grasses were important forage plants in the ground vegetation, including *Cenchrus ciliaris, Cympopogon spec., Cynodon dactylon* and *Tetropogon villosus. Cympopogon spec.* and *Tetrapopgon villosus* were often found in between rocks, where the goats could not easily reach the leaves. In contrast, *Cenchrus ciliaris* and *Cynodon dactylon* showed a very low plant height, so that the goats were not able to harvest the full plants, and formed densely vegetated patches. Recent studies showed the high potential of *Cenchrus ciliaris* as a livestock forage for the arid and semi-arid rangelands due to its high biomass production and adaptation to the climatical conditions (El-Kharbotly et al., 2003; Shinde et al., 1998).

Effects of grazing on the vegetation of the pastures

In comparison to the plateau area of Al Hawz, which served as a sort of enclosure, because the access for goats was limited, the vegetation of the Sayq plateau showed clear signs of livestock grazing. Thus, the ground cover (2% - 4%) and the biomass production (14 – 21 kg DM ha^{-1}) of the vegetated patches was much lower than those observed in the enclosure (20% - 25%; 753 kg DM ha^{-1}). While the herbs and grasses of the pastures are continuously grazed and fresh biomass regrows, the maturation of the plants on the Al Hawz plateau is possible, resulting in the lower nutrient concentrations and digestibility and the higher concentration of NDF on the one hand, but also allowing the seed production of the grasses and herbs.

Furthermore, the vegetation of the enclosure showed a higher species diversity, including plants such as *Fingerhuthia africana*, *Helianthemum lippii, Heteropogon contortus* and *Linum corymbosulum.* These species are also characteristic for the natural vegetation of the Al-Jabal-al-Akhdar mountains. However, the broad-leaved perennial grass *Heteropogon contortus* and the tender leaves of the annual herb *Linum corymbosulum* are preferred fodder plants of livestock and were therefore missing or less abundant on the grazed rangelands. In contrast, *Daphne mucronata* was not found in the enclosure and *Dodonea viscosa* and *Euryops arabicus* were more abundant on the Sayq plateau. While just the young leaves and flowers of *Dodonea viscosa* are foraged by the goats, *Euryops arabicus* and *Daphne mucronata* are poisonous and therefore avoided by the animals.

Consequently, they are less affected by livestock grazing and can easily spread. These evergreen shrubs gradually replace the natural vegetation of the *Olea-Reptonia* woodlands (Mandaville, 1977) in heavily grazed areas. In Masayrat, animals only browsed on flower buds of *Euphorbia larica* (March 2005) and did not ingest *Acridocarpus orientalis* and *Nerium mascatense,* the latter being poisonous to the animals. Therefore the intensively pastures are characterized by open stands of *Euphorbia larica* on the hillslopes and evergreen shrublands of *Acridocarpus orientalis, Ficus cordata* ssp. *salicifolia* and *Nerium mascatense* in the wadis.

Figure 5.5. Euryops arabicus, plant on pastures of the Al-Jabal-al-Akhdar mountains, Oman, October 2005

The approximate herd size during grazing was about 70 animals in Qasha' and Masayrat and 150 animals in Ash Sharayjah. Since the habitual grazing areas encompassed 800 ha and 400 ha in Ash Sharayjah and Qasha', this results in stocking rates of about 5 ha per goats. Additionally, livestock of Al 'Ayn, Sayq Qattanah and Salut as well as donkeys that were used as draught animals in the past, forage in these areas. In Masayrat, where the grazing area is strongly limited by the topographic conditions, the stocking density is about twice as high. The values are lower than the stocking rates reported for experimental settings in studies of semi-arid and arid rangelands (Anonymous, 2002; Osman et al., 2006). However, the carrying capacity of a rangeland strongly depends on the local environmental conditions, the vegetation composition and the pasture management and therefore might be different for the pastures of the Al-Jabal-al-Akhdar mountains.

The biomass production of the vegetation of the enclosure allows an estimation of the available forage on the pastures in absence of livestock grazing. The average weighted biomass production of the ground vegetation on vegetated patches of 753 kg DM ha^{-1} is equivalent to 4895 MJ ME ha^{-1} (ME concentration of 6.5 MJ kg^{-1} DM; SD 0.26). This would be sufficient to cover the fodder and energy requirements of 1.1 goats (40 kg LW) for maintenance and locomotion (NRC, 1981), which demonstrates the production potential of the landscape. Considering a loss of about 50% due to trampling, the stocking rates could therefore be set to 2.5 ha per goat. Besides the rainfall, the quantity of browse foliage available for the animals strongly depends on the cover of shrubs and trees on pasture and the vegetation composition, since the biomass production varies between different species and the proportion of impala table plants reduces the amount of edible foliage biomass.

Hence, Richardson et al. (2005) assumed that only 15% of the wooden plant biomass were available for the livestock on the rangelands of Namaqualand, South Africa, due to the expansion of impala table species. While moderate grazing may increase the biomass production on pastures, heavy livestock grazing can strongly decrease the productivity of rangelands (Richardson et al., 2005). The intensive use of the past when herd sizes were bigger as well as the continuous grazing nowadays most likely reduced the carrying capacity of the pastures of the Al-Jabal-al-Akhdar mountains. While the grass and herb strata of the Sayq plateau showed a much lower ground cover than the vegetation of the enclosure in October 2005, the cover of shrubs and trees was higher on the pastures of the Sayq plateau.
However, the high proportion of *Dodonea viscosa* and *Euryops arabicus* in the shrub and tree strata was also significantly higher on the Sayq plateau. Since the browse foliage is an important source of forage for the animals, especially during the dry seasons (Ramirez et al., 1999), the determination of the biomass production of the indigenous forage shrubs and trees of the Al-Jabal-al-Akhdar mountains would allow to describe the actual carrying capacity of the pastures and to recommend stocking rates adjusted to the local conditions.

The degradation of the natural vegetation due to livestock grazing has been described for large regions of the Arabian Peninsula, including Syria (Osman et al., 2006), Jordan (Rowe, 1999) and Saudi Arabia (Peacock et al., 2003) as well as the Hazar mountains in Yemen (Grosser, 1988) and the coastal and mountain areas of Oman (El-Kharbotly et al., 2003; Mandaville, 1977). The reduction of the stocking rates, the introduction of high potential forage species and the pasture rotation are considered strategies to reduce the grazing pressure on the natural vegetation.
A potential reduction of the stocking rates on the pastures of the Al-Jabal-al-Akhdar mountains appears to be limited. While herd sizes have already decreased over the past, the expansion of the settlements on the Sayq plateau and the military area reduces the available land for livestock grazing. Furthermore, the benefits of livestock husbandry for the families strongly depend on the number of animals per household. Similarly, the rotation of different pastures is also limited. Especially in Masayrat, all the available grazing area is divided between the farmers and grazed daily, so that no periods for the recovery of the vegetation are possible. Finally, the climatic conditions described in the beginning reduce the potential forage plants that can successfully be introduced into the rangeland vegetation.

However, a reduced grazing pressure on the vegetation is necessary to avoid the further degradation and the decrease in the carrying capacity of the pastures. The results of the marker study showed that farmers can influence the grazing behavior of the animals. An adapted feeding at the homestead and a higher proportion of cultivated fodder in the diet offer an alternative solution to reduce the grazing pressure on the vegetation.

6 Conclusions

The results of the study conducted in the three mountain oases of the Al-Jabal-al-Akhdar showed that goat husbandry is a substantial part of the agricultural systems and is closely linked to its other components. The sale of animals for slaughter generates an additional income at flexible times of the year, while meat and milk are contribute to the family's nutrition. The animal manure is the main source of organic matter and nutrients for maintaining soil fertility for crop cultivation. Furthermore, the OM intake of goats on pasture accounted for 47% - 71% of the total feed intake, showing the strong reliance of the livestock husbandry on the pastures.

The evident problems of the goat husbandry of the Al-Jabal-al-Akhdar are the nutrition of the animals and the grazing of the pastures. Goats showed clear signs of nutrient deficiencies, in particular of phosphorus, and the feed intake failed to provide sufficient energy for potential growth and production of the animals. The heavy livestock grazing on the pastures resulted in a severe degradation of the natural vegetation of the Al-Jabal-al-Akhdar mountains, which has been replaced by open stands of rather unpalatable species. The ground cover, species diversity and biomass production of the ground vegetation were significantly reduced in comparison to an enclosure area, where goat grazing was strongly limited.

The farmers can strongly influence the animal's health and performance as well as the grazing behavior of goats on pasture by their feeding and grazing practices. While an increased offer of fodder at the homestead, and in particular of cultivated and collected fodder, reduced the feed intake of goats on pasture, supplements, such as dates and fish, are an important source for energy and nutrients. Similar to the crop cultivation, where the cultivated area and the crops change throughout the seasons, these management factors enable the farmers to balance the variable climatical constraints. Additionally, they offer solutions for the nutritional problems identified above and can reduce the grazing pressure on the pasture vegetation.

However, livestock husbandry is labor intensive, and results showed that the majority of families on the Al-Jabal-al-Akhdar mountains have an additional off-farm income. Additionally, the demographic data of the country indicates a strong migration of the rural population towards the cities. Therefore, a deeper insight in the socio-economic aspects of the oasis agriculture is necessary in order to develop concepts that combine the sustainable use of the natural resources as well as the needs of the rural families in the future.

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Appendix

Appendix 1 Questionnaire for the interviews with the livestock keepers in three villages of the Al-Jabal-al-Akhdar mountains

Date: **Interviewing person:**

Village: **Family name:**

1 General questions

Number of family members: adult:

children:

Who is involved in the livestock husbandry?

Do you have your own garden?

Do you additionally purchase animal manure to fertilize your fields; if so, how much and where from?

Is there an additional, non-agricultural income; if so, which kind and how much?

What are the reasons for keeping livestock?

Is there somebody to take over in the future?

2 Herd management

Number of livestock:

Species	Male	Female	Mature animals	Young stock (<1 year)
Goats				
Sheep				
Cattle				
Chickens				
Rabbits				

Has the herd size been constant over the past, if so, how and since when?

Does it change throughout the year?

Production:

Product	Private consumption	Sale	Amount (n, kg)	Market place
Meat				
Milk				
Hair				
Manure				
Other				

3 Animal breeding

Number of breeding bucks:

Where do the bucks come from: Own breeding:

Neighboring farmers:

Other village:

Do you purchase, trade or borrow breeding animals?

How is the breeding done: Randomly:

Selective:

Are there seasonal differences in the reproduction or the breeding?

Number of kids born per year:

Number of female kids kept for replacement:

What are important selection criteria?

How long are the animals kept?

4 Animal health

Health problems in the herd:

How is the medical treatment?

Are the sick animals isolated from the herd?

Do you practice regular vaccinations or worming?

5 Animal nutrition

Who is feeding the animals and has the control over the feeding?

Animal fodder offered at the homestead:

Feed	Own cultivation	Purchase	Market place
Green fodder			
Supplements			
Other			

Does the feeding differ between animals; if so, how and why?

Does the feeding change throughout the year; if so, how and why?

Does the herd size depend on the fodder available?

Are there any problems related to the animal feeding?

6 Pasture management

Do the animals have access to pasture?

If so: why?

how often?

for how long?

Which animals go out together?

Are the animals herded during grazing?

If so: How often?

Who is herding?

How long?

Why are the animals herded or not herded?

Where are the different grazing areas?

Is there a special grazing routine; if so, which and what does it depend on?

Are the pastures and grazing routines adjusted to the ones of other villages?

Are there any seasonal differences in the grazing practices?

Have the grazing areas and practices changed in the past?

Has the vegetation changed in the past?

Are there any problems related to the livestock grazing and pasture management?

Appendix 2 Questionnaire for the interview with the herder of Ash Sharayjah, Al-Jabal-al-Akhdar mountains

Date: **Interviewing person:**

Herder name:

1 General

Since when are you herding the animals of Ash Sharayjah?

Were the animals herded before and if so, who herded the animals?

How often do you take out the goats?

Which and how many animals do you take out?

Is it the same herd every day of the week and are there any seasonal differences?

What are the advantages or disadvantages of the livestock grazing and of the herding of the animals?

How is the payment?

2 Pasture management

Where are the different grazing areas of the herd of Ash Sharayjah?

Is there a special grazing routine; if so, which and what does it depend on?

Are the pastures and grazing routines adjusted to the ones of other villages?

Are there any seasonal differences in the grazing practices?

Have the grazing areas and practices changed in the past?

What does the number and size of pastures of the different villages and farmers depend upon?

Are there any regulations from the government?

Do any differences exist in the fodder quality and quantity between the pastures?

What are the most important pasture plants for the animal grazing?

What are impalatable pasture plants that are avoided by the animals?

Has the vegetation changed in the past?

Are there any problems related to the pasture management?

Appendix 3 TiO_2 medium for the spectophotometrical determination

Mixture I

Components	Concentration (%)	Amount (ml)
H_2O_2	35	40
H_3PO_4	85	120
H_2SO_4	96	200
dest. H_2O		360

Mixture II

Components	Concentration (%)	Amount (ml)
H_3PO_4	85	120
H_2SO_4	96	200
dest. H_2O		400

Appendix 4 Hohenheim Gastest medium

	Components		Final concentration	Amount
	HFT buffer		16%	500 ml
	Macrominerals		16%	500 ml
	Microminerals		0,016%	0,500 ml
0,4%	Resazurine		0.008%	0.625 ml
	dest. H_2O			1098 ml
	Sodium sulfite			625 mg
6N	NaOH			0.667 mg
	Rumen fluid			1050 ml
	Total volume	# of syringes	95	**3150 ml**
		Volume/syr.	30 ml	
		Buffer capacity	low	

HFT buffer

Components	Molecular weight	Final concentration	Amount
Ammonium bicarbonate	79.1	0.05 M	8.0 g
Natrium bicarbonate	84.0	0.42 M	70.0 g
ddH_2O			2000 ml
Total volume			**2000 ml**

Macrominerals

Components	Molecular weight	Final concentration	Amount
diNatrium Hydrogen Phosphate	142.0	0.040 M	11.4 g
Potassium diHydrogen Phosphate	136.1	0.046 M	12.4 g
Magnesium Sulfate $7xH_2O$	246.5	0.002	1.2 g
Total volume	make up to with dH_2O		**2000 ml**

Microminerals

Components	Molecular weight	Final concentration	Amount
Calcium Chloride $2xH_2O$	147.0	0.45 M	6600 mg
Mangan Chloride $4xH_2O$	197.9	0.25 M	5000 mg
Cobald Chloride $6xH_2O$	237.9	0.02 M	500 mg
Ferric triChloride $6xH_2O$	270.3	0.15 M	4000 mg
Total volume	make up to with dH_2O		**2000 ml**

Resazurine (0.4% w/v)

Components	Final concentration	Amount
Resazurine	0.4 %	400 mg
Total volume		**100 ml**

NaOH (6N)

Components	Molecular weight	Final concentration	Amount
NaOH	40.0	6.0 N	7.2 g
Total volume	make up to with dH_2O		**30 ml**

Appendix 5 List of wild plant species described in the thesis for the pastures and gardens of three villages of the Al-Jabal-al-Akhdar mountains

Botanical name	Family	Remarks
Acacia gerardii Benth	*Mimosaceae*	tree of the wadis at elevations < 2200 m asl
Achyranthes aspera L.	*Amaranthaceae*	weed in the fields; fed to the goats
Acridocarpus orientalis A. Juss.	*Malpighiaceae*	perennial shrub in wadis at lower elevations, not grazed by animals
Aristida adscensionis L.	*Poaceae*	annual, sometimes perennial grass
Capparis spinosa L.	*Capparaceae*	perennial shrub
Cenchrus ciliaris L.	*Poaceae*	perennial grass; good potential fodder grass
Cympopogon spec.	*Poaceae*	perennial grass; *C. schoenanthus* or *C. commutatus*
Cynodon dactylon (L.) Pers.	*Poaceae*	perennial grass; spreading over rhizomes
Daphne mucronata Royal		perennial shrub; poisonous; characteristic species of the *Juniperus* woodlands
Dodonea viscosa Jack.	*Sapindaceae*	perennial shrub; characteristic species of the *Olea-Reptonia* woodlands
Dyerothum indicum (Gibs. ex Wight) Kuntze	*Plumbaginaceae*	perennial shrub of lower elevations; characteristic species of the *Euphorbia larica* shrublands
Enneapogon persicus Boiss.	*Poaceae*	perennial grass
Eragrostis papposa (Roemer & Schultes) Steudel	*Poaceae*	annual grass
Euphorbia larica Boiss.	*Euphorbiaceae*	perennial shrub on mountain slopes at lower elevation; stems with milky sap; characteristic species of the *Euphorbia larica* shrublands

Botanical name	Family	Remarks
Euryops arabicus Steud. ex. Jaub & Spach	Asteraceae	perennial, impalatable shrub; characteristic species of the Juniperus woodlands; syn. *Euryops pinifolius*
Ficus cordata Tunb. ssp. *salicifolia* (Vahl) C.C. Berg	*Moraceae*	tree or shrub in wadis
Fingerhuthia africana Lehm.	*Poaceae*	perennial grass
Grewia erythraea Schweinf.	*Tiliaceae*	perennial shrub
Helianthemum lippii (L.) Dum. Cours.	*Cistaceae*	perennial herb
Heliochrysum glumaceum DC.	*Asteraceae*	perennial herb of higher elevations
Juniperus excelsa M. Bieb ssp. *polycarpos* (K. Koch) Takhtajan	*Cupressaceae*	tree of higher elevations; not browsed by animals; characteristic species of the *Juniperus* woodlands
Linum corymbosulum Reichb.	*Linaceae*	annual herb
Moringa peregrina (Forssk.) Fiori	*Moringaceae*	tree on mountain slopes at lower elevations
Nerium mascatense L.	*Apocynaceae*	perennial, shrub in wadis; poisonous, not grazed; characteristic species of the *Pteropyrum scoparium* woodlands
Olea europaea L. ssp. *cuspidata* (Wall. ex G. Don) Ciferri	*Oleaceae*	tree at higher elevations; characteristic species of the *Olea-Reptonia* woodlands
Potagometon nodosus Poir.	*Potamogetonaceae*	water plant
Pteropyrum scoparium Jaub & Spach	*Polygonaceae*	perennial shrub of wadis at lower elevations, heavily browsed by goats; characteristic species of the *Pteropyrum scoparium* woodlands (Mandaville, 1997)
Saccharum ravennae (L.) Murr	*Poaceae*	perennial grass in wadis near water, often strongly grazed
Sageretia thea (Osb.) M.C. Johns.	*Rhamnaceae*	tree of higher elevations

Botanical name	Family	Remarks
Salvia aegyptica L.	*Lamiaceae*	annual or short-lived perennial herb; aromatic; characteristic species of the *Juniperus* woodlands
Setaria verticillata (L.) P. Beauv.	*Poaceae*	annual weed in the fields; fed to the goats
Sideroxylon mascatense (A. DC.) Penn.	*Sapotaceae*	characteristic tree of the *Olea-Reptonia* woodlands; syn. *Monotheca buxifolia* and *Reptonia mascatense*
Tavernia glabra Boiss.	*Leguminosae*	perennial shrub of wadis of lower elevations
Teucrium spec.	*Lamiaceae*	perennial herb; *T. stocksianum* or T. *scoparium;* aromatic
Tetrapogon villosus Desf.	*Poaceae*	perennial grass
Ziziphus hadjarensis Duling, Ghaz. & Prendergast	*Rhamnaceae*	tree of higher elevations
Ziziphus spina-christi (L.) Willd.	*Rhamnaceae*	tree of the wadis

Appendix 6 Pictures taken during the data collection in three villages of the Al-Jabal-al-Akhdar mountains in October until December 2005

a)

b)

Oral administration of a gelatin capsule filled with 3 g TiO_2 (a) and weighing of supplement feed offered during evening feeding at the homestead (b).

c)

d)

Buck fitted with faecal collection bag (c) and feeding of a group of goats with dates and dried sardines (d).

e) f)

Wadi vegetation on the Sayq plateau, Al-Jabal-al-Akhdar mountains, Oman, with *Juniperus excelsa* ssp. *commutatus* and *Dodonea viscosa* and the so far unidentified wooden species, which is possibly related to the date palm *(Phoenix* ssp.*)* (e, f).

g) h)

Unidentified wooden species (g) and *Cympopogon spec. (h) on pastures of the Al-Jabal-al-Akhdar mountains, Oman, both* and showed clear signs of livestock grazing in October 2005