Social and economic aspects of crop and livestock husbandry, and development of sustainable management options for Al Jabal al Akhdar oases agriculture in Oman

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Introduction

The Sultanate of Oman has undergone significant economic and social changes since 1970 favoured 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 and the annual per capita income rose to 9,070 US$, although Oman's population (2.57 million) is simultaneously growing by 4% per year (WRI, 2006). Mountain regions account for about 15% of the total land area. These regions benefited from the country's development in form of an expansion of the road network, infrastructure, such as schools, telephones and extension services, the establishment of groundwater wells ameliorating the water supply, and dams to reduce water runoff and increase infiltration. Nevertheless, the rapid increase of the urban population and a rather slow growth in the rural areas indicate a strong migration of people towards the cities. Agriculture in Oman is largely constrained by water scarcity. While most of the country receives an average rainfall of less than 100 mm per year, precipitation in the mountain areas is estimated to be more than 300 mm per year (Fisher, 1994). Therefore, only about 0.3% of the country's surface area (309,500 km^2; WDI, 2006) are arable and permanently cropped land and as much as 0.2% are irrigated (FAOSTAT, 2006). 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, 34% of the total labour force (FAOSTAT, 2006).

In the last phase (2006-2008) of the DFG-funded research project “Transformation processes in mountain oases of Oman” (1999-2008), the agricultural project aimed to analyse the effects of the social and economic changes on the life in the mountain oases of Northern Oman, focussing on the traditional agriculture in villages of the Al Jabal al Akhdar mountain range, which stretches from the northwest to the southeast of the country, reaching elevations of about 3000 m a.s.l. (Ghanzafar, 1991). In the agro-pastoral oases systems of this region irrigated crop cultivation is combined with livestock husbandry. The date palm (*Phoenix dactylifera* L.) is an important perennial crop grown at lower elevations (<1500 m), while it is replaced by pomegranate (*Punica granatum* L.) in oases of higher altitude. Other perennial crops are banana (*Musa* ssp.), various citrus and other fruit trees, but also roses (*Rosa damascena* L.*).* Annual crops include vegetables like garlic (*Allium sativum* L.) and onion (*Allium ceta* L.) as well as several fodder plants for the animals such as maize (*Zea mays* L.), barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.) and alfalfa (*Medicago sativa* L.), which are partially grown under the cover of the trees (Nagieb et al., 2004; Buerkert et al., 2005). Alkhanjari et al. (2005) differentiated several wheat landraces and therefore proved that the remote mountain oases are a niche for the conservation of traditional germplasm. Similarly, Gebauer et al. (2007) analysed the crop species richness cultivated in the terrace systems and also stressed the high potential of these mountain oases for *in situ* conservation of agricultural diversity. Livestock husbandry is an important part of the oasis agricultural system, not only as a source of manure for the cultivation of crops (Buerkert et al., 2005), but also of food and income. Goats (*Caprus hircus*), sheep (*Ovis aries*), cattle (*Bos ssp*.), but also chickens (*Gallus domesticus*) and rabbits (*Oryctolagus cuniculus*) are kept, mainly to produce meat, but also milk and eggs and traditionally to sell fibre. The goat is the main livestock in communities of the Al Jabal al Akhdar range with more than 60% of the farmers keeping less than 40 animals (Zaibet et al., 2004). In the traditional husbandry system of local farmers, the goats are only kept in the barn over night, where supplement feeds such as dates, dried sardines or cultivated green fodder are offered. During the day, the animals graze on the mountain pastures. The natural vegetation is the main source of feed for goats, supplying between 47 - 71% of the daily OM intake even after long periods without rainfall (Dickhoefer, 2006). Because of the low nutritional quality of the pasture plants, partly due to the presence of tannins (Predotovaet al., 2006), growth and production of goats in the traditional systems appears to be limited.

The natural vegetation of the mountain pastures is characterised by open shrublands. *Sideroxylon mascatense* (A. DC.) Penn., *Olea europaea* L. *subsp. cuspidata* (Wall. ex G. Don) Ciferri and *Dodonaea viscosa* (L.) Jacq. are abundant tree and shrub species in higher elevations, but are replaced by *Acacia gerrardii* Benth., *Ziziphus spina-christi* (L.) Desf. and *Pteropyrum scoparium* Jaub. & Spach in lower elevations and in valleys (Ghazanfar, 1991; Brinkmann et al., 2008). As a consequence of the continuous grazing, the vegetation shows clear signs of overgrazing and the amount and quality of fodder available for the goats is diminishing (Kharbotly et al., 2003; Schlecht et al., 2008).

Crop cultivation and livestock husbandry are mainly undertaken for sustaining livelihoods, and only surplus production is sold on local markets. However, fruits such as pomegranate or

walnut, rosewater and garlic as well as livestock also serve as a source of income. Zaibet et al. (2004) studied the modern goat production systems on Al Jabal al Akhdar and found that output is increasing with increasing input by non-farm income and purchased feed, but that both are used rather inefficiently, resulting in decreasing returns-to-scale. Furthermore, the functioning of these agro-pastoral systems largely depends on the labour force available (Norman et al., 2001; Zaibet, 2004). Since the proportion of people in Oman working in agriculture has decreased from 45.1% in 1990 to 35.2% in 2002 (FAOSTAT, 2006), and non-farm income is becoming more important, the changes in Oman's economy and society will strongly affect the traditional farming in the mountain areas and might lead to changes in its sustainability. While various aspects of these changes have already been studied in detail as reflected in the above cited publications, the social and economic role of the traditional agriculture in general and in particular of the goat husbandry, as an important source of food and income, is still not fully understood. The Ph.D. research of Mrs. Uta Dickhoefer therefore aimed at analysing the social and economic aspects of livestock and crop husbandry in order to identify factors limiting their productivity and to develop agriculture-based, sustainable management options for the future of the mountain oases settlements in Northern Oman.

Thereby, the study departed from the following hypotheses:

1. The current productivity of goats relies to more than 50% on feed intake from natural pastures.
2. Therefore, the natural pastures are exposed to a grazing pressure that exceeds their carrying capacity and leads to irreversible productivity loss.
3. Supplementation of goats with energy and protein-rich feeds at the homestead will reduce the grazing pressure exerted on the rangelands and will increase the overall productivity of goat husbandry.
4. The high revenue from sold goats as well as from special oases products such as pomegranates, rosewater and garlic justifies high inputs of labour, feed and (organic) fertilizer.
5. High prices for the locally produced meat and fruits will encourage Al Jabal al Akhdar farmers to further pursue their agricultural activities.

Against the background of these hypotheses, this subproject addressed the following aspects:

1. Productivity of goats under the current feeding practices of local farmers.
2. Actual and potential biomass production of the herbaceous and ligneous vegetation on Al Jabal al Akhdar rangelands, and impact of goats' grazing on the carrying capacity of grazing areas.
3. Effect of different supplementation strategies (homestead feeding) on feed intake of goats on pasture.

4. Requirements of crop and livestock husbandry in terms of labour and financial inputs, and contribution of different agricultural activities to household income.
5. Development options to be envisaged for the agricultural component of the mountain oases in order to sustain its role as source of food and income for the local population, and preserve the oases as niches for the genetic diversity of food crops and as points of attractiveness to tourists.

The field work, which started with the MSc thesis of Mrs Dickhoefer in autumn 2005, was continued in form of a Ph.D. research project from August 2006 until April 2008. Since not all publications ensuing from this work are so far published by peer-reviewed journals, the following chapters summarize the key approaches, results and conclusions of this work and point to already accessible publications wherever applicable.

Materials and methods

Sites

The study was carried out in the three villages Masayrat ar Ruwajah (23.05°N, 57.67°E; 1070 m a.s.l.; further referred to as Masayrat), Qasha' (23.06°N, 57.67°E; 1700 m a.s.l.) and Ash Sharayjah (23.07°N, 57.66°E, 1980 m a.s.l.) in the central Al Jabal al Akhdar mountain range (Figure 1). The villages are located within a distance of 10 km of Sayh Qatanah, the central settlement of the Al Jabal al Akhdar Mountains; they were selected due to their representative character for the altitudinal differences in the agricultural systems of the Northern Hajar Mountains.

Socio-economic surveys

In an initial survey with all households in the three study villages, basic information was collected regarding household composition, land and livestock endowment and the importance of off-farm activities for the overall household income. These criteria were subsequently applied to distinguish four different household (HH) types. To determine the gross margin of individual farming activities via cost-benefit analyses, as well as the resource and labour use efficiency for different activities, the allocation of resources such as money, manure, feed and in particular hired and household labour force to various agricultural activities was quantified. To this end, regular interviews were conducted in four representative households per HH type from November 2006 until November 2007.

Economic and social factors have a major influence on the persistence of the traditional agriculture in the mountain oases. To identify development possibilities that would be accepted by the local population, group interviews were conducted with women (n=70) and men (n=70) older than 25 years as well as with girls (n=70) and boys (n=70) between 15 and 25 years of age in the different villages on Al Jabal al Akhdar. Besides attitudes towards developments in agriculture such as the increasing use of agro-chemicals or the decreasing size of goat herds, questions concerning the increasing national and international tourism in the region as well as personal expectations for the future were discussed.

Forage availability and quality on pasture

Biomass production of the herbaceous vegetation was determined in the main grazing area of goats of Ash Sharayjah and in two reference enclosures, where goat grazing hardly occurs in September 2006, January, May and September 2007 and again in April 2008 after five months with less than 5 mm of rainfall. The biomass production of the ground vegetation was calculated from the stratified ground cover and the average above-ground biomass yield of grasses and dicotyledonous herbaceous plants. The ground cover was estimated by recording the proportion of bare, low, medium and highly vegetated spots in 10x10 m^2 plots (n=5-10) located at every 150 m and every 70 m along one transect per location on the grazed (≥1000 m length) and ungrazed sites (≥500 m length), respectively. At each sampling point, the ground vegetation was harvested within four 1x1 m² quadrats and weighed to quantify the above-ground biomass. Samples were analysed for concentrations of dry matter (DM) and organic matter (OM), nitrogen (N) and phosphorus (P).

To determine the abundance and cover of shrub and tree species at the different locations, the point-centred quarter method was applied) along transects (1400 m at the grazed and 700 m at ungrazed sites) in September 2007 – January 2008 (Cottom and Curtis, 1956). At 30 and 20 sampling points at the grazed and ungrazed sites, respectively, an imaginary line perpendicular to the transect line was drawn describing four quarters. In each quarter, the nearest shrub (<30 cm) or tree was recorded, including information on the species name, the bottom and top height, width and length of the crown as well as the distance to the sampling point. To identify correlations between the crown cover and the available leaf and twig biomass of each species, 30 individuals of each of the five most abundant species on the Sayh plateau (*Olea europaea subsp. cuspidata*, *Sideroxylon mascatense*, *Dodonaea viscosa*, *Euryops arabicus* and *Sageretia* thea) were sampled. Bottom and top of the crown, its length and width were measured and all leaves and twigs (<3mm) were harvested, weighed and samples taken to determine the DM concentration. For larger individuals, representative parts were stripped and the weight of the collected leaves and twigs multiplied by an estimated factor to calculate the leaf and twig biomass of the whole plant. The biomass of the shrub and tree strata as a whole was calculated from the cover of the species in the area and the respective leaf and twig biomass.

Livestock production and productivity

Selected goats of twelve farmers in the three villages were weighed at monthly intervals in November 2006 - March 2008 to determine the growth of goats under farmers' current management practices. Since weighing only provides a limited insight in overall herd productivity, progeny history interviews were conducted in the three villages. This survey tool provides information on the number of offspring per doe (prolificacy rate), the kidding intervals, and the frequency of abortions, twin births as well as the off-take and destiny of the offspring (Kaufmann, 2005).

Feed intake of goats

To determine the feed intake of goats during grazing in response to different feed rations offered at the homestead, two feeding trials were conducted with twelve male goats each in Qasha' in October 2006 and in February 2008. In the first trial, two rations similar in metabolizable energy and crude protein content were offered covering the animals' requirements for maintenance, activity and daily growth of 50 g bodyweight. A daily organic matter (OM) intake of 90 g $kg^{-0.75}$ per animal and a minimum intake on pasture of 10% of the total OM intake were assumed. During a 9d adaptation and a 7d experimental period, six animals were offered ration R1 (18% dried dates; 2% dried fish; 70% fresh pre-bloom maize) and six animals ration C1 (40% dried dates; 4% dried fish; 45% green maize) during the morning and evening feeding, with the quantity of feed ingested by each individual being quantified. In the second trial the animals were again offered two rations similar in metabolizable energy and crude protein content, again assuming a daily OM intake of 90 g OM $kg^{-0.75}$ per animal, but a. minimum intake on pasture of 30% of the total OM intake. While the first ration (R2) contained 30% fresh pre-bloom oat, 36% dates and 4% dried fish, the second ration (C2) consisted of 53% dates, 7% dried fish and 10% Rhodes grass hay.

The total amount of feed ingested by each animal was determined using TiO_2 as external faecal marker (Titgemeyer et al., 2001) and the faecal nitrogen concentration as an indicator for overall diet digestibility (Lukas et al., 2005; Schlecht et al., 2006). Intake on pasture was defined as the difference between total OM intake and OM intake at the homestead. Samples of offered feeds, of pasture vegetation and of faeces were analysed for organic matter, nitrogen and phosphorus concentrations.

Results and discussion

Forage availability and quality on pasture

Livestock feeding on natural vegetation is an important asset to the food security of the rural population in semi-arid and arid environments, using resources otherwise unavailable for human consumption. However, degradation caused by grazing is a common problem leading to reduced pasture productivity, therefore risking long-term food security. Foliar biomass of the trees and shrubs ranged between 3 – 6 t DM ha^{-1} on the grazed and ungrazed plateau areas, and attained even 41 t DM ha^{-1} on the mountain slopes and in shallow valleys. Herbaceous mass yields varied over the seasons ($P<0.05$) and contributed at maximum 11% to total biomass of the natural vegetation, underlining the importance of browse for livestock nutrition in particular during dry periods. While ligneous and herbaceous biomass differed clearly between grazed and ungrazed sites and edible biomass was lower on the grazed plateau, species composition, canopy cover and biomass yields were similar on the 15-year old enclosure and a naturally ungrazed mountain plateau. Hence, these pastures inhibit characteristics of an equilibrium system where natural vegetation is strongly influenced by livestock grazing, but has the ability to recover in its absence, despite the highly variable climatic conditions. Fodder availability on pastures could be secured by dedicating sufficiently large areas to livestock grazing and by adhering to the traditional grazing

practices of farmers, where grazing areas of single villages are well-defined (Figure 1) and rotation of single pasture areas as well as resting periods over several months are possible.

The results of the vegetation studies were published / submitted as follows:

Brinkmann, K., Gebauer, J., Patzelt, A., Schlecht, E. & Buerkert, A. 2007. Effects of altitude and grazing on Jebel al Akhdar. Pride. Al Roya Press and Publishing House, Muscat, Oman, pp. 90-96.

Brinkmann, K, Dickhoefer, U., SChlecht, E. & Buerkert, A. 2008. Classification of rangeland vegetation and modelling of vegetation patterns in the Jabal al Akhdar mountain, Northern Oman. In: Proceedings Multifunctional Grasslands in a Changing World, Vol. I. XXI International Grassland Congress, VIII International Rangeland Congress, 67.

Brinkmann, K., Gebauer, J., Patzelt, A., Schlecht, E. & Buerkert, A. Effects of altitude and grazing on Jebel al Akhdar. Journal of Arid Environments, submitted Dec. 2008

Dickhoefer, U., Buerkert, A., Brinkmann, K. & Schlecht, E. The role of pasture management for sustainable livestock production in semi-arid subtropical mountain regions. Journal of Arid Environments, submitted Dec. 2008.

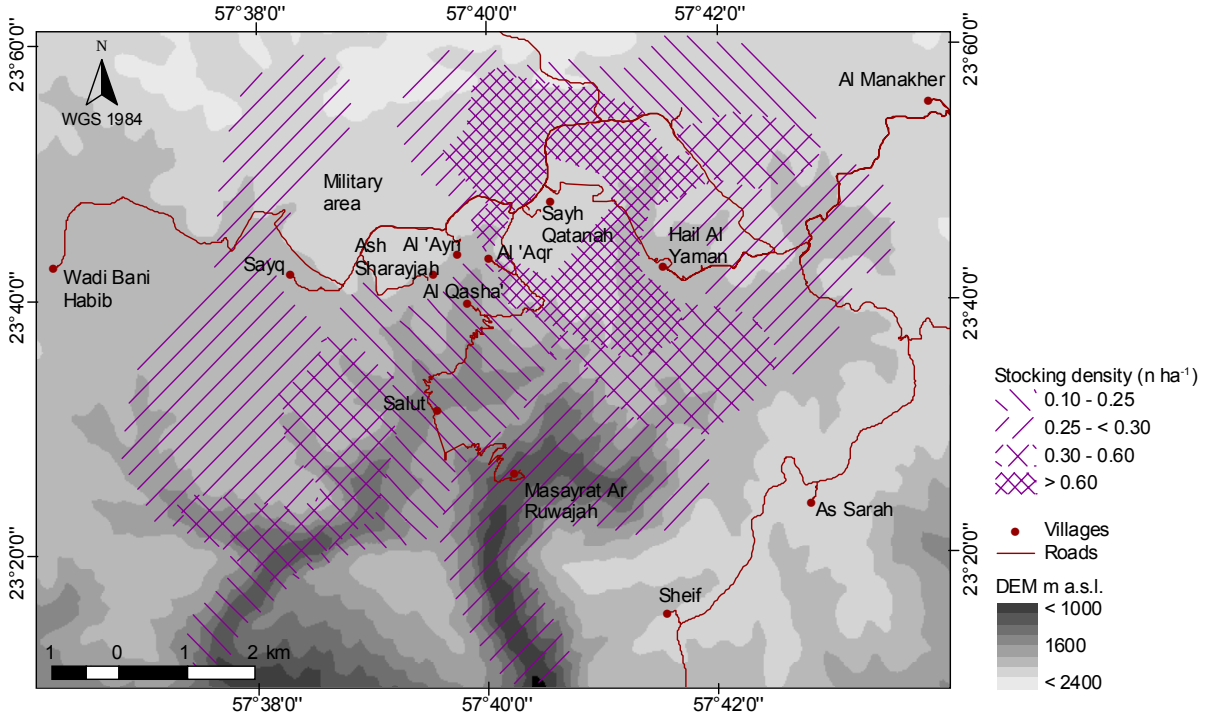

Fig. 1. Stocking densities on pastures grazed by goats and sheep of nine villages on Al Jabal al Akhdar in Northern Oman as determined during key informant interviews (n=10) conducted in winter 2007/08.

Livestock production and productivity

Twenty-nine of the 40 households living in the three villages owned goats or sheep, however the number of animals per farmer ranged between only one to 56 animals and the average herd size of goats and sheep was higher in Masayrat (26, SD 15.6) and Qasha' (21, SD 22.2) than in Ash Sharayjah (7, SD 3.3; Table 1). Preliminary results showed that does in medium sized herds, where on average 345 g DM $head^{-1}$ d^{-1} (SD 129.6) of dates and dried sardines are fed, had a daily weight gain of 99 g (SD 37.6; n=22), 51 (SD 25.2, n=31) and 10 g (SD 13.5, n=10) at a bodyweight of 0-15 kg, >15-30 kg and >30-40 kg, respectively. Bucks grew faster at 104 g (SD 54.1, n=12), 68 (SD 24.5, n=24) and 45 g (SD26.9, n=20) at the same weight classes.

Tab. 1. Number of animals and of households (HH) keeping livestock and average herd sizes in the three study villages as determined in autumn 2006.

Village	HH	Goats	Sheep	Herd size		
		n		Mean	Max	Min
Masayrat	12	291	0	26	56	3
Qasha'	6	107	18	21	55	1
Ash Sharayjah	11	54	18	7	14	2

From the progeny history interviews conducted with 16 farmers on 126 female goats' reproductive performance, an average age at first parturition of 22.2 months (SD 7.1) was determined (Figure 2). The mean kidding interval was 14.0 months (SD 6.5) and the prolificacy rate 1.1 (SD 0.2). Frequently encountered health problems in goat husbandry as named by 14 women were external parasites (n=13), diarrhoea in particular in the young stock (n=12) as well as pneumonia (n=14), abscesses (n=10), injuries (n=11) and malformation in newborns (n=8). The feeding, milking, cleaning of the stables, harvest of the cultivated fodder as well as the collection of tree leaves and grasses in the mountains can take up to six hours per day (average time budget for these activities as given by 14 women); additionally, household members may stay up to eight hours per day with the goats in the mountains. The data on growth and reproduction rates, the regular occurrence of diseases and the high labour demand indicate that the productivity of the traditional goat husbandry is low.

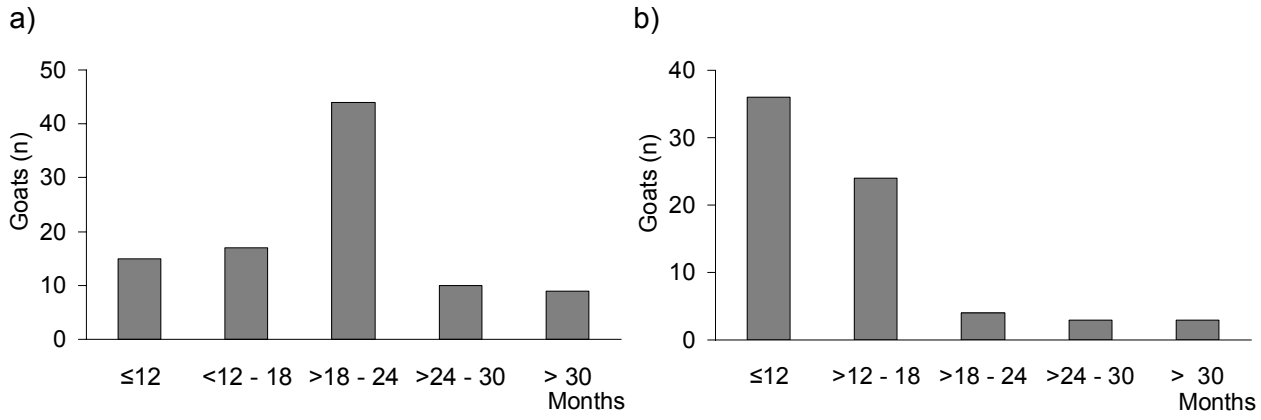

Fig. 2. Age at first parturition (a) and kidding interval (b) of goats in villages of Al Jabal al Akhdar as determined in progeny history interviews conducted in winter 2007/2008.

Feed intake of goats

Since grazing areas of different villages overlap and road and housing construction activities continue to decrease the area available for livestock grazing (Figure 1) and fewer animals are herded today than in the past, stocking densities are very high in the vicinity of settlements and the natural vegetation showed clear signs of overgrazing. Moreover, the nutritional quality of the pasture vegetation is low (Figure 3), but supplementation of goats with cultivated roughages, dates and fish increased their nutrient and energy intake to the level where the nutritional demands for maintenance, locomotion and slow growth were met. The feeding of green fodder at a level of 21 g OM $kg^{-0.75}$ d^{-1} significantly reduced goats' feed intake during grazing on pasture (Figure 4; R2 *vs.* C2). Results therefore suggest that an improved pasture management incorporating farmers' traditional grazing practices and the feeding of green fodder to goats improves livestock nutrition and allows a sustainable use of the natural fodder resources in the future.

The results of the intake studies were published / submitted as follows:

Schlecht, E., Dickhoefer, U., Predotova, M. & Buerkert, A. 2008. Grazing itineraries and feed intake of goats on communal pastures of the Jabal al Akhdar mountain range, Northern Oman.In: Proceedings Multifunctional Grasslands in a Changing World, Vol II. XXI International Grassland Congress, VIII International Rangeland Congress, 77.

Schlecht, E., Dickhoefer, U., Gumpertsberger, E. & Buerkert, A. 2008. Grazing itineraries and forage selection of goats in the Al Jabal al Akhdar mountain range of northern Oman. Journal of Arid Environments. doi:10.1016/j.jaridenv.2008.10.013

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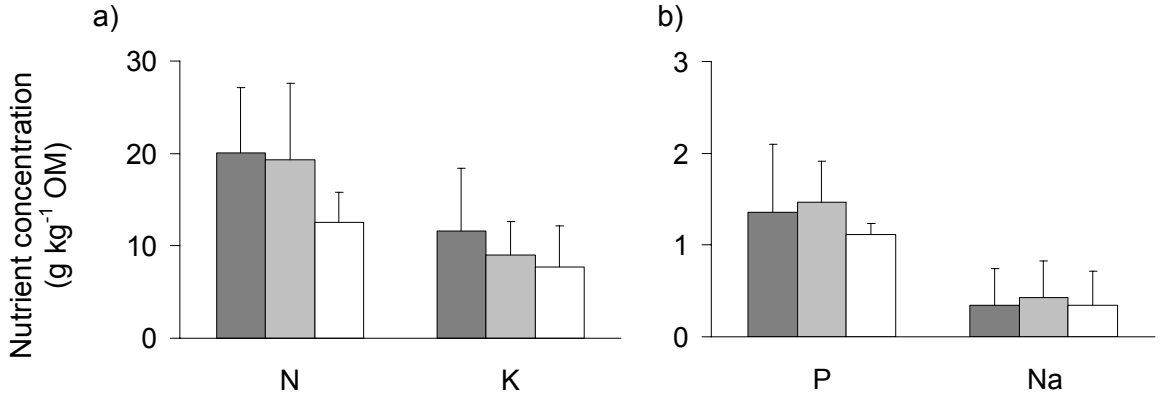

Fig. 3. Nitrogen (N) and potassium (K) concentrations (a) and phosphorus (P) and sodium (Na) concentrations (b) of samples of ligneous foliage (dark grey), dicotyledonous herbaceous species (light grey) and grasses (white) collected on the mountain pastures on Al Jabal al Akhdar in autumn 2006.

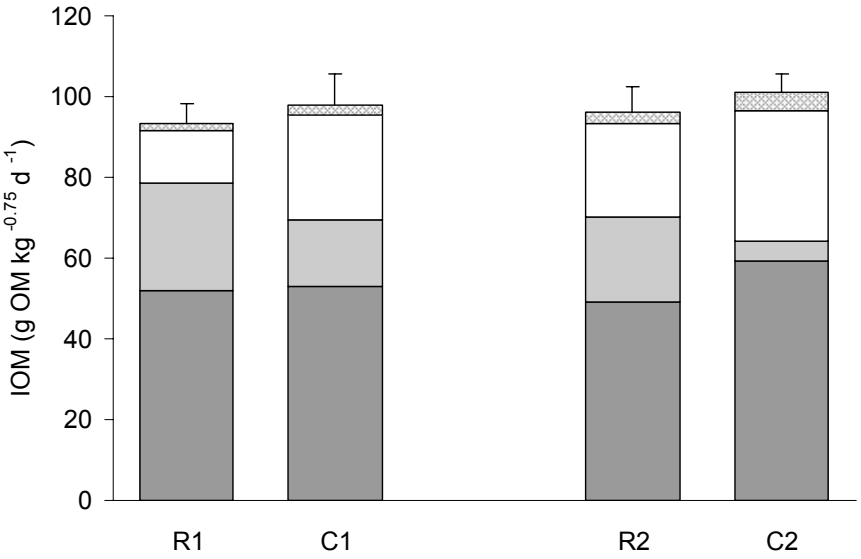

Fig. 4. Organic matter intake (IOM) from different feedstuffs of goats fed roughage-based (R) and concentrate-rich (C) rations during two feeding trials on Al Jabal al Akhdar in October 2006 (1) and February 2008 (2). Pasture vegetation: dark grey; cultivated roughage: light grey; dates: white; dried sardines: patterned.

Socio-economic situation and development options of the local population

The information collected in the initial HH survey in Masayrat (n=12 HH), Qasha' (n=10 HH) and Ash Sharayjah (n=18) on household composition, land and livestock endowment and the importance of non-farm activities for the overall household income was subjected to a hierarchical cluster analysis using the Ward's method and Squared Euclidean Distance (SPSS software; SPSS Inc., Chicago, USA). The selected variables included the number of goats and sheep owned, the number of Jelbahs (= smallest irrigation unit) cultivated and the number of persons with non-farm income per household. Four HH types were differentiated:

group A (n=8) comprised farmers who cultivated relatively large gardens (= crop farmers), group B (n=9) owned large goat herds (= livestock keepers), and group C (n=8) was characterized by a high non-farm income, whereas group D (n=15) included families with little non-farm income, only owning a few animals and cultivating small areas. The data collected in regular interviews in four representative households per group during November 2006 – November 2007 will be used to calculate the gross margin of individual farming activities via cost-benefit analyses as well as the resource and labour use efficiency for the different household types.

The problems perceived by farmers and their attitudes towards future developments of oasis agriculture were structured and their causes and effects analyzed to identify the key problems (Figure 5). The social and economic developments in the country changed farmers' objectives, needs and obligations. They also accelerated the loss of traditional agricultural knowledge on the one hand and the modernization of the crop and livestock husbandry on the other hand. The problems resulting from these developments are the over-exploitation of the natural resources, the inefficient resource management practices as well as the strong reliance on the external infrastructure and governmental support.

The lack of irrigation water and of fodder on pasture, the labour- and cost-intensity of farming activities, plant and animal diseases and the need for improved local education and health services as well as the lack of employment opportunities on Al Jabal al Akhdar were frequently mentioned problems. Nevertheless, the oases agriculture is seen as a source of income and food and as an important part of the families' cultural heritage: live goats and sheep as well as pomegranates, walnuts, garlic and the locally produced rose water are the main products of the oasis agriculture sold to local tourists and on the lowland markets, and prices for these products are high. Therefore, and despite the mentioned problems, 36 of the 40 interviewed farmers would like to continue farming.

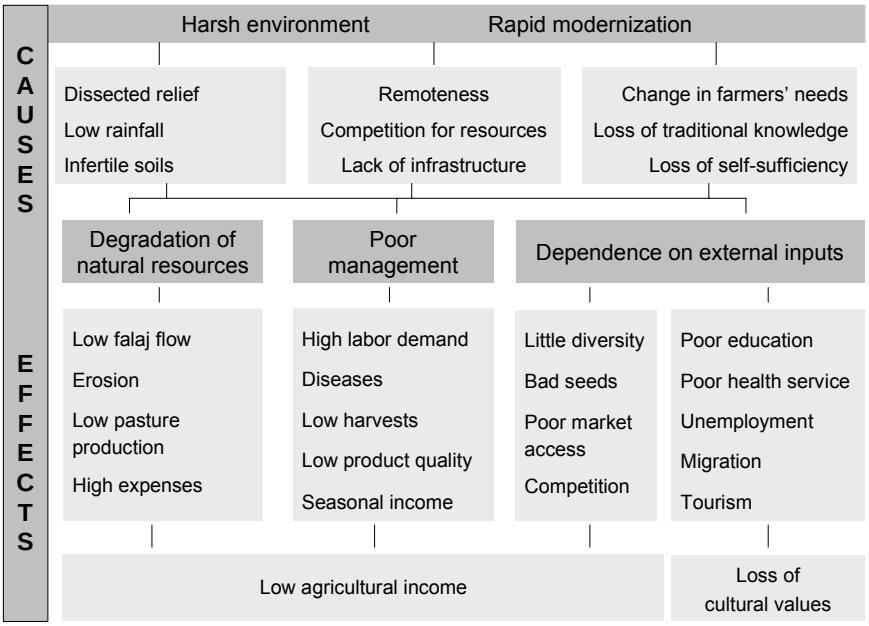

Fig.5. Hierarchically structured problems encountered by farmers of Al Jabal al Akhdar, Northern Oman as determined during interviews in August 2006 – April 2008.

Conclusions and outlook

The degradation of the natural resources, poor management practices and the strong reliance on external inputs are the main factors limiting the productivity of the traditional oases agriculture on Al Jabal al Akhdar under the present economic, social and environmental conditions. However, farmers nonetheless acknowledge the benefits derived from crop and livestock husbandry and the goats of the Jabal Akhdar showed a high production potential under feedlot conditions (Mahgoub et al., 2005). Thus, development opportunities must be found to address these key problems. Against the background of the data analysed so far, some livestock management options for improving the sustainability and efficiency of the goat husbandry could already be identified such the increased supplement feeding of individual animals according to their requirements and the season-specific nutritional quality of the pasture vegetation. The completion of the analysis of the data collected during the animal surveys, the regular household surveys as well as the group interviews will further add to this task. Using simple herd models such as the software PRY (Baptist, 1988), current off-take rates will be calculated and the effects of an improved feeding and herd management on the productivity of the goat husbandry simulated. Simple regression analyses and land use models will enable us to determine the agricultural resource use efficiency, to weigh alternative land uses and to evaluate the sustainability of different scenarios, including the introduction of new cash-crops, the involvement in the increasing tourism sector or the potential of niche-marketing of organically produced oases vegetables and meat. Hereby the likelihood of adoption of these management options will be discussed and it is hoped to identify perspectives for a long-term preservation of the oases

agriculture on Al Jabal al Akhdar, as an agricultural heritage sustaining a valuable genetic diversity of cultivated plants, a spectacular scenery for tourists as well as the livelihoods of the local population.

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