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Tradition and transformation

Steps towards a sustainable goat husbandry in mountain oases of Oman

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Summary

Tradition and transformation –
Steps to a sustainable goat husbandry in mountain oases of Oman

National trade liberalization and the societal and economic development in Oman since 1970 have profoundly transformed the life of rural communities in the northern Al Jabal al Akhdar Mountains. They threaten the continuation of the traditional agriculture in local mountain oases, which, however, is an important asset to local people's livelihoods and the conservation of natural resources, agro-biodiversity and cultural heritage. This thesis presents scientific evidence for the negative side effects of ongoing transformation processes on the traditional goat husbandry in the mountain oases and explores farmers' perspectives on crop and livestock husbandry. Options for an ecologically and economically sustainable agriculture at the scale of individual farm households, oases settlements and the Al Jabal al Akhdar region are discussed.

Through household interviews in three villages of Al Jabal al Akhdar in autumn 2006, data on farm households, agricultural management practices and farmers' objectives was collected. Smaller village and household sizes than those reported by Scholz (1984) point to the emigration of people from the oases and changing social structures within families and villages. Since increasing off-farm activities largely withdraw family labor, farmers frequently hire foreign laborers to assist them in crop and livestock husbandry. Owners of larger goat herds regularly sell animals on local markets, and supplemental feeding of goats strongly relies on purchased feeds. Hence, farmers' production and livelihood objectives have profoundly changed and farm households and agriculture increasingly depend upon external inputs.

To evaluate the impact of goats' grazing on the natural vegetation of mountain pastures, species composition, ground cover and biomass yields of the ligneous and herbaceous vegetation were analyzed at grazed and ungrazed sites. The shrubland pastures exhibit typical characteristics of equilibrium systems. Absence of herding of livestock, overlapping village pastures and decreasing grazing areas resulted in high stocking densities near settlements of >0.6 goats per hectare. Goat grazing modified the botanical composition and severely reduced ground cover and herbaceous biomass yields of the natural pasture vegetation. Low energy and nutrient concentrations in the pasture plants consumed by goats appear to limit animals' growth and production, in particular during the dry, cold winter months (November-January), when quantity and quality of fodder on pastures are lowest.

Growth and reproductive performance of grazing Jabal Akhdar goats were quantified through regular animal weighing and progeny history interviews with farmers. The data was analyzed using the herd model PRY to estimate monetary revenues from traditional goat husbandry. High prices for goats on local markets promote annual revenues of 38 € per animal. Due to goats' high feed intake during grazing, the use efficiency of cultivated and purchased feeds offered at the homestead was higher under farmers' traditional management compared to the feed use efficiency simulated for goats in zero-grazing systems. Nevertheless, low daily weight gains of young does after weaning and prolonged kidding intervals limit herd expansion and thus the potential annual animal offtake from goat herds. Improving growth and reproduction of goats would increase revenues from goat husbandry, but require higher investments in supplement feeding.

The potential to enhance nutrient and energy supply to goats through a feeding of locally available concentrate feeds and cultivated green fodder from the oasis gardens was evaluated in two feeding trials. Goats' feed intake during grazing in response to four different rations offered at the homestead was quantified. Metabolizable energy intake of goats covered their requirements for maintenance, locomotion on pasture and a weight gain of about 100 g d^{-1} at a bodyweight of 30 - 40 kg, which is higher than the actual post-weaning weight gain of goats in the oases. Intake from cultivated green fodder at the homestead significantly reduced goats' feed intake during grazing from 71% to 46% - 65% of their daily organic matter intake. Adjusting homestead feeding of grazing goats can thus be a means to simultaneously increase animal production and to conserve natural fodder resources. The use of locally available feedstuffs renders farmers less dependent on the purchase of expensive concentrate feeds.

An improved agricultural production, based on farmers’ traditional management practices and a skilled regional development and land use planning are needed to address the key problems in agriculture that were identified in this study. A regional label would sustain high product prices on local markets and thus provide the incentive for young people to continue crop and livestock husbandry. Improving infrastructure and developing regional employment opportunities could counteract the emigration of people from villages. It would thus assure the transfer of elders’ knowledge on farming to younger generations. A land use plan that coordinates the diverging interests of different parties could prevent overexploitation of the scarce natural resources. A combination of such measures would allow the conservation of the unique oases agriculture in the future as a highly appreciated asset to local people’s livelihoods and a valuable part of Oman’s cultural heritage.

Zusammenfassung

Tradition und Wandel –
Schritte zu einer nachhaltigen Ziegenhaltung in den Bergoasen Omans

Die Liberalisierung des nationalen Handels und die gesellschaftliche und ökonomische Entwicklung in Oman seit 1970 veränderten das Leben der landwirtschaftlichen Bevölkerung im nördlichen Al Jabal al Akhdar Gebirge grundlegend. Sie gefährden das Fortbestehen der traditionellen Landwirtschaft in den Bergoasen, welche aber einen wichtigen Beitrag zum Lebensunterhalt der Menschen und zum Erhalt der natürlichen Resourcen, der landwirtschaftlichen Biodiversität und des Kulturerbes leistet. Diese Studie liefert wissenschaftliche Beweise für die negativen Auswirkungen dieser Umwandlungprozesse auf die traditionelle Ziegenhaltung in den Bergoasen und erforscht die Sichtweisen der Bauern bezüglich Ackerbau und Tierhaltung. Möglichkeiten einer ökologisch und ökonomisch nachhaltigen Ziegenhaltung auf Ebene einzelner Haushalte, der Oasensiedlungen und der Al Jabal al Akhdar Region werden diskutiert.

Durch Haushaltsbefragungen in drei Dörfern des Al Jabal al Akhdar Gebirges im Herbst 2006 wurden Daten zu den Haushalten, landwirtschaftlichen Praktiken und Zielen der Bauern gesammelt. Kleinere Dorf- und Haushaltsgrößen als die von Scholz (1984) berichteten deuten auf die Auswanderung der Menschen aus den Oasen und sich ändernde Sozialstrukturen in den Familien und Dörfern. Da zunehmende außerlandwirtschaftliche Aktivitäten die familiäre Arbeitskraft entziehen, stellen Bauern häufig ausländische Arbeiter ein, die sie in der Landwirtschaft unterstützen. Besitzer größerer Ziegenherden verkaufen regelmäßig Tiere auf lokalen Märkten und die Fütterung der Ziegen beruht stark auf zugekauften Futtermitteln. Folglich haben sich die Produktions- und Lebensziele der Bauern grundlegend verändert und Familien und Landwirtschaft hängen vermehrt von externen Mitteln ab.

Artenzusammensetzung, Bodendeckung und Biomasseerträge der holzigen und krautigen Vegetation an beweideten und unbeweideten Standorten wurden untersucht, um die Auswirkung der Ziegenbeweidung auf die natürliche Weidevegetation zu bewerten. Die Strauchlandweiden weisen typische Charakteristika von Gleichgewichtssystemen auf. Fehlendes Hüten der Tiere, sich

überschneidende Dorfweiden und kleinere Weideflächen erhöhten die Besatzdichten nahe Siedlungen auf >0.6 Ziegen pro Hektar. Die Beweidung veränderte die Artenzusammensetzung und verringerte Bodendeckung und Biomasseerträge der Krautvegetation. Geringe Energie- und Nährstoffgehalte in den von Ziegen gefressenen Weidepflanzen scheinen das Wachstum und die Produktion der Tiere zu begrenzen, vor allem in den trockenen, kalten Wintermonaten (November-Januar), wenn die Futtermenge und -qualität am niedrigsten ist.

Wachstum und Reproduktion weidender Jabal Akhdar Ziegen wurden durch regelmäßige Tierwiegungen und "Progeny History"- Interviews erfasst und die Daten mit dem Herdenmodell PRY analysiert, um das Einkommen aus der traditionellen Ziegenhaltung abzuschätzen. Hohe Preise für Ziegen auf lokalen Märkten ermöglichen einen Jahreserlös von 38 € pro Tier. Aufgrund der großen Futteraufnahme der Ziegen auf der Weide war die Nutzungseffizienz der im Stall angebotenen Futtermittel bei traditionellem Management höher als simulierte Ergebnisse für Ziegen in "zero-grazing"-Systemen. Dennoch limitieren die niedrige Geburtenrate und Gewichtszunahme der weiblichen Jungtiere nach Absetzen die Herdenentwicklung und folglich die mögliche Tierentnahme aus den Ziegenherden. Eine Verbesserung von Wachstum und Reproduktion der Tiere würde das Einkommen aus der Ziegenhaltung erhöhen, erforderte aber höhere Investitionen in die Zufütterung.

Das Potenzial einer Fütterung lokal verfügbarer Konzentratfutter und des in den Oasen angebauten Grünfutters für eine verbesserte Nährstoff- und Energieversorgung der Ziegen wurde bewertet. Die Futteraufnahme der Ziegen auf der Weide in Abhängigkeit von vier verschiedenen, im Stall angebotenen Rationen wurde in zwei Fütterungsversuchen bestimmt. Die Aufnahme umsetzbarer Energie deckte den Bedarf der Ziegen für Erhaltung, Bewegung auf der Weide und eine Gewichtszunahme von ungefähr 100 g d^{-1} bei 30 - 40 kg Körpergewicht. Dies ist höher als die tatsächliche Gewichtszunahme der Ziegen in den Oasen. Der Konsum von Grünfutter im Stall verringerte die Futteraufnahme der Ziegen auf der Weide von 71% auf 46% - 65% ihrer täglichen Aufnahme an organischer Masse. Eine angepasste Stallfütterung weidender Ziegen bietet daher die Möglichkeit, die Produktion der Tiere zu erhöhen und gleichzeitig die natürlichen Futterresourcen zu schonen. Die Verwendung lokal vorhandener Futtermittel verringert die Abhängigkeit der Bauern vom Zukauf teurer Konzentratfutter.

Eine verbesserte landwirtschaftliche Produktion basiernd auf den traditionellen Bewirtschaftungsformen der Bauern und eine erfahrene regionale Entwicklungs- und Flächennutzungplanung sind notwendig, um die in dieser Studie erkannten Hauptprobleme in der Landwirtschaft zu lösen. Eine Kennzeichnung regionaler Produkte würde die hohen Produktpreise aufrecht erhalten und der jungen Bevölkerung den Anreiz bieten, die Landwirtschaft in den Oasen fortzusetzen. Die Verbesserung der regionalen Infrastruktur und die Entwicklung lokaler Arbeitsplätze könnte der Abwanderung der Leute aus den Dörfern entgegenwirken und somit die Überlieferung des Wissens der Älteren über die Landwirtschaft an die Jüngeren ermöglichen. Ein Flächennutzungplan, der die Interessen verschiedener Parteien koordiniert, könnte die Übernutzung der knappen Naturresourcen verhindern. Die Kombination solcher Maßnahmen würde den zukünftigen Erhalt dieser einzigartigen Oasenlandwirtschaft erlauben, als ein hoch geschätzter Beitrag zum Lebensunterhalt der lokalen Bevölkerung und als wertvoller Bestandteil des Kulturerbes Omans.

I Introduction

I.1 Globalization and smallholder farming in developing countries

In the past decades, much research focused on the advantages and disadvantages of the advancing liberalization of international trade and the consequently growing globalization of world markets for the economy and population of developing countries. It aimed at understanding if and how they can benefit from the new import and export opportunities, the rising foreign investments in their economy as well as the improved access to information, knowledge and modern technologies on the one hand, and by which means they can counteract the negative effects of their participation in world trade and politics on the other hand. Globalization does not only have an impact on countries' economy at a national level, but it also influences the development of selected regions and, in the case of agriculture, directly or indirectly induces changes in traditional farming systems. As a result of increasing imports due to the liberalization of national trade, a variety of products becomes available to people on local markets such as clothing, household items, convenience products, but also meat, vegetables, fruits, flour and other foodstuffs (Scholz, 1977; Scholz, 1984). While this reduces people's dependence on subsistence farming, it also strongly raises their living costs and therefore their need for monetary income.

However, getting access to local markets to sell their products is particularly difficult for smallholder farmers in rural areas (Rodríguez-Pose and Gill, 2006; Markelova et al., 2009). While product type or quality might not meet customers' preferences (Markelova et al., 2009), the demanded quantity may at least temporarily exceed the potential production of local agriculture, so that stores or supermarkets often hesitate to collaborate with individual smallholder farmers (Vorley et al., 2007). The introduction of imported and often cheaper foodstuffs to local markets additionally represents a strong competition for farmers and results in decreasing prices for their own products (Scholz, 1984; Markelova et al., 2009). Their costs for transport and transactions as well as for investments and the manufacturing of raw products are higher than for farmers in urban areas, where infrastructure and markets and therefore the supply of agricultural inputs are well developed (Rodríguez-Pose and Gill, 2006; Markelova et al., 2009). Hence, as a consequence of liberalized trade, it becomes a major challenge for rural smallholder farmers to remain competitive and to actually generate an income from the sale of their products that covers their increasing expenses.

The export of agricultural commodities might ease market access for smallholder farmers directly, if they are able to participate in this market share, or indirectly by reducing competition on local markets (Rodríguez-Pose and Gill, 2006). Hence, under these circumstances the rural population will benefit from a country's increasing export of agricultural products (Rodríguez-Pose and Gill, 2006). In contrast thereto, it may only gain little, if the export of natural resources such as oil or natural gas, manufactured products or services accounts for most of the country's foreign trade activities (Rodríguez-Pose and Gill, 2006). These are either produced in only small regions or strongly rely on a well-developed infrastructure and the availability of skilled labor (Rodríguez-Pose and Gill, 2006). In countries, where industry, administration and institutes of higher education are largely concentrated in the main cities, the incentive is higher for foreign trade companies to settle here rather than in remote industrial zones (Rodríguez-Pose and Gill, 2006), so that the increasing export of non-agricultural products appears to further amplify rural-urban disparities.

The resulting lack of employment opportunities in rural areas and the increasing need for monetary income promotes the migration of the rural population towards urban regions within the country or internationally. The additional income and remittances benefit the remaining families, allowing them to raise their standard of living and to further invest in education, thereby indirectly generating more income (de Haas, 2006; Mendola, 2008). However, since revenues from non-farm employments are higher, the need for an agricultural income decreases and labor force is largely withdrawn from agriculture. Hence, rural-urban or international migration together with the increasing competition on local markets due to global trade liberalization favor the abandonment of the traditional, labor-intensive agriculture (de Haas, 2006; Stroosnijder et al., 2008). Nevertheless, if remittances are invested in agriculture, its productivity can be increased, such as in the case of the traditional agricultural system in the Atlas Mountains of Morocco, where international remittances enabled farmers to invest in agriculture and thereby increase agricultural outcome (de Haas, 2006). However, while households that obtained an additional non-farm income were able to invest in buildings, education or in agriculture, resource-poor households lacked the opportunity to improve agricultural production (de Haas, 2006; Mendola, 2008). They therefore become more dependent on non-farm income and the purchase of food and are particularly affected by changes in prices on markets due to trade liberalization. Thus, globalization not only amplifies rural-urban but also social disparities.

Finally, globalization and economic development are often associated with the degradation of natural resources in developing countries (Barbier, 2000). This has significant effects for the traditional farming systems in rural areas, because they strongly rely on their environment (Aggrawal, 2006). Since trade liberalization and governmental policies foster agricultural intensification in case marketable commodities are produced (Barbier, 2000; Bardhan, 2006) and population growth in many of the developing countries is high (WRI, 2007), the pressure exerted on their natural environment increases. Moreover, the specialization on the production of only a few high-value products reduces agricultural diversity and limits farmers' ability to adapt to changing environmental conditions, which is, however, essential for the sustainability of agro-ecosystems in variable environments (Altieri, 2002; Aggrawal, 2006). And while community-based institutions regulated the use of communal resources in the past, these were often dissolved within the course of the countries' development (Aggarwal, 2006). However, the open (uncontrolled) access to communal resources results in their overexploitation and degradation ("tragedy of the commons", Hardin, 1968), thereby threatening long-term sustainability of the traditional agricultural systems.

I.2 Common approaches in rural development

Various strategies were developed to counteract the negative side-effects of globalization, to balance the disparities between rural and urban regions and to conserve traditional agricultural systems in developing as well as in developed countries. For example, farmers in rural areas of Europe are directly rewarded for their contribution to the conservation of cultural landscapes and the natural and agricultural biodiversity by national and international subsidies (Lütz and Bastian, 2002; Stroosnijder, 2008). Governmental interventions and payments can also indirectly encourage farmers to continue farming. Hence, many countries strongly regulate wheat prices to compensate for national and global price fluctuations (Sarris, 2007). In Iran, the government purchases the surplus wheat harvest to reduce competition on the local markets due to overproduction and to thereby maintain constant prices (Amid, 2007). The supply of agricultural inputs to farmers such as machinery, propagates or fertilizers and the investment in their education and training as well as in processing chains to manufacture raw products are important measures to support rural smallholder farmers, who often lack sufficient capital, knowledge and infrastructure to increase agricultural production by themselves (Bardhan, 2006; de Haas, 2006; Stroosnijder, 2009). They aim to increase productivity of smallholder farming and to diversify agricultural production, thereby reducing farmers' risks and assuring their market access. The latter was also achieved by establishing agricultural cooperatives for the marketing of cereal grain produced in the Ethiopian highlands (Bernard and Spielman, 2009). A different approach to facilitate product marketing is to develop niche markets such as in the case of organic food production. It strengthens farmers' competitiveness and increases their agricultural income through an access to highly specialized markets (Stolze and Lampkin, 2009).

Many of these projects were stimulated by national and international governments as well as non-governmental organizations. However, not all of them succeeded, since not every approach is appropriate in every case (Markelova et al., 2009). The ease of market access or the manufacturing of raw products is not an effective way to support agricultural production, if there is no demand for farmers' products or if agriculture serves auto-consumption. A holistic approach considering all parts of the farming system and the indigenous knowledge of farmers therefore appears to be essential for a successful rural development (Stroosnijder, 2009).

I.3 Farming systems approach and the role of indigenous knowledge

While in the past, natural resource management rather focused on distinct resources such as flora, fauna, soil or water, emphasis is nowadays put on the complexity of interactions between these single components in natural ecosystems. Based on these close relationships, ecosystems reach a state of equilibrium through constant adaptation to their biotic and abiotic environment over time, which then is more or less resilient to short-term environmental changes (Altieri, 2002; Aggrawal, 2006).

Agricultural systems resemble these natural ecosystems (Altieri, 2002), exhibiting the same complexity of relationships between their different components. An agro-ecosystem is therefore defined as a "community of plants and animals interacting with their physical and chemical environments that have been modified by people to produce food, fiber, fuel and other products for human consumption and processing" (Altieri, 2002). However, not only does the farmer shape this environment by using the natural resources, but environmental factors in return determine the output he or she can gain from farming activities. And farmers themselves are part of a social and economic environment, where cultural, religious and societal circumstances determine individual farming objectives and management decisions. This social and economic environment is constantly modified by national and international developments and the advancing liberalization (Figure I.1).

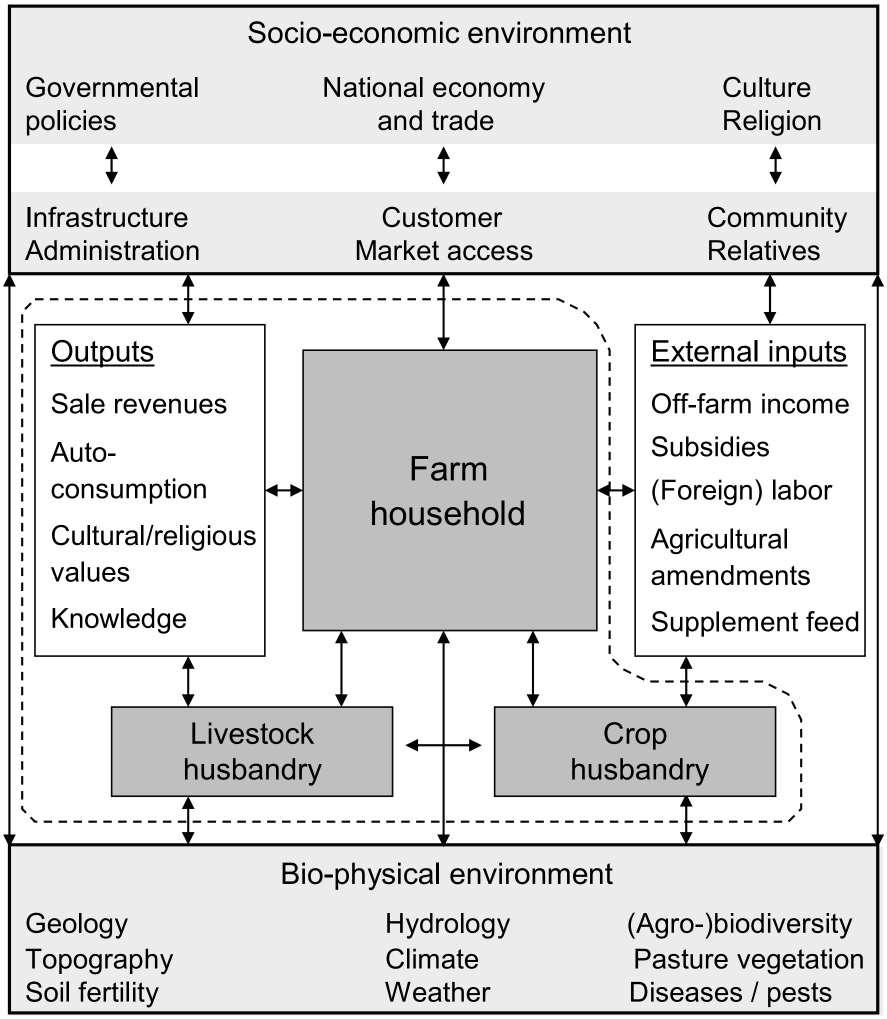

Figure I.1. Schematic representation of different components of agricultural systems (- - -) and relationships (arrows) between them and their bio-physical and socio-economic environment (modified after a presentation by Prof. Dr. Gerold Rahmann at the University Kassel in Witzenhausen in spring 2005).

Similar to natural ecosystems, traditional agro-ecosystems are the result of long-term adaptation processes of agricultural production to the specific natural environment. Management practices were constantly modified to meet farmers' needs on the one hand without compromising the conservation of natural resources on the other hand. These systems are thus by definition sustainable (Altieri, 2002) and more or less resilient to short-term environmental changes. While the underlying idea of the systems approach in natural resource management is to look at local natural ecosystems, to mimic their basic principles, structures and functions and to thereby achieve long-term sustainability (Altieri, 2002), farmers have generated a comprehensive knowledge of their local environment through long-term observations (Berkes and Folke, 2002). This indigenous knowledge and the corresponding traditional management practices therefore offer a valuable basis for the conservation of local agricultural systems, a sustainable natural resource management and a successful rural development.

I.4 Social and economic modernization of Oman since 1970

Since Sultan Qaboos bin Said superseded his father Said bin Said Taymur in 1970, Oman has undergone profound political, social and economic developments. A hierarchically structured government was established replacing the complex tribal structures of the past, and cultural, societal and custom restrictions were eased to strengthen the national and international collaboration and trade (Scholz, 1977; Petersen, 2004). The increasing exploitation of oil and natural gas and the rising prices for both of these resources on the world market facilitated these developments (Peterson, 2004). The oil and gas industry accounts for about 40% of Oman's gross domestic product (GDP) and about 75% of its annual export value (CIA, 1999), stressing the importance of this industry for the country's economy. Besides financing the expanding oil and gas industry itself as well as Oman's military forces (Peterson, 2004), revenues were invested in the development of the national infrastructure. The main port and the airport in Muscat were expanded, a road system was established and schools, hospitals as well as a university were built (Scholz, 1977). Large numbers of immigrants from India, Pakistan, Bangladesh, Eastern Africa as well as North America and Europe entered Oman in search for employment in the flourishing economy (Scholz, 2001). In 2003, foreigners are employed in all sectors of the economy and accounted for 24% of Oman's population and 49% of the country's total labor force (MNE, 2004). To increase agricultural production and to thereby meet the food demand of its growing population, the country furthermore invested in the modernization of agriculture by installing desalinization plants and automatic groundwater wells and by introducing machinery, chemical fertilizers and pesticides. In addition, large research and production farms were established along the northern coast, the Batinah region (Scholz, 1977; Scholz, 2001, Figure I.2). In rural areas agricultural extension centers were founded to improve agricultural practices on traditional smallholder farms. Veterinary services, livestock feeds and improved breeding animals were provided to livestock keepers, whereas propagates, machinery and chemicals were made available for crop production (Scholz, 1977 and 1984). In consequence thereof, arable and permanent crop land increased from 42,000 ha in 1970 to 80,000 ha in 2003 (FAOSTAT, 2009). In 2003, Oman's total number of cattle (302,000), goats (1,557,000) and sheep (351,000) was two to three times higher than in 1992/93 (MAF, 1994 and 2005), and the agricultural export value rose from 5.5 billion US$ in 1990 to 18.7 billion US$ in 2005 (FAOSTAT, 2009).

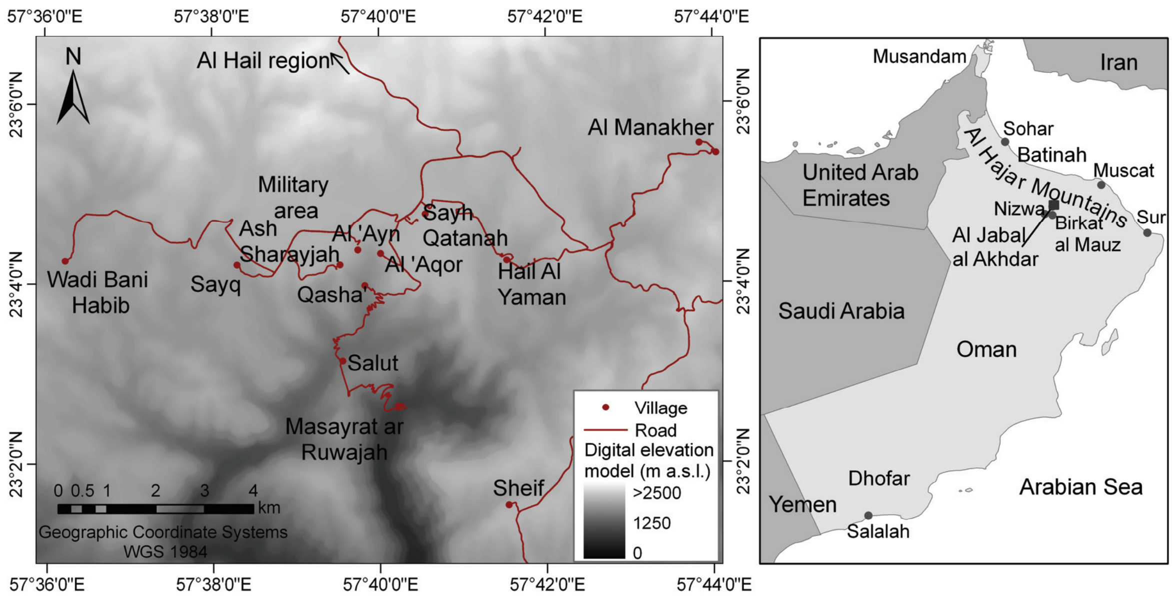

Figure I.2. Oasis settlements in the vicinity of Sayh Qatanah (left) in the Al Jabal al Akhdar region of the Al Hajar Mountains in Northern Oman (right).

However, Oman's population grew rapidly by an average of 3.5% per year (1970 - 2006) from 0.8 million people in 1970 to 2.5 million people in 2006 (FAOSTAT, 2009). Since simultaneously the per capita meat consumption rose from only 7 kg in 1970 to nearly 50 kg per year in 2002 (WRI, 2007), the demand for food and particularly for meat and meat products steadily increased. Despite the increase in agricultural exports, the value of agricultural imports largely exceeded exports in 2005 (FAOSTAT, 2009), which indicates the growing dependence on food imports despite all efforts to improve agricultural production in the country. The growing population resulted in an increasing unemployment rate to an estimated 15% of the total labor force in 2004 (CIA, 2008). While production and consequently revenues from the oil and gas industry has declined from 47.5 million tons in 2001 to 36.7 million tons in 2006 (WRI, 2007), the manufacturing and service sectors remained rather small, accounting for only 8% and 43% of the national GDP in 2004 (WRI, 2007). Since these industries are mainly located in the greater capital area around Muscat, the Batinah region and near Salalah in the South (see Figure

I.2), unemployment rates are likely to be higher in the rural than in the urban areas. Moreover, private investments largely concentrated on the purchase of land property or the formation of construction and trade companies in the capital area, whereas little investments were made in the agriculture of the country's hinterlands (Scholz, 1977). The persisting concentration of administration, high-level education and health services in the capital region further amplifies the bias between rural and urban areas in Oman. The steep increase of the urban population by annually 8.1% in contrast to an annual growth of the population in rural regions by an average of 0.8% from 1970 to 2005 (WRI, 2007) reflect the migration of people from the country's hinterlands to the cities as the consequence of these rural-urban disparities in the past 30 - 40 years. Hence, although the comprehensive development of Oman's governance, economy and society in the past four decades deserve great appreciation (Scholz, 2001), the growing population and unemployment, the need for rural development as well as the dependence on imports impose major challenges for the country's future.

I.5 Agricultural system in the mountain oases of Al Jabal al Akhdar

Most of Oman's land area (309,500 km^2; FAOSTAT, 2009) is characterized by rocky desert landscapes at altitudes below 500 m a.s.l., where annual rainfall of <100 mm and mean daily temperatures of 29°C (Fisher, 1994) do not allow a permanent vegetation cover. In the northern part of the country, a large mountain range stretches parallel to the coast line from Musandam in the North to the coast of the Arabian Sea near the town of Sur in the East (Figure I.2). This Al Hajar mountain range is mainly composed of limestone (Glennie, 2005). While it is covered by other metamorphic, crystalline and sedimentary rocks in most areas, the limestone was excavated by continuous erosion in the Al Jabal al Akhdar region of the central Al Hajar range (Glennie, 2005; Luedeling and Buerkert, 2008). Here the mountains reach elevations of almost 3000 m a.s.l. (CIA, 2008) and are characterized by steep slopes and deep dissecting valleys leading the surface runoff water to the coastal and interior plains. The average annual rainfall on Al Jabal al Akhdar of 318 mm (Department of Civil Aviation and Meteorology, Oman) is substantially higher than in the country's lowlands. However, inter-annual variability is high with years of less than 200 mm of rainfall on the one hand and precipitation occasionally exceeding 400 mm per year on the other hand (Department of Civil Aviation and Meteorology, Oman). While most of this rainfall occurs during February – April and again in July – September, probability of rainfall and average daily temperatures decrease in the winter months, resulting in a cold and dry season during November - January and a warm and rainy period during July – September (Figure I.3). The natural vegetation is characterized by open shrublands, giving the region its name “The Green Mountain”. Abundant ligneous species are *Olea europaea* L. ssp. *cuspidata* (Wall. ex G. Don) Ciferri, *Sideroxylon mascatense* (A.DC.) Penn. and *Dodonaea viscosa* (L.) Jacq. at about 2000 m a.s.l., whereas *Ziziphus spina-christi* (L.) Desf., *Acacia gerrardii* Benth. and *Pteropyrum scoparium* Jaub. & Spach. are dominant ligneous species in the deep valleys below 1500 m a.s.l. (Brinkmann et al., 2009).

The karstic mountain body stores rainwater, which then emerges from permanent springs on the mountain slopes (Luedeling and Buerkert, 2008). Near these springs, oases settlements have established, using the spring water for human and livestock consumption as well as for the irrigation of adjacent gardens (Wilkinson, 1977). In large terrace systems of up to 14 hectares per village (Luedeling and Buerkert, 2008), farmers cultivate a large variety of perennial crops such as pomegranates (*Punica granatum* L.), peaches (*Prunus persica* L.), walnuts (*Juglans regia* L.) and roses (*Rosa damascena* Mill.) in oases above 1500 m a.s.l. as well as dates (*Phoenix dactyilifera* L.), bananas (*Musa ssp.*) and limes (*Citrus aurantiifolia* (L.) Swingle) in gardens at lower altitudes (Figure I.4).

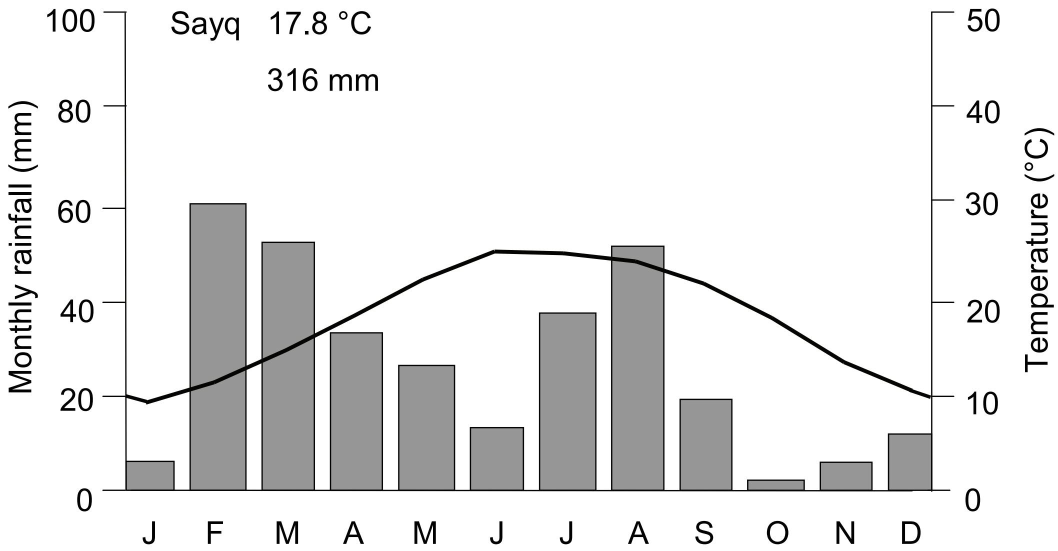

Figure I.3. Climate diagram for Sayq (57°38’17’’E, 23°40’12’’N, 1900 m a.s.l.) on Al Jabal al Akhdar, Oman, showing average rainfall in mm (bars; primary y-axis) and mean monthly temperatures in °C (line; secondary y-axis) for the single months of the year as determined during 1979 - 2004 (Department of Civil Aviation and Meteorology, Oman).

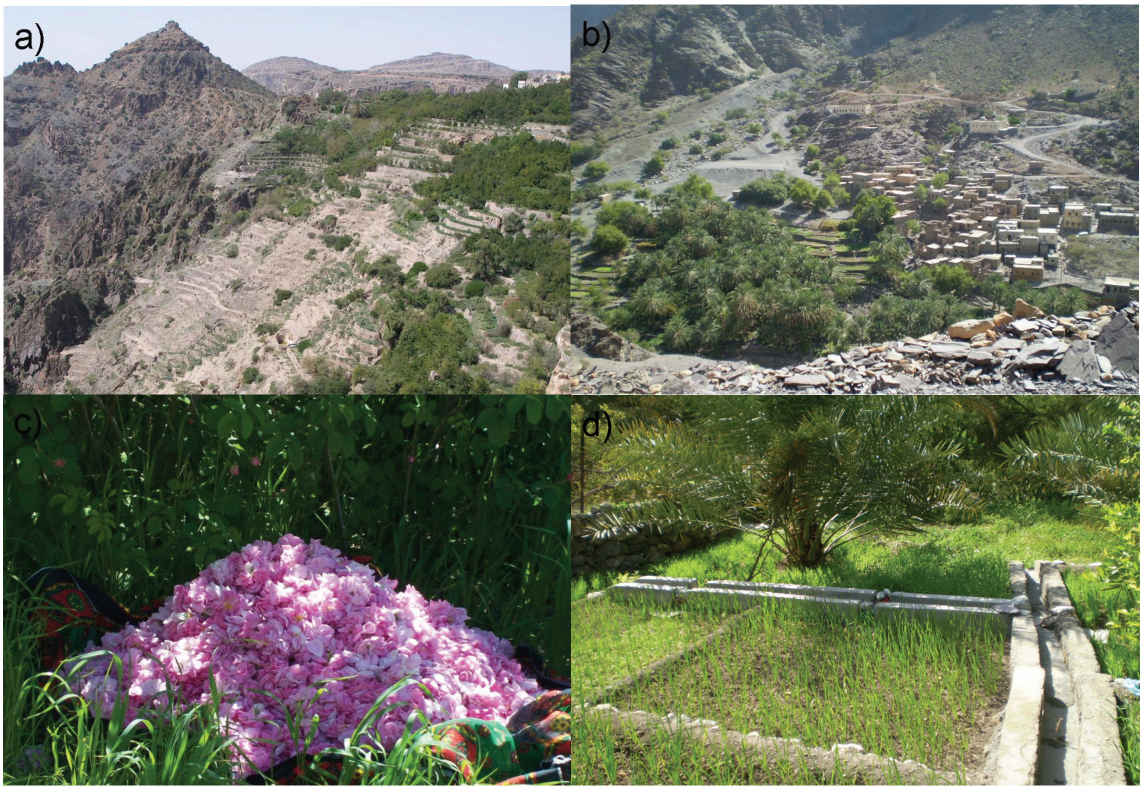

Figure I.4. Cultivated and abandoned terrace gardens of Ash Sharayjah (a); the oasis settlement and adjacent date palm groves of Masayrat ar Ruwajah (b); rose petals collected for the traditional rose water production (c); and irrigation channels leading water to small fields of garlic and fodder (background) grown under the cover of trees (d) on Al Jabal al Akhdar, Oman.

Besides other fruit and citrus trees, vegetables such as garlic (*Allium sativum* L.), onions (*Allium cepa* L.) and potato (*Solanum tuberosum* L.) as well as different fodder crops are grown, including maize (*Zea mays* L.), barley (*Hordeum vulgare* L.s.L.), oat (*Avena sativa* L.), sorghum (*Sorghum bicolor* Moench s.L.) and alfalfa (*Medicago sativa* L.). Irrigation relies on the traditional *Falaj* system, the typical irrigation system in the countries of the Arabian Peninsula (Wilkinson, 1977). Channels lead the water from the springs into the gardens and distribute it to the single fields. The water distribution among farmers follows a rotational system and complex principles of shareholding (Wilkinson, 1977), so that detailed time schedules exist for the irrigation of individual plots. And while vegetables are mainly grown during the winter months when trees such as walnuts, roses, pomegranates and peaches are not irrigated and surplus water is therefore available, farmers grow green fodder under the cover of the trees in the summer to better exploit the water needed to sustain fruit production (Figure I.5). The clearly defined distribution of irrigation water among farmers together with their ability to flexibly decide about the kind of crop and the size of area being cultivated or left fallow enables farmers to efficiently use this scarce resource (Siebert et al., 2007).

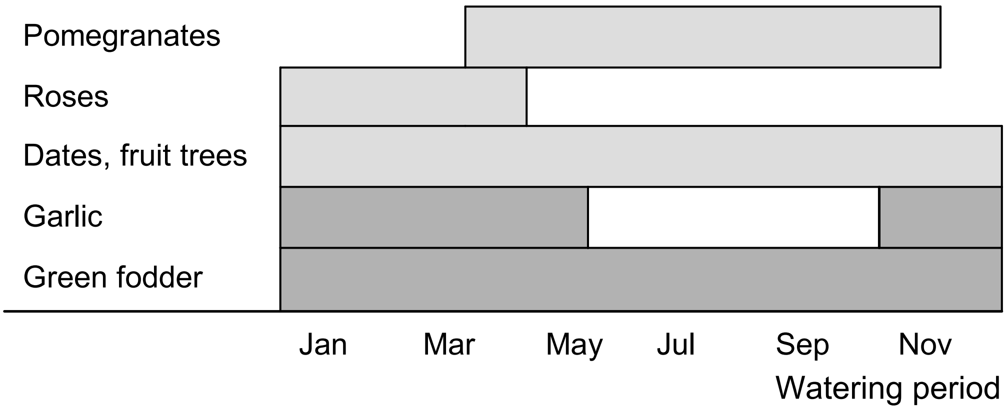

Figure I.5. Seasonal calendar for the irrigation of perennial (light grey) and annual (dark grey) crops cultivated in mountain oases of Al Jabal al Akhdar, Oman, as determined during household interviews in three villages in August 2006 – April 2008.

Livestock is an important component of the agricultural system and goats of the local Jabal Akhdar breed are the most numerous animal species kept in the oases. While cattle are solely stall-fed, goats and sheep graze the natural pasture vegetation during the day, thereby striving on natural resources that are otherwise unavailable for human consumption (Figure I.6). In the evening, the animals return to the homestead and are fed small amounts of dates, dried sardines, meal rests as well as cultivated green fodder and collected tree leaves from the mountains. Over night, the goats are kept in the barn and their manure is collected and used as a fertilizer in crop cultivation, maintaining the fertility and preventing salinization of the irrigated oases soils (Wichern et al., 2004; Luedeling et al., 2005). However, animals are mainly raised for the purpose of slaughter or sale. In particular during religious holidays or to honor guests, cattle, sheep or goats are slaughtered and prices for Jabal Akhdar goats on local markets are high, reaching up to 200 Omani Rial (approximately 400 €) for adult bucks (Zaibet et al., 2004). While leather and hair are nowadays not used anymore, farmers still collect the surplus milk after the offspring has suckled and use it for auto-consumption.

Figure I.6. Herder taking out goats to pastures on the Sayq plateau on Al Jabal al Akhdar, Oman, (a), a goat browsing a *Grewia erythraea* (Schweinf.) shrub (b) and group feeding of Jabal Akhdar goats with dates and dried sardines (c).

I.6 Study objectives and structure

Several authors stressed the importance of traditional agricultural systems in tropical and subtropical highlands for the conservation of (agro-) biodiversity and cultural landscapes, the prevention of soil erosion and a sustainable resource use as well as the supply of food and income for rural people (de Haas, 2006; Stroosnijder et al., 2008; Nyssen, 2009). However, the increasing trade liberalization and the resulting constraints to smallholder farming in rural highlands mentioned above have commonly led to profound land use changes or even the abandonment of these valuable systems. Similarly, the importance of the traditional agro-pastoral system in the mountain oasis of Al Jabal al Akhdar has since long been acknowledged (Birks, 1978; Scholz, 1984). However, initial transformations of the traditional agriculture due to the social and economic changes in Oman have already been recognized as early as the 1970s (Birks, 1978; Scholz, 1984) and the abandonment of these unique crop and livestock husbandry systems was suspected. Hence, the main objectives of the present study were to analyze the effects of the ongoing social, political and economic changes in Oman on the traditional agro-pastoral system of Al Jabal al Akhdar and to identify the key problems that limit its future sustainability. Data presented in this study were collected during field surveys and on-farm experiments in the central Al Jabal al Akhdar region from August 2006 to April 2008 and focuses on the traditional goat husbandry in the mountain oases. In Chapter II, general characteristics of farm households in the study oases and farmers' views on crop and livestock husbandry are presented. Chapter III analyzes the effects of goat grazing on the natural pasture vegetation and discusses the role of pasture management for a sustainable use of these fodder resources. In Chapter IV, a modeling approach was used to estimate monetary output from traditionally managed goat herds in the study villages based on their current growth and reproductive performance. The potential to increase herd production through intensive supplement feeding in addition to grazing or the introduction of a zero-grazing system are discussed. Chapter V presents the results of two feeding trials conducted on Al Jabal al Akhdar that aimed at analyzing the potential contribution of an improved homestead feeding of goats to the conservation of the natural rangeland vegetation. Based on these analyses, Chapter VI discusses to which extent the current agricultural practices still meet farmers' needs and objectives, reflects on the importance of the traditional agricultural system for the region and discusses the applicability of common approaches in rural development. Finally, conclusions are drawn on how this system, based on farmers' traditional practices, can be conserved in the future as a unique part of Oman's cultural heritage as well as an important contribution to local people's livelihoods (Chapter VII).

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II Characteristics and perspectives of farm households

In autumn 2006, an initial survey was conducted in all permanent households* of Masayrat ar Ruwajah (57°40’13’’E, 23°02’37’’N, 1050 m a.s.l., n=12), Qasha’ (57°39’50’’E, 23°04’00’’N, 1700 m a.s.l., n=10) and Ash Sharayjah (57°39’30’’E, 23°04’10’’N, 1950 m a.s.l., n=17), three oases in the vicinity of Sayh Qatanah, the main settlement on Al Jabal al Akhdar. A household was hereby defined as a unit of family members who live, sleep and eat together and share the same income (de Haas, 2006). Family members who were working elsewhere during the week, but returned for the weekend and whose salary was used for household purposes were therefore considered part of this unit. Qualitative and quantitative information on household size, land and livestock endowment, off-farm income, management practices and the use of agricultural products was collected during interviews with one male or female adult of each household. Moreover, farmers were asked about their views on problems in crop and livestock husbandry and their objectives for the future oasis agriculture.

Household characteristics

In autumn 2006, the households in the three villages on Al Jabal al Akhdar comprised on average 10 (SD 6.5) persons. While four households included more than 20 persons due to a second or third marriage of a male household member, ten households had only five or less people and in 67% of the households, persons of less than three generations were living together. Total village inhabitants amounted to 140, 152 and 127 persons in Ash Sharayjah, Qasha’ and Masayrat ar Ruwajah, respectively (Table II.1). While children aged 6 – 16 years go to school, at least one person was studying at a college or university or undergoing a professional training in 12 households. With the exception of three households, all families obtained an off-farm income, including governmental payments, pensions or salaries from off-farm employments. While all households had access to running water within the house, partly being supplied by water tanks on roofs, most households had a television (n=35), a phone (n=32) and a washing machine (n=30), and 25 households owned a car.

All farmers in the study villages owned fields in the oasis gardens and 29 households additionally kept some livestock, including cattle (n=10), goats (n=27), sheep (n=6), chickens (n=5) or rabbits (n=2). Total number of goats and sheep

*One household in Ash Sharayjah refused to participate in initial household survey.

and average herd sizes per household were higher in Masayrat ar Ruwajah and Qasha' compared to Ash Sharayjah. Farmers in the three oases claimed to keep fewer goats and sheep today than in the past: 21 of the livestock keepers kept more animals ten years ago than in autumn 2006 and four households had given up livestock husbandry in the last ten years. Total number of goats and sheep of farmers who are still living in the villages today therefore amounted to about 200, 250 and 400 animals in Ash Sharayjah, Qasha' and Masayrat ar Ruwajah in 1996, respectively. Of all households in the study villages, 21% employed a full-time and 13% a half-time worker, whereas 36% of the households in the three villages at least occasionally paid a person to complete specific tasks, such as the transport of manure, the plowing of fields, the repair of terrace walls or to assist in date harvest. Moreover, 49% of households in the study villages owned a motorized plough and 31% were regularly applying chemical fertilizers.

Table II.1. Characteristics of farm households and livestock keepers in three villages of Al Jabal al Akhdar, Oman, as determined during a household survey in autumn 2006.

Village	House-holds	Inhabi-tants	Household size (n)	Livestock keepers	Goats/ Sheep	Herd sizes (n)
	n	n	Mean ± SD	n	n	Mean ± SD
Ash Sharayjah	17	134	8 ± 6.0	10	74	6 ± 3.2
Masayrat ar Ruwajah	12	127	10 ± 5.6	12	306	26 ± 15.6
Qasha'	10	152	15 ± 7.3	6	126	21 ± 22.2

Farmers' attitudes towards crop and livestock husbandry

Besides high labor demand (n=10), water scarcity was a major constraint to crop cultivation mentioned by 14 farmers in the oases during the initial household interviews (Figure II.1). Moreover, plant diseases and pests in crops such as pomegranates, limes, dates, roses and garlic as well as the splitting of pomegranate fruits during ripening are considered to limit agricultural production (n=7). The decrease in fodder available on mountain pastures, the lack of irrigation water for the cultivation of fodder, the high labor demand and expenses for purchased feedstuffs were the problems in livestock husbandry mentioned by farmers. Despite the cheap veterinary health care provided by the government, health problems were reported for 20 of the 28 goat and sheep herds, including abscesses, pneumonia, diarrhea, external parasites or nutritional disorders.

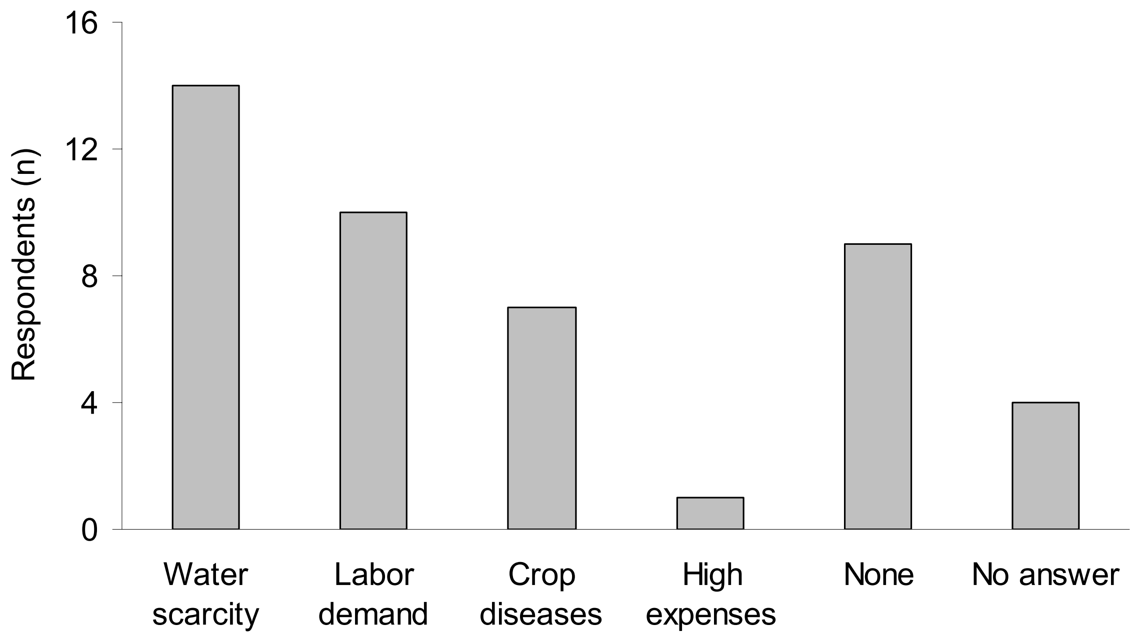

Figure II.1. Constraints perceived by farmers (n=39) in oasis crop cultivation as determined during household interviews in three villages of Al Jabal al Akhdar, Oman, in autumn 2006. Multiple answers were possible.

To identify the key problems that limit the long-term sustainability of traditional agriculture in the mountain oases, a problem tree analysis was conducted (Snowdon et al., 2008). Problems mentioned by male and female farmers during household and individual interviews were listed, grouped and hierarchically structured depending on whether they represented causes or effects of the recent changes in people's lives (Figure II.2).

Besides above mentioned constraints related to crop and livestock husbandry, farmers perceived the low diversity of cultivated crops, the difficult market access and the strong competition on local markets due to the seasonal sale of fruits and vegetables as important factors limiting their income from agriculture. Social problems perceived by farmers were a poor health and education system in the region, the lack of local employment opportunities, rising costs of living and the migration of people to the cities. Farmers perceived that this migration accelerates the abandonment of terrace cultivation as well as the loss of traditional farming knowledge, but also loosens social structures and contacts. Tourism was seen as a potential source of income, but farmers worried about possible conflicts related to the increasing number of strangers coming to their villages and considered it one of the reasons for the gradual loss of their cultural values.

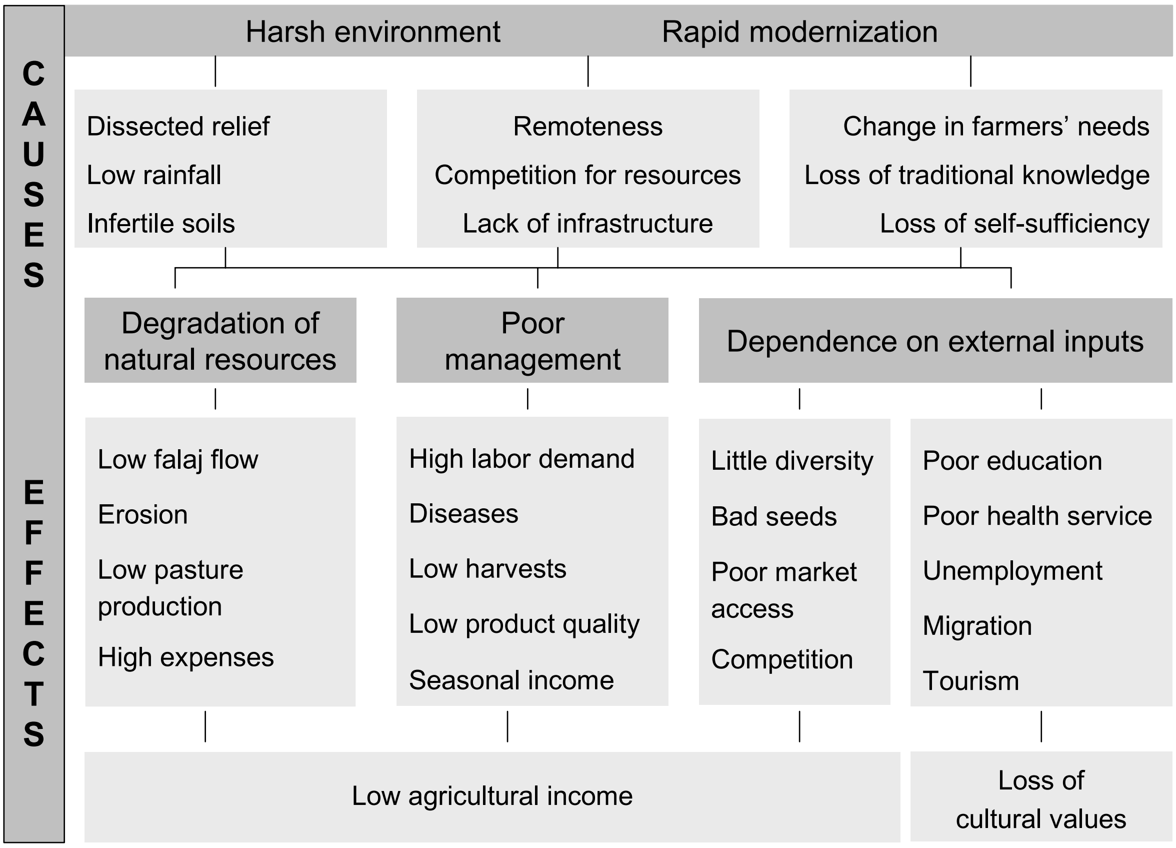

Figure II.2. Hierarchically structured problems encountered by farmers of Al Jabal al Akhdar, Oman, as determined during interviews in August 2006 – April 2008.

These problems appear to be caused by the degradation of natural resources, maladapted agricultural management practices and the strong reliance of people and agriculture on external inputs, which can therefore be defined as the key problems of the contemporary agricultural system in the mountain oases of Al Jabal al Akhdar. These problems are not only caused by the harsh environmental conditions and the intensive use of water, land and natural vegetation for competing purposes, but are also a consequence of the changing needs and objectives of farmers and the rapid social and economic modernization of the country, resulting in the loss of elders' knowledge about traditional agricultural practices.

Nevertheless, the benefits of crop and livestock husbandry as perceived by farmers are the supply of income (n=11) and food (n=13). Products are considered healthier and of higher quality than foodstuffs available in local stores and supermarkets (n=4, Figure II.3). All of the goat-keeping households slaughter one to six animals each year, especially during religious holidays. The fiber of goats and sheep is nowadays not used anymore, but farmers still consume the surplus milk after the offspring has suckled (n=25). While nine of these households additionally purchase goats or sheep for slaughter, nine farmers sell one to six and two even more than 15 animals per year. Livestock is seen as an important part of the system, valuing cheap fodder such as meal rests, weeds and fodder from the fields. All interviewed goat keepers collect the manure at the overnight enclosure (yard, stable) to apply it to their gardens. Similarly, 25 farmers regularly sell part of their crop harvest, including pomegranates (n=19), limes (n=4), walnuts (n=5), garlic (n=14) and the rose water produced in the oases (n=13) on the market in Nizwa (see Figure I.2, page 7) but also directly from the farm (n=14) or in Sayh Qatanah (n=7). Moreover, nine farmers said that they enjoy the work itself. But above all, agriculture is regarded as part of the village tradition which farmers inherited from their ancestors.

Figure II.3. Reasons of farmers (n=39) for continuing oasis agriculture as determined during household interviews in three villages of Al Jabal al Akhdar, Oman, in autumn 2006. Multiple answers were possible.

Of the 39 interviewed farmers, 34 want to continue crop cultivation and none of the farmers presently keeping livestock stated that he or she would like to reduce or abandon livestock activities. While 18 households acknowledged that they would like to increase the number of their animals, if the mentioned problems were solved, 17 livestock keepers recently invested in the renovation or construction of stables. And although six farmers claimed that there is nobody in the family to continue crop and livestock husbandry in the future, 26 farmers confirmed that a family member will take over the farm.

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III The role of pasture management for sustainable livestock production in semi-arid subtropical mountain regions

Abstract

Grazing livestock is an important asset to the livelihoods of people in most semi-arid environments, where natural resources cannot be used directly for human consumption. However, overgrazing commonly reduces pasture productivity, therefore threatening people's long-term food security. Ligneous and herbaceous vegetation on grazed and ungrazed sites in the Hajar Mountains, Oman, was studied to evaluate the possibilities of improving pasture management to maintain fodder production. Foliar biomass was 3 – 6 t DM ha^{-1} on the grazed and ungrazed plateau areas and 41 t DM ha^{-1} in the shallow valleys. Herbaceous yields changed over seasons and contributed ≤11% to total biomass, stressing the importance of ligneous foliage for livestock nutrition in particular during dry periods. While botanical composition and biomass of the vegetation differed between grazed and ungrazed sites, canopy cover and biomass yields were similar in a 15-year old enclosure and on a naturally ungrazed mountain plateau. Despite the climatic conditions, pastures encompass characteristics of equilibrium systems, where vegetation is strongly influenced by grazing livestock but recovers in its absence. The sustainable use of the natural fodder resources by an improved pasture management is therefore a valuable alternative to intense supplement feeding or the introduction of zero-grazing management.

III.1 Introduction

In the past decades, much research has been directed towards interactions between grazing herbivores and pasture vegetation. The overall aim of most studies was to develop management options that avoid the degradation of natural vegetation on the one hand without comprising its use for livestock production on the other hand. In this context, arid and semi-arid rangelands were originally understood as equilibrium systems with a strong interdependency between livestock and natural vegetation. According to the equilibrium concept, changes in vegetation are reversible and continuous towards a climax vegetation depending on the grazing intensity, while lack of rainfall is perceived as an increase in grazing pressure (Illius and O'Connor, 1999; Briske et al., 2003; Vetter, 2005). In contrast thereto, the non-equilibrium concept assumes that climatic factors rather than livestock grazing are the decisive driving forces in many rangeland ecosystems and that changes in the vegetation are therefore discontinuous and irreversible (Illius and O'Connor, 1999; Briske et al., 2003; Vetter, 2005). In non-equilibrium systems, herbivore grazing has no effect on vegetation and overgrazing does not occur, because livestock mortality during drought years maintains herbivore numbers below the normal carrying capacity. Therefore, management recommendations shifted from conservative to opportunistic strategies (Illius and O'Connor, 1999; Briske et al., 2003; Vetter, 2005). Most research addressing these concepts, however, has focused on ecosystems dominated by herbaceous vegetation, such as those in Africa, Australia and the United States, while only little work has so far been done in shrubland ecosystems of the highlands in the Middle East and Northern Africa, such as the Atlas Mountains in Morocco, the Asir and Hijaz Mountains in Saudi Arabia, the southern Zagros Mountains in Iran as well as the highlands of Ethiopia, Oman and Yemen. Agricultural production in these countries is largely constrained by scarce and variable rainfall, and due to rapid population growth and increasing meat consumption, they increasingly rely on the import of staple foods, meat and meat products as well as animal feed (Sarris, 2000; Amid, 2007). In the context of raising import prices for all these commodities, the improvement of livestock production in traditional systems, which is commonly criticized for its low productivity (Hamadeh et al., 2001; Thomas et al., 2002; Zaibet et al., 2004) and strongly relies on the natural shrublands as fodder resources, has consequently become an important task. The objective of this study was therefore to evaluate the importance of pasture management for an improved and sustainable livestock production in the highlands of the Middle East and Northern Africa and to study the contribution of current rangeland concepts to the understanding of pasture ecology in these regions.

III.2 Materials and methods

III.2.1 Study location and agricultural system

Our study focused on the traditional agro-pastoral system in the central Al Jabal al Akhdar region of the Al Hajar range in Northern Oman, where the deeply dissected limestone mountains reach elevations of about 3000 m a.s.l. (Ghanzafar, 1991). While in most of the country's lowlands, the annual mean temperature is 28°C and rainfall is less than 100 mm per year, precipitation on Al Jabal al Akhdar is substantially higher (318 mm; mean annual temperature of 18°C measured at Sayq; Fisher, 1994). Most of this rainfall occurs in February – March and in July - October, whereby the coefficient of variation in rainfall of 48% reflects the high inter-annual variability (Fisher, 1994). The natural vegetation is characterized by open shrublands dominated by *Sideroxylon mascatense*, *Olea europaea* ssp. *cuspidata* and *Dodonaea viscosa* and, above 2000 m a.s.l., by *Juniperus excelsa* ssp. *polycarpos* (Mandaville, 1977; Ghanzafar, 1991; Brinkmann et al., 2009), giving this region its name "The Green Mountain". The oasis agriculture on Al Jabal al Akhdar combines goat husbandry with the cultivation of food and fodder crops. The goats graze the natural vegetation surrounding the settlements, thereby covering distances of 12 - 20 km each day (Schlecht et al., 2009).

For this study, vegetation analyses were carried out at five different locations near Sayh Qatanah (57°40'35''E; 23°40'51''N, 2050 m a.s.l.), the main settlement of Al Jabal al Akhdar: i) the grazed plateau areas (P_{Gr}) surrounding Sayh Qatanah; ii) the grazed wadi Al 'Ayn (W_{Gr}), a shallow valley crossing the plateau; iii) the ungrazed plateau areas (P_{Ref}) including an enclosure (P_{Ref1}) and the Al Jabul plateau (P_{Ref2}), a mountain plateau, where goat grazing is very limited due to difficult access; iv) the grazed mountain slopes (S_{Gr}) and v) the grazed valley (V_{Gr}) near Qasha' (57°39'50''E, 23°04'00''N, 1700 m a.s.l.; Figure III.1, Table III.1). The grazed plateau and Wadi Al 'Ayn belong to the main grazing area of the village of Ash Sharayjah (57°39'30''E, 23°04'10''N, 1950 m a.s.l.). However, also goats and sheep of Sayh Qatanah, Al 'Ayn (57°39'44''E, 23°04'22''N, 1950 m a.s.l.) and Al 'Aqr (57°39'58''E, 23°04'22''N, 1900 m a.s.l.) are grazing in this region as well as an unknown number of feral donkeys.

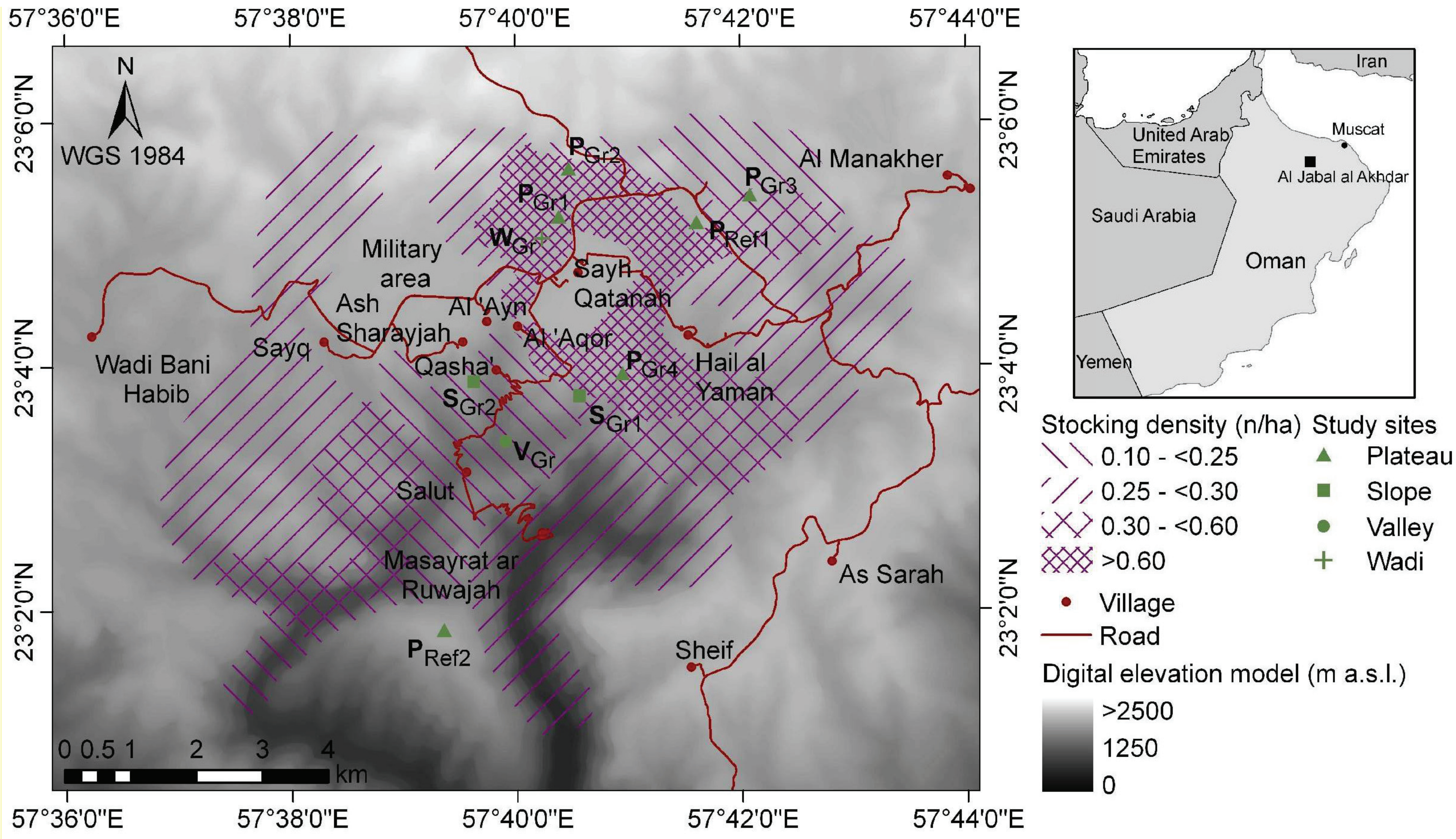

Figure III.1. Stocking densities on pastures grazed by goats and sheep of nine villages on Al Jabal al Akhdar, Oman, as determined during key informant interviews (n=10) conducted in winter 2007/08.

The enclosure (P_{Ref1}) was established by the Ministry of Agriculture and Fisheries in 1992/93 and comprises an area of 10 ha near Sayh Qatanah (2050 m asl). While one half is used for the cultivation of various agricultural crops, the other remains unused. The Al Jabul plateau (P_{Ref2}; about 80 ha at 2000 m a.s.l.) is almost at the same elevation as the grazed plateau (2050 m a.s.l.) and both are situated on the same limestone rocks. In the past, the Al Jabul vegetation has been used for occasional animal grazing, but most importantly to collect fodder for livestock. Nowadays, this plateau is nearly undisturbed, since the forage is not harvested anymore and no donkeys or sheep and hardly any goats are grazing there. Thus, the enclosure and the Al Jabul plateau were used as reference sites in the analysis of the pasture vegetation. The grazed slopes (S_{Gr}) and valleys (V_{Gr}) are the main grazing area of goats from Qasha', but at higher altitude also animals of Hail al Yaman (57°41’31’’E 23°4015’’N, 1950 m a.s.l.), Al ‘Aqr and Sayh Qatanah graze there. The vegetation of the slopes and valleys benefits from the runoff water of the surrounding plateau and the consequently higher water availability. Thus, in contrast to the shallow wadis, permanent water flow and small water pools characterize the deep mountain valleys. In addition to vegetation measurements, map-based interviews were carried out with two key informants per village in Hail Al Yaman, Sayq (57°38’17’’E, 23°40’12’’N, 1900 m a.s.l.), Ash Sharayjah, Qasha' and Masayrat ar Ruwajah (57°40’13’’E, 23°02’37’’N, 1050 m a.s.l.) on Al Jabal al Akhdar to identify village pasture areas as well as the seasonal grazing intensity.

Table III.1. Altitude, exposition, inclination (%) and stone cover (%) of study sites on Al Jabal al Akhdar, Oman.

Location	Site	Altitude	Main exposition	Inclination	Stone cover
		m a.s.l.		Mean ± SD	Mean ± SD
Ungrazed plateau	P_{Ref1}	2050	S-E	3 ± 3.4	28 ± 19.4
	P_{Ref2}	2000	S-SW	14 ± 15.1	52 ± 32.8
Grazed plateau	P_{Gr1}	2050	S-SW	7 ± 10.1	60 ± 27.9
	P_{Gr2}	2100	S-SE	7 ± 9.0	53 ± 28.4
	P_{Gr3}	2070	SE-NE	4 ± 4.4	61 ± 31.6
	P_{Gr4}	2050	E-SE	4 ± 2.7	38 ± 35.5
Grazed wadi	W_{Gr}	2040	S-SW	2 ± 1.0	27 ± 22.8
Grazed slope	S_{Gr1}	1850	S-SW	15 ± 13.0	32 ± 22.8
	S_{Gr2}	1750	E-NE	33 ± 18.9	12 ± 12.3
Grazed valley	V_{Gr}	1550	S-SW	1 ± 0.5	24 ± 18.4

III.2.2 Sampling of tree and shrub vegetation

The point-centered quarter (PCQ) method (Cottam and Curtis, 1956) was applied from September 2007 – January 2008 to record the composition of the tree and shrub strata as well as the distribution and density of single shrub and tree species. Data were collected along four transects at P_{Gr} and one transect each at P_{Ref1} and P_{Ref2}. At W_{Gr}, tree and shrub density is much higher than on the plateau areas and smaller shrubs grow under the cover of trees. Since according to the PCQ method, only the shrub or tree nearest to the sampling point is recorded, data for shrubs with a height <2.5 m and for trees ≥2.5 m high were collected separately at W_{Gr}, to avoid an underestimation of the tree density. The length of the transects was 700 m at P_{Ref} and 1400 m at the grazed sites. Additional sites were chosen at S_{Gr} (n=2) and V_{Gr} (n=1) to cover other landscape types of Al Jabal al Akhdar. While at the grazed sites data were collected at 30 randomly arranged sampling points per transect with a minimum distance of 30 m between each point, only 20 sampling points per transect were chosen at P_{Ref} due to the limited extension of these sites. At each sampling point, the nearest shrub or tree above 30 cm height was recorded in each quarter, including the species name, distance to the sampling point (m), the minimum and maximum height (m) and crown diameter (m) measured at two axes at 90 degrees to each other. Any sign of woodcutting was recorded and the browsing intensity estimated by five classes from ungrazed or very little grazed (1) to very highly grazed (5) according to the percentage of browsed branches. Dead trees or shrubs were also included in the measurements and in 30 trees of the most abundant browse species the maximum browsing height (m) was recorded. Additionally, for each sampling point, the three most abundant herbaceous species were listed together with their individual ground cover (%) and grazing intensity in five classes from none or very little (1) to very high (5). To describe growing conditions at each sampling plot, exposition, inclination (%) and stone cover (%) were recorded. Tree and shrub density (n ha^{-1}) was calculated for each transect using the mean distance (m) of trees or shrubs to the sampling point (Cottam and Curtis, 1956). The average crown cover was calculated as a circle (m^2) and the volume as a cylinder (m^3) for each species and multiplied by the respective density to obtain the total crown cover (m^2 ha^{-1}) and crown volume (m^3 ha^{-1}). Importance values (IV) for different ligneous and herbaceous species were calculated as the sum of the relative density, frequency and canopy cover (IV = rel. density (%) + rel. frequency (%) + rel. canopy cover (%); Cottam and Curtis, 1956). Since for the herbaceous layer only frequency and canopy cover were determined, the importance value was adapted and the sum of the two parameters taken to compare species composition at different locations (IV = rel. frequency (%) + rel. canopy cover (%)).

To identify relationships between the crown cover (m^2) or crown volume (m^3) and the available leaf and twig biomass per species (kg dry matter, DM), 30 individuals of each of the four most abundant species on the grazed plateau, namely *Olea europaea* L. ssp. *cuspidata* (Wall. ex G. Don) Ciferri, *Sideroxylon mascatense* (A. DC.) Penn, *Dodonaea viscosa* (L.) Jacq. and *Euryops arabicus* Steud. ex Jaub. & Spach were sampled from December 2006 – February 2007. Bottom and top height (m) of the crown and the crown diameter (m) at two axes at 90 degrees to each other were measured and all leaves and twigs (diameter ≤3 mm) harvested and weighed. In September 2007, the relationship between allometric variables and the available leaf and twig biomass was additionally determined for *Sageretia thea* (Osb.) M.C. Johnst, a summer-green shrub. For larger individuals, representative parts were stripped and the weight of the collected leaves and twigs (kg) multiplied by the number of twigs to estimate the leaf and twig biomass (kg) of the whole plant. Four composite samples were taken for each species to determine the dry matter (DM), organic matter (OM), nitrogen (N) and phosphorus (P) concentrations following standard procedures (Naumann et al., 2004). To calculate total plant DM of the most abundant species on the mountain pastures, the leaf and twig biomass was calculated for individual plants recorded along the transects based on the established allometric regression equations. Additionally, the regression equation determined by Sanon et al. (2007) between the crown diameter and foliar biomass of *Acacia senegal* trees was used to calculate foliar biomass of *Acacia gerrardii* Benth., an abundant species on the mountain slopes and in valleys at lower altitudes. The average biomass (kg DM) determined for each species was multiplied by the number of individuals of the respective species per hectare (= species density) and summed up to the total foliar biomass of the tree and shrub stratum.

III.2.3 Sampling of ground vegetation

Ground vegetation was analyzed at P_{Gr1}, P_{Gr2}, W_{Gr}, P_{Ref1} and P_{Ref2} in September 2006, January, May and September 2007 to capture the seasonal differences in the standing herbaceous biomass (Figure III.2). Since farmers claimed that after a long period without any significant rainfall no forage was available on the mountain pastures, further data were collected in April 2008 at P_{Gr1}, P_{Gr2}, W_{Gr} and P_{Ref2}. To better account for differences in the herbaceous biomass at different locations, above-ground biomass was additionally quantified at S_{Gr1} in April 2008. Herbaceous biomass has previously been quantified on Al Jabal al Akhdar by harvesting representative sample plots along transects and in minimum sampling areas (Schlecht et al., 2009). Following this approach, 10x10 m^2 sampling plots (n=5-10) were laid out at every 150 m and at every 70 m along transects of a minimum length of 1000 m on the grazed and of 500 m at the ungrazed sites, respectively. In these sampling plots, which were equivalent to the minimum suitable area for vegetation analyses determined by Brinkmann et al. (2009), the proportion (%) of highly, moderately and sparsely vegetated areas as well as of bare ground was estimated. Subsequently, the above-ground biomass of herbaceous plants was harvested in four quadrates (1 m^2) representative for the biomass cover classes sparsely (n=1), moderately (n=2), and highly (n=1) vegetated. In case the class highly vegetated was not represented, two samples were collected each for the classes sparsely and moderately. The samples were weighed, air-dried and weighed again. Subsequently, all samples per location were pooled and analyzed for DM, OM, N and P content. For each location and season, average biomass (kg DM ha^{-1}) for the three cover classes was calculated and multiplied by the average proportion of the respective cover class to determine the weighted standing biomass (kg DM ha^{-1}) of the herbaceous vegetation.

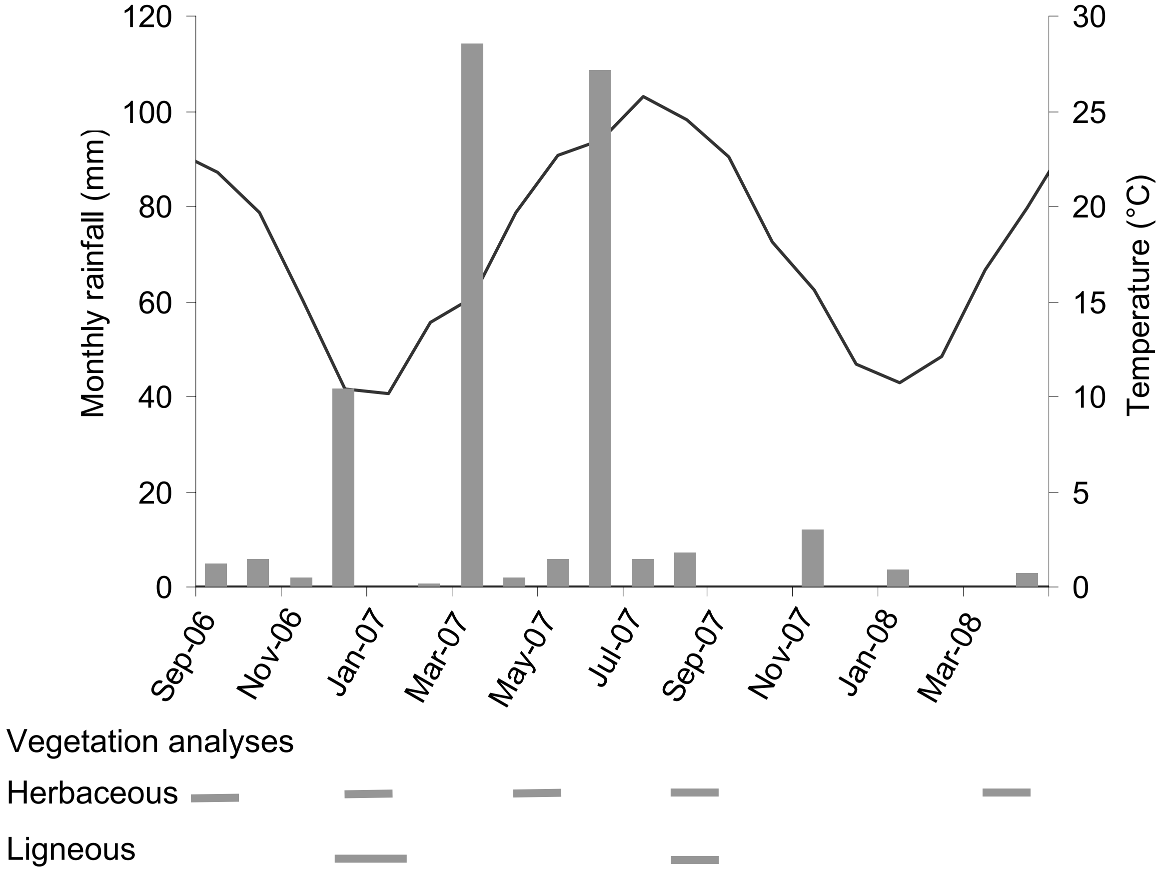

Figure III.2. Monthly rainfall (mm, bars) and mean daily temperature (°C, line) on Al Jabal al Akhdar, Oman, from 15. September 2006 - 15. April 2008 according to a Hobo Pro climate logger (Onset Computer Corp., Pocasset, MA, USA) and own rainfall measurements with standard gauge at Sayh Qatanah (23.20°N, 57.40°E; 2040 m a.s.l.); and time periods of measurements of the herbaceous and ligneous vegetation (horizontal bars below climate diagram).

III.2.4 Statistical analysis

Means and standard deviations of the measured variables were calculated for locations and transects at P_{Gr} (n=4), W_{Gr} (n=1), S_{Gr} (n=2), P_{Ref} (n=2) and V_{Gr} (n=1). Statistical analyses were carried out using the SPSS software 12.0 for Windows XP (SPSS Inc., Chicago, USA). Data were analyzed for significant differences between the seasons and locations, applying the independent t-test for normally distributed and the Mann-Whitney U-Test for not normally distributed sample sets (Zöfel, 1988). Linear, exponential, logarithmic and power regression between the canopy cover (m^2, x) or volume (m^3, x) and the total leaf and twig biomass (kg DM, y) were tested to define allometric regression equations.

III.3 Results

III.3.1 Species composition of the ligneous vegetation

At $P_{Ref1,}$ and P_{Ref2}, the number of trees and shrubs was with 279 and 300 individuals per hectare much smaller than at P_{Gr} (439 - 636 shrubs and trees per hectare). A very low density of ligneous species was determined at P_{Gr4} (220 trees ha^{-1}), where goats of four different villages as well as those of Sayh Qatanah were grazing (Table III.2). At W_{Gr}, the shrub and tree density of 2,751 individuals per hectare was more than six times higher than at P_{Gr}. At 3.7% – 4.8%, the canopy cover at P_{Ref} was similar or higher than at P_{Gr} (4.3%, SD 2.23), despite the low tree and shrub density. While it reached 12.5% (SD 6.34) at S_{Gr}, canopy cover was highest at W_{Gr} (30%). Between 4 – 9 different ligneous species per transect were recorded at P_{Gr} and at P_{Ref}; however, species composition differed between locations (Figure III.3). *Olea europaea* ssp. *cuspidata* and *Sideroxylon mascatense* were the main trees found at P_{Ref}, P_{Gr} and at W_{Gr}. While *Sideroxylon mascatense* showed a higher frequency and density at the grazed than at the ungrazed sites, relative density of *Olea europaea* ssp. *cuspidata* was lowest at P_{Gr} with 6%, equivalent to 27 trees ha^{-1}. At S_{Gr} and V_{Gr}, where 9 - 17 ligneous species per transect were recorded, the dominant species were *Acacia gerrardii* (20 – 94 trees ha^{-1}), *Ziziphus spina-christi* (L.) Desf. (7 – 24 trees ha^{-1}) and *Salix acmophylla* Boiss. (1 tree ha^{-1}). Further tree species at W_{Gr} were *Phoenix dactylifera* L. (90 trees ha^{-1}), *Ziziphus hajarensis* Duling, Ghaz. & Prendergast (1 tree ha^{-1}), and *Juniperus excelsa* M. Bieb. ssp. *polycarpos* K. Koch (1 tree ha^{-1}).

Table III.2. Relative density (%) of selected tree and shrub species on grazed and ungrazed study locations of Al Jabal al Akhdar, Oman (means ± one standard deviation).

	P_{Ref}	P_{Gr}	W_{Gr}	S_{Gr}
Density (n ha^{-1})	289 ± 15	390 ± 187	2751 .	759 ± 526
Trees (%)				
Acacia gerrardii	1 ± 0.7	0.2 ± 0.4	0 .	13 ± 6.4
Olea europaea ssp. *cuspidata*	21 ± 7.1	10 ± 5.1	11 .	2 ± 2.1
Sideroxylon mascatense	10 ± 2.1	17 ± 2.4	22 .	13 ± 9.2
Shrubs (%)				
Dodonaea viscosa	36 ± 25.5	67 ± 9.5	43 .	46 ± 37.5
Euryops arabicus	0 .	1 ± 1.3	16 .	2 ± 2.1
Grewia erythraea	4 ± 5.0	4 ± 4.4	0 .	18 ± 22.6
Sageretia thea	1 ± 0.7	0.4 ± 0.5	3 .	1 ± 0.0

For abbreviations of locations see Table III.1 and for authorities see text.

Dodonaea viscosa and *Euryops arabicus* were the main shrub species at the grazed sites. Although *Dodonaea viscosa* was also abundant at P_{Ref} (53 - 150 shrubs ha^{-1}), its density was lower than at P_{Gr} (135 – 433 shrubs ha^{-1}) and W_{Gr} (1707 shrubs ha^{-1}). At the latter two sites, this species together with *Euryops arabicus* (866 shrubs ha^{-1}) characterized the shrub stratum. Both species were less abundant at S_{Gr} and V_{Gr} and were partly replaced by *Capparis spinosa* L. (≤ 59 shrubs ha^{-1}) and *Ochradenus arabicus* Chaudhary (≤ 24 shrubs ha^{-1}) at S_{Gr} as well as by *Nerium oleander* L. (29 shrubs ha^{-1}) and *Chrozophora oblongifolia* (Delile) Juss. ex Spreng. (26 shrubs ha^{-1}) at V_{Gr}, where water availability is higher. *Grewia erythraea* (Schweinf.) and *Sageretia thea* were two species recorded at grazed and ungrazed sites across different elevations. While *Sageretia thea* was most abundant at W_{Gr} (27 shrubs ha^{-1}), *Grewia erythraea* is a common shrub at S_{Gr} (24 – 130 shrubs ha^{-1}) and at P_{Ref2} (22 shrubs ha^{-1}), where together with *Ebenus stellata* Boiss. and *Farsetia aegyptiaca* Turra it dominated the shrub strata. Although the latter two species each represented 23% of the total shrubs and trees per hectare at this location, they were not recorded at P_{Gr} and *Ebenus stellata* was only recorded once at S_{Gr}.

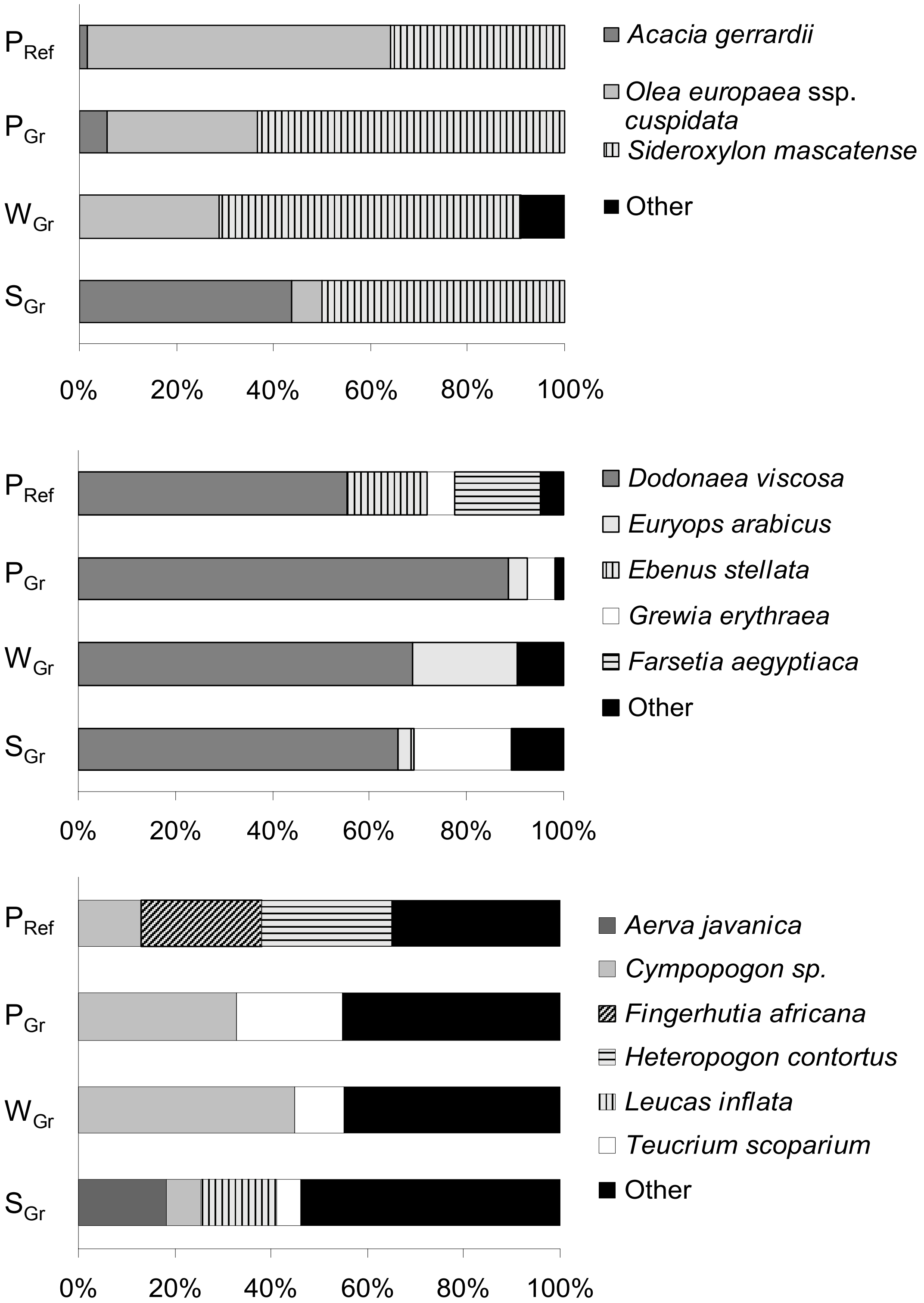

Figure III.3. Relative importance values (%) of selected tree (top), shrub (middle) and herbaceous (bottom) species on grazed and ungrazed study sites of Al Jabal al Akhdar, Oman. For abbreviations of locations see Table III.1 and for authorities see text.

III.3.2 Species composition of the herbaceous vegetation

Overall ground cover of the herbaceous vegetation ranged between 8% (SD 5.0) at P_{Gr} and 15% (SD 7.4) at W_{Gr} and was significantly ($P<0.05$) lower than at P_{Ref} (25%, SD 14.0; Table III.3). With the exception of S_{Gr} (n=18), 9 - 12 different species per site were recorded. Abundant species at the grazed sites were grasses such as *Chrysopogon plumulosus* Hochst., *Cymbopogon schoenanthus* (L.) Spreng., *Cenchrus ciliaris* L., *Cynodon dactylon* (L.) Pers., *Eragrostis* sp. and *Tetrapogon villosus* Desf. as well as dicots such as *Salvia aeqyptiaca* L., *Teucrium* sp. *(T. mascatense* Boiss. and *T. stocksianum* Boiss. ssp. *stenophyllum* R.A. King) and *Helianthemum lippii* (L.) Dum.-Cours. ($P>0.05$). Importance values of *Chrysopogon plumulosus* were almost two to three times higher at the grazed than at the ungrazed sites (IV=22, SD 1.0).

Fingerhutia africana Lehm. and *Heteropogon contortus* (L.) Roem. & Schultes were dominant grass species at P_{Ref} with a mean ground cover of 10% (SD 10.4) and 9% (SD 7.3) respectively, while both species were not recorded at the grazed sites. In contrast thereto, *Teucrium mascatense* was a common dicot at P_{Gr}, recorded at 21% - 59% of the sampling points, but not at P_{Ref}. *Chrysopogon plumulosus* and *Cymbopogon schoenanthus* were found in grazed and ungrazed areas. Ground cover of *Cymbopogon schoenanthus* was higher at P_{Ref} (5%, SD 3.2) than at P_{Gr} (2%, SD 1.9; $P<0.01$). However, the species was only recorded at 65% and even 8% of the sampling points at P_{Ref1} and P_{Ref2} respectively, whereas the frequency of *Cymbopogon schoenanthus* reached up to 76% (SD 20.0) at P_{Gr} and 80% at W_{Gr}. Therefore, its importance values (IV) of 45 (SD 10.9) and 58 were higher at P_{Gr} than at P_{Ref} (IV=23, SD15.8), although its ground cover was not significantly lower at P_{Ref}.

Leucas inflata Benth and *Aerva javanica* (Burm.F.) Juss. ex J.A. Schultes were characteristic species at S_{Gr} (IV=25 – 29), the latter also being recorded at V_{Gr} (IV=8), where overall ground cover of the herbaceous vegetation was only 6% (SD 5.6). The main species were here *Juncus rigidus* Desf. (IV=76), *Cenchrus ciliaris* (IV=21) and *Cynodon dactylon* (IV=16).

Table III.3. Ground cover (%) of selected herbaceous species at grazed and ungrazed study sites on Al Jabal al Akhdar, Oman (means ± one standard deviation).

	P_{Ref}		P_{Gr}		W_{Gr}		S_{Gr}		P
Species (n)	11		12		9		18		
Total ground cover	25	± 14.0	8^{a}	± 5.0	15	± 7.4	10^{a}	± 7.0	< 0.01
Chrysopogon plumulosus	3^{a}	± 1.9	4^{a}	± 3.8	7	± 6.2	4^{a}	± 4.7	< 0.05
Cymbopogon schoenanthus	5^{b}	± 3.2	2^{a}	± 1.9	8^{b}	± 6.7	3^{a}	± 3.4	< 0.01
Eragrostis sp.	0.5^{a}	± 0.2	0.3^{a}	± 0.2	1^{a}	± 0.2	0.3^{a}	± 0.5	> 0.05
Helianthemum lippii	3^{a}	± 1.0	0.7^{b}	± 0.5	0	.	1^{ab}	± 1.0	< 0.05
Teucrium sp.	0	.	2^{a}	± 1.6	1^{a}	± 0.5	1^{a}	± 0.4	< 0.001
Tetrapogon villosus	4^{b}	± 2.6	0.9^{a}	± 0.4	2.3^{ab}	± 1.5	1.1^{a}	± 0.5	< 0.05

Within rows values with different letters (a, b) differ at the indicated probability level. For abbreviations of locations see Table III.1 and for authorities see text.

III.3.3 Grazing intensity, grazing areas and fodder quality

The grazing intensity as evaluated on a scale of 0 to 5 was high in *Olea europaea* ssp. *cuspidata* (Mdn=5, n=78), *Sideroxylon mascatense* (Mdn=4, n=95) and *Grewia erythraea* (Mdn=5, n=65), followed by *Sageretia thea* (Mdn=3, n=12) and *Ziziphus spina-christi* (Mdn=3, n=58). In contrast thereto, no or little signs of browsing were observed in *Euryops arabicus* (Mdn=1; n=48)*, Nerium oleander* (Mdn=1, n=22) and *Dodonaea viscosa* (Mdn=1, n=524) at the different study locations. The maximum height at which signs of browsing were determined was 188 cm (SD 11.7). Heavily grazed herbaceous species were *Chrysopogon plumulosus* (Mdn=5, n=128), *Salvia aegyptiaca* (Mdn=4.5, n=6) and *Cynodon dactylon* (Mdn=5, n=17), whereas no or few signs of grazing were visible in *Cymbopogon schoenanthus* (Mdn=1, n=125), *Teucrium* sp. (Mdn=1, n=58) and *Aristida sp.* (Mdn=1, n=25). The different tree species also showed clear signs of woodcutting at all grazed sites. Thus, in 69% of *Sideroxylon mascatense*, 46% of *Olea europaea* ssp. *cuspidata*, 30% of *Acacia gerrardii* and 19% of *Ziziphus spina-christi* trees woodcutting was visible. While at P_{Ref2} no signs of cutting were recorded for those tree species, cut branches were found in 19% of *Olea europaea* ssp. *cuspidata* and 22% of *Sideroxylon mascatense* trees at P_{Ref1}. Also both individuals of *Juniperus excelsa* ssp. *polycarpos* at W_{Gr} showed signs of woodcutting and were browsed by goats, sheep or donkeys (Mdn=3).

Organic matter and nutrient concentrations of the sampled tree and shrub species ranged between 912 – 949 g OM kg^{-1} DM, 10.2 – 13.7 g N and 0.5 – 1.3 g P kg^{-1} DM (Table III.4). Nutrient concentrations were highest in *Euryops arabicus*, which is poisonous to goats (Jongbloed et al., 2003), followed by *Olea europaea* ssp. *cuspidata*, whereas N and P concentrations of *Sageretia thea* samples collected in September 2007 were relatively low. OM, N and P concentrations of the herbaceous vegetation varied between locations. OM concentrations ranged between 866 – 901 g kg^{-1} DM at P_{Gr} and W_{Gr} and 909 – 939 g kg^{-1} DM at P_{Ref}. In contrast thereto, N and P concentrations of the vegetation at the grazed sites (7.1 – 15.9 g N kg^{-1} DM; 0.6 – 1.4 g P kg^{-1} DM) were higher than for the herbaceous biomass collected at P_{Ref} (5.8 – 8.8 g N kg^{-1} DM; 0.3 – 0.5 g P kg^{-1} DM). While nutrient concentrations at P_{Ref} did not differ between the seasons, P concentration was highest in September 2006 and N concentration of the vegetation at the grazed sites was highest in September 2006 and 2007.

Table III.4. Dry matter (DM; g kg^{-1} FM*) and organic matter (OM), nitrogen (N) and phosphorus (P) concentrations (all in g kg^{-1} DM) of selected tree and shrub species on pastures on Al Jabal al Akhdar, Oman. Values are means ± one standard deviation for pooled samples collected during January – March 2007 and September 2007; n=4 for all species.

Species	DM		OM		N		P	
Dodonaea viscosa	488	± 6.2	949	± 4.9	10.5	± 0.51	0.7	± 0.08
Euryops arabicus	361	± 12.5	912	± 3.8	13.7	± 3.58	1.3	± 0.33
Olea europaea ssp. *cuspidata*	638	± 21.4	940	± 5.1	12.4	± 0.44	0.7	± 0.03
Sageretia thea	687	± 20.6	937	± 8.1	10.2	± 1.88	0.5	± 0.12
Sideroxylon mascatense	666	± 63.7	947	± 2.0	11.7	± 1.82	0.7	± 0.06

*FM = Fresh matter
For authorities see text.

The average grazing area as determined by key informants for eight villages and the new settlement Sayh Qatanah ranged from 4 - 17 km^2 (Table III.5). While grazing areas of Ash Sharayjah, Al ‘Ayn, Al ‘Aqr, Sayq and Sayh Qatanah were located on the plateau, pastures of villages at lower altitudes mainly comprised mountain slopes and deep valleys. The average stocking density ranged between 0.03 - 0.28 small ruminants per hectare for the village pastures and 0.57 animals per hectare on pastures of Sayh Qatanah. However, since pastures of different villages overlapped (Figure III.1), actual stocking density was partly more than twice as high.

Table III.5. Size and composition of pastures, herd sizes and calculated stocking densities of six villages on Al Jabal al Akhdar, Oman, as determined in winter 2007/08.

Village	Grazing area	Plateau	Wadi	Slopes	Valley	Goats/ Sheep*	Stocking density
	km^2	% of grazing area				n	$n\ ha^{-1}$
Al 'Aqr	3.6	24	28	47	0	12	0.03
Al 'Ayn	5.0	56	27	16	0	138	0.28
Qasha'	11.4	8	0	69	23	123	0.11
Ash Sharayjah	7.1	45	41	15	0	189	0.27
Hail Al Yaman	14.8	25	12	52	11	377	0.26
Masayrat ar Ruwajah	10.5	0	0	73	27	295	0.28
Salut	11.7	5	0	78	17	140	0.12
Sayh Qatanah	6.7	73	20	6	0	433	0.63
Sayq	17.0	29	14	36	21	473	0.28

* Ministry of Agriculture and Fisheries, 2001

III.3.4 Leaf and twig biomass

Although power functions between the crown cover and the leaf and twig biomass gave best results (r^2=0.72 – 0.89, Table III.6), regression equations based on the crown volume were chosen, because the proportion of the leaf and twig biomass accessible to goats (<188 cm crown height) was calculated subsequently by multiplying the total leaf and twig biomass per tree by the percentage of the crown volume below 188 cm. The leaf and twig biomass edible by goats was defined as the accessible leaf and twig biomass per hectare minus the biomass of *Dodonaea viscosa* and *Euryops arabicus,* which showed little or no signs of browsing. Since between 3% – 5% of the trees and shrubs per hectare at P_{Ref2} and at most grazed sites and up to 13% at P_{Gr4} were dead, dead trees were not considered in the calculation of the leaf and twig biomass. The dead shrubs and trees recorded at all sites (n=33) belonged to the most abundant species, 69% being *Dodonaea viscosa*.

Table III.6. Relation between canopy cover (m^2, x) or volume (m^3, x) and leaf and twig biomass (kg DM, y) of five species on pastures of Al Jabal al Akhdar, Oman – parameters of power regression equations* ($y= b\ x^a$).

Species	a	b	r^2	SE
Canopy cover				
Dodonaea viscosa	1.71	1.25	0.89	0.52
Euryops arabicus	1.30	0.79	0.82	0.53
Sideroxylon mascatense	1.93	10.20	0.72	0.63
Olea europaea ssp. *cuspidata*	1.68	4.16	0.81	0.60
Sageretia thea	1.52	1.54	0.77	0.66
Canopy volume				
Dodonaea viscosa	1.17	1.17	0.88	0.54
Euryops arabicus	1.05	1.12	0.85	0.46
Sideroxylon mascatense	1.33	9.61	0.63	0.71
Olea europaea ssp. *cuspidata*	1.19	3.57	0.78	0.65
Sageretia thea	1.00	1.70	0.73	0.72

All correlations were significant at a 0.1% level. For authorities see text.

At P_{Gr}, total leaf and twig biomass of the six species ranged between 2.8 – 6.0 t DM ha^{-1} near Sayh Qatanah (P_{Gr1}, P_{Gr2}, P_{Gr4}) and reached 10.7 t DM ha^{-1} at P_{Gr3}, where the tree and shrub cover was higher (7.4% versus 2.1% – 4.3%). Similarly, foliar biomass was high at S_{Gr} (17.7 t DM ha^{-1}, SD 11.91) as well as at W_{Gr}, where it reached 40.8 t DM ha^{-1} as a result of the very high shrub and tree density. Due to either a large crown volume or a high canopy cover, *Sideroxylon mascatense*, *Olea europaea* ssp. *cuspidata* and *Dodonaea viscosa* contributed most to the total leaf and twig biomass at W_{Gr} as well as at P_{Gr} and P_{Ref} (Figure III.4). While 84% of the foliar biomass was provided by *Sideroxylon mascatense* at P_{Ref2}, leaf and twigs of this species and of *Olea europaea* ssp. *cuspidata* accounted for 52% and 40% of the foliar biomass at P_{Ref1}. Total leaf and twig biomass at P_{Ref1} (5.1 t DM ha^{-1}) and P_{Ref2} (5.7 t DM ha^{-1}) did not differ from P_{Gr} (P>0.05). At P_{Gr}, 2.1 – 7.8 t DM ha^{-1} were accessible and 2.0 – 7.5 t DM ha^{-1} edible for goats, equivalent to 81% and 71% of the total foliar biomass. At W_{Gr} and S_{Gr}, trees above 188 cm crown height accounted for 9% and 21% and unpalatable species for 60% and 47% of the total trees and shrubs per hectare. Therefore only 37% and 84% of the total leaf and twig biomass were accessible and 27% and 55% edible for goats at the two locations, respectively. While most of the species were ever-green, *Sageretia thea* and *Grewia erythraea* were leafless from November – February, the dry winter months.

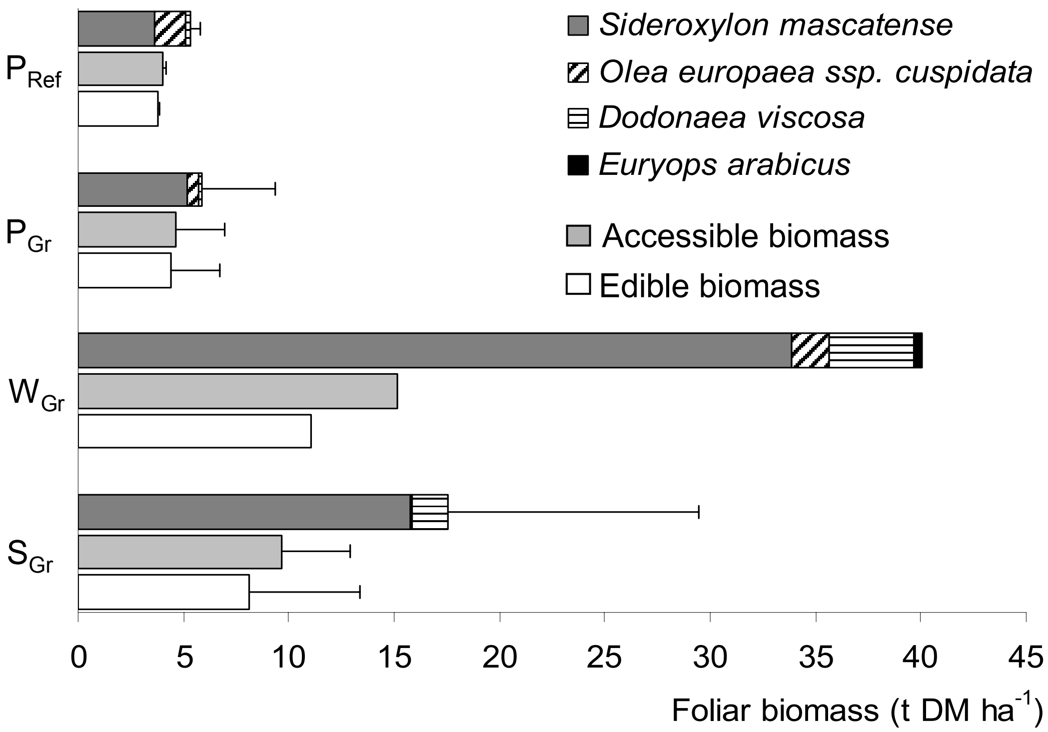

Figure III.4. Total, accessible and edible foliar biomass at grazed and ungrazed study sites on Al Jabal al Akhdar, Oman (bars indicate one standard deviation).

While at P_{Gr}, P_{Ref}, W_{Gr} and S_{Gr}, the six selected ligneous species accounted for 94% - 100% of the total canopy cover, they only summed up to 30% at V_{Gr}, and other species such as *Nerium oleander* and *Ziziphus spina-christi* were more abundant. Thus, the calculated leaf and twig biomass of 334 kg DM ha^{-1} only represents part of the total foliar biomass there. However, since 29% of the trees recorded were higher than the maximum browsing height of goats and 24% of the trees per hectare were unpalatable species, accessible and edible foliar biomass was much lower at this site than at the other ones.

III.3.5 Herbaceous biomass

The proportion of bare ground was significantly higher at P_{Gr} and W_{Gr} than at P_{Ref}, with the exception of May 2007, when values determined for P_{Ref1} at 29% (SD 13.9) were similar to those obtained at W_{Gr} (30%, SD 11.4; $P<0.05$; Table III.7). While the proportion of bare ground was <20% at P_{Ref2} and P_{Ref1} for all other sampling dates ($P>0.05$), 29% (SD 12.6) and 47% (SD 10.2) of the ground were not vegetated at W_{Gr} and at P_{Gr}, respectively. In April 2008, after five month without significant rainfall, the proportion of bare ground even reached 56% (SD 11.2) at P_{Gr}, being significantly higher than during the other seasons ($P<0.05$).

Table III.7. Proportion of bare ground (%) at grazed and ungrazed study sites on Al Jabal al Akhdar, Oman, during different seasons (means ± one standard deviation).

	P_{Ref1}		P_{Ref2}		P_{Gr}		W_{Gr}		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	P
Aug-06	$13^{a;\alpha\beta}$	9.7	$7^{a;\alpha}$	3.9	$42^{b;\alpha}$	7.6	$28^{b;\alpha}$	10.4	< 0.05
Jan-07	$9^{a;\alpha}$	8.3	$9^{a;\alpha}$	4.9	$44^{b;\alpha}$	10.8	$25^{c;\alpha}$	13.3	< 0.05
May-07	$29^{ab;\beta}$	13.9	$13^{b;\alpha\beta}$	10.1	$47^{c;\alpha}$	6.7	$30^{ad;\alpha}$	11.4	< 0.05
Sep-07	$16^{a;\alpha\beta}$	14.2	$19^{a;\beta}$	10.5	$45^{b;\alpha}$	10.1	$36^{c;\alpha}$	13.6	< 0.01
Apr-08	.	.	$18^{a;\alpha\beta}$	15.8	$56^{b;\beta}$	10.4	$26^{c;\alpha}$	13.1	< 0.001
P	< 0.05		< 0.05		< 0.05		> 0.05		

Within rows (a, b, c, d) and columns (α, β, γ) respectively, values with different letters differ at indicated probability level. For site abbreviations see Table III.1.

While the proportion of sparsely vegetated ground was higher at P_{Gr} and W_{Gr}, moderately and highly vegetated areas increased at P_{Ref}. Between 0.2% - 2.6% at P_{Gr} and 3.5% - 5.6% at W_{Gr} were highly vegetated, whereas 7% - 26% of the ground were highly vegetated at P_{Ref}. The average biomass yield (kg DM ha^{-1}) for the three biomass classes ranged between 8 – 30 kg DM and 106 – 282 kg DM for sparsely and highly vegetated areas at P_{Gr}, respectively, and was significantly lower than at W_{Gr} (36 – 51 kg DM for sparsely and 384 – 539 kg DM ha^{-1} for highly vegetated areas, P<0.001). At P_{Ref}, biomass yields of 111 – 322 kg DM ha^{-1} in sparsely vegetated patches and 990 – 2150 kg DM ha^{-1} in highly vegetated areas were significantly higher than at P_{Gr} and W_{Gr} for the different sampling dates (P<0.001).

Table III.8. Overall herbaceous biomass at grazed and ungrazed study sites on Al Jabal al Akhdar, Oman, during different seasons (means ± one standard deviation).

	P_{Ref1}		P_{Ref2}		P_{Gr}		W_{Gr}		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	P
Aug-06	$637^{a;\alpha}$	183	$840^{a;\alpha}$	100	$19^{b;\alpha}$	1.3	$85^{c;\alpha}$	21.7	< 0.001
Jan-07	$494^{a;\alpha}$	130	$553^{a;\beta}$	71	$8^{b;\beta}$	3.2	$66^{c;\alpha}$	18.0	< 0.001
May-07	$209^{a;\beta}$	89	$602^{b;\beta}$	68	$14^{c;\alpha}$	3.1	$77^{d;\alpha}$	27.3	< 0.01
Sep-07	$505^{a;\alpha}$	182	$629^{a;\beta}$	171	$20^{b;\alpha}$	8.2	$64^{c;\alpha}$	21.0	< 0.01
Apr-08	.	.	$318^{a;\gamma}$	143	$8^{b;\beta}$	2.8	$62^{c;\alpha}$	23.7	< 0.01
P	< 0.05		< 0.05		< 0.001		> 0.05		

Within rows (a, b, c, d) and columns (α, β, γ) respectively, values with different letters differ at indicated probability level. For site abbreviations see Table III.1.

As a result of the variations in the ground cover and yield per biomass class, the total herbaceous biomass of the ground vegetation (kg DM ha^{-1}) differed between locations (Table III.8). While at W_{Gr} standing herbaceous biomass ranged between 62 – 85 kg DM ha^{-1} and did not vary between seasons (P>0.05), herbaceous biomass at P_{Gr} was significantly lower, reaching 14 - 20 kg DM ha^{-1} in the spring and summer months and only 8 kg DM ha^{-1} in December 2006 and in April 2008 after a long drought spell. Thus, values were significantly lower than those calculated for P_{Ref1} and P_{Ref2}, where 209 – 637 kg DM ha^{-1} and 318 – 840 kg DM ha^{-1} were obtained. With the exception of May 2007, differences between the herbaceous biomass at the two P_{Ref} sites were not significant (P>0.05). The biomass of 37 kg DM ha^{-1} determined at S_{Gr1} in April 2008 was lower than the value recorded at W_{Gr} in the same month, but almost five times as high than at P_{Gr}.

III.4 Discussion

III.4.1 Species composition and grazing intensity

The natural vegetation of Al Jabal al Akhdar is characterized by open shrublands of broad-leafed tree and shrub species. The ligneous and herbaceous species identified at the different locations are typical for the Al Jabal al Akhdar region (Ghanzafar, 1991; Brinkmann et al., 2009; Schlecht et al., 2009). As little quantitative data on the natural vegetation in the highlands of the Middle East and Northern Africa is available, comparisons with rangelands of West and Central Africa were partly necessary. The tree and shrub densities in our study area were higher than those of rangelands in the West African Sahel at <500 m a.s.l. (Sanon et al., 2007), but similar to the highlands of Ethiopia at 1500 – 2500 m a.s.l. (Mekuria et al., 2007). Tree and shrub density, ground cover and species composition of the ligneous and herbaceous vegetation clearly differed between the grazed and ungrazed sites. As a result of continuous livestock grazing, tree and shrub density was higher at P_{Gr} than at P_{Ref}, which is seen as an indicator for overgrazing (Todd and Hoffmann, 1999). Furthermore, *Dodonaea viscosa*, an unpalatable shrub species, and *Sideroxylon mascatense*, which is more resistant to browsing due to its thorny physiology, characterized the vegetation at the grazed sites at 2000 m a.s.l.. In contrast thereto, *Olea europaea* ssp. *cuspidata* and *Grewia erythraea*, which were preferably grazed by livestock, were dominant at the ungrazed sites. Unpalatable plants and species resistant to herbivore grazing can even proliferate under high grazing pressure and replace valuable fodder species (Todd and Hoffmann, 1999). Therefore, the dominance of

Sideroxylon mascatense and *Dodonaea viscosa* and the low density of *Grewia erythraea* and *Olea europaea* ssp. *cuspidata* at P_{Gr} in comparison to P_{Ref} further reflected the effect of grazing on the ligneous vegetation.

Ground cover of the herbaceous vegetation was strongly reduced at P_{Gr} as compared to P_{Ref} and the proportion of bare ground was much higher than described for the Ethiopian Middle Awash valley at 809 – 1028 m a.s.l. (Abule et al., 2007a) and the Tigray highlands at 1500 - 2500 m a.s.l. (Merkuria et al., 2007). The methodology we applied did not aim to generate a complete species lists for the different study sites. Results nevertheless showed that *Cymbopogon schoenanthus* and *Teucrium* sp. were important species at P_{Gr} and their frequency and canopy cover were particularly high at the intensively grazed P_{Gr4}. Both species contain aromatic compounds and are not grazed by livestock (Jongbloed et al., 2003). In contrast thereto, *Heteropogon contortus* and *Fingerhutia africana* were two perennial grasses exclusively found at P_{Ref}.

Tree and shrub density as well as canopy cover of the herbaceous layer increased at S_{Gr} and W_{Gr}. The unpalatable species found at P_{Gr}, namely *Dodonaea viscosa, Euryops arabicus, Cymbopogon schoenanthus* and *Teucrium* sp. also characterized the ligneous and herbaceous vegetation at W_{Gr}, whereas *Acacia gerrardii*, *Grewia erythraea*, *Leucas inflata, Aerva javanica* and *Chrozophora oblongifolia* were dominant at S_{Gr}. While *Acacia gerrardii* and *Grewia erythraea* were preferred fodder shrubs, *Aerva javanica* and *Chrozophora oblongifolia* showed only light signs of goat grazing. Similar to *Teucrium* sp., also *Leucas inflata* belongs to the family of *Labiatae*, whose species commonly contain aromatic compounds, which likely render them less palatable for livestock.

III.4.2 Leaf and twig biomass

Allometric regression equations based on easily measurable phenotypic parameters are frequently used to predict biomass of single ligneous species or the total shrub and tree stratum, because they minimize the need for destructive sampling. Allometric regressions based on logarithmic transformations of the trunk diameter at breast height are commonly used (Salis et al., 2006; Sanon et al., 2007). However, the selected species included multi-stemmed tree as well as several shrub species; thus, using the trunk diameter was not suitable for the purpose of this study. Crown parameters were tested instead and power functions gave best results for the data collected here. Regressions between the foliar biomass and the crown volume were significant at a probability level of 0.1% and coefficients ($0.64 < r^2 < 0.89$) were only slightly lower or similar to results obtained by Sanon et al. (2007; $0.68 < r^2 < 0.98$).

The importance of foliage for livestock nutrition in semi-arid rangelands has been stressed (Le Houerou, 1980; Schlecht et al., 2009) and the results obtained during this study confirm these findings. Due to the higher tree and shrub density, total foliar biomass at P_{Gr} was higher than yields described for the highlands of Ethiopia (196 - 3311 kg DM ha^{-1}; Abule et al., 2007a), but similar or even lower than average biomass determined for shrublands in central Kenya (4737 – 11,991 kg DM ha^{-1}; Rosenschein et al., 1999). Dry matter yields obtained for P_{Gr} and P_{Ref} on Al Jabal al Akhdar were therefore within the range of the African values. However, total foliar biomass at S_{Gr} and W_{Gr} was higher than the maximum values determined for rangelands in Africa, stressing the importance of these areas of higher water availability for forage production and livestock grazing. Moreover, *Acacia gerrardii* is an abundant tree on the mountain slopes (20 – 94 trees ha^{-1} at S_{Gr}). *Acacia* species are valuable fodder trees, since nutrient and mineral concentrations in their leaves are high (Le Houerou, 1980) and their pods are readily eaten by livestock. Sanon et al. (2005) determined an average amount of fallen *Acacia raddiana* pods of 4.1 kg DM per tree. Assuming a similar pod production of *Acacia gerrardii* on Al Jabal al Akhdar, additional 406 kg DM ha^{-1} of high quality fodder would be available for livestock on the mountain slopes and in the valleys at lower altitude. These areas are therefore valuable grazing areas, in particular during September and October, when the pods are produced and farmers preferentially use these areas for livestock grazing.

Accessible foliar biomass calculated by multiplying the total foliar biomass by the percentage of the crown volume <188 cm assumes a regular cylindrical crown shape and does not consider that women are collecting the foliage of *Olea europaea* ssp. *cuspidata*, *Ziziphus spina-christi*, *Sideroxylon mascatense* as livestock fodder from higher parts of the crown. Nevertheless, calculations still provide a more plausible estimation of the amount of fodder accessible to goats than the total leaf and twig biomass. At P_{Gr}, 71% - 81% of the total foliar biomass were accessible to goats. These values are much higher than the proportion described by Sanon et al. (2007) for browse species in West Africa, since the maximum grazing height of goats used by this author was 165 cm compared to 188 cm in our study. At W_{Gr} and S_{Gr}, where the density of trees >188 cm was higher, only 37% - 84% of the foliar biomass was accessible to livestock. The proportion of edible foliar biomass was particularly low at W_{Gr} (27% of the total foliar biomass), where *Dodonaea viscosa* and *Euryops arabicus* were abundant. The high abundance of unpalatable species on mountain pastures of Al Jabal al Akhdar as a result of intense livestock grazing therefore strongly decreased foliar biomass edible for goats.

III.4.3 Herbaceous biomass

Herbaceous biomass differed significantly between P_{Gr}, W_{Gr} and S_{Gr} as well as P_{Ref} and was similar to results obtained by Schlecht et al. (2009) at the grazed plateau and wadi and the ungrazed Al Jabul plateau in October 2005. The comparison of the herbaceous vegetation at P_{Gr} and at P_{Ref} not only showed the effects of livestock grazing, but also the high production potential of the natural vegetation. Thus, biomass at P_{Ref} was higher than in the highlands of Ethiopia (422 – 437 kg DM ha^{-1}; Abule et al., 2007b) and the mountain plains in central Yemen (290 – 420 kg DM ha^{-1}; Kessler, 1995). However, it only contributed little to the total biomass at P_{Gr}, W_{Gr} and S_{Gr}, where the ground cover of herbaceous vegetation was low and unpalatable species such as *Teucrium* sp. and *Cymbopogon schoenanthus* were important. Even at P_{Ref}, where herbaceous biomass was high, it only accounted for 11% of the total biomass. At P_{Gr} and at P_{Ref2}, herbaceous biomass varied between seasons and was particularly low in January 2007 during the cold winter months with daily mean temperatures of 10°C (SD 1.8; December 2006 – January 2007) and in April 2008 after five months with <5 mm of rainfall. In contrast thereto, values were highest at the end of the rainy summer months in September 2006 and 2007 (23°C, SD 1.9 in September 2007), each time two weeks after rainfall events of >5 mm. These seasonal changes in fodder availability comply with results of studies in the highlands of Ethiopia, where highest leaf litter production was observed after summer rainfall (Descheemaeker et al., 2006). Similar to the ligneous stratum, herbaceous biomass was higher at W_{Gr} and S_{Gr} and did not vary throughout the seasons. Thus, the herbaceous vegetation in these areas appears to be more resistant to the lack of rainfall.

Although the fodder quality of the herbaceous biomass did not differ between seasons, N and in particular P concentrations of the herbaceous samples as well as of the samples of the five shrub and tree species were lower than recommended for maintenance and locomotion of goats grazing on arid, mountain rangelands (NRC, 1981). Low nutrient contents, seasonal changes in the available herbaceous biomass and the leaf fall of deciduous fodder shrubs such as *Grewia erythraea* and *Sageretia thea* point to the need of supplementing animals during dry periods and in particular during the main kidding period of local goats in November – February.

III.4.4 Pasture management options

Different concepts and underlying theories for the management of rangeland ecosystems have been developed in the past. The low and highly variable rainfall with a coefficient of variation >33% suggests that the conditions on Al Jabal al Akhdar resemble typical non-equilibrium environments, where the natural vegetation is rather influenced by water availability than by livestock grazing (Ellis et al., 1993, Vetter, 2005). Our results also show that water availability has indeed an effect on the natural vegetation. Thus, foliar and herbaceous biomass was higher on the mountain slopes and wadis than on plateau areas and changed over the seasons depending on rainfall events. However, comparing the results from the grazed and the ungrazed plateau with similar elevation and identical geomorphology and climatic conditions reveals the strong influence of livestock grazing on the natural vegetation. Since according to key informants as well as the Omani Ministry of Agriculture and Fisheries, livestock numbers in villages of Al Jabal al Akhdar were similar or even higher in the past, grazing pressure on the natural vegetation appears to be high for a long time, which supports reports of Mandaville (1977). Nevertheless, tree and shrub density, ground cover of the herbaceous layer and the foliar and herbaceous biomass in the 15 year old enclosure (P_{Ref1}) did not differ from the ligneous and herbaceous vegetation on the traditionally ungrazed Al Jabul plateau (P_{Ref2}). And although *Dodonaea viscosa* and *Cymbopogon schoenanthus* were more abundant in the enclosure and *Fingerhutia africana* and *Ebenus stellata* were in contrast more important on the Al Jabul plateau, overall species composition was similar at both sites. These similarities and in particular the increased relative density of the highly grazed *Olea europaea* ssp. *cuspidata* trees in the enclosure (P_{Ref1}) indicate the ability of the landscape to recover from livestock grazing. Our data therefore suggest that despite the highly variable rainfall, the open shrublands of Al Jabal al Akhdar exhibit the resilience typical of equilibrium systems. Other research showed that many grazing systems include characteristics of both, equilibrium and non-equilibrium systems. Thus, Illius and O'Connor (1999) argued that even in non-equilibrium environments, livestock numbers will be in equilibrium with key resources, which delay mortality during drought, so that the impact of livestock grazing on the vegetation might be even larger than in equilibrium systems. In contrast to the herbaceous biomass that fluctuates over the seasons, the high foliar biomass particularly on the mountain slopes and in wadis of Al Jabal al Akhdar is less dependent on rainfall and the main fodder trees *Sideroxylon mascatense* and *Olea europaea* ssp. *cuspidata* are ever-green. Moreover, small ruminants on Al Jabal al Akhdar are offered supplement feeds at the homestead and an extended veterinary service has been established. Hence, the presence of these key resources and key resource areas as well as human interventions in natural ecosystem processes reduce livestock mortality during dry seasons and drought years and thus increase the grazing pressure on the less productive plateau areas.

Rangeland management is fundamentally different depending on the concept it is based upon (Vetter, 2005). While the non-equilibrium model promotes opportunistic livestock numbers, the equilibrium concept suggests conservative stocking rates to avoid overgrazing. On Al Jabal al Akhdar, average edible foliar (3.8 t DM ha^{-1}, SD 0.13) and herbaceous biomass (532 kg DM ha^{-1}; SD 184) as determined on the ungrazed plateau (P_{Ref}) was high. Even assuming a potential loss of 30% of the herbaceous biomass due to trampling and decomposition as well as a resting period of four months per year to allow plant re-growth (Penning de Vries and Djitèye, 1991), edible forage biomass per hectare would cover the DM demand of five goats of a bodyweight of 40 kg for maintenance and locomotion in the mountainous landscape (1.41 kg DM d^{-1} at a metabolizable energy content of 8 MJ kg^{-1} DM; NRC, 1981). Considering that at least 26% of the village pastures are highly productive wadis and mountain slopes, the carrying capacity should even be higher. Current stocking rates per village of 0.25 goats and sheep per ha (SD 0.17) are similar to values determined earlier by Schlecht et al. (2009), but lower than described or experimentally tested for other arid and semi-arid rangelands (Osman et al., 2006). Although actual stocking rates might be at least five times higher than the calculated values, because grazing areas of different villages overlap and the number of donkeys grazing in the mountains is up to now unknown, the stocking rates are still much lower than the calculated carrying capacity. Nevertheless, the pasture vegetation shows clear signs of overgrazing; thus, more differentiated management recommendations about the timing, duration and intensity of grazing need to be developed, which consider the temporal variation in herbaceous biomass as well as the spatial heterogeneity of the vegetation in the semi-arid mountain landscape.

Traditional grazing practices of livestock keepers were the basis for management recommendations in many parts of the world: the *Hema* system in the highlands of Saudi Arabia, the *Mahjur* areas in the Dhamar Mountains of Yemen Arab Republic or the *Agdal* areas in Northern Africa all aimed to preserve feed resources for dry periods and droughts, and the maintenance and re-establishment of these protected areas was recommended (Saleh, 1998; Kessler, 1999). While livestock exclosures are criticized to accelerate overgrazing in remaining rangelands (Descheemaeker et al., 2006), the use of the traditional grazing reserves temporarily eased grazing pressure and therefore allowed the natural vegetation to recover. Although, according to farmers, there were no grazing reserves on Al Jabal al Akhdar in the past, grazing areas of villages on Al Jabal al Akhdar were clearly defined and the mountain slopes and wadis were important feed resources preferentially used during the dry seasons. Nowadays however, roads, residential, governmental and military areas on the plateau surrounding Sayh Qatanah cover an area of about 500 ha and according to municipal plans, the town itself is projected to double its size in the near future, severely minimizing the area available for livestock grazing and limiting the access to highly productive pasture areas. Furthermore, pastures of different villages overlap and fewer animals are herded during grazing than in the past, leading to locally very high grazing pressure (Turner et al., 2005). Thus, systems of directed grazing or allowing certain pasture areas to remain ungrazed for a period of time as in the past are nowadays not found anymore.

Contemporary research on pastoral livestock production in the Middle East and in Northern Africa has mainly focused on the possibility to increase pasture production by irrigation (Oatham et al., 1995) or the seeding and propagation of highly productive species (Osman et al., 2006; El-Kharbotly et al., 2007) and the potential of supplementation of livestock with concentrate feeds (Mahgoub et al., 2005). The introduction of such management schemes and the shift from traditional grazing systems towards stall-feeding has also been recommended for livestock husbandry on Al Jabal al Akhdar (Zaibet et al., 2004). However, both strategies neglect the high yield potential of the natural highland pastures and the potential of goat husbandry to use these resources by adapted grazing schemes. Supplementation of livestock will strongly raise feeding costs for farmers (Zaibet et al., 2004) and in particular the use of cereal grains for animal feeding has commonly been criticized to increase competition with human consumption (Bradford, 1999). The import of meat and livestock feed into Oman is nowadays three and five times higher than in 1980, and although exports of both commodities increased simultaneously, import of meat and feedstuffs largely exceeded exports in 2005 (FAOSTAT, 2008). Hence, in combination with raising per capita meat consumption and growing livestock numbers, the supplementation of livestock will increase rather than reduce the dependence on food and feed imports.

III.5 Conclusions

In the highlands of the Middle East and Northern Africa, which are characterized by open shrublands, the foliage of trees and shrubs represents an important source of animal fodder, in particular in areas of higher water availability. Since ligneous plants are less affected by the distribution and amount of rainfall than the herbaceous vegetation, these rangelands exhibit typical characteristics of equilibrium systems despite a high variability in rainfall. Livestock grazing strongly influenced species composition, ground cover and biomass yields on pastures of Al Jabal al Akhdar, whereas resting periods allowed the natural vegetation to recover. The dedication of sufficiently large areas to livestock grazing including access to highly productive areas, coordinated grazing to avoid simultaneous use by several herds as well as the herding of livestock would enable farmers to decide when pastures might be put at rest. It would allow a rotational grazing, in particular of those areas that serve as key resources during periods of fodder scarcity. A temporarily increased supplement feeding of goats at the homestead, shorter grazing times or grazing of only part of the herds could further reduce grazing pressure during flowering and seed development of the herbaceous vegetation. Together with the control of the increasing number of feral donkeys, management based on scientific and traditional knowledge could therefore allow for stocking rates that exceed conservative recommendations without exploiting the pasture vegetation beyond its natural carrying capacity. Although at least temporary supplementation appears necessary, goats can effectively use the natural vegetation otherwise of little direct use for human consumption. An improved pasture management therefore appears to be a valuable alternative to sustain livestock production in semi-arid subtropical highlands, thereby limiting the need for food and feed imports and increasing the food security of their population.

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IV Modeling herd development and revenues for Jabal Akhdar goats under current and intensified management practices

Abstract

Pastoral goat husbandry supplies meat and income to farm households in villages of Al Jabal al Akhdar, Oman, where farmers offer little supplement feeds to grazing goats. However, the low nutritive value of the pasture plants consumed by animals during grazing appears to limit their growth and production. Goats' daily weight gain was measured for twelve farmers (2 types of livestock farms x 3 villages) from November 2006 – October 2007. Progeny history interviews were conducted on does (n=114) of 14 households to determine age at first parturition (AFP, months), kidding interval (KI, months) and prolificacy (PR, n of kids parturition^{-1}). To estimate annual output (€ animal^{-1}) from traditionally managed goat herds, data were analyzed using the herd model PRY. To evaluate the potential of an improved supplement feeding of goats and the introduction of a zero-grazing system, output was also simulated for AFP, KI and PR being 18 months, 10 months and 1.2 kids for semi-intensive and 14 months, 8 months and 1.3 kids for zero-grazing management.

Post-weaning weight gain of traditionally managed bucks (73 g d^{-1}, SD 34.6) and does (48 g d^{-1}, SD 25.7) was lower than growth rates observed in goats of the same breed under feedlot conditions and in particular young does were not able to compensate for growth retardation with advancing maturity. Together with late AFP (22, SD 9.7), prolonged KI (12, SD 4.3) and low PR (1.0, SD 0.26), the slow growth resulted in a low annual output of 38 € animal^{-1}, irrespective of farm type and village. The simulated annual output of semi-intensive goat management was 51 € animal^{-1} and for the zero-grazing option 66 € animal^{-1} were obtained. Accounting for daily feed dry matter (DM) intake of goats at the homestead of 394 g and 600 g DM animal^{-1} in large and medium-sized goat holdings and the recommended total DM intake for tropical goat breeds raised under feedlot conditions, the use efficiency of the feeds offered at the homestead amounted to 0.26 € and 0.18 € kg^{-1} DM in the traditionally managed goat holdings compared to 0.22 € kg^{-1} DM under zero-grazing management. An improved individual feeding of female goats at the homestead in addition to grazing the mountain pastures can increase goats' growth and reproductive performance and overall herd productivity without reducing the use efficiency of feeds offered at the homestead.

IV.1 Introduction

Meat is an important constituent of people's diets in the Sultanate of Oman, and per capita meat consumption has continuously increased from 7 kg in 1970 to nearly 50 kg per year in 2002 (WRI, 2007). Goat meat and mutton are preferred over beef (Mahgoub et al., 2005) and in particular during religious festivals market prices for locally raised animals are high with up to 200 Omani Rial (approximately 400 €) for a two-year old buck (Zaibet et al., 2004). Livestock husbandry can thus be an important asset to households' food supply and income in rural areas. While there is only one sheep breed native to Oman, three autochthonous goat breeds are distinguished: the Dhofari goat, originating from the south of Oman (Dhofar), the Batinah goat, which is mainly kept in the country's lowlands and the Jabal Akhdar goat. The latter is the largest of the three goat breeds and is typically kept in goat herds of the Al Hajar mountain range in northern Oman. In the central Al Jabal al Akhdar region of the Al Hajar Mountains, grazing the natural vegetation accounts for 47% - 71% of the daily organic matter intake of goats kept in mountain settlements even after long periods without rainfall (Dickhoefer, 2006; Schlecht et al., 2009). Since average metabolizable energy (ME) concentrations in the plants grazed on the mountain pastures are very low (7.2 MJ kg^{-1} OM; Dickhoefer et al., 2009a), daily ME intake does not meet the goats' requirements for maintenance, locomotion and substantial growth (Dickhoefer et al., 2009a). Moreover, continuous grazing of pastures by goats, sheep and feral donkeys, the increasing use of grazing areas for road and housing construction and the abandonment of traditional herding practices severely reduce the fodder resources on the mountain pastures (Dickhoefer et al., 2009b). Although farmers offer small amounts of dates and dried sardines as well as cultivated and collected fodder to their animals, the reduced biomass production of the rangelands and its low nutritive value appear to limit growth and production of goats in these extensive pastoral systems.

Body weight gains of kids and lambs of the native goat and sheep breeds have been studied under intensive feedlot conditions, where adult animals were fed with 400 - 500 g of concentrate feed per animal and day, and breeding programs were initiated to improve growth and production of goats and sheep and to thereby counteract the increasing import of live goats and sheep, meat and meat products into Oman (Al-Nakib, 1996; Mahgoub et al., 2005). However, no information is yet available on the growth and reproduction of native goats and sheep under traditional pastoral husbandry conditions. The objective of this study was therefore to determine these performance traits for traditionally managed goats on Al Jabal al Akhdar and to assess to which extent their nutrient and energy intake limits their overall production. Using the PRY Herd Life modeling tool (Baptist, 1992), different scenarios were tested to determine whether improved feeding and fertility management can increase the benefits derived from goat husbandry.

IV.2 Materials and methods

IV.2.1 Study location

Our study focused on the traditional agro-pastoral system in the Al Jabal al Akhdar region in Northern Oman, where deeply dissected limestone mountains reach elevations of almost 3000 m a.s.l. (Ghanzafar, 1991). Mean annual rainfall of 318 mm measured at 1900 m a.s.l. is substantially higher than in most of the country's lowlands, where precipitation is less than 100 mm per year (Fisher, 1994). Most of this rainfall occurs in February – March as well as in July – August, when mean monthly temperatures reach 25°C, whereas temperatures and probability of rainfall decrease in November - January. The traditional oasis agriculture in the villages near Sayh Qatanah (57°40'35''E; 23°40'51''N, 2050 m a.s.l.), the main settlement on Al Jabal al Akhdar, combines irrigated terrace agriculture with livestock husbandry. The date palm (*Phoenix dactylifera* L.) is an important perennial crop cultivated in gardens below 1500 m a.s.l. and is replaced, among other tree species, by the pomegranate (*Punica granatum* L.) in villages at higher altitudes (Luedeling et al., 2009). Fodder plants such as maize (*Zea mays* L.), barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.), alfalfa (*Medicago sativa* L.) and sorghum (*Sorghum bicolor* (L.) Moench) are often grown under the cover of these trees. Goats (*Caprus hircus*) of the local Jabal Akhdar breed are the most numerous species kept to provide meat, milk and manure, which is intensively applied as fertilizer in crop cultivation (Buerkert et al., 2005). The animals are kept in the barn over night, where farmers offer supplement feeds such as dates, dried sardines, cultivated green fodder or collected tree foliage. In the morning, the animals are taken out to the mountain pastures, partly being herded until the late afternoon or left to graze on their own, thereby covering distances of 12 - 20 km each day (Schlecht et al., 2009). The natural pasture vegetation is characterized by open shrublands of *Sideroxylon mascatense* (A.DC.) Penn., *Olea europaea* L. ssp. *cuspidata* (Wall. ex G. Don) Ciferri and *Dodonaea viscosa* L. on the plateau areas at 2000 m a.s.l. as well as of *Acacia gerrardii* Benth., *Ziziphus spina-christi* L. and *Pteropyrum scoparium* Jaub. & Spach. on the mountain slopes and in the valleys at lower altitudes (Dickhoefer et al., 2009b).

IV.2.2 Household survey

In autumn 2006, an initial survey was conducted in all households keeping livestock in the focus villages Qasha' (57°39'50''E, 23°04'00''N, 1700 m a.s.l., n=10), Masayrat ar Ruwajah (57°40'13''E, 23°02'37''N, 1050 m a.s.l., n=12) and Ash Sharayjah (57°39'30''E, 23°04'10''N, 1950 m a.s.l., n=17), three oases in the vicinity of Sayh Qatanah. Qualitative and quantitative information regarding livestock endowment, feeding and grazing practices and the use of livestock products were collected during interviews. On the occasion of these first contacts, all goats and sheep kept in the three villages were weighed using a tri-pod-based suspension balance (range 0 – 100 kg, accuracy 500 g) to determine the average weight of animals in different age and sex classes as well as the typical herd composition. To classify different types of livestock keepers, the baseline data were subjected to a hierarchical cluster analysis and three types of livestock keepers were distinguished: farmers with large (farm type M), medium sized (farm type H) and small herds (farm type S). While 56% of the farmers in the latter group did not allow their animals to graze during the day, 67% of the type M farmers either just released their animals for grazing in the morning or took them out to the pastures and left them to graze by themselves (= free-grazing). Instead, goats of 50% of the type H farms were herded during grazing (= herded). Since the type S farms only kept 3 (SD 2.2) goats and sheep, the subsequent research only focused on the type H and type M holdings.

IV.2.3 Livestock survey

From November 2006 – October 2007, goats of six households each of farm type M and H were weighed every five weeks using the tri-pod system to determine daily weight changes of animals in the following four bodyweight classes of ≤15 kg, >15 - ≤30 kg, >30 - ≤40 kg and >40 kg. The feed intake of goats at the homestead was quantified in the selected households every six weeks. By dividing the quantities of the different feed stuffs offered to all goats by the number of animals fed and using published feed dry matter (DM) concentrations (Dickhoefer 2006; Dickhoefer et al., 2009a), animals' daily DM intake from dates, dried sardines, other concentrate feeds as well as cultivated and collected fodder was calculated. To be able to compare bodyweight changes of the traditionally managed goats and sheep in the three focus villages to those of grazing animals raised in semi-intensive systems, that are offered larger amounts of supplement feeds at the homestead, live weight gain and feed intake were additionally quantified in goats and sheep of six farmers in Al Hailailat (57°33'39"E, 23°08'01"N, 2040 m a.s.l.), a village in the Al Hail region of Al Jabal al Akhdar (see

Figure I.2, page 7). Animals in this village are of the same breeds and graze similar mountain pastures during the day, but while no or little cultivated fodder is offered, adult goats and sheep are fed with larger amounts of concentrate feeds at the homestead, including dates, dried sardines and commercial feed mixtures.

To determine the age at first parturition, the frequency of abortions, of still and multiple births, the average kidding interval as well as mortality and prolificacy rates, progeny history interviews (Kaufmann, 2005) on female goats (n=114) were conducted with women of the selected farm households of type M (n=5) and H (n=7). To increase the sample size, three additional households representative for type M (n=1) and H (n=2) were interviewed in a nearby oasis settlement (57°41’31’’E 23°40’15’’N, 1950 m a.s.l.; n=3), which used the same pasture areas as the households of the three focus villages. If women did not remember the exact month of birth of a kid, the season of the year was recorded and January, April, July and October were taken as the approximate date for the winter, spring, summer and autumn parturitions.

IV.2.4 Scenario analysis

To estimate the output of the traditional goat husbandry system in the mountain oases of Oman, data on growth and reproduction of goats in the focus villages were entered in the herd model PRY Herd Life (Baptist, 1992; upgraded test version for Windows). The model simulates the development of the growth and composition of livestock populations over time by accounting for the age at first parturition, the kidding interval, the prolificacy and mortality rate as well as the percentage of breeding females that are culled due to sickness or low performance (= selective culling rate). It therefore allows estimating the potential animal offtake per year for specific culling ages of breeding females, males and surplus females, respectively, if population size was kept at a steady state. Subsequently, the model calculates the monetary output value according to the prices paid for males and females of different bodyweight. Considering the proportion of breeding females, surplus females and males in the herd, the weighted average output for a standard animal in the herd is given.

Herd development and offtake were modeled separately for M and H farms using the respective reproductive performance values. In addition, offtake was also modeled for all goats across the focus villages using the respective mean values for all input parameters (scenario 1). The maximum life time of does determined during the progeny history interviews of 84 months was taken as the cull-for-age threshold for breeding females and the average age at slaughter and at sale determined during this study of 26 months and 10 months, respectively, for males and of 19 months (slaughter) and 10 months (sale) for female goats was chosen as the culling (= slaughter or sale) age for males and surplus females. Prices (in Omani Rial, OMR) for Jabal Akhdar bucks and does determined regularly on the lowland market of Nizwa were converted into Euro (€) using a conversion rate of 1 OMR = 2.02 € (World Bank, February 2009) and were divided by the respective bodyweight to obtain the price per kg of weight.

To simulate the productivity of Jabal Akhdar goats under improved management and thereby evaluate the possibilities to increase the performance of the traditionally managed goat herds in the oases of Al Jabal al Akhdar (*status quo* = scenario 1), two additional scenarios were defined (Table IV.1). For scenario 3, the prolificacy of 1.3 kids per litter as determined by Al-Nakib et al. (1996) in Jabal Akhdar goats raised under feedlot conditions was taken, while age at first parturition and kidding interval were set at 14 months and 8 months, which is similar or slightly higher than reported for other tropical goat breeds (García and Gall, 1981; Devendra and Burns, 1983). Initial growth rates of animals until 6 months of age were taken from Al-Nakib et al. (1996). Thereafter, weight development was interpolated until the age of 24 months when goats normally reach 80% of their final bodyweight (Gall, 2001), which in this study was determined at 75 kg for bucks and 55 kg for does. While scenario 3 represents an intensive livestock production system where goats do not graze any pasture, scenario 2 was supposed to mirror herd development and offtake rates under semi-intensive management conditions such as of goats in Al Hailailat, with increased homestead feeding of goats grazing the natural highland pastures. Here, the values for bodyweight changes determined in goats of Al Hailailat were used, while assumed values for prolificacy, age at first parturition and kidding interval were in-between those of scenarios 1 and 3. To solely simulate the effects of an improved fertility and feeding management on herd expansion and offtake rates, the rates of selective culling and mortality were kept constant in all three scenarios.

Table IV.1. Reproductive performance and bodyweight gain as determined in goats in the mountain oases of Al Jabal al Akhdar, Oman (scenario 1) and as defined for animals of the same breed under two improved management regimes (scenarios 2 and 3) and simulated by the PRY herd model.

Parameter	Unit	Scenario 1	Scenario 2	Scenario 3
Reproduction				
Age at first parturition	months	22	18	14
Kidding interval	months	12	10	8
Litter size	n parturition^{-1}	1.1	1.2	1.3[b]
Bodyweight (bucks/does)				
At 6 months	kg	22 / 20	22 / 20[a]	24 / 24[b]
At 24 months	kg	49 / 33	52 / 37[a]	60 / 44[c]
Final bodyweight	kg	75 / 50	75 / 55[a]	75 / 55[a]

[a] as determined for Jabal Akhdar goats in Al Hailailat
[b] according to Al-Nakib et al. (1996)
[c] equivalent to 80% of the final bodyweight (Gall, 2001)

IV.2.5 Statistical analysis

Quantitative household information was tested for its variance among the livestock keeping households and the number of breeding females (n), the number of animals sold annually as the proportion of the total offtake per herd (%) and the amount of dates and dried sardines fed to goats (g DM head^{-1} d^{-1}) were chosen as the major determinants of the animal husbandry systems investigated. These variables were standardized by subtracting the minimum value from each value of the variable and then dividing it by the difference between the maximum and minimum value ($y = (x - x_{Min})*(x_{Max} - x_{Min})^{-1}$; option “range 0 to 1”). Subsequently, a cluster analysis was conducted to distinguish different types of livestock keepers using the Ward’s method and Squared Euclidean Distance. Means and standard deviations for household variables and management and production parameters were calculated for the identified farm types and different villages, respectively. Data were analyzed for significant differences between farm types and villages, applying the independent t-test for normally distributed and the Mann-Whitney U-Test for not normally distributed sample sets (Zöfel, 1988). Statistical analyses were carried out using SPSS 12.0 for Windows (SPSS Inc., Chicago, USA).

Growth curves of animals of different weight classes were combined to one mixed longitudinal data set (Fitzhugh, 1976). To be able to determine the bodyweight of animals at the moment of slaughter or sale (events for which only the age was known), the following four nonlinear models commonly used to describe the weight development of livestock (Brown et al., 1976; Fitzhugh, 1976) were fitted to the mixed longitudinal weight-age data using the function “nls” provided by the R version 2.8.0 (R Foundation for Statistical Computing, Vienna, Austria):

Brody: $y = A * (1-b*e^{-k*t})$

Gompertz: $y = A * e^{b*e^{-k*t}}$

Bertalanffy: $y = A * (1-b*e^{-k*t})^3$

Logistic: $y = A * (1+b*e^{-k*t})^{-1}$,

where y = bodyweight (kg);

A = value (kg) of the asymptote when age advances infinity;

t = age of goats (days);

b, k = function variables.

Model parameters were estimated by the Gauss-Newton iterative procedure (Brown, 1976).

IV.3 Results

IV.3.1 The livestock system

Ten, six, five and two of the 28 livestock keeping households (HH) in the three focus villages kept cows, sheep, chickens or rabbits, respectively, but the goats were the main livestock species with 26 of the households in the three oases keeping at least one animal. In autumn 2006, the total number of goats and sheep amounted to 74, 126 and 306 animals in Ash Sharayjah, Qasha’ and Masayrat ar Ruwajah, respectively. The average number of goats and sheep per household was higher in Masayrat ar Ruwajah (26, SD 15.6) and Qasha’ (21, SD 22.2) than in Ash Sharayjah (6, SD 3.2; $P<0.01$; Table IV.2). In autumn 2006, does accounted for a fraction of 0.65 (SD 0.169) and suckling and young animals for 0.41 (SD 0.148) of herds with more than four animals. With the exception of one animal, all goats in the three oases were of the local Jabal Akhdar breed and sheep were of the Omani breed.

Table IV.2. Size and composition of small ruminant herds in three focus villages of Al Jabal al Akhdar, Oman, as determined in autumn 2006.

Village	House-holds	Goats	Sheep	Herd size		
		n		Mean	Max	Min
Qasha'	6	107	19	21	55	1
Ash Sharayjah	10	64	10	6	14	2
Masayrat ar Ruwajah	12	306	0	26	56	3

While sheep were left to graze in the vicinity of the villages, goats were taken out to graze the mountain pastures each morning (n=24 HH). Feedstuffs offered to goats and sheep at the homestead included dates (n=27 HH), dried sardines (n=26 HH) and dried bread (n=5 HH) as well as occasionally small amounts of wheat meal (n=5 HH) or barley grain (n=10 HH). According to interview data, average daily offers per animal varied from 95 – 1045 g DM of dates and 15 – 138 g DM of dried sardines. Additionally, farmers (n=23 HH) fed the green fodder they cultivated in their gardens to their goats and sheep. In households keeping cattle the cultivated fodder was mainly given to these solely stable-fed animals. Based on the number of breeding females per household, the number of goats sold as a proportion of the total animal off-take per year and the amount of dates and dried sardines fed to goats and sheep, three types of livestock holdings were differentiated (Table IV.3). While type M farms comprised livestock keepers with large herds (34, SD 18.0), who regularly sell animals on the local markets (= marketing), farmers of type H farms owned less goats and sheep (15, SD 7.6) and only occasionally sell single animals (= home consumption). Type S included farmers who keep a few animals (5.5, SD 3.0) for slaughter and feed high amounts of concentrate feeds at the homestead (= small-scale).

Table IV.3. The number of breeding females, of sold animals and the amounts of dates and dried sardines (= concentrates) fed to goats in three livestock farm types as determined in a survey in three villages on Al Jabal al Akhdar, Oman, in autumn 2006 (means ± one standard deviation).

Type **	Farms	Breeding females	Animals sold	Animals slaughtered	Concentrate feeding *
	n	n	n a^{-1}		kg DM $head^{-1}$ d^{-1}
M	9	19 ± 10.3	7.0 ± 5.15	5.8 ± 2.44	0.24 ± 0.098
H	10	8 ± 4.6	0.1 ± 0.32	3.3 ± 1.34	0.33 ± 0.127
S	8	3 ± 2.2	0	1.8 ± 0.71	0.72 ± 0.254

* DM dry matter

** Type M farms own large herds and regularly sell animals (= marketing). Type H farms keep medium sized herds and only occasionally sell goats (= home consumption). Type S farms own few animals for slaughter (= small-scale).

IV.3.2 Feeding

The daily amount of feed offered to goats and sheep at the homestead as quantified through regular weighing of feed averaged 394 g DM (SD 226.4) and 600 g DM head^{-1} (SD 140.3) for farm types M and H, respectively (P>0.05). Dates and dried sardines were the most frequently offered concentrate feeds at 235 g DM (SD 98.2) and 22 g DM head^{-1} (SD 11.0) in M type farms and 349 g DM (SD 134.7) and 23 g DM head^{-1} (SD 11.0) in H type farms (P>0.05; Figure IV.1). While type M farmers only fed small amounts of collected and cultivated fodder, goats on farms H received about twice as much green fodder from the gardens (82 g DM head^{-1} d^{-1}, SD 63.0, P>0.05), along with garden weeds or tree leaves collected in the mountains (96 g DM head^{-1}; SD 63.0, P>0.05). In Al Hailailat, cultivated and collected fodder was mainly offered to individual stable-fed fattening goats. Adult bucks and does grazing the pasture vegetation during the day were supplemented with 272 – 561 g DM head^{-1} of concentrate feeds each day, including dates (206 g DM, SD 72.9), dried sardines (47 g DM, SD 26.7) or a commercial concentrate feed mixture purchased from Omani Flour Mills (155 g DM, SD 93.7).

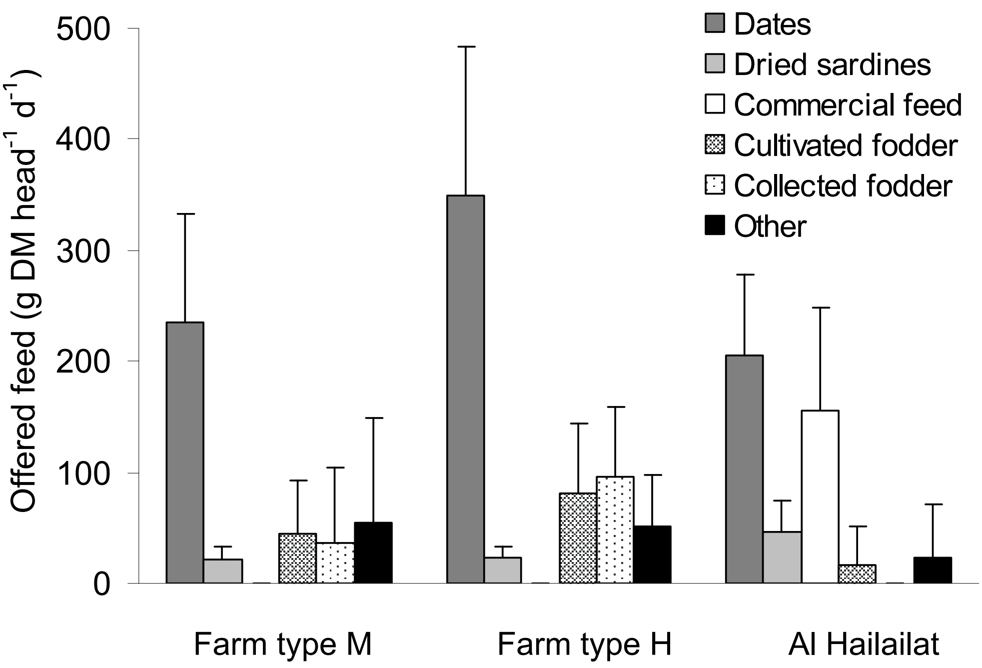

Figure IV.1. Feed given to goats on farms of type M and H and of farmers of Al Hailailat as determined during regular feed weighing in villages of Al Jabal al Akhdar, Oman, during November 2006 – October 2007. For definition of farm types see table IV.3.

IV.3.3 Growth rates

Goats' average bodyweight as determined during the initial animal weighing in the three focus villages was 45 kg (SD 11.6) for adult bucks (n=49) and 35 kg (SD 5.2) for adult, non-pregnant does (n=154), reaching a maximum of 78 kg in male and 54 kg in non-pregnant female animals. Average bodyweight of goats determined during the first weighing in Al Hailailat was higher than in the focus villages, averaging 53 kg (SD 14.3) for adult males (n=8) and 43 kg (SD 7.6) for adult females (n=98). Maximum bodyweight recorded in Al Hailailat during the first weighing was 78 kg for bucks and 68 kg for non-pregnant does.

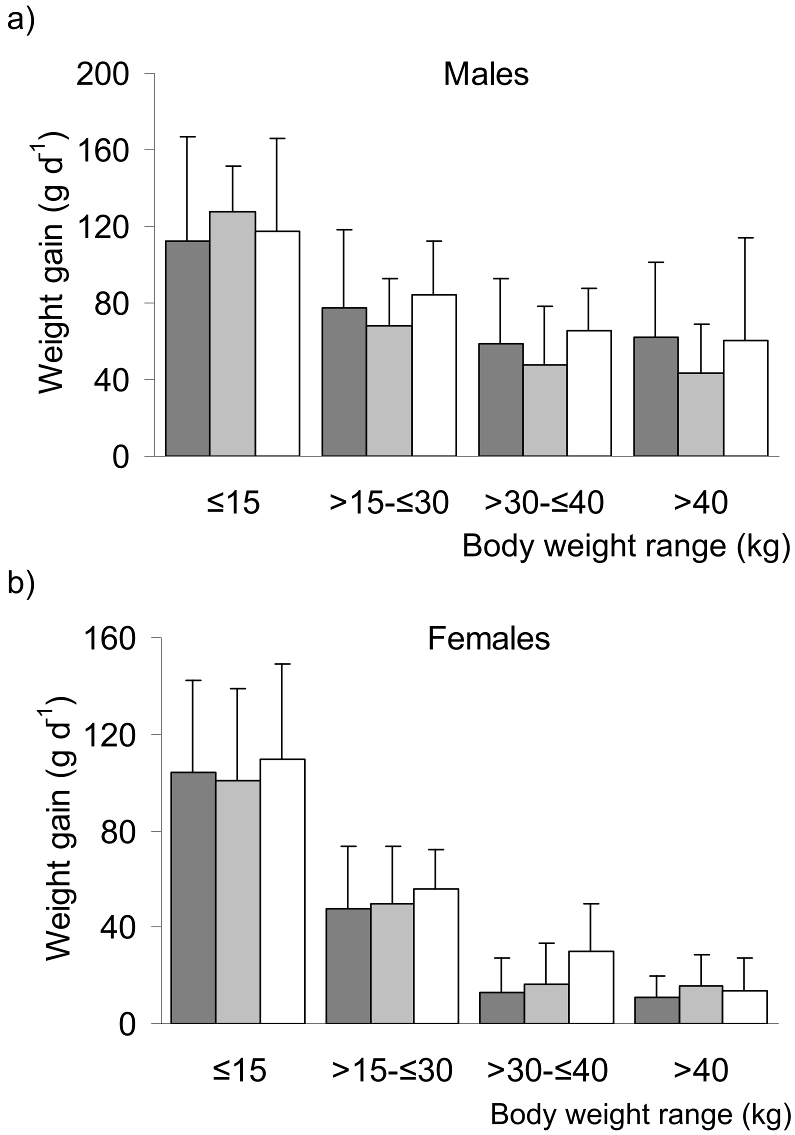

Figure IV.2. Daily weight gain of four different weight classes of male (a) and female (b) goats on farms M (dark grey) and H (light grey) and of farmers of Al Hailailat (white) as determined by regular weighing of animals in villages of Al Jabal al Akhdar, Oman, during November 2006 – October 2007. For definition of farm types see table IV.3.

Average weight at birth was 2.93 kg (SD 0.382, n=15) and was only slightly lower in female (2.89 kg, SD 0.290) than in male kids (3.04 kg, SD 0.547; P>0.05). Daily weight gain as determined for the four weight classes did not differ between animals of farm types M and H (Figure IV.2, P>0.05). Male and female kids grew at 118 g d^{-1} (SD 46.3, n=28) and 103 g d^{-1} (SD 38.0, n=58) until a bodyweight of 15 kg, respectively, when animals were about 3 - 4 months old and close to being weaned. Thereafter, daily bodyweight gain dropped to 73 g d^{-1} (SD 34.3, n=56) for bucks and 48 g d^{-1} (SD 25.5, n=94) in does until the animals reached a bodyweight of 30 kg. Daily weight gain in bucks at 30 - 40 kg bodyweight and females at 15 - 30 kg and 30 - 40 kg bodyweight, respectively, was lower in Masayrat ar Ruwajah than in Ash Sharayjah (P<0.05).

From the four non-linear functions tested, the Brody model best fitted to the longitudinal weight-age data, although differences between the single models were small (Table IV.4, Figure IV.3). According to the model, bucks weighed on average 28 kg at the age of 300 days (approximately 10 months) when most kids were sold (see previous section), whereas the average bodyweight of doe kids was 25 kg at that moment. In contrast thereto, male goats had a bodyweight of 49 kg and females of 30 kg at their respective slaughter age of 780 days (approximately 22 months) and 570 days (approximately 19 months; see following section), equivalent to 63% of the maximum bodyweight of bucks and does recorded for the three focus villages.

Up to a bodyweight of 30 kg, the initial growth rates of male and female goats of Al Hailailat were similar to the values determined in the three focus villages. However, at a bodyweight of 30 - 40 kg, their daily weight gain was higher (females: 30 g d^{-1} SD 19.7, males: 66 g d^{-1}, SD 22.0) than that of the other animals. At 300 days of age, Al Hailailat does weighed on average 27 kg and bucks 32 kg, being 2 kg and 5 kg heavier than animals of the same age in Masayrat ar Ruwajah, Qasha' and Ash Sharayjah, with differences becoming more pronounced with increasing age. The average weight at maturity (A) when estimated with the Brody model was higher than with the other three functions, namely 70.4 kg for bucks and 33.0 kg for does in the three focus villages. While it was similar for bucks in Al Hailailat (70.7 kg), average weight of mature does in this village was higher (40.3 kg).

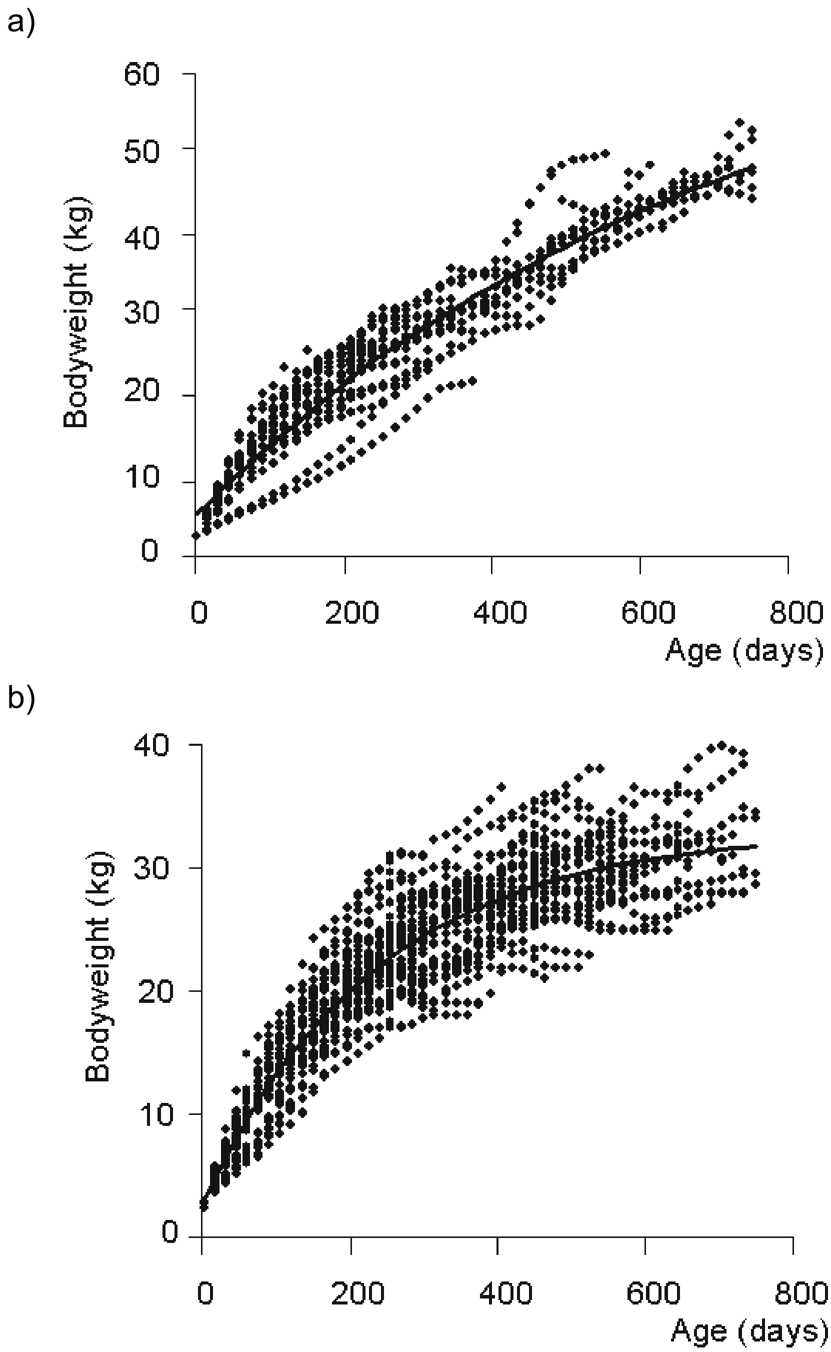

Figure IV.3. Body weight of growing male (a) and female (b) goats until the age of 750 days in traditional husbandry systems of Al Jabal al Akhdar, Oman, as determined by repeated weighing of selected animals during November 2006 - October 2007. Regression lines represent the Brody model fitted to the weight-age dataset, model parameters are presented in Table IV.5.

Table IV.4. Parameters (mean ± standard error) of four nonlinear regression functions fitted to growth curves of male and female goats raised in traditional and semi-intensive systems on Al Jabal al Akhdar, Oman.

	Parameter*	Brody		Gompertz		Bertalanffy		Logistic	
Bucks		Mean	SE	Mean	SE	Mean	SE	Mean	SE
Traditional	A	70.4	3.47	53.5	1.24	56.4	1.54	49.2	0.84
t ≤ 750	b	0.92	0.004	1.91	0.029	0.49	0.006	4.34	0.126
n=37	k	0.001	0.0001	0.004	0.0002	0.003	0.0001	0.006	0.0002
	RS	8430		9263		8985		10040	
Semi-intensive	A	70.7	7.21	49.1	1.98	52.5	2.59	44.2	1.22
t ≤ 465	b	0.93	0.006	1.97	0.048	4.47	0.206	0.51	0.009
n=31	k	0.002	0.0003	0.005	0.0004	0.008	0.0005	0.004	0.0003
	RS	4689		4931		4849		5160	
Does									
Traditional	A	33.0	0.34	31.1	0.24	31.5	0.26	30.3	0.20
t ≤ 750	b	0.90	0.009	1.75	0.039	0.47	0.008	3.5	0.126
n=67	k	0.004	0.0001	0.007	0.0002	0.006	0.0002	0.009	0.0002
	RS	13680		14370		14100		15240	
Semi-intensive	A	40.3	0.71	36.5	0.43	37.3	0.48	35.1	0.34
t ≤ 645	b	0.91	0.009	1.77	0.042	0.47	0.009	3.59	0.14
n= 37	k	0.003	0.0001	0.006	0.0002	0.005	0.0002	0.008	0.0003
	RS	2501		2716		2634		2971	

* A: value (kg) of the asymptote if age advances infinity; ~ average weight at maturity;
b, k: Function variables; function descriptions are given in section 2.5
t: age in days
RS: residual sum of square

IV.3.4 Reproductive performance of does and destiny of offspring

The average age at first parturition was with 22.3 (SD 9.70) months not significantly different between females of type M and H farms (P>0.05). The number of goats that had their first kidding before the age of twelve months was more than twice as high on type M than on type H farms, but 7% of the does on farms M only had their first kidding at the age of >36 months (Figure IV.4a). The average kidding interval was with 12.1 (SD 5.98) months also not significantly different between the two farm types (P>0.05; Figure IV.4b). Of all pregnancies recorded across the two farm types (n=303), 4% were aborted, 1% were still births and in 3% the kids were born out on the mountain pastures and died as a consequence thereof. Ignoring the latter as well as the aborted pregnancies, 7.8% of the live parturitions (n=280) were twin births. No triple births were recorded. Prolificacy was therefore 1.03 (SD 0.183) kids per parturition for the primiparous goats and increased to 1.07 (SD 0.207) for the multiparous animals.

The frequencies of abortions and still births as well as the prolificacy rate were similar for both farm types and for the three focus villages (P>0.05). With 72% of offspring being born during November – February, the main kidding season was in winter. Males accounted for 48% of the kids born alive (n=280) and dead (n=3). Not considering the animals that were still at suckling age (<4 months) when the interviews were conducted, 12% of the male (n=110) and 9% of the female (n=144) offspring on both farm types had died due to injuries or diseases or were lost on mountain pastures. Since 77% of the deaths occurred before weaning (<4 months), kid mortality was 9% and 7% of all live born bucks and does. Accidents and births on pasture accounted for 19% of the animal losses and mortality was therefore higher in free-grazing than herded flocks.

While type M farmers slaughtered 15% and sold 34% of the male offspring, only 4% of the males born on farms H were sold and instead 29% of them were slaughtered. In contrast thereto, the female offspring of both farm types largely remained in the herds (81%) and only few animals were sold (11%) or slaughtered (3%). Average slaughter age was 26 (SD 10.3) and 19 (SD 6.8) months for the male and female goats, respectively, whereas the average selling age was 10 (SD 7.4) months for both sexes (P>0.05) and for both types of farms (P>0.05).

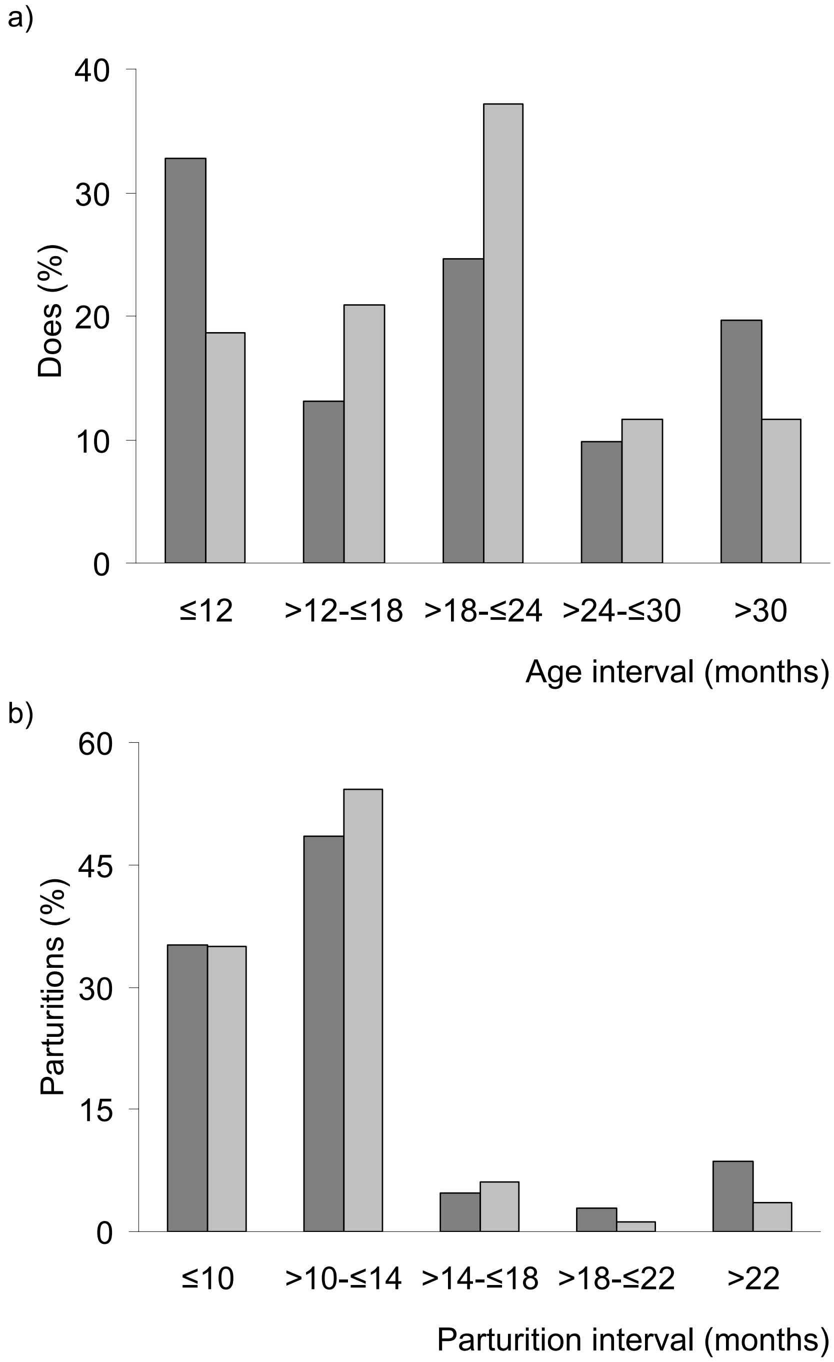

Figure IV.4. Age at first parturition (a) and parturition interval (b) of goats on farms M (dark grey) and H (light grey) as determined by progeny history interviews in villages on Al Jabal al Akhdar, Oman, in winter 2007/08. For definition of farm types see table IV.3.

IV.3.5 Scenario analyses

Due to the slightly better reproductive performance and the lower mortality of animals on type H farms compared to those on type M farms, potential herd expansion and offtake rates were higher for H farms (Table IV.5). At culling ages for males and surplus females of 10 and 12 months similar to the average age of male and female goats in the focus villages at sale (see previous chapter), annual monetary output for an average herd animal was 30 € and 31 € for type M and H farms, respectively. When culling age was set to 21 months on farms M and to 23 months on farms H, similar to the average age of offspring at slaughter, the respective annual output per average herd animal increased to 37 € (M) and 39 € (H).

Table IV.5. Production and output characteristics of traditionally managed goat herds in villages of Al Jabal al Akhdar, Oman, based on culling ages, growth and reproductive performance parameters determined in November 2006 – April 2008 and analyzed with the PRY herd model.

Parameter	Unit	Farm type M		Farm type H	
Cull-for-age threshold for breeding females	months	84	84	84	84
Culling age for surplus females and males	months	10	21	12	23
Breeding females	% of animals kept	67	51	58	43
Annual herd expansion rate	% of animals kept	22.3	22.3	29.3	29.3
Offtake rate	% of animals kept	38	28	40	29
Males	% of culls	61	61	59	59
Surplus females	% of culls	33	33	38	38
Output	€ per animal-year	30	37	31	39

For definition of farm types see table IV.3.

Annual herd expansion rates were higher for scenario 2 (38.6%) and scenario 3 (59.0%) than for scenario 1 (23.4%), which represents the traditional goat management system on Al Jabal al Akhdar. Consequently, the annual output per animal increased from 38 € for scenario 1 to 51 € and 66 € per animal for scenario 2 and scenario 3, respectively (Table IV.6). Output per animal and year was highest if culling ages for breeding females, males and surplus females were fixed at 46, 22 and 11 months for scenario 1, 34, 18 and 14 months for scenario 2 and 28, 28 and 7 months for scenario 3. The resulting annual output per animal was then estimated at 52 €, 70 € and 87 € for scenario 1, 2 and 3, respectively.

Table IV.6. Production and output characteristics of Jabal Akhdar goat herds raised under three different management scenarios* as determined by the PRY herd model for different culling ages of breeding females, males and surplus females.

Parameter	Unit	Scenario 1	Scenario 2	Scenario 3
Cull-for-age threshold for breeding females	months	84	84	84
Culling age for surplus females and males	months	22	18	28
Breeding females	% of animals kept	49	42	24
Annual herd expansion rate	% of animals kept	23.4	38.6	59.0
Offtake rate	% of animals kept	29	39	33
Males	% of culls	60	56	54
Surplus females	% of culls	34	39	42
Output	€ per animal-year	38	51	66

* For scenario descriptions, see table IV.1.

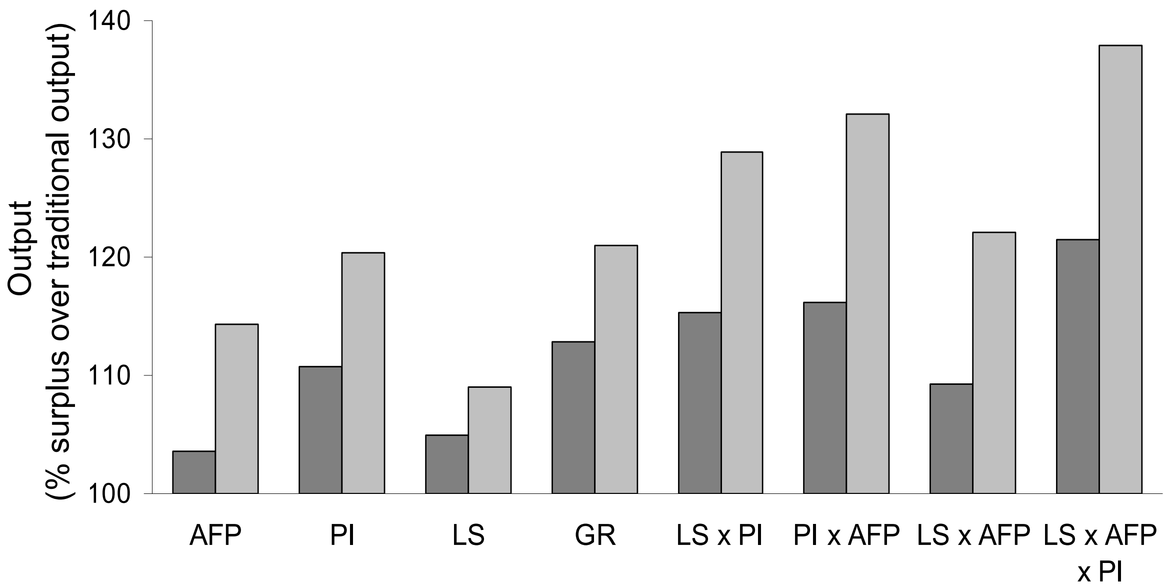

Figure IV.5. Relative increase in monetary output per animal and year for single or combined production parameters (AFP = age at first parturition, PI = parturition interval, LS = litter size, GR= growth rate) as modeled for scenario 2 (dark grey) and scenario 3 (light grey) in comparison to scenario 1 (100%). For scenario descriptions, see table IV.1.

At similar culling ages for growing males and surplus females, decreasing the parturition interval from 12 months (scenario 1) to 10 months (scenario 2) and 8 months (scenario 3) increased the annual output per animal by 11% and 20% (Figure IV.5). Similarly, improving only the growth rates of the goats increased animal output per year by 13% (scenario 2; males 55 g d^{-1}, females 31 g d^{-1}) and 21% (scenario 3; males 66 g d^{-1}, females 36 g d^{-1}) as compared to the present situation (scenario 1; males 49 g d^{-1}, females 24 g d^{-1}). Increasing the litter size and reducing the age at first parturition improved the annual output per animal by <15% for scenarios 2 and 3 as compared to scenario 1.

IV.4 Discussion

IV.4.1 Feed intake at the homestead

Given the low ME concentration of the natural pasture vegetation on Al Jabal al Akhdar, average feed intake on pasture barely covers animals' energy and nutrient requirements for maintenance and locomotion (Dickhoefer et al., 2009a). Since under the traditional management regime concentrate feeds largely account for the daily ME intake, growth and production of goats is mainly determined by their feed intake at the homestead. Measured total DM intake from dates and dried sardines amounted to 257 and 372 g DM $head^{-1}$ d^{-1} for goats on M and H type farms, respectively. Although these values are similar to the DM intake of concentrate feeds derived from the initial household survey (240 g and 330 g DM $head^{-1}$ d^{-1}), they are lower than those determined during feeding trials with goats in the same villages (Dickhoefer, 2006; Schlecht et al., 2008). In this study, energy intake of goats was 690 – 784 kJ ME $kg^{-0.75}$ W d^{-1}. Considering that these animals need about 637 kJ ME $kg^{-0.75}$ W d^{-1} for maintenance and locomotion (Dickhoefer et al., 2009a) and an additional 30 kJ ME for each gram of bodyweight gain (NRC, 1981), the ME intake determined for the traditional management would allow a weight gain of 23 - 78 g d^{-1} for goats of 30 - 40 kg bodyweight. This compares well to the actual weight gain of bucks observed in our study, but is higher than the growth rates obtained for female goats. Since animals in the study by Dickhoefer (2006) were fed individually in contrast to the group-feeding commonly practiced in the oases, these earlier results may overestimate the actual DM and ME intake of goats and especially of does at the homestead. Daily weight gain was particularly low in goats of Masayrat ar Ruwajah. The pastures of this oasis mainly comprise mountain valleys at about 1000 m a.s.l.. Although pasture plants of high nutritive value grow in these areas (Dickhoefer et al., 2009a), the amount of consumable biomass available to goats is low (Dickhoefer et al., 2009b). Thus, animals of this oasis particularly rely on the supplement feeding at the homestead.

IV.4.2 Growth rates

Non-linear regression functions are commonly applied to describe the weight development of growing animals. The asymptotic weight A offers a good opportunity to compare predicted values to actual weights of animals and therefore to evaluate goodness of fit of different models (Brown et al., 1976; Fitzhugh, 1976). Although it does not equal the maximum weight reached by an animal, it provides an estimate for the mean weight of animals at maturity (Brown et al., 1976). Average mature weight determined by the Brody model for traditionally managed bucks in our study (70.4 kg) was higher than estimates by the other three models (49.2 – 56.4 kg). Similarly, Brown et al. (1976) determined larger values for A with the Brody than with the Bertalanffy, Gompertz and Logistic model. However, while these models' estimates for the asymptotic weight of bucks in the focus villages were very low, the value estimated by the Brody model was similar to the maximum bodyweight of male goats recorded during the initial animal weighing (78 kg). The model therefore appears to well describe bodyweight gain of Jabal Akhdar bucks. In contrast thereto, asymptotic weight of traditionally managed does on Al Jabal al Akhdar was much lower than the highest bodyweight of non-pregnant does determined in the focus villages (48 kg). The asymptote value therefore appears to underestimate the average mature weight of does, although the Brody model reliably predicted their growth until the age of two years. Brown et al. (1970) found that growth models underestimate the asymptotic weight if weights at full maturity are not included in the dataset. This suggests that does in our focus villages had not yet reached their final bodyweight at the age of 750 days. Since fully grown bucks are normally 1.3 times heavier than mature does of the respective breed (Gall, 2001), final bodyweight of female Jabal Akhdar goats should average 50 - 55 kg.

Previous studies focused on the performance of the local Al Jabal al Akhdar goat and sheep breeds under feedlot conditions to evaluate their potential for commercial livestock husbandry. Al Shorepy et al. (2001) determined a daily weight gain of 207 g for the first and 97 g for the second and third month of age in purebred Omani rams, resulting in an average daily weight gain of 134 g d^{-1} until the age of three months. Al-Nakib et al. (1996) emphasized the high productivity of the local sheep breed under optimal feeding, and reported that at the age of six months, Jabal Akhdar goat kids were heavier than kids of the Batinah and Dhofari goat breeds. Maximum bodyweight of Jabal Akhdar bucks and does raised in the semi-intensive systems of Al Hailailat exceeded earlier reports for this breed raised under feedlot conditions (60 kg and 50 kg; Mahgoub et al., 2005) as well as the final bodyweight of other tropical goat breeds (Devendra and Burns, 1983).

This stresses the high production potential of the breed even if animals are grazing the low quality pasture vegetation during the day. However, early growth of traditionally managed goats in our three focus villages until a bodyweight of 15 kg, when animals were close to being weaned, was lower than pre-weaning weight gain of goats (92 – 144 g d^{-1}; Mahgoub et al., 2005) and sheep (weighted average 134 g d^{-1} in the first three months; Al-Shorepy, 2001) of the same breeds raised under feedlot conditions. After weaning, daily weight gain of female kids decreased rapidly to 47 g and 49 g d^{-1} in doe kids of >15 – 30 kg bodyweight on type M and H farms. This was only 58% of the weight gain of stable-fed female kids after weaning (83 g d^{-1}; Mahgoub et al., 2005). At 13 g d^{-1} (farms M) and 16 g d^{-1} (farms H), the traditionally managed does of >30 – 40 kg bodyweight grew even slower than respective animals in the semi-intensive pastoral systems of Al Hailailat (30 g d^{-1}). Thus, female goats in our focus villages only weighed 19.5 kg at 180 days of age, which is 5 kg less than the weight of Jabal Akhdar goats kept under feedlot conditions (Al-Nakib et al., 1996). While average weight determined by the Brody model for does at the age of 730 days was only 60% of the maximum female bodyweight recorded in our focus villages, tropical goat breeds raised under adequate feeding conditions normally reach at least 80% of their final bodyweight at the age of two years (Gall, 2001). Moreover, asymptotic weights determined by the Brody model and maximum bodyweight recorded for female goats in the focus villages were lower in traditionally managed does than in female goats raised in the semi-intensive system of Al Hailailat, whereas for bucks both values were similar to results obtained in Al Hailailat. Results therefore indicate that in the traditional husbandry systems of our focus villages male goats are offered more supplement feeds than female goats and that the latter are therefore not able to compensate for the growth retardation at young age with advancing maturity.

IV.4.3 Reproductive performance

In contrast to long-term studies where selected animals and their offspring are monitored, data collection through the progeny history interview technique relies on the remembrance of livestock keepers of the destiny and reproduction of offspring born in their herd. In our study, not all farmers were able to recall the needed information, so that only data of selected livestock herds could be used. The interviewed women often did not remember the exact month when an animal was born, slaughtered, sold or when it died. Nevertheless, the use of approximate dates for the seasons of the year yielded good estimates of the age at first parturition and the length of kidding intervals in goat herds on Al Jabal al Akhdar.

Although livestock keepers mentioned the occurrence of several diseases as well as of external and internal parasites, overall mortality rates for male (12%) and female goats (9%) were lower than values reported for grazing sheep (Mukasa-Mugerwa and Lahlou-Kassi, 1995) and goats (Berhane and Eik, 2006) in the highlands of Ethiopia, and lower than average mortality rates in Omani goat husbandry systems reported in literature (Zaibet et al., 2004). Nevertheless, since kid mortality can severely limit herd productivity in extensive pastoral systems of semi-arid and arid environments (García and Gall, 1981; Devendra and Burns, 1983) and overall mortality was higher in free-grazing than herded flocks, an improved care for young stock as well as herding of goats during grazing might contribute to an increased production of traditional goat herds on Al Jabal al Akhdar.

Age at first parturition of goats in our focus villages of 22.3 months was much higher than of Begait and Abergelle goats grazing the Ethiopian highlands (12 – 14 months; Berhane and Eik, 2006) and most other tropical goat breeds (García and Gall, 1981; Devendra and Burns, 1983). And while the average kidding interval of 12.1 months was longer than that of various local goat breeds in the dry tropics (García and Gall, 1981), prolificacy rate of goats on Al Jabal al Akhdar was below the average litter size of 1.3 kids per parturition determined in Jabal Akhdar does kept under feedlot conditions (Al-Nakib et al., 1996). The slow growth of the traditionally managed doe kids on Al Jabal al Akhdar (see previous section) appears to delay puberty and therefore results in a high age at first parturition. Since 71.5% of the offspring were born in the winter months, the pronounced seasonality in breeding of traditionally managed Jabal Akhdar goats in the summer contributed to their prolonged kidding intervals and consequently low number of parturitions per year and doe. Seasonal breeding has also been observed in local goat and sheep breeds in Spain (Zarazaga et al., 2005 and 2009) and Ethiopia (Mukasa-Mugerwa and Lahlou-Kassi, 1995; Berhane and Eik, 2006) at latitudes similar to our study location. Distinct breeding seasons of grazing small ruminants in the Tropics and Subtropics were often ascribed to the seasonal fluctuations in quantity and quality of rangeland vegetation (Berhane and Eik, 2006). And although seasonal reproduction patterns persisted under improved feed availability, feeding the animals above their maintenance requirements shortened seasonal anoestrus in does and increased sexual activity of bucks of the Payoya goat breed in Spain (Zarazaga et al., 2005 and 2009). Moreover, ovulation and pregnancy rates were higher in grazing Mexican does receiving additional supplement feeding as compared to unsupplemented does (Fitz-Rodríguez et al., 2009). Since fodder quantity and quality on mountain pastures of Al Jabal al

Akhdar decrease in the cold and dry season (December – February; Dickhoefer et al., 2009 a, b), an increased feeding of goats at the homestead during this time might increase their sexual activity in the winter months and enhance frequency of summer parturitions, thereby reducing kidding intervals.

Type H farmers offered almost twice as much supplement feed to their animals at the homestead than type M farmers. However, feeding practices of individual farmers within each group strongly varied resulting in high standard deviations and thus explaining why nevertheless, no significant differences in LWG and reproductive performance were determined. Moreover, management practices other than supplement feeding might have influenced the animals' performance, such as health care, hygiene, grazing practices leading to a higher nutrient and energy intake of goats at pasture, or the breeding management. Since type H herds were smaller than type M herds, the level of inbreeding might have been higher in these herds, limiting the performance of goats. Taken together, these factors might explain the limited effect of homestead feeding on LWG and reproductive performance in our study.

IV.4.4 Scenario analyses and management implications

Reproductive performance is a key factor determining the productivity of livestock herds, in particular if meat is the main product (Naudé and Hofmeyr, 1981). Analyzing the reproductive performance and growth of goats in our focus villages with the herd model PRY predicted an annual monetary output of 37 € and 39 € per animal for farm types M and H at the current prices for Jabal Akhdar goats on the local markets. Considering the average number of goats in both farms of 34 (M) and 15 (H), the annual output from goat husbandry would amount to 1292 € for farms M and 570 € for farms H. This is similar to the total monetary value of home consumption and sales (about 350 – 500 OMR) determined during household interviews by Zaibet et al. (2004) for goat herds of similar sizes on Al Jabal al Akhdar. Despite the goats' low performance these values are higher than the revenues from pastoral goat systems in Lebanon (8.7 – 11.4 US\$ head^{-1}, approximately 10 – 13 € head^{-1} in 2001; Hamadeh et al., 2001). The results suggest that the high market prices for Jabal Akhdar goats largely account for the high revenue from traditional goat husbandry in the mountain villages. By improving growth rates and reproductive performance of goats, the annual monetary output per animal could be increased from presently 38 € a^{-1} (scenario 1) to 51 € a^{-1} (scenario 2) and 66 € a^{-1} (scenario 3) through increased herd expansion and offtake rates and an improved feeding and reduced locomotion.

The production parameters used for the improved management scenarios were determined in Jabal Akhdar goats of Al Hailailat, where more concentrate feeds are offered in addition to grazing (scenario 2), or were taken from literature for goats of the same or similar tropical breeds raised under intensive management (scenario 3). The simulated herd performance and output values described in scenarios 2 and 3 with improved supplement feeding of Jabal Akhdar goats thus seem realistic. The highest monetary output per animal in scenario 3 suggests a more intensive supplement feeding of goats in combination with a reduced or no access to pasture to obtain maximum herd production, which has previously been recommended to improve goat husbandry on Al Jabal al Akhdar (Zaibet et al., 2004). However, farmers of type M and H only offer 394 g d^{-1} and 600 g d^{-1} of supplement feeds (DM) at the homestead, equivalent to an annual 144 kg and 219 kg DM $animal^{-1}$. At annual monetary outputs of type M farms (37 € $animal^{-1}$) and type H farms (39 € $animal^{-1}$), use efficiencies for supplement feeds of 0.26 € and 0.18 € kg^{-1} DM intake can thus be calculated. Tropical goats of 30 kg bodyweight raised under feedlot conditions and growing at 50 g d^{-1} require 690 g DM d^{-1} at dietary ME concentrations of 10 MJ kg^{-1} DM (NRC, 1981), equivalent to 252 kg DM a^{-1}. Pregnant does of 40 kg bodyweight raised under similar conditions need 1260 g DM d^{-1} (NRC, 1981), equivalent to 460 kg DM a^{-1}. Since breeding females account for 24% of the herd in scenario 3 and growing males and females of <28 months (culling age) constitute 76% of the herd, the weighted average feed requirement for one herd animal would be 302 kg DM a^{-1}. At an annual output of 66 € per animal in scenario 3, the feed use efficiency for this modeled zero-grazing system would therefore approximate 0.22 € kg^{-1} DM. While this is higher than the value calculated for goats on type H farms, use efficiency of supplement feeds appears to be highest in goats on type M farms that offer little supplements at the homestead. This underlines the high importance of the natural pasture vegetation for the profitability of the traditional goat husbandry system. Nevertheless, annual output per animal was higher in scenario 2 (semi-intensive supplementation and grazing) than in scenario 1 (little supplementation and grazing). Dickhoefer et al. (2009b) determined a reduction in intake of pasture vegetation from 71% to 46% - 65% of total intake in goats that were ingesting 44 – 51 g DM $kg^{-0.75}$ W d^{-1} of improved supplement rations at the homestead. In scenario 2, breeding females (of about 40 kg bodyweight) accounted for 42% and growing males and surplus females (of about 20 kg bodyweight) for 58% of the herds at culling ages for males and surplus females of 18 months. Applying these model rations, DM intake of an average herd animal would be 540 g – 630 g DM d^{-1} and 200 – 230 kg DM a^{-1}. Considering the annual output of 51 € $animal^{-1}$ determined for scenario 2, the feed use efficiency for such a ration would be 0.22 – 0.26 € kg^{-1} DM intake.

This feed use efficiency is similar to the one calculated for the traditional management and higher than the value calculated for the zero-grazing scenario; it points to the potential of improving the local goat production system by increasing growth and reproduction rates through an adapted feeding in addition to grazing. The introduction of individual feeding instead of the currently practiced group feeding would allow a nutrient and energy supply to goats according to their specific requirements, which is necessary to achieve improved growth and reproduction rates.

IV.5 Conclusions

The current homestead feeding of Jabal Akhdar goats, especially of young does, appears to be insufficient to balance the limited nutrient and energy supply of the vegetation ingested on mountain pastures and to meet the animals' requirements for substantial growth and reproduction. The resulting prolonged kidding intervals and low post-weaning weight gains of does reduce farmers' annual revenues from the sale or slaughter of goats. An early culling of females that show extended kidding intervals and a late onset of puberty along with the selection for highly productive does would enable farmers to better exploit the breed's potential and to thereby improve herd production. Scenario analyses indicate that the annual output per animal is increased substantially if farmers adopt a zero-grazing management. However, since goats' feed intake on pasture is high, the use efficiency of the (purchased) supplementary feeds offered to goats at the homestead is highest under the traditional goat management system. An increased homestead feeding of individual goats in addition to the traditional grazing might be a valuable alternative to the introduction of high-input zero-grazing systems. It would allow farmers to further use the natural fodder resources on pastures, while remaining rather independent from the purchase of feedstuffs.

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V Adjusting homestead feeding to the requirements and nutrient intake of grazing goats on semi-arid highland pastures

Abstract

Continuous livestock grazing can largely deplete the natural fodder resources in semi-arid subtropical highlands and together with the low nutritional quality of the pasture vegetation limits growth and production of grazing livestock. To determine goats' feed intake on pasture in response to supplementary feeding at the homestead, different rations of locally available feedstuffs were tested during two feeding trials on Al Jabal al Akhdar in Oman. Feed intake of goats was determined using titanium dioxide as external fecal marker, and overall diet digestibility was derived from the fecal nitrogen concentration. The nutritional quality of selected fodder plants on pasture was analyzed to estimate the animals' nutrient and energy intake during grazing.

The pasture vegetation accounted for 46% - 65% of the goats' total OM intake (87 - 107 g $kg^{-0.75}$ W), underlining the importance this fodder resource for the husbandry system. However, metabolizable energy (7.2 MJ kg^{-1} OM) and phosphorus concentrations (1.4 g P kg^{-1} OM) in the consumed pasture plants were low. Offering nutrient and energy-rich by-products of the national fishery and date palm cultivation to grazing goats at the homestead increased their daily OM intake (r^2=0.36; P=0.005) by balancing these nutritional deficiencies and enabled them to cover their requirements for growth and production. While OM intake during grazing was highest in animals fed a concentrate-based diet (P=0.003), the daily intake of 21 g OM $kg^{-0.75}$ W of cultivated green fodder reduced animals' feed intake on pasture (r^2=0.44, P=0.001). Adjusting homestead supplementation with locally available feedstuffs to the requirements of individual goats and to the nutritional quality of the pasture vegetation improves the animals' performance and eases the grazing pressure exerted on the natural vegetation. This management strategy is therefore a valuable alternative to intensive livestock feeding in zero-grazing systems and can contribute to a sustainable livestock production in ecologically fragile semi-arid mountain regions.

V.1 Introduction

In the semi-arid and arid subtropical highlands, traditional livestock husbandry strongly relies on the feed intake from natural rangelands and in particular small ruminants are able to efficiently exploit these resources (Papachristou et al., 2005). Although annual biomass yields of the ligneous and herbaceous vegetation of such pastures can be as high as 41 t DM ha^{-1} (Dickhoefer et al., 2009), continuous grazing has largely depleted the natural fodder resources in many regions such as the highlands of Oman (Dickhoefer et al., 2009), the central mountains in Yemen (Kessler, 1995) or the Middle Awash Valley in Ethiopia (Abule et al., 2005). Additionally, low concentrations of energy and macro- and micronutrients of most pasture plants and seasonal changes in the biomass yields and in the nutritional quality of the rangeland vegetation can strongly limit growth and production of grazing animals (Ramírez et al., 2006; Dickhoefer et al., 2009). Hence, the low digestibility of the pasture vegetation limited feed intake of goats in Brazil (Kawas et al., 1999), whereas pubertal age and lamb mortality in sheep grazing the Ethiopian highlands declined when they were supplemented with concentrate feeds (Mukasa-Mugerwa and Lahlou-Kassi, 1995).

Nutrient and energy requirements of goats grazing semi-arid highland pastures are often high, because they may walk long distances searching for fodder (Lachica and Aguilera, 2005; Schlecht et al., 2009). The optimum supply of additional energy and nutrients according to animals' requirements and the quality of the fodder plants on pasture can therefore substantially improve animal production (Ben Salem and Smith, 2008). Zaibet et al. (2004) reported higher revenues from goat husbandry on Al Jabal al Akhdar in Northern Oman with an increased supplementation of the animals and recommended the feeding of purchased, energy-rich feedstuffs combined with the conversion of the current grazing systems to zero-grazing systems. While Al Jabal al Akhdar farmers traditionally cultivate green fodder for their livestock to compensate for the low nutrient and energy intake on pasture (Schlecht et al., 2008), they appear to use purchased feeds rather inefficiently (Zaibet et al., 2004). Moreover, symptoms of mineral deficiencies in goats on Al Jabal al Akhdar were reported by farmers or have been observed during earlier studies (Dickhoefer, 2006).

The present study therefore aimed to exploit whether a strategic supplement feeding with locally available feedstuffs improves the nutritional situation of grazing goats on Al Jabal al Akhdar and similar semi-arid subtropical highlands. Furthermore, it investigated if and how different rations offered at the homestead affect goats' feed intake during grazing in order to maintain pasture yields and to assure a sustainable livestock husbandry in the future.

V.2 Materials and methods

V.2.1 Study location

In the central Al Jabal al Akhdar region of the Al Hajar range in Northern Oman, the deeply dissected limestone mountains reach elevations of about 3000 m a.s.l. (Ghanzafar, 1991). Mean annual rainfall of 318 mm measured at 1900 m a.s.l. is substantially higher than in most of the country’s lowlands, where precipitation is less than 100 mm per year (Fisher, 1994). Most of this rainfall occurs in February – March as well as in July – September, when mean monthly temperatures reach 25°C (warm, rainy months). In contrast thereto, probability of rainfall and mean temperatures decrease in November - January (cold, dry months; Department of Civil Aviation and Meteorology).

The traditional oasis agriculture in the villages near Sayh Qatanah (57°40’35’’E; 23°40’51’’N, 2050 m a.s.l., Figure III.1), the main settlement on Al Jabal al Akhdar, combines irrigated terrace agriculture with livestock husbandry. The date palm (*Phoenix dactylifera* L.) is an important perennial crop cultivated in the gardens below 1500 m a.s.l. and is replaced by the pomegranate (*Punica granatum* L.) in villages at higher altitudes. Several fodder plants for animals such as maize (*Zea mays* L.), barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.), alfalfa (*Medicago sativa* L.) and sorghum (*Sorghum bicolor* (L.) Moench) are often grown under the cover of these trees and are fed to farmers’ livestock.

Goats (*Caprus hircus*) of the local Jabal Akhdar breed are the most numerous species kept to provide meat, milk and manure, which is used as a fertilizer in crop cultivation. The animals stay in the barn over night, where farmers offer supplement feeds such as dates, dried sardines, cultivated green fodder or collected tree foliage. In the morning, goats are taken out to the mountain pastures, partly being herded until the late afternoon or left to graze on their own, thereby covering distances of 12 - 20 km each day (Schlecht et al., 2009). The natural vegetation on Al Jabal al Akhdar is characterized by open shrublands. Pastures of villages at 2000 m a.s.l. mainly comprise plateau areas with trees and shrubs such as *Sideroxylon mascatense*[1], *Olea europaea* ssp. *cuspidata* and *Dodonaea viscosa* (Dickhoefer et al., 2009). *Acacia gerrardii*, *Grewia erythraea* and *Sageretia thea* are abundant browse species on the mountain slopes and in the shallow gullies (Arabic: wadis) and are replaced by *Ziziphus spina-christi,*

[1] Authorities for names of pasture plants are given in footnote of table V.2.

Capparis spinosa and *Pteropyrum scoparium* in the valleys below 1350 m a.s.l. (Schlecht et al., 2009; Dickhoefer et al., 2009). Ligneous biomass on the slopes and valleys is high, reaching 41 t DM ha^{-1}, and goats of oases at lower altitude grazing these areas spend most of their feeding time browsing the ligneous foliage (Schlecht et al., 2009; Dickhoefer et al., 2009). In contrast thereto, tree and shrub density is lower on the plateau areas and animals grazing these pastures spend more time feeding on the herbaceous vegetation. Stocking densities on pastures are very high in the vicinity of settlements (Figure III.1, page 26) and as a consequence of the year-round grazing by goats, sheep and feral donkeys, the natural vegetation shows clear signs of overgrazing, impalatable plant species are abundant and yields of edible biomass are strongly reduced (Schlecht et al., 2009; Dickhoefer et al., 2009). Our study was conducted in the oasis Qasha' at 1700 m a.s.l. (57°39'50''E, 23°04'00''N), where the village herd of 123 goats (Ministry of Agriculture and Fisheries, 2001) grazes the natural vegetation within an area of 11 km^2 on the surrounding mountain slopes and valleys (Dickhoefer et al., 2009).

V.2.2 Determination of the quality of the pasture vegetation

To determine the nutritional quality of the selected fodder plants identified by Schlecht et al. (2009) and Dickhoefer et al. (2009), samples of ligneous (n=17), dicotyledonous (n=7) and monocotyledonous (n=9) herbaceous species were collected on the grazed plateau, the mountain slopes and valleys near Sayh Qatanah in August – September 2006. The samples (ca. 50 g fresh weight) were weighed, air-dried, weighed again, ground to pass a 1 mm mesh and analyzed for dry matter (DM), organic matter (OM), digestible organic matter (DOM), neutral detergent fiber determined in OM (NDF), acid detergent fiber (ADF), metabolizable energy (ME), nitrogen (N), phosphorus (P), potassium (K) and sodium (Na) concentrations following standard procedures (Close and Menke, 1986; Van Soest et al., 1991; Naumann et al., 2004). To determine the seasonal changes in the N, P, calcium (Ca) and magnesium (Mg) concentrations of important browse species, one individual each of the ten most abundant ligneous species on the plateau, the mountain slopes and in the valleys was selected and marked. Samples of the leaves and twigs <2 mm at browsing height were taken every three months from May 2007 - April 2008 and were analyzed separately for DM, OM, N, P, Ca and Mg concentrations following standard procedures (Naumann et al., 2004).

V.2.3 Determination of feed intake

To determine the feed intake of goats during grazing in response to different rations offered at the homestead, two feeding experiments involving the fecal marker TiO_2 were conducted in Qasha' in October 2006 and February 2008, each time after four weeks with less than a total of 5 mm of rainfall. During both experiments, two rations very similar in ME and crude protein concentration were offered to six male goats each, covering the animals' requirements for maintenance, activity and a daily gain of 50 g bodyweight. To calculate the amounts of feed to be offered at the homestead, a daily OM intake of 90 g per metabolic bodyweight ($kg^{-0.75}$ W) per animal was assumed as well as a minimum OM intake on pasture of 10% and 30% of total OM intake for the first and second experiment, respectively. In October 2006, six animals were offered the roughage-based ration R1 (on OM basis: 18% dates; 2% dried sardines; 70% pre-bloom maize plants) and six animals the concentrate-rich ration C1 (on OM basis: 40% dates; 4% dried sardines; 45% pre-bloom maize plants). In February 2008, one group of goats was fed ration C2 with 53% dates, 7% dried sardines and 10% Rhodes grass hay (on OM basis), whereas the second group (R2) received 36% dates, 4% dried sardines and 30% green pre-bloom oat (on OM basis). While dates and dried sardines were fed in two portions at 6:30 a.m. and 4:30 p.m. before and after grazing on pasture, green fodder and Rhodes grass hay were only offered during the evening feeding (Table V.1).

The quantity of feed ingested by each individual animal was recorded during a 9d adaptation and a 7d experimental period in the first and an 18d adaptation and a 7d experimental period in the second feeding trial. To determine the average weight of animals and to calculate individual feed rations, goats were weighed before the experiment and in the beginning and at the end of the experimental period using a tri-pod-based suspension balance (range 0 – 100 kg, accuracy 500 g). Using a bolus gun, gelatine capsules containing 3 ± 0.05 g TiO_2 were administered daily at the evening feeding starting 5 days prior to each experimental period. During the latter, the total amount of feces excreted over night was collected in a cotton bag fitted to each goat at evening feeding. The following morning, the collected feces were weighed, homogenized and a representative sample of approximately 100 g fresh matter (FM) taken from each animal and deep-frozen. At the end of the experimental period, samples were pooled into three fecal samples per animal and stored frozen until the analyses of fecal DM and N concentrations according to Naumann et al. (2004). The TiO_2 concentration in the feces was determined according to Wang et al. (2009). One composite fecal sample per animal was air-dried, ground to pass a 1 mm mesh and analyzed for OM and P concentrations (Naumann et al., 2004). Samples of the feeds offered and refused were taken, weighed, air-dried and weighed again to determine air-dry weight. Subsequently, three composite samples of each feed type were ground to pass a 1 mm mesh and analyzed for DM, OM, DOM, NDF, ADF, N, P and ME following standard procedures (Close and Menke, 1986; Naumann et al., 2004).

Table V.1. Daily rations offered to goats of two feeding groups each (Roughage = R; Concentrate = C) during two feeding trials on Al Jabal al Akhdar, Oman, in October 2006 (1) and February 2008 (2).

	Animals	Live weight (kg)	Dates	Dried sardines	Cultivated roughage*
Group	n	Mean ± SD	g OM kg$^{-0.75}$ W		
C1	5	37 ± 7.7	36	4	41
R1	5	34 ± 7.0	12	2	68
C2	5	36 ± 13.4	48	6	9
R2	5	31 ± 11.3	32	4	27

* Roughage consisted of pre-bloom maize in R1 and C1, of pre-bloom oat in R2 and of Rhodes grass hay in C2

The total fecal excretion was calculated from the administered amount of TiO_2, the TiO_2 concentration in fecal OM (Lippke, 2002) and the recovery rate of TiO_2 for ruminants of 0.93 (Titgemeyer et al., 2001). The fecal crude protein (CP = N*6.25) concentration was used to estimate overall diet digestibility (Lukas et al., 2005) and based on total fecal excretion and overall diet digestibility, total OM intake was then calculated according to Gordon (1995). OM intake on pasture was calculated as the difference between total OM intake and the measured OM intake at the homestead. Total ME, CP and P intake of animals and ME, CP and P intake of goats on pasture was derived from their OM intake during grazing multiplied by the average nutrient and energy concentration of the pasture vegetation. Metabolizable energy concentrations similar to dark fish meal (Close and Menke, 1986) were assumed for the dried sardines offered.

V.2.4 Statistical analysis

Means and standard deviations of the DM, OM, NDF, ADF, nutrient, mineral and energy concentrations and of the OM, nutrient and energy intake were calculated for the different plant groups and for goats of the four treatments, respectively. Statistical analyses were carried out using SPSS 12.0 for Windows XP (SPSS Inc., Chicago, USA). Data were analyzed for significant differences between treatments, applying the independent t-test for normally distributed and the Mann-Whitney U-Test for not normally distributed sample sets (Zöfel, 1988). Linear and logarithmic regressions between the metabolic bodyweight, the intake of concentrate and of roughage feed at the homestead (independent variables) and the total OM intake as well as the OM intake of goats at pasture (dependent variables) were tested for significant correlations between these variables. For each treatment group, data of one animal had to be omitted from the calculations, because they did not return from pasture (n=1), fell sick (n=1) or refused their rations (n=2) during the experiments.

V.3 Results

V.3.1 Quality of the pasture vegetation

The nutritional quality of the plant species collected on the mountain pastures of Al Jabal al Akhdar varied between different plant groups, species growing at different locations and between seasons. NDF and ADF concentrations (g kg^{-1} OM) ranged between 272 – 769 g and 264 – 559 g, respectively, and were lowest in the foliage of the ligneous species (Table V.2). While ADF concentrations were similar in species of all plant groups, NDF concentrations were highest in the grass species (727 ± 59.2 g). Within the NDF fraction, the proportion of hemicellulose was 0.38 ± 0.036 in the latter group, whereas it was 0.19 ± 0.120 in the foliage of the trees and shrubs sampled. The ME concentration in OM ranged from 4.1 – 11.0 MJ kg^{-1} across all plant groups, and N, P, K and Na concentrations (g kg^{-1} OM) were between 8 – 35 g N, 0.5 – 3.4 g P, 3 – 28 g K and 0.04 – 10.22 g Na. While average ME and Na concentrations were similar across all plant groups, N, K and P concentrations were lower in grasses than in ligneous browse and in dicotyledonous herbaceous species (Figure V.1).

Table V.2. Dry matter (DM), organic matter (OM), digestible organic matter (DOM), neutral detergent fiber (NDF), acid detergent fiber (ADF) and metabolizable energy (ME) concentrations of samples of ligneous and herbaceous plants collected on the mountain pastures on Al Jabal al Akhdar in autumn 2006 (means ± one standard deviation).

Plant group*	n	DM	OM	DOM	NDF	ADF	ME
		g kg^{-1} FM**	g kg^{-1} DM	g kg^{-1} OM			MJ kg^{-1} OM
Ligneous species	17	462 ± 127.1	924 ± 26.5	490 ± 117.2	464 ± 122.0	392 ± 87.5	7.0 ± 2.06
Dicotyledonous herbaceous species	7	424 ± 101.9	891 ± 43.9	527 ± 157.8	485 ± 116.4	388 ± 104.7	7.6 ± 2.77
Grasses	8	540 ± 120.0	915 ± 12.8	505 ± 66.6	727 ± 59.2	442 ± 56.1	7.3 ± 1.14

* Ligneous: *Acacia gerrardii* Benth., *Capparis spinosa* L., *Ecbolium viride* (Forssk.) Alston, *Ehretia obtusifolia* Hochst. ex DC., *Dodonaea viscosa* (L.) Jacq., *Grewia villosa* Willd., *G. erythraea* (Schweinf.), *Maerua crassifolia* Forssk., *Moringa peregrina* (Forssk.) Fiori, *Ochradenus arabicus* (Chaudhary, Hillcoat & Miller), *Olea europaea* L. ssp. *cuspidata* (Wall. ex G. Don) Ciferri, *Phoenix dactylifera* L., *Pteropyrum scoparium* Jaub. & Spach., *Sageretia thea* (Osb.) M.C. Johnst, *Sideroxylon mascatense* (A.DC.) Penn., *Ziziphus hajarensis* Duling, Ghaz. & Prendergast; *Z. spina-christi* (L.) Desf.; Dicotyledonous herbaceous: *Helianthemum lippii* (L.) Dum.-Cours., *Lantana petitiana* A. Rhich., *Lavendula subnuda* Benth., *Pergularia tomentosa* L., *Salvia aegyptiaca* L., *Taverniera glabra* Boiss; *Teucrium mascatense* (Boiss.); Grasses: *Chrysopogon plumulosus* (Hochst.), *Cymbopogon schoenanthus* (L.) Spreng., *Cyperus rubicundus* Vahl, *Eragrostis barrelieri* Daveau, *Fingerhutia africana* Lehm., *Heteropogon contortus* (L.) Roem. & Schultes, *Juncus rigidus* Desf.; *Saccharum spontaneum* L.

** FM: Fresh matter

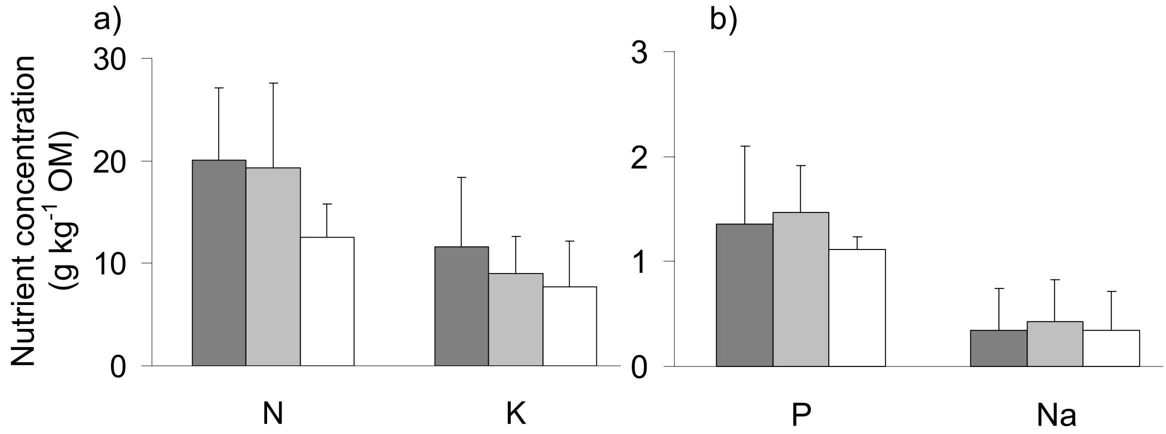

Figure V.1. Nitrogen (N) and potassium (K) concentrations (a) and phosphorus (P) and sodium (Na) concentrations (b) in samples of ligneous foliage (dark grey), dicotyledonous herbaceous species (light grey) and grasses (white) collected on the mountain pastures on Al Jabal al Akhdar, Oman, in autumn 2006. Bars indicate one standard deviation. For plant names of the three groups see footnote of table V.2.

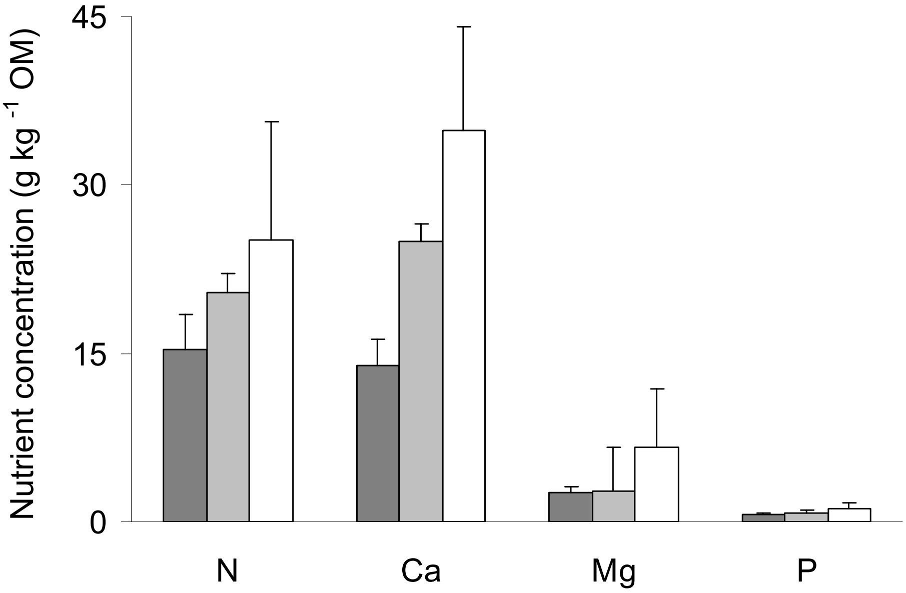

Figure V.2. Average nitrogen (N), calcium (Ca), magnesium (Mg) and phosphorus (P) concentrations of the foliage of the most abundant ligneous browse species growing on the plateau (dark grey), the mountain slopes (light grey) and in the valleys (white) on Al Jabal al Akhdar, Oman, collected every three months during August 2006 – April 2008. Plateau: *Dodonaea viscosa* (L.), *Olea europaea* L. ssp. *cuspidata* (Wall. ex G. Don) Ciferri and *Sideroxylon mascatense* (A.DC.) Penn.; Slopes: *Acacia gerrardii* Benth., *Sageretia thea* (Osb.) M.C. Johnst and *Grewia erythraea* (Schweinf.); Valleys: *Capparis spinosa* L., *Pteropyrum scoparium* Jaub. & Spach., *Ziziphus* hajarensis Duling, Ghaz. & Prendergast and *Z. spina-christi* (L.) Desf..

The average nutrient and mineral concentrations determined every three months in the foliage of the most abundant browse species was higher in the trees and shrubs growing on the mountain slopes and in the valleys than in species characterizing the vegetation on the plateau areas at 2000 m a.s.l. (Figure V.2). While N and P concentrations (g kg^{-1} OM) were high in the leaves of the tree species *Acacia gerrardii* (29 ± 4.0 g N; 1.5 ± 0.58 g P) and *Ziziphus spina-christi* (23 ± 3.1 g N; 1.6 ± 0.28 g P) growing on the mountain slopes and in the valleys, Ca concentrations (g kg^{-1} OM) were 14 ± 2.4 g, 25 ± 1.5 g and 35 ± 9.2 g in the browse foliage on the plateau, the slopes and the valleys, respectively. Similarly, average Mg concentrations (g kg^{-1} OM) were more than twice as high in the foliage of trees and shrubs growing in the valleys (7 ± 4.0 g) than of those found on the plateau (2.6 ± 0.5 g) and the slopes (2.7 ± 0.9 g), reaching up to 11 ± 1.2 g in *Capparis spinosa*, a small shrub found on the mountain slopes. Due to the low P concentrations, Ca/P-ratios varied between 17 – 37 and even reached 67 ± 7.6 in leaves of *Pteropyrum scoparium,* an abundant shrub in valleys at 1000 m a.s.l., for which Ca concentrations of 46 ± 2.1 g kg^{-1} OM were determined.

Nutrient and mineral concentrations differed between seasons: after several rainfall events, the N concentration in the foliage of seven out of the sampled ten ligneous species was higher in May and September 2007 than in February 2008, when temperatures were low and in April 2008, after five months with less than a total of 5 mm of rainfall. In contrast thereto, the Ca concentration and the Ca/P-ratios in the ligneous foliage of five species increased in the cold dry season as compared to the warm rainy season.

V.3.2 Feed intake of goats

Based on the fecal CP concentration (average 26.8 ± 2.83 g N kg^{-1} OM), the OM digestibility of the entire diet was determined at 0.679 – 0.749 and was significantly lower in group R2 (0.691 ± 0.0036) than in group C1 (0.729 ± 0.0211; P=0.009). Since goats of the different feeding groups excreted between 9 - 18 g DM kg^{-1} W of feces per day (P=0.114; Table V.3), their total daily OM intake was determined at 87 - 107 g $kg^{-0.75}$ W d^{-1}, whereby intake was significantly higher in group C2 than in group R1 (P=0.030; Figure V.3). Dates accounted for a fraction of 0.14 ± 0.008, 0.27 ± 0.006, 0.24 ± 0.017 and 0.32 ± 0.021 of the total OM intake of goats of group R1, C1, R2 and C2, respectively, whereas 1.1 – 4.8 g OM $kg^{-0.75}$ W d^{-1} of dried sardines were eaten by the goats, with highest intakes recorded for group C2 (P=0.001). In contrast thereto, intake of roughage (g OM $kg^{-0.75}$ W d^{-1})

was much lower in animals of this group (5 ± 1.5 g) than in goats fed ration R2 (21 ± 3.2 g), C1 (17 ± 3.0 g) and R1 (27 ± 3.2 g; P=0.001; Figure V.4). Although animals of group C1 and R1 only consumed a fraction of 0.63 ± 0.130 of the total amount of pre-bloom maize offered, the difference in the green fodder intake was significant between both groups (P=0.002).

Table V.3. Fecal concentration of dry matter (DM), organic matter (OM), nitrogen (N), phosphorus (P), and titanium dioxide (TiO_2) and daily fecal excretion of goats fed roughage-based (R) and concentrate-rich (C) diets during two feeding trials conducted on Al Jabal al Akhdar, Oman, in October 2006 (1) and February 2008 (2) (means ± one standard deviation).

	Feces quality					Fecal excretion
	DM	OM	N	P	TiO_2	
Group	g kg^{-1} FM*	g kg^{-1} DM	g kg^{-1} OM			g DM kg^{-1} W d^{-1}
R1	437 ± 31.3	841 ± 15.1	27 ± 3.8	3.9 ± 0.35	7.2 ± 0.84	14.0 ± 2.00
C1	443 ± 49.3	850 ± 8.2	29 ± 3.1	4.1 ± 0.71	7.3 ± 0.64	12.5 ± 2.08
R2	500 ± 45.8	835 ± 18.2	25 ± 1.6	2.8 ± 0.20	7.7 ± 2.46	15.2 ± 1.68
C2	494 ± 76.5	849 ± 16.7	26 ± 1.6	4.4 ± 0.93	6.9 ± 1.63	14.6 ± 1.93

* FM: fresh matter; W: weight

OM intake of goats on pasture accounted for 46% - 65% of the total OM intake and was higher in heavier animals (r^2=0.14; P=0.100). While daily OM intake on pasture (g $kg^{-0.75}$ W) was similar for groups R1 (52 ± 6.8 g), C1 (50 ± 4.3 g) and R2 (49 ± 5.5 g; P>0.686), goats offered ration C2 consumed significantly more OM during grazing (59 ± 3.8 g) than all other groups (P=0.003). OM intake from roughages at the homestead (that is cultivated green fodder and Rhodes grass hay) significantly reduced OM intake of goats on pasture (r^2=0.44; P=0.001). In contrast thereto, the OM intake of the concentrate feeds (that is dates and dried sardines) significantly increased total OM intake of goats (r^2=0.36; P=0.005) and showed a positive although not significant effect on their OM intake during grazing (r^2=0.13, P=0.126).

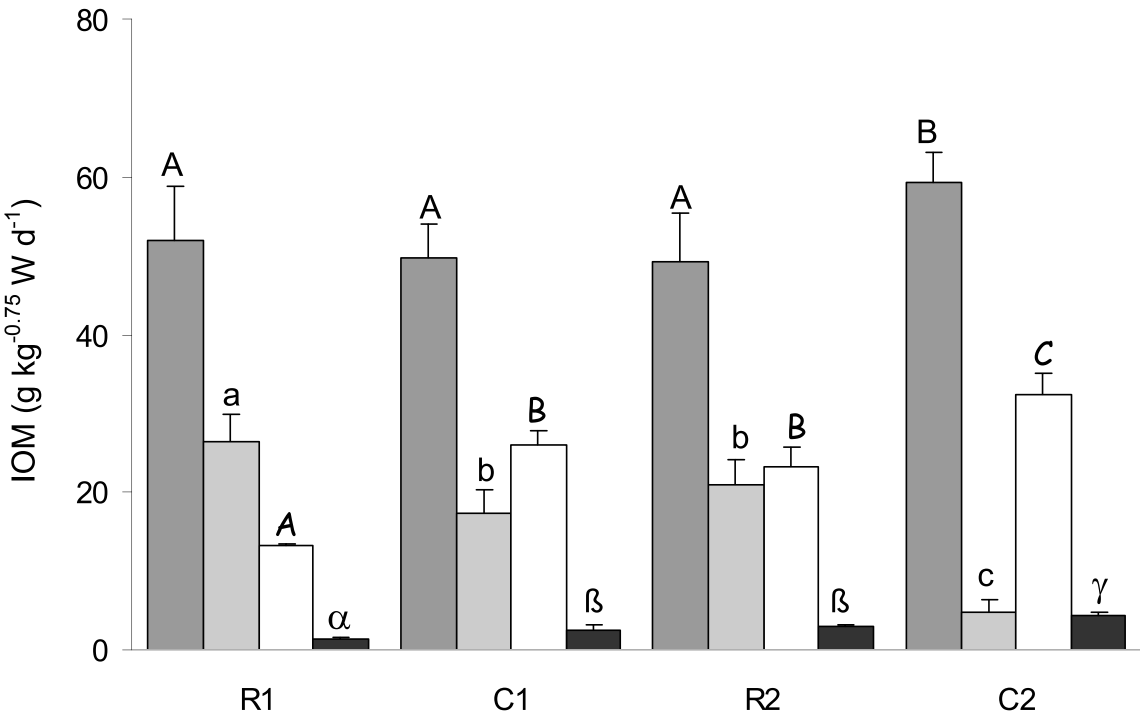

Figure V.3. Mean organic matter intake (IOM) from different feedstuffs of goats offered roughage-based (R) and concentrate-rich (C) rations during two feeding trials on Al Jabal al Akhdar, Oman, in October 2006 (1) and February 2008 (2). Pasture vegetation = dark grey; cultivated roughage = light grey; dates = white; dried sardines = black. Bars indicate one standard deviation. Different letters mark significant treatment differences (P<0.05) in the intake of pasture vegetation (A, B), cultivated roughage (a, b, c), dates (*A, B, C*) and dried sardines (α, ß, γ), respectively.

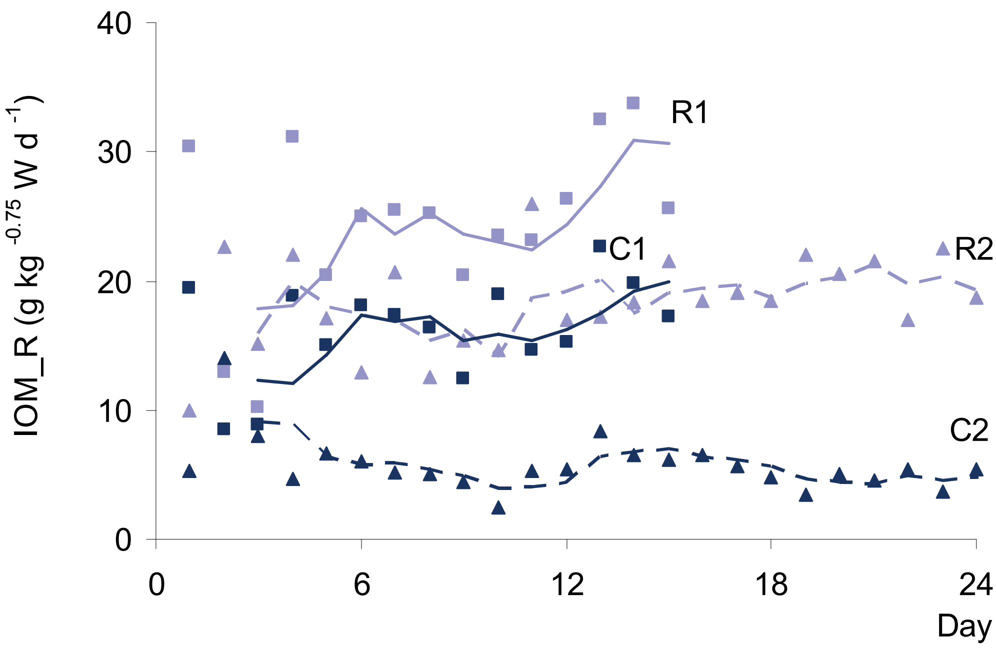

Figure V.4. Average cultivated roughage intake (IOM_R) of goats fed roughage-based (R) and concentrate-rich (C) diets during two feeding trials on Al Jabal al Akhdar, Oman, in October 2006 (1) and February 2008 (2). Points indicate daily means per treatment, lines show 3-day moving averages.

At average nutrient concentrations (g kg^{-1} OM) of the pasture vegetation of 114 ± 44.8 g CP and 1.4 ± 0.61 g P, total daily CP and P intake (g $kg^{-0.75}$ W d^{-1}) of goats of all treatments ranged between 10 - 13 g CP and 0.18 - 0.24 g P (Figure V.5). Due to the high OM intake on pasture, the pasture vegetation supplied 43% - 61% of the total CP and 28% - 46% of the total P intake, despite the low nutrient concentrations of the pasture plants (see section V.3.1.). However, since the dried sardines were rich in CP and P (Table V.5), the small amounts of dried fish consumed by goats accounted for 9% - 37% and 17% - 51% of the total CP and P intake of the different groups. Hence, total CP and P intake were higher in animals offered ration R2 and C2, which included larger amounts of dried sardines than the rations offered during the first feeding trial. At an average fecal P concentration of 3.8 ± 0.80 g kg^{-1} OM, 33% - 70% of the ingested P was excreted, with the lowest excretion determined for group R2 (P=0.010).

Table V.4. Parameters of linear (y = a * x + b) or logarithmic (y = a * ln (x) + b) regressions between the daily organic matter intake (IOM; g $kg^{-0.75}$ W d^{-1}) of concentrate feeds (IOM_C), the IOM of cultivated roughage (IOM_R), the IOM on pasture (IOM_P) and the total IOM (IOM_T) of goats (n=20) during two feeding trials conducted in a mountain oasis on Al Jabal al Akhdar, Oman, in October 2006 and February 2008.

x	y	a	b	r^2	SE	P
Linear						
IOM_C	IOM_T	0.41	86	0.36	4.64	0.005*
IOM_R	IOM_T	-0.29	101	0.19	5.20	0.052
IOM_C	IOM_P	0.27	45	0.13	6.14	0.126
IOM_C	IOM_R	-0.87	40	0.71	4.75	< 0.001*
Logarithmic						
IOM_R	IOM_P	-5.91	68	0.44	4.89	0.001*

At average ME concentrations in the ligneous and herbaceous pasture plants of 7.2 ± 2.15 MJ kg^{-1} OM, total ME intake was similar for groups C1, R2 and C2 (P>0.118), but was significantly lower for goats offered ration R1 (P<0.047), since they did not consume all pre-bloom maize offered. Metabolizable energy was mainly supplied by the feed consumed at the homestead, due to the low ME concentration of the pasture vegetation. While in groups C1 and C2 dates supplied a fraction of 0.36 ± 0.007 and 0.44 ± 0.023 of the total ME intake, they only provided a fraction of 0.20 ± 0.008 and 0.33 ± 0.018 of the total ME intake to groups R1 and R2. In contrast, the roughage groups ingested 0.32 ± 0.043 and 0.23 ± 0.030 of their total ME through the green fodder offered at the homestead.

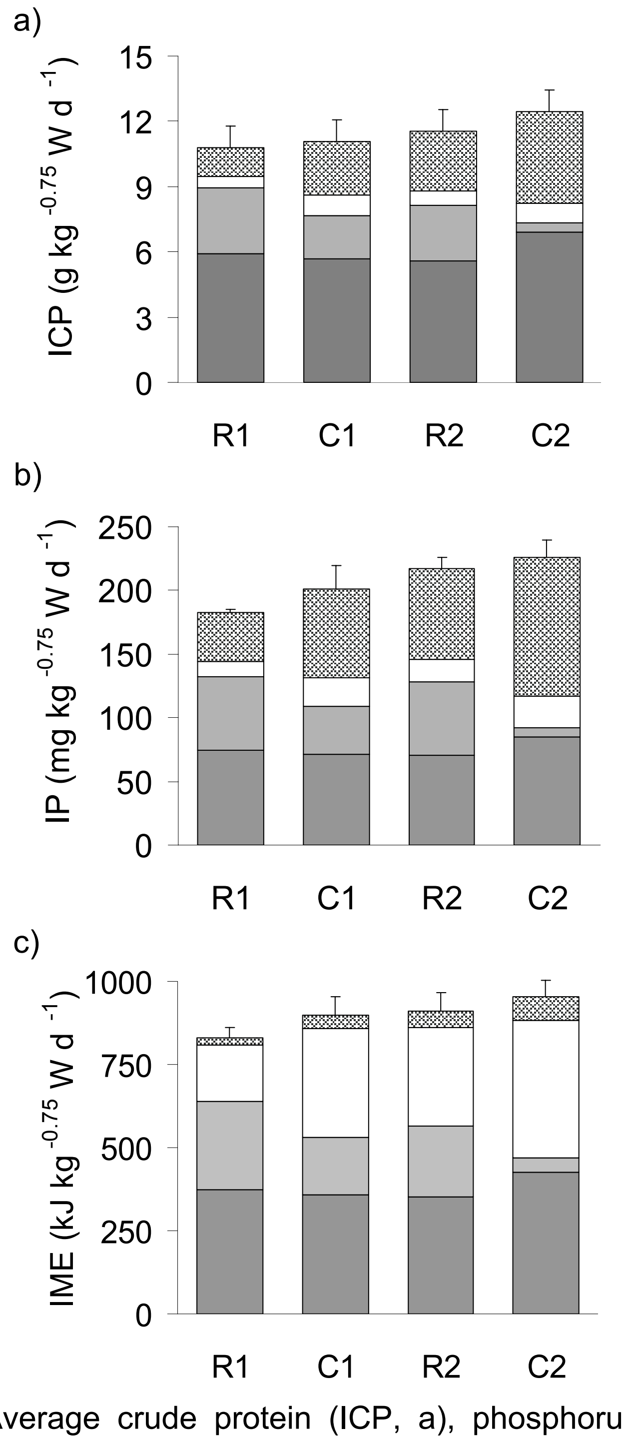

Figure V.5. Average crude protein (ICP, a), phosphorus (IP, b) and metabolizable energy (IME, c) intake of goats fed roughage-based (R) and concentrate-rich (C) rations during two feeding trials on Al Jabal al Akhdar, Oman, in October 2006 (1) and February 2008 (2), supplied by pasture vegetation (dark grey), cultivated roughage (light grey), dates (white) and dried sardines (patterned). Bars indicate one standard deviation for total nutrient and energy intake per day.

Table 5. Dry matter (DM), organic matter (OM), neutral detergent fiber (NDF), acid detergent fiber (ADF), metabolizable energy (ME), crude protein (CP) and phosphorus (P) concentration of feed stuffs offered to goats during two feeding trials conducted on Al Jabal al Akhdar, Oman, in October 2006 and February 2008 (means ± one standard deviation).

	Samples	DM	OM	DOM	NDF	ADF	CP	P	ME
Feed	n	g kg^{-1} FM*	g kg^{-1} DM	g kg^{-1} OM					MJ kg^{-1} OM
Dates	6	863 ± 33.7	981 ± 6.7	840 ± 21.5	.	.	31 ± 6.5	0.8 ± 0.08	12.6 ± 0.38
Dried sardines	5	959 ± 21.0	761 ± 23.9	.	.	.	948 ± 23.2	26.1 ± 1.42	.
Pre-bloom maize	3	218 ± 23.0	893 ± 18.8	665 ± 46.1	660 ± 27.8	409 ± 28.8	111 ± 27.0	2.2 ± 0.21	10.1 ± 0.84
Pre-bloom oat	3	195 ± 36.1	873 ± 7.1	673 ± 31.8	645 ± 7.8	400 ± 6.6	122 ± 16.9	2.8 ± 0.31	10.2 ± 0.60
Rhodes grass hay	4	788 ± 9.3	910 ± 10.9	585 ± 50.6	781 ± 38.8	462 ± 41.2	90 ± 14.0	1.4 ± 0.21	8.7 ± 0.88

* FM: Fresh matter

V.4 Discussion

V.4.1 Quality of the pasture vegetation

The low nutritional quality of the natural vegetation on arid and semi-arid mountain ranges is widely limiting livestock production (Ramírez et al., 2006; Ben Salem and Smith, 2008) and much research was therefore dedicated to improve the nutrition of grazing livestock by adequate energy and nutrient supply. Low CP concentrations in the rangeland vegetation widely limit digestibility of diets consumed by grazing ruminants and the supply of a protein-rich concentrate mixture can therefore increase total DM intake of animals (Ben Salem and Smith, 2008). Nitrogen concentrations of the ligneous and herbaceous species on Al Jabal al Akhdar were slightly lower or similar to those of fodder plants grazed by sheep in the Tigray region of northern Ethiopia (Yayneshet et al., 2009). However, ME concentrations of the natural vegetation of the Ethiopian pastures were higher than of the browse foliage, herbs and grasses sampled in our study. Moreover, the present P concentrations and Ca/P-ratios of > 20:1 in the foliage of most browse species were within the range of values determined in the tree and shrub foliage on semi-arid calcareous rangelands in northeastern Mexico (Ramírez et al., 2006).

The nutritional quality of the pasture vegetation on Al Jabal al Akhdar varied between different plant groups, locations and seasons. While CP and P concentrations were low in the herbaceous vegetation, they were highest in the ligneous fodder species, pointing to the importance of browse foliage for livestock nutrition in this and similar regions. Nutrient and energy concentrations were lower in fodder species growing on the plateau areas at 2000 m a.s.l. than in species growing on mountain slopes and valleys at lower altitudes, which benefit from the run-off water of the upper plateau areas. Together with the high yield of ligneous biomass at these sites (Dickhoefer et al., 2009), the good nutritional quality of their vegetation makes the slopes and valleys key resources for goat nutrition on Al Jabal al Akhdar. Nitrogen and Ca concentrations in the foliage of the main browse species on Al Jabal al Akhdar varied between seasons, and similar changes in response to rainfall were reported by Ramírez et al. (2006). While N concentrations were highest in the rainy season, Ca concentrations and Ca/P-ratios in the foliage increased in February and April 2008 after three to five month with less than 5 mm of rainfall. Together with the seasonal changes in the available herbaceous biomass and the gradual decline in the region’s grazing resources (Dickhoefer et al., 2009), the low nutrient, energy and mineral concentrations of the fodder consumed by goats on these pasture might therefore limit their growth and production.

V.4.2 Feed intake

The total daily OM intake (g $kg^{-0.75}$ W d^{-1}) of goats of 87 - 107 g determined during the two feeding trials was similar to values obtained for goats in villages of Al Jabal al Akhdar in 2005 (Dickhoefer, 2006; Schlecht et al., 2008). Farmers commonly feed dates and dried sardines as well as cultivated green fodder to their livestock, and animals receive 29 – 35 g OM $kg^{-0.75}$ W d^{-1} of concentrate feed and 2 - 16 g OM $kg^{-0.75}$ W d^{-1} of roughage (Dickhoefer, 2006; Schlecht et al., 2008). However, in our experiments the OM intake at the homestead was higher than under farmers' usual feeding practices at the same oasis. Although goats did not consume all green roughage offered during the first feeding trial, the proportions of green fodder in rations R1 and C1 as well as in ration R2 were much higher than the daily intake of 2 g OM $kg^{-0.75}$ W reported by Dickhoefer (2006). The natural pasture vegetation supplied 46% - 65% of total OM intake of goats and despite the large amounts of supplements offered, OM intake at the homestead did not fully substitute the fodder consumed by animals on pasture as they are allowed to graze for several hours per day. The results therefore indicate the importance of the natural fodder resources for the current goat husbandry on Al Jabal al Akhdar. However, the present OM intake on pasture was lower than values determined for goats of Qasha' in 2005 (Dickhoefer, 2006; Schlecht et al., 2008), which points to the fact that an increased offer of feed at the homestead can reduce OM intake of goats on pasture. Since group R2 consumed significantly less fodder during grazing than group C2, results furthermore indicate that especially roughage feeding was influencing goats' feed intake on pasture. The logarithmic regression between the roughage OM intake at the homestead and the OM intake on pasture showed a significant decrease in the amount of fodder consumed on pasture in response to higher roughage intake at the homestead. In our study, the decrease of 0.47 g OM intake on pasture per 1 g OM of roughage consumed at the homestead was higher than the decrease of 0.26 g OM and 0.37 g OM reported by Kawas et al. (1999) for supplemented goats grazing semi-arid woodlands in Brazil during the dry and wet season. These findings illustrate the potential of roughage feeding for rangeland conservation in semi-arid grazing systems. However, although the intake of green maize was significantly higher in group R1 than in group C1, OM intake on pasture was similar for both treatments. In contrast thereto, feeding roughage at a daily level of 21 g OM $kg^{-0.75}$ W as in group R2 appears to be sufficient to significantly reduce feed intake on pasture. An additional feeding of roughage prior to grazing in the morning might even further reduce grazing pressure, but since women harvest the green fodder in the afternoon and the majority of animals are not fed in the morning, this currently does not appear an appropriate strategy for farmers on Al Jabal al Akhdar. Moreover, the Rhodes grass hay purchased on the local markets had a much lower nutritional quality than the cultivated green fodder, and since goats refused 64% - 79% of the offered hay, it does not appear to be an effective alternative for supplementing grazing livestock.

V.4.3 Nutrient, mineral and energy intake

Goats are known for their selective grazing behavior and their ability to feed on species of higher nutritional quality, thereby enhancing their nutrient and energy intake (Papachristou et al., 2005). However, this ability makes it difficult to exactly determine nutrient and energy intake of goats during grazing, and in the present study it was not possible to quantify to which extent individual plant species contributed to the feed intake of goats on pasture. Instead, the average ME and nutrient concentration of ligneous, dicotyledonous herbaceous and grass species was taken to estimate the energy and nutrient intake from pasture vegetation.

During grazing on pasture, goats of Qasha' daily cover horizontal and vertical distances of 11.3 km and 2.6 km (Schlecht et al., 2009). At daily ME requirements of 422 kJ $kg^{-0.75}$ W for maintenance (Lachica and Aguilera, 2005), 3.31 kJ kg^{-1} W per meter of horizontal and 18.5 kJ kg^{-1} W per meter of vertical movement (Lachica et al., 1997), ME requirements for maintenance and locomotion would amount to 637 kJ $kg^{-0.75}$ W d^{-1}. The values of Lachica et al. (1997) were determined in goats walking on a treadmill belt and requirements will likely be higher for locomotion on rough surface (Lawrence and Pearson, 1999). However, the calculated energy requirement for maintenance and locomotion is within the range of 600 - 742 kJ $kg^{-0.75}$ W recommended by NRC (1981) for goats of 30 - 40 kg bodyweight grazing arid, mountainous rangelands. The daily ME intake of goats of all groups during the two feeding trials of 898 ± 63.9 kJ $kg^{-0.75}$ W was therefore sufficient to cover their energy requirements for maintenance and locomotion, and it would even have allowed for a daily weight gain of 100 g (NRC, 1981), which however, was not determined given the short experimental period. Similarly, goats' daily CP intake in the present trials of 10 – 13 g $kg^{-0.75}$ W d^{-1} (78 – 122 g CP d^{-1}) exceeded the estimated requirements for maintenance, locomotion and a weight gain of 50 g CP d^{-1} (NRC, 1981) and dietary CP/ME-ratios were similar to values recommended for goats by Underwood and Suttle (2001). Moreover, the feeding with highly digestible concentrate feeds improved overall diet digestibility and therefore increased animals' total feed intake.

At 24 g Ca and 4 g Mg kg^{-1} OM, the average concentrations of these minerals in leaves and soft twigs of ligneous fodder species were much higher than concentrations recommended for diets of grazing sheep growing at 100 g W d^{-1} (2.4 – 3.7 g Ca and 1.0 g Mg kg^{-1} DM; Underwood and Suttle, 2001). Similarly, Na and K concentrations in the pasture plants were adequate or much higher than required by goats for maintenance, locomotion and slow growth (0.7 g Na and 1.8 – 2.5 g K kg^{-1} DM; NRC, 1981; Underwood and Suttle, 2001). Therefore, these minerals do not appear to limit growth and production of grazing goats on Al Jabal al Akhdar. Due to the high P concentration in the offered sardines, total daily P intake of 0.17 – 0.24 g $kg^{-0.75}$ W during our study also covered the requirements of goats of 20 – 40 kg W growing at 50 g W d^{-1} (2.1 – 3.5 g P d^{-1}; NRC, 1981). However, the natural pasture vegetation was low in P and Ca/P-ratios in the foliage of most browse species were much higher than the ideal ratio of 1:1 to 2:1 (Underwood and Suttle, 2001). Although goats are tolerant to wider Ca/P-ratios when concentrations of both elements cover their requirements, an increased Ca intake can intensify the symptoms of a P deficiency, if dietary P concentrations are low (Underwood and Suttle, 2001). As indicated by the fecal P concentrations and the daily fecal excretion, 0.8 – 2.4 g P per day were excreted by goats in the feces during the two feeding trials, equivalent to 33% - 70% of their daily P intake. Hence, the high Ca concentrations in the natural vegetation should not have had any adverse effect on P absorption in animals fed with P-rich feeds at the homestead. However, under traditional feeding, when feed intake on pasture is higher and only little dried fish is offered, wide Ca/P-ratios in the natural vegetation in combination with a P intake below animals' daily requirements (calculated at 0.13 g P $kg^{-0.75}$ W d^{-1} at 3 g OM $kg^{-0.75}$ W d^{-1} of dried fish; Dickhoefer, 2006; Schlecht et al., 2008) might impair P absorption by goats.

V.4.4 Feeding management

The supply of additional energy and nutrients to grazing animals that balance their requirements and the quantity and quality of fodder available on pasture can substantially improve animal production (Ben Salem and Smith, 2008). Farmers in oases settlements of Al Jabal al Akhdar traditionally offer dates and dried sardines to their goats and the animals' nutrient and energy intake covers their requirements for maintenance and locomotion even in dry seasons (Schlecht et al., 2008). However, feed intake of traditionally managed goats appears to be insufficient for substantial growth and production (Schlecht et al., 2008). And since only a few animals are fed individually according to their growth and production requirements, the feed stuffs are used rather inefficiently (Zaibet et al., 2004).

Extra nutrients and energy are required by growing offspring for a fast weight gain after weaning and, since the main kidding period of goats on Al Jabal al Akhdar is from November – February, when fodder quantity (Dickhoefer et al., 2009) and quality on pasture decreases, by pregnant and lactating does. Moreover, nutrient and energy intake of goats grazing the high altitude plateaus of Al Jabal al Akhdar is limited by the lower quantity and quality of the foliage there as compared to lower lying areas with more productive and higher quality vegetation. A temporary supplementation of these goats with energy- and nutrient-rich supplements during the cold, dry season and when their requirements for growth and production are high could therefore significantly improve their nutritional situation.

Dates largely contributed to the total ME intake of goats and dried sardines are a valuable protein and P supplement (Early et al., 2001). Both feeds are by-products of the traditional date palm cultivation and fishery in Oman (El Hag and El Khanjari, 1992) and therefore offer a cheap alternative to expensive cereal-based supplement feeds (Ben Salem and Smith, 2008), which are largely imported into Oman (FAOSTAT, 2008). Traditionally, farmers in the oases of Al Jabal al Akhdar cultivate green fodder in their gardens, producing about 0.5 kg OM m^{-2} of fodder per harvest (Dickhoefer, forthcoming). Taking R2 as the model ration (see section V.4.2.), 0.3 kg OM d^{-1} of green fodder would be needed for a goat of 35 kg bodyweight. Since the fodder is harvested 6 – 8 weeks after seeding and is directly re-sown (Luedeling et al., 2008), about 25 - 35 m^{-2} of fodder area would be needed to feed a goat of 35 kg bodyweight at 21 g OM $kg^{-0.75}$ W per day on a year-round basis. In April 2006, alfalfa, maize, barley, oat and sorghum cultivation in the oasis gardens on Al Jabal al Akhdar covered an area of 2000 – 7600 m^{-2} per village (Luedeling et al., 2008). Thus, oasis forage cultivation appears to have a high potential for supplying green fodder to the livestock.

V.5 Conclusions

The natural pasture vegetation on Al Jabal al Akhdar is an important source of fodder for grazing goats and largely contributes to their daily feed intake, even if supplement feed is offered at the homestead. Due to the low ME and P concentrations in the foliage of the most abundant fodder species, nutrient and energy intake of the animals on pasture only covers their requirements for locomotion during grazing. Homestead feeding of individual animals according to their specific requirements for maintenance and production and with respect to seasonal and location-specific variations in the nutritional quality of the pasture vegetation is therefore necessary to increase their nutrient and energy intake and to compensate for nutritional imbalances in the fodder available on pasture. Feeding by-products of the national fishery and date palm production in combination with cultivated green fodder significantly reduces goats' OM intake on pasture. It thereby eases the grazing pressure exerted on the rangeland vegetation and contributes to the maintenance of this fodder resource. Such strategies are therefore valuable alternatives to the introduction of zero-grazing systems and the purchase of expensive concentrate feeds, because they enable the goat farmers to efficiently use their available fodder resources, render them independent of global changes in feed cereal prices and thereby enhance the food and income security of the rural population.

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VI Discussion

VI.1 Methodology

The highly variable topographic and climatic setting of Al Jabal al Akhdar with large altitudinal differences between locations, seasonal changes in rainfall and temperatures and small-scale variation in water availability and grazing intensity results in a very heterogeneous natural vegetation on the mountain pastures (Chapter III). Accurate description of botanical composition, plant cover and biomass of the natural vegetation in such environments is a major challenge. While vegetation analyses were conducted at different locations (plateau areas, shallow gullies, mountain slopes and valleys) and at different altitudes to account for the large-scale spatial variation, transect methods were chosen to capture small-scale variation in plant communities. Natural vegetation was studied at grazed and ungrazed sites to assess the effect of livestock grazing, and analyses of the herbaceous vegetation were conducted repeatedly over a period of 1.5 years to capture seasonal variation in plant cover and biomass yield. The Point-Centered quarter method has successfully been applied in studies of semi-arid shrublands (Barroso et al., 1995) and therefore appears to reliably predict the density and cover of the ligneous species on Al Jabal al Akhdar. Relationships between phenotypic parameters and ligneous biomass are commonly used to estimate total, woody or foliar biomass and the correlations identified in our study were highly significant ($P<0.001$). However, only the five most abundant ligneous species were considered, so that the ligneous biomass calculated for the different sites and locations does not represent total foliar biomass. Nevertheless, these species accounted for 92%, 85% and 94% of the total tree cover at the grazed and ungrazed plateau and the grazed wadi. In addition, the ligneous biomass of *Acacia gerrardii*, an abundant tree species on the mountain slopes, was determined using published regression functions for another Acacia species. The results should thus represent a good approximation of total foliar biomass at all locations.

The stratified approach used to quantify herbaceous biomass production has previously been applied by Schlecht et. al. (2009) on pastures of Al Jabal al Akhdar. Although the methodology cannot quantify the total annual biomass production at the different study sites, because consumption by animals and plant re-growth are not considered, it provides a reliable estimate of the standing herbaceous biomass irrespective of the seasonal and spatial heterogeneity. The comparison of the natural vegetation at grazed and ungrazed plateau sites at similar altitudes and under identical geological and climatic settings allowed the evaluation of the impact of livestock grazing on botanical composition, plant cover and biomass of the ligneous and herbaceous vegetation.

To determine a representative average daily weight gain for goats in the different mountain oases, animals of different villages and of two types of farms (farm type M: large herds, little concentrate feeding and marketing of goats; farm type H: medium-sized herds, high concentrate feeding and auto-consumption of goat meat) were regularly weighed (Chapter IV). The number of goats used per farm type and weight class was larger than in the study by Mahgoub et al. (2005) who examined the growth of Jabal Akhdar goats under feedlot conditions (n=15). Goats' reproductive performance was determined using the progeny history interview technique, which relies on the memory of farmers about the history of their animals. This method was developed in Africa and has successfully been applied in on-farm research in smallholder livestock systems (Kaufmann, 2005), where long-term *in situ* studies of fertility parameters cannot be conducted. Several questions were included in the interview that allowed crosschecking of farmers' answers on reproduction of does. Specific events such as religious holidays or births of children were used as temporal reference points and seasons instead of exact dates were recorded. The interview results therefore provided a reliable estimate of the reproductive performance and the overall development of and potential offtake for goat herds on Al Jabal al Akhdar.

The two feeding trials conducted on Al Jabal al Akhdar (Chapter V) aimed at analyzing the potential of feeding different rations composed of locally available feedstuffs at the homestead for increasing goats' nutrient and energy supply, reducing their feed intake during grazing on pasture and thereby conserving natural fodder resources. TiO_2 has been recommended by Titgemeyer (1993) as an external marker for the determination of animals' daily fecal excretion. The CP concentration in fecal OM has been used to estimate overall diet digestibility of traditionally managed goats in the same mountain oases (Schlecht et al., 2008), but also in grazing lambs in the Inner Mongolian Steppe (Glindemann et al. 2009; Wang et al., 2009). The digestible organic matter (DOM) concentration of goats' diets as calculated from the CP in fecal OM in our study was 709 g kg^{-1} OM (SD 23.0) across all feeding groups. The weighted average DOM concentration in the animals' diets as calculated from the DOM concentration of individual feedstuffs consumed by goats at the homestead and from the average DOM concentration of all ligneous, dicotyledonous herbaceous and grass species sampled on mountain pastures was lower at 624 g kg^{-1} OM (SD 15.1). Hence, the CP-derived DOM estimation might slightly overestimate overall diet digestibility and consequently animals' total OM intake as well as their OM intake on pasture. Similarly, Lukas et al. (2005) found that in diets containing high concentrations of crude fiber the calculation of overall diet digestibility from fecal CP concentration appeared to slightly overestimate actual diet digestibility. The method appears nevertheless reliable enough to assess the animals' daily OM intake.

VI.2 Recent developments on Al Jabal al Akhdar and their effects on the traditional agricultural system

The social and economic changes in Oman since 1970 (Chapter I.4) have strongly affected the daily life of people on Al Jabal al Akhdar. While the region was more or less isolated in the past due to the mountainous topography, the completion of the road from Birkat Al Mauz to Sayq in the 1980s and later also to a majority of the villages on Al Jabal al Akhdar (Scholz, 1984, see Figure I.2, page 7) allowed an easy transport of goods from and to the lowland markets and facilitated a more intensive exchange with the rest of the country. As a consequence thereof, building and construction materials as well as a variety of foodstuffs, household items and agricultural inputs became available to people of Al Jabal al Akhdar (Scholz, 1984; Melamid 1992). A hospital as well as several primary and secondary schools were built, providing basic health care and education to the local population. The traditional falaj channels built from mud were fortified with cement to reduce water losses due to leakage. Ground water wells were dug to supply additional irrigation water for crop cultivation as well as drinking water to households (Scholz, 1984; Melamid, 1992). The government financially supported the renovation and construction of houses (Scholz, 1984), so that most buildings are now made of cement. These developments greatly eased people's lives by reducing the daily work load. In autumn 2006, almost all interviewed households in the study villages had running water and electricity, 64% of the households owned a car and 72% a washing machine (Chapter II).

This rapid modernization induced social changes within the villages and families. Scholz (1984) described village sizes of 35, 7 and 11 houses for Ash Sharayjah, Qasha' and Masayrat ar Ruwajah in 1978, respectively. At 3.5 households per building and an average of 6 persons per household (Scholz, 1984), the total population in Qasha' and Masayrat ar Ruwajah was thus around 147 and 231 persons in 1978, respectively. In Ash Sharayjah, 48 (of the originally 66) households were still living in the village in the same year (Scholz, 1984), resulting in a total population of approximately 288 people. While 214, 145 and 111 people were living in Ash Sharayjah, Qasha' and Masayrat ar Ruwajah in 2001/2002 (MNE, 2004), these villages had 140, 152 and 127 inhabitants in autumn 2006 (Chapter II). During the study period from August 2006 until April 2008, an additional three families from Ash Sharayjah, two from Qasha' and three from Masayrat ar Ruwajah left their village. Thus, although the population in Qasha' was similar in autumn 2006 to 28 years earlier, the number of people living in Ash Sharayjah and Masayrat ar Ruwajah decreased significantly in recent years, reflecting the emigration of whole or at least parts of the households from the oases. The majority of people moved to Sayh Qatanah or the village of Sheif (57°41'32''N, 23°01'32'', 1950 m a.s.l.) on Al Jabal al Akhdar, but also to Birkat Al Mauz, other lowland towns and even to the capital area of Muscat.

After 1970, spring water as well as land became governmental property. While up to date, non-locals are not allowed to buy land on Al Jabal al Akhdar, cheap property on the Sayq plateau has been available to local people since 1980. Since transport costs for building materials are lower for the plateau around Sayh Qatanah than for the more remote villages at the mountain slopes and building space is limited within these oases, the incentive for people to build in Sayh Qatanah is high. As a consequence thereof, this town, which has developed on the Sayq plateau over the last three decades, had grown to a total of 1600 inhabitants by 2001/2002 (MNE, 2004), covering an area of approximately 180 ha in 2007. The average household size in the mountain oases determined in this study of 10 people (Chapter II) was lower than the number of approximately 21 persons living in one house in 1978 (Scholz, 1984). While in the past, an average of 3.5 households were living in one house (Scholz, 1984), each house comprised only one household in autumn 2006 and only 33% of the households in the three villages hosted more than two generations. This development not only points to the increasing number of men founding their own household at marriage instead of staying in the parents' house, but also indicates the changing social structures within the villages and families. Hence, besides the proximity to schools and the hospital, relationships with people in the new neighborhood (relatives, friends, former neighbors, etc.) were a further reason for people to leave the oases.

These developments affected the traditional agriculture in the mountain oases in the vicinity of Sayh Qatanah. The government largely invested in the modernization of the local agriculture. New crops were provided to farmers, including plums (*Prunus domestica* L.), pears (*Pyrus communis* L.) and apples (*Malus domestica* Borkh.) and a station was established to collect farmers' harvests and promote their collective marketing (Scholz, 1984). Moreover, the agricultural ministry has initiated several projects to monitor and control plant diseases and supply agricultural machinery, chemical fertilizers and pesticides to farm households. In autumn 2006, 49% of households in the study villages owned a motor plough and 31% were regularly applying chemical fertilizers (Chapter II). Veterinary services are available to livestock keepers, offering vaccination of animals, cheap drugs as well as artificial insemination technology, and although farmers mentioned the occurrence of diseases, mortality rates in the traditionally managed goat herds were low (Chapter IV). Moreover, farmers were able to obtain financial support for the construction of new stables and 62% of the livestock keepers in the study villages had recently built or renovated a barn, allowing animals the access to fresh air and daylight and farmers easier cleaning of stables in comparison to the traditional goat houses.

Yet, Luedeling and Buerkert (2008) found that while bare fields comprised 0 ha and 1.45 ha in Masayrat ar Ruwajah and Ash Sharayjah in 1978, 0.34 ha and 3.71 ha were not cultivated by farmers of the respective oases' gardens in 2007. Although the oasis of Qasha' had a relatively small area of bare fields in 1978 (0.67 ha), and even fewer uncultivated terraces in 2007 (0.52 ha, Luedeling and Buerkert, 2008), the total cropped area in this oasis has decreased immensely since before the Jabal Akhdar war in 1955-59. Once out of use, the terrace walls rapidly collapse and soil erodes within a few years, so that large proportions of the abandoned terraces are nowadays destroyed and hardly recognizable.

The farmers of Al Jabal al Akhdar have traditionally cultivated a large variety of crops, including many kinds of fruit trees, wheat and different types of vegetables, as recorded during a visit by Scholz (1984) in 1978. Several new varieties of wheat and durum wheat have recently been identified in the oasis of Balad Seet in the Al Hajar Mountains (Al Khanjari et al., 2005). Gebauer et al. (2007) stressed the high potential of traditional oasis agriculture for *in situ* conservation of agricultural biodiversity. Since Scholz' visit, wheat and many of the traditional vegetables have disappeared from the oases (Gebauer et al., 2007). Of the trees in Qasha' and Ash Sharayjah, 70% and 85% were pomegranates or roses in 2006, and dates and banana plants accounted for 80% of all trees in the gardens of Masayrat ar Ruwajah (Luedeling and Buerkert, 2008). These findings indicate that in addition to the decay of the agricultural infrastructure, the diversity of crops in the oases is rapidly declining.

Although goats remained the main livestock species in the villages with 64, 107 and 306 animals in Ash Sharayjah, Qasha' and Masayrat ar Ruwajah in autumn 2006 (Chapter IV), village herds were smaller than determined during the national animal census in 2001 (189, 123, 295 animals; MAF, 2001). During the household interviews, farmers claimed that they even owned more animals ten years earlier so that farmers still living in the oases in autumn 2006 had owned about 200, 250 and 400 goats and sheep in 1996, indicating that average herd sizes and the total number of animals in the villages are continuously decreasing. While by-products such as wool, hair and leather are no longer used, owners of larger herds (type M farms) nowadays frequently sell animals on the local markets to generate income (Chapter IV). These farmers do not feed any or only little amounts of cultivated fodder to their goats. Instead, dates and dried sardines are major supplement feeds offered to goats (Chapter IV). Market integration through the purchase of supplement feeds and the sale of animals reflects the recent transition in the livestock system and in farmers' objectives (Zaibet et. al. 2004). Similarly in crop husbandry, the expanding cultivation of roses and the dominance of cash crops such as pomegranates or garlic in oases at higher altitudes in comparison to 1977/1978 (Luedeling and Buerkert, 2008) point to the increasing crop production for the purpose of sale.

Already 30 years ago, Scholz (1984) noted that male household members frequently pursued off-farm employment such as in the military camp that had been established on Al Jabal al Akhdar in 1959 (Scholz, 1984). In autumn 2006, at least one member per household was working outside the farm in 64% of all interviewed households. Moreover, children aged 6 – 16 years went to school and in 28% of the households at least one family member was studying at a college or university or undergoing professional training (Chapter II). Much of the family labor force is thus no longer available for crop and livestock husbandry and farmers consequently hire foreign laborers to work in their gardens. In autumn 2006, 21% of the households employed a full-time and 13% a part-time worker and 36% of the households in the three villages at least occasionally paid a person to complete specific tasks (Chapter II). The use of foreign labor may significantly reduce the work load for remaining household members. However, external laborers are not aware of the fine-tuned management practices that were based on the indigenous knowledge of farmers. Moreover, they may not perform the tasks as consciously as the farmers themselves, who feel responsible for the farm they inherited from the ancestors and enjoy the work itself (Chapter II).

VI.3 Natural resource degradation, goat management and dependence on external inputs: scientific evidence, farmers' perceptions and possible solutions

Natural resource degradation

Foliar biomass was 3 – 6 t DM ha^{-1} at the plateau sites and reached 41 t DM ha^{-1} in the grazed wadi. Herbaceous yields at all sites decreased during the dry, cold season. The results presented in Chapter III therefore highlight the restricting effect of the low and variable rainfall on forage production on natural rangelands. However, the study also unveiled that despite the high inter-annual and intra-annual variability in rainfall, these rangeland systems resemble equilibrium systems. Livestock grazing can severely disrupt this equilibrium, and high stocking densities resulted in severe degradation of the natural fodder resources. Hence, while the botanical composition, ground cover and herbaceous biomass were similar for a 15-year old enclosure and a naturally ungrazed mountain plateau, unpalatable species were more dominant at grazed than at ungrazed sites and ground cover of the herbaceous vegetation was significantly higher at the ungrazed plateau than at the grazed plateau and wadi. Hence, livestock grazing has severely degraded the natural vegetation on Al Jabal al Akhdar and strongly reduced edible plant biomass for goats on the mountain pastures.

The military camp that was established on the Sayq plateau after the Jabal Akhdar War in 1955-59 (Scholz, 1984) covered an area of more than 300 ha in 2008, of which approximately 70 ha were permanently fenced. Simultaneously, a road system was built and while Sayh Qatanah grew steadily to about 180 ha in 2007 and is planned to double in size in the near future, the establishment of new settlements on the Sayq plateau are envisaged. These building and construction activities and the exclusion of large areas for military purposes steadily decreased the area available for animal grazing in particular on the Sayq plateau.

Simultaneously, increased off-farm activities, reduced household sizes and the migration of people made farmers progressively cease the herding of goats during grazing. While nowadays distant pastures are only occasionally used, grazing areas near the villages are continuously grazed. Moreover, pastures of different villages largely overlap, so that despite the decreasing village herd sizes on Al Jabal al Akhdar, stocking densities and consequently grazing pressure are nowadays very high near settlements. Similarly, in the highlands of Ethiopia, the expansion of other land uses as a result of societal transformations and economic incentives reduced pasture areas and amplified the degradation of the natural fodder resources on remaining rangelands (Nyssen, 2009). In semi-arid sub-Saharan Africa, abandonment of herding was found to concentrate grazing pressure on specific areas and thereby induce overgrazing (Turner et al., 2005).

Drawbacks of the current goat management

Due to the large distances goats cover during grazing on mountain pastures (Schlecht et al., 2009), nutrient and energy requirements of animals for locomotion are high. As shown in Chapter V, the nutritional value of the analyzed pasture plants grazed by goats was low and their ME concentrations only covered the animals' requirements for maintenance and locomotion during grazing. Low P concentrations in combination with high Ca/P-ratios in the foliage of the most abundant ligneous species appear to limit P absorption. As a consequence, negative P balances as well as symptoms of P deficiency (i.e. malformations, retarded growth or chewing of bones) were already observed in goats of these oases under traditional feeding management (Dickhoefer, 2006). Since nutrient and energy concentrations of pasture plants further decrease during the dry, cold winter months, the main kidding period of goats, their growth and reproduction strongly depends on supplemental feeding at the homestead. Animals' performance may thus vary significantly among individual herds due to individual farmers' management practices and environmental conditions.

As discussed in Chapter V, growth rates of male and female goats in the study villages were low irrespective of the different management practiced by the two types of livestock keepers. In particular daily weight gain of young females declined rapidly after weaning and was much lower than that of does of the same breed raised under feedlot conditions or in the semi-intensive pastoral system of Al Hailailat. Consequently, the traditionally managed does had a comparatively lower bodyweight at first parturition and final bodyweight at maturity. Similarly, reproductive parameters of goats on the two distinguished farm types were low despite the higher supplement feeding of animals in medium-sized herds (farm type H). The simulation of the effect of improved reproductive and growth performance on herd development and offtake rates pointed to the potential of increasing herd production by increasing daily weight gain and reducing kidding intervals.

Possible management options

Results discussed in Chapters III and IV confirm the key problems in agriculture perceived by farmers (Chapter II). These problems could be resolved by increasing supplement feeding of goats at the homestead combined with reduced or no access to pasture, which has been recommended for goat husbandry on Al Jabal al Akhdar (Zaibet et al., 2004). However, farmers consider grazing an important asset to goat husbandry, not only providing free fodder to their animals, but also allowing them access to fresh air and daylight, which together with the physical activity is regarded as beneficial for animal health. As a consequence, farmers stated that the meat quality of grazing goats is higher than of exclusively stable-fed animals. This perception is also the main reason for customers' willingness to pay high prices for Jabal Akhdar goats. The use of the fodder resources on pasture resulted in a higher use efficiency of the supplement feed offered at the homestead (farm type M) calculated as the herd output per kg of DM intake at the homestead as compared to a zero-grazing system. Since production efficiency can be increased by grazing goats despite their lower growth and reproductive performance, it is a valuable alternative to intense livestock systems. Nevertheless, increased feeding of goats' at the homestead would enhance animal growth and reproductive performance by covering their nutrient and energy requirements. The use of locally available feedstuffs, such as low-quality dates and dried sardines as by-products from the national date palm cultivation and fishery (El Hag and El Khanjari, 1992), or of own cultivated fodder could be used to limit the increasing feeding costs for farmers due to the purchase of concentrate feeds.

As shown in Chapter V, ME intake of goats during the two feeding trials was sufficient to cover their requirements for maintenance, locomotion on pasture and a daily weight gain of 100 g at a bodyweight of 30 – 40 kg. This is much higher than the observed growth rates of the traditionally managed bucks and does in the study villages (Chapter IV). In the feeding trials, total OM intake at the homestead was higher than that of traditionally managed goats in the same oasis (31 g OM

$kg^{-0.75}$ W d^{-1}; Dickhoefer, 2006; Schlecht et al., 2008). However, purchased feeds (dates, dried sardines and other concentrate feeds) accounted for 74% and 63% of the feed DM normally offered by type M and H farmers. Instead, green fodder cultivated in the oasis gardens supplied 47% (R2) and 67% (R1) of the daily DM intake of goats offered the roughage based rations during the feeding trials. The increased consumption of roughage at the homestead reduced the goats' feed intake during grazing on pasture. Hence, feeding cultivated green fodder not only decreases farmers' need for purchasing external feedstuffs, but can also contribute to the conservation of fodder resources on village pastures. In combination with the herding of goats on pasture to evenly distribute grazing pressure and a rotational grazing of pasture areas to assure the recovery of the natural vegetation, it would thus allow the continued exploitation of the natural fodder resources without resulting in their long-term degradation. The potential and costs of fodder production in the oasis gardens, for example under the cover of tree species, should thus be studied. The high market prices for Jabal Akhdar goats might induce strong increases in herd sizes on Al Jabal al Akhdar in the future resulting in intensified resource degradation. Thus, government interventions that limit livestock populations and designate sufficiently large areas for grazing would contribute to the sustainability of goat production.

VI.4. Develop or abandon: the future of traditional oasis agriculture

Several studies in tropical and subtropical highland regions have highlighted the importance of traditional farming systems for the rural population and natural environment and the need to conserve them in the future (Stroosnijder, 2008; Nyssen, 2009; Chapter I.6). On Al Jabal al Akhdar, goat husbandry contributes significantly to farmers' agricultural revenues (Chapter IV). All interviewed households also slaughter goats for home consumption and use animal manure as fertilizer in the oasis gardens. Hence, goat husbandry is an essential part of the agricultural system, not only diversifying the agricultural outputs for farmers, but also enabling the use of additional natural resources. In addition to animal products, high-altitude farmers sell fruits, nuts and vegetables, such as pomegranates, walnuts or garlic, and the traditionally produced rose water in local stores, at the roadside or on outside markets. Since these products are highly appreciated by customers, prices of these commodities are high, averaging around 2 OMR (approximately 4 €) for a large pomegranate (approximately 450 g fresh weight) and 5 - 6 OMR for a bottle of traditional rose water (approximately 10

VI.5 Sustainable agriculture - develop on the past

According to the farming systems approach, an agro-ecosystem reaches a stage of equilibrium through continuous adaptation to its biotic and abiotic environment, making it more or less resilient to short-term environmental changes (Scheffer et al., 2001; Altieri, 2002; Chapter I.3). Natural ecosystems may have several stages of equilibria depending on the level of environmental stress they ares exposed to (Scheffer et al., 2001). As an example, the natural vegetation on Al Jabal al Akhdar clearly differed between grazed (= degraded equilibrium stage) and ungrazed sites (= original equilibrium stage) due to the impact of livestock grazing (Chapter III), while the natural vegetation fully recovered to its original stage in the absence of goat grazing (Figure VI.3 a). However, in case of environmental shocks (i.e. natural disasters) or increasing environmental stress past a certain threshold, a return to the previous equilibrium stage is not possible without occurrence of major external impacts (Scheffer et al., 2001; Aggrawal, 2006; Figure VI.3 b). Similar dynamics can also be found in artificial systems (Scheffer et al., 2001; Aggrawal, 2006) that are influenced by their socio-economic and bio-physical environment (see Figure I.1, page 5).

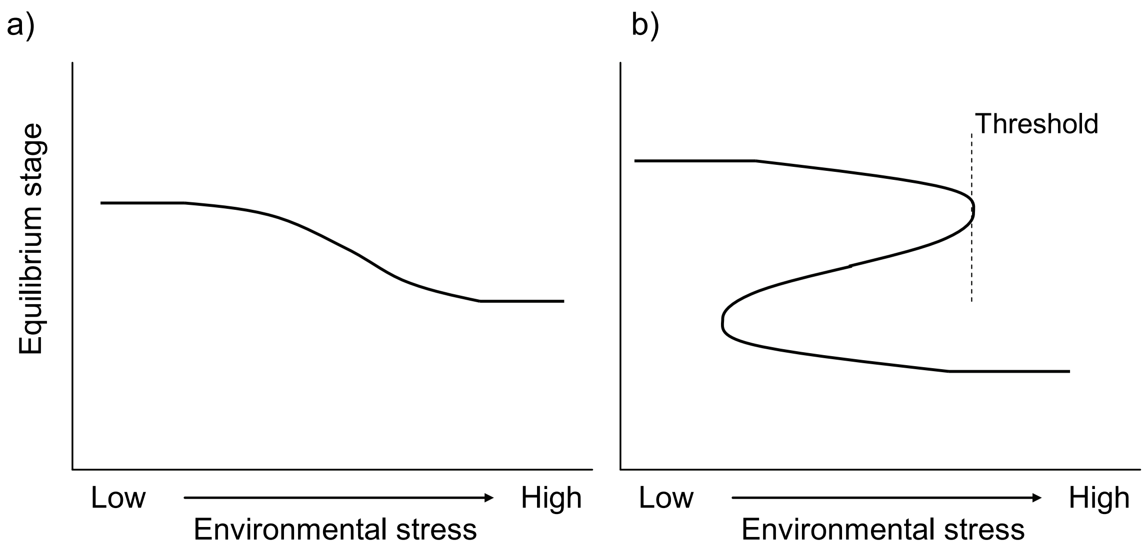

Figure VI.3 a and b. Schematic representation of two possible transition processes of ecosystems between different equilibrium stages in response to increasing environmental stress (adapted after Scheffer et al., 2001).

In case of the traditional agro-pastoral system in the mountain oases of Al Jabal al Akhdar, environmental stress has passed a threshold and caused the system to change (Type VI.3 b). Reverting to the subsistence agriculture of the past, when agriculture largely served auto-consumption (Birks, 1976; Scholz, 1984; Zaibet et al., 2004) is unrealistic, if not impossible (Figure IV.3 b), and also not desired by the local people. Hence, an adaptation of the agricultural system itself (i.e. livestock management, labor allocation) and, to the extent possible, the bio-physical (i.e. transport systems, cementing of irrigation channels or terrace walls) and socio-economic conditions (i.e. infrastructure, market access, governmental policies) is needed to reach a new stage of equilibrium and assure a sustainable agriculture in the future.

From the problem tree given in Chapter VI.2, three universal development goals for mountain oasis agriculture at the level of the individual farm, the oasis settlements as well as the Al Jabal al Akhdar region can be identified:

i) reduced reliance on external inputs by increasing self-sufficiency,

ii) improved agricultural management practices and

iii) prevention of environmental degradation.

Agriculture and farm households on Al Jabal al Akhdar largely rely on external inputs, such as governmental services, the use of foreign labor, increasing off-farm activities as well as sale revenues and purchases on external markets (Chapters VI.1 and VI.2). Subsidies that are for example paid for the conservation of cultural landscapes or biodiversity (Stroosnijder et al., 2008; Nyssen, 2009) would even increase farmers' dependence on governmental inputs. On the contrary, a higher income from agriculture that covers the expenses for agricultural production and the households' costs of living would render farmers more self-sufficient and thus less vulnerable to changes in their bio-physical and socio-economic environment. In this respect, even a household income derived from off-farm activities can be beneficial for families' self-sufficiency, if it is invested in agriculture and thereby increases the revenues from agriculture (de Haas, 2006).

To strengthen agricultural income in rural areas, development approaches aim to either improve agricultural production or to facilitate a reliable market access (Chapter I.2). A continued extension of agricultural infrastructure, such as through the construction of roads and transport facilities to ease access to remote terrace gardens, the cementing of walls to reduce soil erosion and advices on how to reduce labor input in crop and livestock husbandry, could improve agricultural production on Al Jabal al Akhdar. However, access to markets is often difficult for farmers in rural areas (Aggraval, 2006; Markelova et al., 2009). In case of niche markets, such as for organic, fair trade or high-value products, it requires high investments into infrastructure and organization and marketing is very knowledge-and cost-intensive (Bardhan, 2006; Markelova et al., 2009). Since customers in Oman highly appreciate agricultural products sold by farmers of Al Jabal al Akhdar, a niche market for their fruits, rose water and goats already exists. To meet customer demand in the future and thus to maintain high agricultural revenues, it is necessary that farmers continue their extensive agricultural practices (Chapter II). Secondly, it must be prevented that fruits or live Jabal Akhdar goats produced in other regions of the country or abroad fill this market niche. This would increase the competition for farmers and consequently reduce product prices. A regional label for the products and animals from Al Jabal al Akhdar, along the lines of a protected denomination of origin (PDO) label (Stroosnijder et al., 2008), would enable customers to distinguish between local and imported commodities. According to Van der Lans and Van Ittersum (2001), customers need to be aware of the region and have positive associations with it for this approach to be successful. Since both is the case for agricultural products and goats sold by farmers on Al Jabal al Akhdar, it appears appropriate to strengthen their market position. A collective marketing would additionally lower their transport and transaction costs (Markelova et al., 2009). However, the agricultural marketing station, which had previously been established on Al Jabal al Akhdar (Scholz, 1984), no longer existed in 2006, and the functioning of cooperatives strongly relies on collaboration among farmers (Markelova et al., 2009). Therefore, further research should assess whether or not this approach is appropriate for the region and would be implemented by farmers.

Alternatively, regional marketing through an intensified sale in local stores, hotels or directly to customers would open up agricultural marketing possibilities at low transport and transaction costs. The production of (new) high-value crops (i.e. fresh fruits and vegetables) or the processing and manufacturing of products (i.e. (drying fruits or meat, processing of fruits to juices and jams) would diversify cultivated and marketable products, reduce the seasonality of sales and thereby counteract the competition among farmers. However, in particular small, resource-poor farmers who cannot invest in agriculture themselves may not benefit from these measures (Markelova et al., 2009). Objectives of different types of farmers and livestock keepers should thus be considered in regional development planning in order to prevent that they do not amplify social disparities among farm households.

VII Conclusions

The societal and economic developments in Oman since 1970 and the country's increasing trade liberalization have profoundly changed the live of people on Al Jabal al Akhdar, altered their needs and objectives and largely transformed the traditional agriculture in the mountain oases. Conflicting land uses reduced available grazing areas and together with farmers' current goat management practices resulted in deteriorating natural fodder resources on mountain pastures. Homestead feeding of goats largely relies on purchased concentrate feeds and is insufficient for a substantial animal and herd production. With respect to crop husbandry, the lack of irrigation water, plant diseases and a high labor demand were problems frequently mentioned by farmers. Farmers' progressing market integration amplifies their dependence on external inputs and thus their vulnerability to changes in their social and economic environment. These developments therefore threaten the future continuation of the traditional oasis agriculture on Al Jabal al Akhdar.

Goat grazing enables farmers to use free fodder resources on mountain pastures, thereby increasing use efficiency of feed offered at the homestead and largely contributing to the profitability of goat husbandry. Increasing homestead feeding of individual goats is necessary to improve animals' growth and reproductive performance and to enhance revenues from goat husbandry. Feeding of green fodder cultivated in oases gardens reduces farmers' reliance on purchased feeds. It can significantly contribute to the conservation of the natural pasture vegetation by reducing goats' feed intake during grazing. Together with farmers' traditional irrigation practices, their soil fertility management and the diversity of outputs in crop husbandry, such strategies were the basis for a century-old agricultural system that developed through a constant adaptation to its bio-physical and socio-economic environment. These practices therefore still offer valuable solutions to a sustainable agriculture in the future. By providing local employment opportunities for people on Al Jabal al Akhdar, social connections within families and between village inhabitants can be maintained. They are essential for the transfer of elders' knowledge on farming to younger generations. Marketing initiatives that aim at sustaining high prices for agricultural products from Al Jabal al Akhdar could offer the incentive for young people to continue and to invest in local crop and livestock husbandry. Hence, only by a holistic approach that considers the social, economic and bio-physical aspects at a farm, oasis and regional level, this unique farming system can be conserved in the future, as a resort for agricultural biodiversity and indigenous farming knowledge and an important part of Oman's cultural heritage and people's livelihoods on Al Jabal al Akhdar.

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“Throughout history, agriculture has always been the backbone of the economic activities of the majority of the Omani people who have thus gained wide experience in that field. We must be proud of that and pass that experience on to the younger generations.”

His majesty Sultan Qaboos bin Said on the occasion of the opening of the 4^{th} term of the State Consultive Council (09/01/1988).