Ja'far Al-Khaza'leh (Autor)

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Institute of Animal Production in the Tropics and Subtropics

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1 General introduction

1.1 Background and research objectives

Goats are well-adapted animals to the diverse ecological zones and more concentrated in the tropics and dry zones of developing countries (Alexandre and Mandonnet 2005; Peacock 2005; Escareño et al. 2013). In the developing countries, goats are valued mainly for meat, followed by milk, fibre, and skins (Solaiman 2010). Goats are multifunctional animals and play a significant role in the livelihoods, economy and nutrition of landless, small and marginal farmers in terms of provision of meat, milk, and income, capital storage, savings, insurance against emergencies and serving cultural purposes (Kosgey 2004; Lebbie 2004; Al-Atiyat and Tabbaa 2009).

In Jordan, livestock is a major component of the agriculture and goat production is an integral part of farming systems. Goats in Jordan are the second most important livestock population after sheep (Ministry of Agriculture 2012). In the country, goats share the highest proportion of the small and medium–scale dairy sector and contribute to food security and poverty alleviation of poor householders (Al-Atiyat 2014). Jordanian goat farming systems consist mainly of sedentary (semi-intensive/agro-pastoral), transhumant (semi-extensive) and nomadic (extensive) systems (Abu-Zanat et al. 2005; Alrousan 2009). Damascus (Shami), Mountain Black, Dhaiwi (Bedouin goat) and Desert goats are the main Jordanian goat breeds (Zaitoun et al 2005; Alrousan 2009). The relative contribution of goats to households varies from breed to breed, zone to zone, and system to system.

In Jordan, small ruminant production systems changed gradually in the middle of the past century because of increasing settlement of the nomadic Bedouin in the marginal areas, shifting to sheep and goat raising instead of camels, spread of the use of vehicles for movement of flocks and equipment and increased dependency on imported feed (Abu-Zanat 1995). In the country, the ratio of nomadic farmers has declined to less than 10% while that of transhumant farmers has increased to more than 70% and the remaining part (20%) consists of agro-pastoralists (Al-Jaloudy 2001).

The provision of good quality drinking water for goats is crucial in the view of the importance of goats to the farmers' livelihood and food security. Water is an essential and critical element for all forms of life on earth. It is required for all vital processes including transport of nutrients and other compounds to and from body cells, digestion and metabolism of nutrients, elimination of waste materials (urine, faeces and respiration) and excess heat (perspiration) from the body and for maintaining a proper fluid and ion balance in the body (Chiba 2009; Schlink et al. 2010). Water is the main constituent of the animal's body, forming 50 to 80% of the live weight, depending on age and degree of fatness (Nicholson 1985; Lardner et al. 2005; Marx 2005), and consuming water is more vital than consuming food (Faries et al. 1997). Loss of the animal body fats and protein is less problematic than loss of body water (Marx 2005) and reduction of 10% of animal body water is considered problematic and dehydration of 15 to 25%, depending on species, can be fatal (Beede 2012).

A sufficient supply of good quality drinking water is required for livestock to ensure their production and health. Animals meet their water requirements directly through drinking water and indirectly through water contained in the feed consumed and from metabolic water, which results from oxidation of organic nutrients during metabolic processes in the body (King 1983; Murphy 1992; Schlink et al. 2010). Voluntary drinking water typically supplies the majority of the required water (Beede 2012). Loss of water from the body of animals occurs through milk production, urine and faecal excretions, sweats and vapour from lungs (Murphy 1992; Kay 1997; Schlink et al. 2010). Quantity of drinking water for livestock is small compared with the quantity required for feed crop production (Peden et al. 2007). Globally, livestock production uses more than 8% of the total water which includes drinking, servicing, processing and the major fraction (7%) is used to irrigate feed crops of livestock (Schlink et al. 2010). In Jordan, over the time period from 1985 to 2000, water for the agricultural sector occupied the largest portion with 70%, while water consumption for livestock production constituted only 0.9% of the total average water consumption (Tabieh and Al-

Horani 2010). Though only a small portion of water is consumed by livestock, it is critical in dry areas like Jordan under low rainfall, high environmental temperature and low feed quality and availability.

Water quality affects the quantity of water consumed, and in turn, the quantity of feed consumed and thus the performance of livestock (Beede 2006). Water quality assessment encompasses physical properties (e.g. temperature), physiochemical properties (e.g. salinity, pH, hardness), excess nutrients (e.g. nitrate), toxic compounds (e.g. heavy metals) and microbiological agents (e.g. fecal coliform, blue-green algae) (Harris and VanHorn 1991; Higgins et al. 2008; Olkowski 2009). Some anti-quality factors in water may directly impact animal health by causing disease and infection, others have a more indirect effect and may affect the overall water intake. Physicochemical properties of water are among the major characteristics that impact water quality for livestock (McGregor 2004; Beede 2006; German and Thiex 2008; Kubkomawa 2010; Beede 2012; Bulle et al. 2012). The total salt content of water is one of the most important properties in assessing the suitability of water for stock (Pallas 1986).

Water scarcity is a result of the difference in supply and demand, both of which vary greatly from time to time and from region to another around the globe (Doreau et al. 2012). Jordan has arid and semi-arid climate and its environmental conditions are harsh. The variation in hydrological parameters such as evaporation, rainfall and runoff, is high during the year (Jaber and Mohsen 2001). The country is ranked among the poorest countries in the world in terms of water scarcity with annual per capita fresh water share of 145 m^3, which is extremely below the international water poverty line of 500 m^3 per year (Rijsberman 2006; Ministry of Water and Irrigation 2009). By the year of 2025, while water resources are limited and population in Jordan is expected to rise, per capita water supply is expected to fall to only 91 m^3/year (Hadadin et al. 2010). Jordan's water resources depend on rainfall which is scarce and unevenly distributed during the winter season and over the country. In the country, the annual renewable water resource was estimated at about 750

million cubic meters (Mohsen 2007). High percentage of the total amount of water in Jordan is lost due to evapotranspiration, which affects water availability (Hadadin et al. 2010).

In addition, population growth and economic development are increasing the demand on the available water resources, which affect not only the quantity, but also the quality of water resources (Hadadin et al. 2010). The different sources of pollution and the over-extraction of groundwater resources impose a major constraint on the sustainability of water resources and deterioration of their quality (Haddadin 2002; Mohsen 2007). Climate change is also expected to have significant impacts on water supplies and agricultural production over the country (Al-Bakri et al. 2013). Due to the impact of climate change, temperature is becoming higher, and rainfall lower, irregular and water availability limited.

The water requirements of domestic animals vary between species and breeds. Moreover, water requirement may vary greatly depending on the animal weight, physiological state, level of activity, type of diet, water quality, and environmental temperature (Schlink et al. 2010).

Water scarcity, intermittent rainfall and the sparse vegetation of poor quality are among the major constraints limiting goats' productivity (King 1983). The existence of high numbers of goats in harsh environmental conditions of the arid regions of the world is an indicator for their adaptive capacity. Goats are more drought-tolerant species among major livestock in the dry regions of the tropics (Silanikove 2000). Indigenous small ruminants like goats are able to thrive under extreme temperatures and shortage of water through their behavioural, morphological and physiological adaptations (Jaber et al. 2013).

Water stress tolerance of goats have been investigated and several studies have linked lowered feed intake rate, performance and body weight loss to the degree of dehydration and/or watering intervals among various goat breeds (Adogla-Bessa and Aganga 2000; Alamer 2006; Casamassima et al. 2008; Alamer 2009; Abdelatif et al. 2010; Abioja et al. 2010; Qinisa et al. 2011; Jaber et al. 2014).

The variation of provision and access of good quality drinking water between the seasons, agro-ecological zone and production systems could have a significant effect on livestock production, productive performance, health and the economic performance and thus profitability of goat enterprises either directly or indirectly. In arid and semi-arid regions where extensive production systems are dominating, the farmers might face the problem of provision and access of enough quantity of good quality drinking water, especially during the hot dry season. Therefore, determining the capacity of certain indigenous goat breeds to cope with water supply restricted in quality and quantity may prove a comparative advantage compared to non-adapted breeds. Due to globally decreasing availability of water, regionally accentuated by climatic change impact, distinguishing between indigenous goat breeds in adaptation to poor water availability is important for sustainable goat production and conservation of indigenous genotypes.

Understanding of the effects of water scarcity and water quality on the performance of different goat breeds under semi-arid environment in Jordan is important to improve goat production and the livelihoods of farmers who depend on goats. In Jordan, water availability, quality and the economic implications of water use for livestock have not been highlighted in literature. Moreover, water availability and quality also have not been considered in previous studies as potentially limiting factor to ensure productivity and performance of goats.

To encompass dry climatic conditions in order to assess the water availability and quality and relate it to the performance of different goat breeds, this study was conducted in two different agro-ecological zones in the Karak Governorate in southern Jordan. This study aimed: (1) to evaluate the seasonal availability, accessibility and utilization of goats' drinking water sources in different production systems of two agro-ecological zones in the Karak Governorate in southern Jordan, (2) to assess the quality of goats' drinking water sources, (3) to investigate the perception of farmers about (a) water quality and water availability, (b) the effects of water restrictions (quantity and quality) on goat production, and (c) breed differences with respect to their tolerance to water

restrictions and production, and (4) to assess the productive and economic performance of goats under different production systems and conditions of water availability with emphasis on water as a core element.

To achieve these general objectives, the following specific objectives were followed:

(a) assess the seasonal patterns of water sources utilization by goats,

(b) assess the goat production constraints with emphasis on water use,

(c) assess the seasonal compliance of water quality used for goats based on physicochemical parameters,

(d) investigate the perception of farmers about water sources quality used for goats,

(e) investigate the potential impact of conditions of water availability on the performance of goat breeds,

(f) examine the economic performance of goat production systems and factors affecting the profitability.

1.2 Study methodology and framework

The study was carried out in the Karak Governorate, located 120 km south-west of Amman, the capital of Jordan. The study region was purposively selected to encompass dry climatic conditions in order to assess the effect of water availability and quality on the performance of different goat breeds. The annual rainfall is relatively lower while the average temperature is slightly higher in the southern than in the northern part of the country. The study area was subdivided into two agro-ecological zones: the mountain zone (MZ) and the semi-desert zone (SDZ). The annual rainfall in the study area ranged from 33 to 393 mm in the mountain zone (Rabbah station) and from 59 to 116 mm in the semi-desert zone (Qutraneh station) during the period from 2006 to 2012.

Jordan's water resources are composed of surface water, groundwater and reclaimed wastewater (Hussein et al. 2005). Groundwater forms the largest contribution (Arabiyat 2005). In general, the study area is characterized by availability of different water sources and their distribution varies

between zones. Based on the secondary data obtained from the water and irrigation office in Karak Governorate, there are 41 functional and non-functional boreholes in the study area in addition to a few privately owned boreholes, which are sometimes used for selling the water to livestock owners. Large water storage structures known as mini-dams and hafa'ir (off-wadi storage ponds) have been built in the study area particularly in the semi-desert zone as an off-farm strategy to harvest rain water during the rainy season.

Three goat production systems were distinguished in the study area: nomadic, sedentary and transhumant (semi-sedentary) systems. The transhumant system is the dominant goat production system. The classification of pastoral production systems was based on the degree of herd movement. In nomadic production systems, farmers lack permanent settlements and their livelihood depends on livestock, the animals are reared under extensive management with high movement, restricted access to water and supplementary feeding, and longer grazing. The transhumant framers have a permanent base and the system is characterized by seasonal movements between complementary ecological zones to take advantage of grazing on the vegetation during late winter and early spring and grazing on stubbles or on barley or wheat crop failures in cultivated areas during summer. The basic pattern of transhumant system movements in the study area has been a west-to-east movement in which farmers and their herds migrate from the more arid region in the east to more humid regions in the west during summer and in the opposite direction during the winter. In the sedentary (agro-pastoral) system, animals' movement is restricted to certain distances around the farm base and is characterized by more supplementary feeding and access to water.

The methodological approach of the study involved the use of different elements, including (1) a questionnaire survey cross-checked by focus group discussions, (2) assessment of physicochemical parameters of water sources used for goats drinking, (3) on-farm performance recording of goat breeds, (4) secondary data for the amount of rainfall in the two agro-ecological zones, water prices and number of goats and goat keepers in study area.

For the questionnaire survey that was conducted in the study area from the beginning of June to the end of October 2012, a multistage sampling technique was applied to select goat keepers for the individual farmer interviews. A total of 120 respondents (59 in mountain zone and 61 in semi-desert zone) were purposively selected for interviews using a structured questionnaire consisting of questions regarding socio-economic profiles, goat production constraints, the availability of goats drinking water resources, perceived water quality and utilization, animal productivity, input and output economic production parameters. In addition to the questionnaire survey, three separate focus group discussions were conducted across the two agro-ecological zones (two in mountain zone and one in semi-desert zone) in order to cross-check the individual farmer responses from the single interviews and to get deeper information about the following research topics: the main constraints and challenges of goat production, sites and kinds of drinking water sources available for goats, the main water problems (quality and quantity), coping with water problems, the common goat diseases and breed differences regarding their tolerance to water stress.

For on-farm performance recording, 30 goat owners were randomly selected in each of the two agro-ecological zone and on average 5 young and 4 adult goats of each flock were randomly selected on each farm (n=1021). Each farm was visited twice . At the first visit the body weight (BW), body condition score (BCS), age, sex and breed type of each goat were recorded. At the second visit one month later, goats were again randomly selected and the same measurements again recorded.

For the assessment of physicochemical parameters of water sources, water samples were collected in June 2012 (mid of dry season (DS)) and October 2012 (end of DS). In total, 68 of water samples from 17 water sources including 9 boreholes (6 and 3 sources in MZ and SDZ, respectively), 6 springs (only in MZ) and 2 wadis (only in MZ) were sampled. During the mid of DS three replicates of water samples per source were collected with one week intervals. Physicochemical parameters, namely electrical conductivity (EC), total dissolved solids (TDS), pH, turbidity,

hydrogen carbonate (HCO_3^-), chloride (Cl^-), nitrate (NO_3^-), sulphate (SO_4^{2-}), sodium (Na^+), potassium (K^+), magnesium (Mg^{2+}), calcium (Ca^{2+}) and $CaCO_3$, the latter as an indicator for water hardness, of selected water sources, were analyzed during both sampling periods. Heavy metals, namely chromium (Cr^{2+}), copper (Cu^{2+}), lead (Pb^{2+}), manganese (Mn^{2+}), nickel (Ni^{2+}), cadmium (Cd^{2+}), iron (Fe^{2+}) and zinc (Zn^{2+}) were analyzed only during the first period. Parameters were selected supposing that their levels largely determine the quality of water for livestock, and in turn, the animal performance and to encompass salinity which may have resulted from over-extraction of ground water.

For secondary data, a list of all goat keepers in each administrative unit of the study area was obtained from officials of the Ministry of Agriculture to select goat keepers for the single farmer interviews. Monthly rainfall data were obtained from the Meteorological Department of Jordan during the period from 2010 to 2012 for mountain and semi-desert to link monthly water shortage in the study area as perceived by goat owners to the average monthly rainfall distribution. Secondary data for water and feed prices, and water-related goat diseases were obtained from the water, agricultural, and veterinary offices in the study area.

1.3 Structure of the thesis

Subsequent to chapter 1 that presents the general introduction, chapter 2 (“Drinking water sources, availability, quality, access and utilization for goats in the Karak Governorate, Jordan”) was accepted for publication in Tropical Animal Health and Production. This chapter describes the seasonal drinking water sources, availability, access and utilization for goats. Goat production constraints with emphasise on water use, the seasonal suitability of water quality and farmers’ perception on water sources quality used for goats are also highlighted in this chapter. Data collection methods of this chapter comprised interviews with purposively selected farmers and quality assessment of water sources.

Chapter 3 ("Goat breeds performance under different farming systems and conditions of water availability in the Karak Governorate, Jordan") was accepted for publication in Jordan Journal of Agricultural Sciences. This chapter investigates the effect of water availability on the performance of goats by taking into considration the effect of factors such as agro-ecological zone, production system, season period, and watering frequency on the performance of goats. Moreover, the socio-economic characteristics of farmers are presented for the agro-ecological zones. In this chapter, individual interviews with purposively selected farmers, group discussions and on farm-data recording were mainly used for data collection.

Chapter 4 ("A comparative economic analysis of goat production systems in Jordan with an emphasis on water use") was accepted for publication in Livestock Research for Rural Development. By using individual interviews with purposively selected farmers and secondary data, this chapter of the thesis examines the economic performance of goat production in different production systems and investigates the economic success of goat production by calculating Gross Margin (GM) and Net Benefit (NB).

In chapter 5 ("General discussion"), all research results from the previous chapters were integrated and discussed. This chapter also highlights the strength and shortcomings in the methodological approaches used in the study and finishes with a general conclusion of the thesis. Finally, in chapter 6 and chapter 7 the whole research with emphasis on the major research findings are summarized in English and German, respectively.

1.4 References

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