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Christian-Albrechts-Universität zu Kiel

**Nutritional, ecological, and economic evaluation of dairy farming
systems and feeding strategies in semi-arid environments**

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Chapter one

Introduction

1.1 Problem statement

Agricultural and rural populations consist of 44.2% of inhabitants in Middle Eastern countries (AOAD 2007). Thus, the livelihood and social welfare of the largest segment of population in the region are still deeply rooted in agriculture and the rural economy. Consequently, the agricultural sector has a potentially significant role to play in achieving higher sustained growth and economic development in the Middle East and North Africa (MENA) region.

Milk and dairy products are very important sources of food in the Middle East due to their nutritional value. They also contribute strongly in the subsistence of a wide number of producers and families in the peri-urban and rural areas (AOAD, 2003). In the last decades, the consumption of dairy products increased at high rates.

In 2010, the per capita consumption of dairy products in the MENA was estimated at 120 kg milk per capita (IFCN, 2011). From the demand side, Alqaisi (2011) reported that around 42 million tons of milk was consumed in the MENA region in 2010. A deficit of 12 million tons was estimated for the same year, with a self-sufficiency of 75% in milk production for the whole region. From the production side, milk production in 2010 has reached 30 million tons.

During the period between 2005 and 2010, per capita consumption increased from 100 to 120 kg milk per capita. Increased consumption of dairy products was mainly driven by the increasing per capita income and a fast growing population, while the growth in national consumption was driven by population growth. In the same period, the gap between milk production and consumption increased from 6 to 12 million tons. This wider gap was driven by the lower production growth compared to the growth in consumption. The per capita consumption of milk is still lower than in the industrial world, but much higher than in most African, Asian and Latin American countries.

For example, increased consumption of dairy products was mainly influenced by the increasing per capita income and a fast growing population of 2.5%, 2.9% and 3.5% in Syria, Jordan and Saudi Arabia, respectively, creating a growing effective demand (FAO 2003; FAO 2005; MEP 2006).

The Middle East is considered as one of the world's largest importers of dairy products from Europe, the United States and New Zealand. The region also has a strong annual growth rate of 4.6% in dairy imports (EII 2002). To reduce the region's dependence on imported dairy products, many countries started to promote their local dairy sectors. Governments focused on modern capital-intensive large scale dairy production to supply urban consumers. This kind of production is highly dependent on huge imports of concentrate feed and fodders, particularly in the arid and semi-arid areas of the Middle East.

Despite the importation of improved breeds, technology and feedstuff, regional self-sufficiency has not yet been reached. However, one of the limiting factors for the development in dairy production was the regional shortage of water and land resources.

The region is endowed with limited arable land, estimated at 53 million hectares in the year 2005, with a per capita arable land of only 0.17 hectares (Siam, 2009). On the other hand, renewable fresh water resource flow amounts to 228 billion cubic metres of water annually in the MENA region, representing 0.5% of total fresh water flows on the earth.

It's well known that semi-arid and arid regions are characterized by low rainfall that results in low primary production and forage quality (Pascual et al., 2000). Grain production and grazing on pasture are limited in such areas because of the extreme shortage in water, arable land and recurrent drought. The rangelands in many countries are not sufficient for dairy cattle due to the low quality and the seasonality (ACSAD 1997). To maintain the development in milk production in MENA countries, natural resources from water and land should be secured to match the growth in milk production. Considering the shortage of these resources, the availability of pasture lands, adequate fodder and feed quantities that fulfil the needs of the sector are limited. As a result, farmers adapt to these adverse circumstances by importing the required feed resources from overseas.

For example, in Jordan, in spite the importation of feed resources at high prices, the efficiency of utilisation of available feed is constrained by failure to use recommended management practices that could improve animal output. On the other hand, there are alternative feed

resources for dairy farming which are unused, undeveloped and poorly utilised. Making available these resources could contribute to increasing the output of dairy farming systems. For instance, food industry by-products such as brewery grains, potato by-products, sesame meal in addition to other by-products when better utilised could make a substantial contribution to the basal feeds available to the dairy animals. These resources, if used in an appropriate way, may reduce the cost of milk production, thus making dairying more competitive, and could reduce greenhouse gas (GHG) emissions as compared to traditional farming systems.

From an economic point of view, feed cost is the single most important factor affecting the profitability of dairy farms. The cost of feeding usually accounts for more than 50% of the total cost of milk production (Hemme, 2010). Several analyses have shown that the economic prosperity and environmental impacts of dairy farming are driven by feed consumption and the level of management of dairy farms (Oishi, et al., 2011; Bampidis and Robinson, 2006).

Generally, there exist three major problems associated with importing basal animal feeds from overseas. **Firstly**, feed prices are volatile and have fluctuated greatly during the last ten years. In this regard, global feed prices have increased by 150% between year 2006 and 2011 (Hemme, 2011). **Secondly**, this increase in feed prices was associated with increasing cost of milk production, which means losing the competitive advantages of milk production in the region. **Thirdly**, from an ecological point of view, importing feeds from overseas has contributed to global emissions of greenhouse gases (GHGs) due to the energy consumption and input factors related to feed production.

Until now, little research has been conducted to evaluate the nutritional, ecological and economic perspectives of dairy farming systems in semi-arid regions of the Middle East and North Africa.

This study reviews previous literature on dairy farming systems in three countries in the Middle East and provides an up-to-date description of farming systems in these countries. Due to the common dairy farming problems in the region, the study focuses on one country (Jordan) for an in-depth evaluation of the nutritional, ecological and economic aspects of dairy farming systems and feeding programs. It is hoped that many of the findings and insights generated for Jordan can be applied to improve milk production systems in other countries of the Middle East region.

1.2 Research objectives

In view of the importance of the above mentioned problems in the dairy farming systems and their impact on the national economy, this study was initiated to find solutions for the deficiency in feed resources and feeding management programs.

The main research question in this study is: How can the nutritional, ecological, and economic situation of dairy farming systems in Jordan be improved?

The key objective of this research project is to evaluate the nutritional, ecological and economic aspects of the dairy farming systems and feeding strategies in Jordan. Another overarching objective is to assess the sensitivity of semi-arid dairy production systems to changes in feed prices and feed items.

The specific objectives of this thesis are to:

1. assess the state-of-the-art of dairy farming systems in the Middle East and to analyse dairy sector developments in the region;
2. analyse the drivers of dairy development in Jordan;
3. evaluate the nutritional and ecological aspects of dairy feeding systems in Jordan; and
4. assess the ecological and the economic impact of feeding alternative feed resources under different feeding scenarios in the Jordanian dairy farming systems.

1.3 Study Area and Approach

Within the Middle East, countries included in the study are: Jordan, Syria and Saudi Arabia. These countries were selected to analyse the development in the Middle East dairy sector and to describe similarities and variation in dairy farming systems. These countries are located in the same geographical region and have common dairy farming practices, similar cow breeds and similar challenges in water and land resources. Additionally, they are the most important countries in terms of the growth in milk production in the region.

A detailed analysis of dairy farming systems and feeding programs was carried out for Jordan as an example for the region. Conclusions were derived from the findings which could contribute in the further development of dairy farming systems in other countries in the Middle East.

Jordan is a small country and has a total surface area of 89.2 thousand km² with about 90% of this area considered as semi-arid (MOA, 2001). The country is divided into three main

geographical areas with different climates: the highlands, the Jordan Valley and the eastern desert. Based on statistics from the Ministry of Agriculture (2006), the Jordanian livestock population consists of 2 million sheep, 450 thousand goats and 50 thousand milking (dairy) cows (MOA 2006). Jordanian total milk production is estimated at 260 thousand tons in 2006. The average dairy farm is estimated to keep cows with an average milk yield of 5.4 tons per cow and year. Holstein Friesian is the dominant breed and represents about 96% of the national dairy herd.

Three regions were used for this study, Al-Duhlel, the highland region and the Jordan valley. Al-Duhlel area is located in the east of Jordan and produces more than 55% of national milk. Intensive production systems are dominant in this region, where the average annual rainfall is less than 200 mm per annum. The highland region has an average annual rainfall of about 300 mm, dairy farm intensities are less than in the Al- Duhlel and milk production represent about 35 % of national milk produced. The Jordan valley has an average annual rainfall of less than 200 mm. In this region mainly small scale dairy farming is practised. Two major production systems exist in Jordan, the extensive and intensive dairy farming.

The methodological approach of data collection and analysis used in this study is a combination of several methods (figure 1.1).

The research program consisted of four phases as follows: 1) Data collection for dairy sector analysis, 2) farm selection and interviews with farmers, 3) collection and analysis of physical samples, 4) collection and analysis of farm data (using the model TIPICAL). Data on dairy sector developments and farming systems were collected and analysed using the IFCN dairy sector model. This model possesses data on milk industry in 90 countries world-wide and can aggregate regional developments of milk production and generate drivers for milk developments in a country or a region. In addition, it analyses trends and enables description of the historical growth in milk production, consumption, demand and the time series analysis of milk and feed prices at national and regional levels.

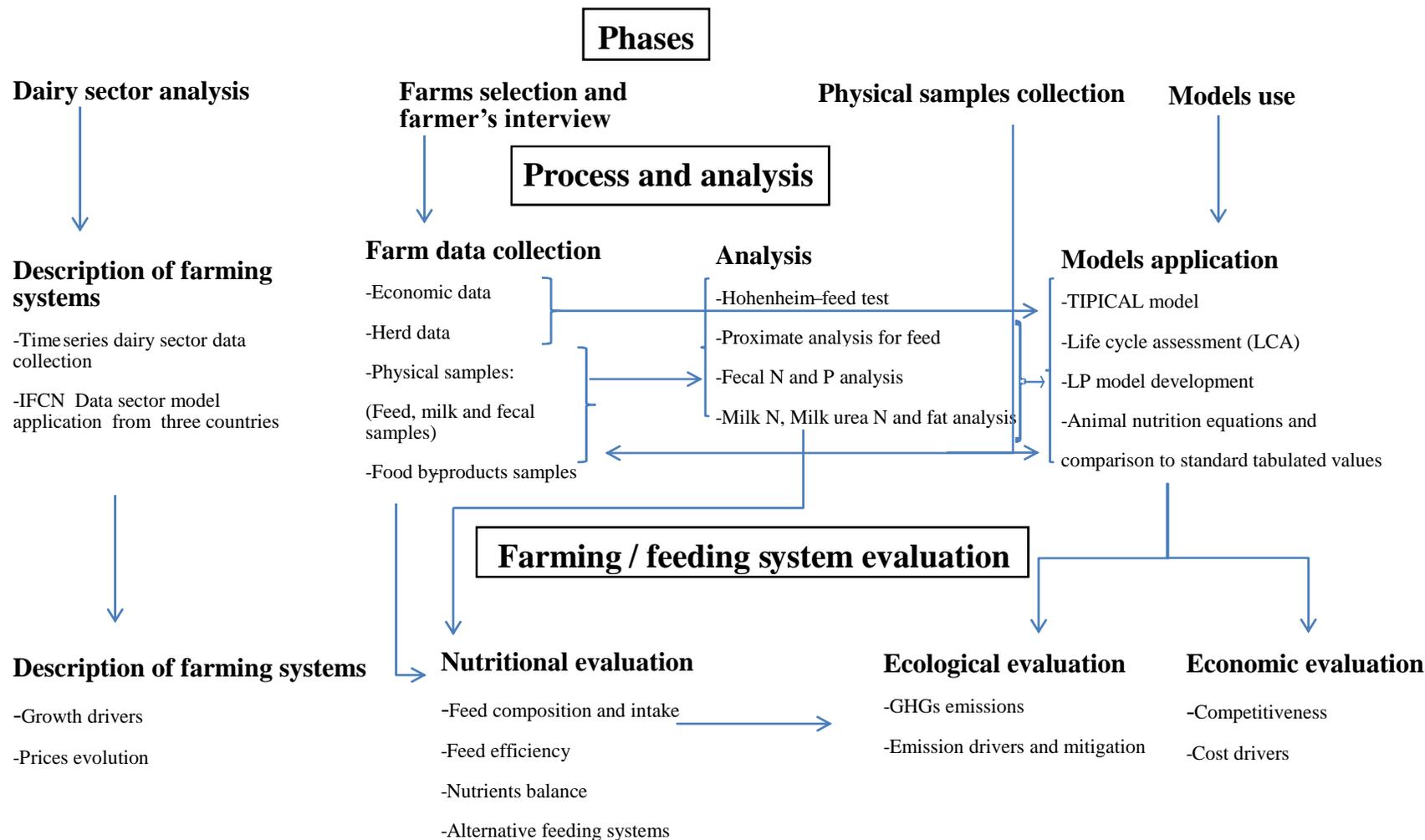
The evaluation of dairy farming systems and feeding programs was studied via farm data collection from the field. A wide range of data was collected concerning the farming system, feeding management, herd management, animal performance and economic farm data, as well as data on feed types, feed intake, milk production and fecal excretion (see figure 1.1). The phases of system evaluation were based on both actual farm data and results of laboratory

analyses and in vitro techniques. These provide a more accurate evaluation on input resources (feed) and outputs (milk and fecal) compared to other approaches which are based on predicted values from tabulated figures on feed composition and animal performance. Additionally, animal intake of feed ingredients was compared to standard tabulated figures for **nutritional evaluation** purposes. To evaluate possible alternative feeding scenarios, the feed values of food industry by-products and their market prices were introduced into a linear programming model developed to generate least cost rations. The **economic evaluation** of dairy farming systems and alternative feeding systems was done using the TIPI-CAL model (Technology Impact, Policy Impact Calculations model) of the International Farm Comparison Network (IFCN). TIPI-CAL calculates for each typical farm the cost of milk production per 100 kg of milk and identifies the drivers for cost differences between dairy farming systems. This model is a think tool for better understanding farming systems. This study applies the concept of typical farms. A typical farm represents the most common farm type within a production system which has an average management and performance level and produces the largest proportion of milk in a region. Typical farms were built and validated by a panel of dairy experts.

TIPI-CAL model has recently been extended with a partial life cycle assessment model to estimate greenhouse gases (GHGs) emissions at the farm level and convert them to their CO₂ equivalents. This model extension was used in the current study for the **ecological evaluation** of dairy farming systems.

Given that model applications in this study were based on physical data, and chemical analysis of the collected samples, the results describe the real situation on the farm and provide recommendations to develop feeding systems from nutritional, ecological and economic points of view on national and regional levels.

Figure 1.1 Schematic presentations of different methodological approaches of data collection and analysis used in the study



1.4 Outline of the thesis

Chapter two titled “Current situation and the development of the dairy industry in Jordan, Saudi Arabia and Syria” analyses the development in dairy production, demand and consumption patterns in three countries in the Middle East region. It also attempts to investigate the drivers for the development of milk production, consumption and trade in the region.

Chapter three, titled “Development of milk production and the dairy industry in Jordan” deeply focuses on the evolution of Jordanian milk production. The chapter includes a macro analysis of milk and feed prices and their development during the last ten years. It also provides in-depth insights into dairy farming systems in Jordan and the available feed resources. **Chapter four** titled “Nutritional and ecological evaluation of dairy farming systems based on concentrate feeding regimes in semi-arid environment of Jordan” focuses on the dairy feeding systems that exist in Jordan. The study is based on nutritional analyses in nine dairy farms of different scale of production and management. It shows the feed resources used on dairy farms, the quantity and the quality of the feed used, and their nutritional impact on the efficiency and performance of the lactating cows. The study also includes an estimation of GHG emissions at farm level. **Chapter five** titled “Evaluating the use of food industry by-products to optimize the economic performance and mitigate GHG emissions of dairy farming systems in semi-arid areas: the case of Jordan” analyses the status-quo of three typical dairy farms in terms of: the typical feed ration used, the cost of milk production, and GHG emissions in each farming system. It also discusses scenarios showing the potential of using alternative feeding systems and their economic and ecological impacts. **Chapter six** is a general discussion of all chapters presented in this thesis. It discusses critically the major findings and their implications on dairy development in Jordan and in the Middle East region.

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Chapter Two

Current situation and the development of the dairy industry in Jordan, Saudi Arabia and Syria

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Abstract

The development of the dairy industry plays an important role in the economy of Middle Eastern countries. Judged by its growth rate, the dairy industry is viewed as one of the most progressive food industries in the Middle East. During the early 70's, countries established executive programs to promote dairy farming, the major objective was to attain self-sufficiency in milk production. A massive investment was set up for importing top class cattle, complying with top industry operating standards, and a simultaneous introduction of the latest technology in processing, packaging and distributing. Milk production has grown tremendously at rates of 6.6% and 4.9% in Syria and Saudi Arabia, respectively between 2002 and 2007, which resulted in these nations being almost self-sufficient. Regarding Jordan, milk production has not yet met this target. An excessive growth in the dairy industry is quite noticeable in this region with an expanding capacity for exports. The aim of this study is to show the most recent trends and future prospects of the dairy industries in Syria, Saudi Arabia and Jordan. It also attempts to investigate the drivers for the development of milk production, consumption and trade in the region.

Keywords: Dairy industry, Market, Dairy products, Processing, Milk production

2.1 Introduction

Despite the prominence of petroleum in the region, agriculture still plays a prominent role to most economies in the Middle East (DeRosa 1997). Agricultural and rural populations consist of 44.2% of inhabitants in Middle Eastern countries (AOAD 2007). Thus, the livelihood and social welfare of the largest segments of population in the region are still deeply rooted in agriculture and the rural economy. Consequently, the agricultural sector has a potentially significant role to play in achieving higher sustained growth and economic development in the Middle East.

According to Moran (2005), dairying originated from the Middle East, between 7000 and 6000 BC, and from there milk consumption spread to the Mediterranean, Europe, Indian subcontinent, and to other parts of the world.

Milk and dairy products are very important sources of food in the Middle East due to their nutritional value. It is also the cheapest source of animal protein and contributes strongly in the subsistence of a wide number of producers and families in the peri-urban and rural areas (AOAD 2003). In the last decades, the consumption of dairy products increased at extremely high rates. Currently, the per capita consumption of dairy products is 117, 78, and 55 kg in Syria, Jordan and Saudi Arabia respectively (Alammouri 2006; MOA 2006; NCB 2006), see the map in figure 2.1. This is still lower than in the industrial world, but much higher than in most African, Asian and Latin American countries. Increased consumption of dairy products was mainly influenced by the increasing per capita income and a fast growing population of 2.5%, 2.9% and 3.5% in Syria, Jordan and Saudi Arabia, respectively, creating a growing effective demand (FAO 2003a; FAO 2005; MEP 2006).

The Middle East is considered as one of the world's largest importers of dairy products from Europe, the United States and New Zealand. The region also has a strong growth rate of 4.6% in dairy imports (EII 2002). In 2005, about 11.206 million tons worth \$US 3.531 million were imported by the Arab world, despite the availability of agricultural resources required to achieve self-sufficiency in milk and dairy products (Abdel Fatah and Hassan 2008). To reduce the region's dependence on imported dairy products, many Middle Eastern countries started to promote their local dairy sectors. Governments focused on modern capital-intensive large scale dairy production to supply the urban consumers. This kind of production is highly dependent on huge imports of concentrate feed and fodders, particularly in the arid and semi-arid areas of the Middle East.

In these countries, the dairy sub-sector is one of the most central components of the livestock sector. Dairy cow population is estimated at 773.000, 50.000 and 111.600 cows for Syria, Jordan, and Saudi Arabia respectively (NCAP 2008; MOA 2006; FAO 2008). Figure 2.1 shows milk production from sheep, goat, cows and camels.

Figure 2.1: Map showing the main milk producing areas in Jordan, Syria, and Saudi Arabia



Despite the importation of improved breeds, technology and feedstuff, self-sufficiency has not yet been attained in Jordan and Saudi Arabia. However, the situation is different in Syria, where the country is almost self-sufficient in terms of milk and dairy products.

During the last decades, local governments have motivated the dairy industry. Syria, Jordan and Saudi Arabia have imported high yielding dairy cows from USA, Europe, Australia and other countries. In Saudi Arabia which has an arid climate, the last ten years may be viewed as the highest period of growth and development in dairy production in the history of the Middle Eastern countries. During this period, the dairy industry established itself as one of the most progressive food industries in this region. This industry has contributed to the regional economy by reducing imports and expanding its exports. Due to the long tradition of consuming milk and milk products in the Middle East, the potential for further development in the dairy sector of this region is greatly possible.

2.2 Dairy sectors development

An analysis was made using the International Farm Comparison Network (IFCN) Dairy Sector Model, to investigate evolution of the dairy sectors in Syria, Jordan and Saudi Arabia. This model is a tool which analyses dairy sector developments in individual countries, aggregated form for specific regions and worldwide from the year 1996 till date. Results are shown in table 2.1. In spite of the lower milk productivity per cow in Syria, milk production is growing faster (6.6%) than in Saudi Arabia (4.9%) and Jordan (5.4%). This could be attributed to the growth in the dairy cow number in Syria by an average of 5.4% throughout the period of 2002 – 2007; while in Saudi Arabia it was lower, with an average growth rate of 1.5% for the same period. However, average dairy cow productivity is much higher in Saudi Arabia compared to Syria. In Almarai and Al-Safi farms located in Saudi Arabia, cows produce more than 10.000 litres of milk per cow per year, while average dairy cows in Syria produce about 1.600 litres per cow per year.

A higher growth rate in milk consumption was noticed in Jordan than in Syria and Saudi Arabia, during the period 2002-2007. The driver for this is the increase in per capita consumption of 6.7% annually in Jordan compared to 1.9% and 0.3% respectively in Syria and Saudi Arabia. The growth consumption of dairy products was highest in Jordan (9.5%) and lowest in Saudi Arabia (2.8%) for the same period. Table 2.1 shows the annual regional changes in Syria, Jordan and Saudi Arabia throughout 2005-2008.

One of the major drivers for growth in the total consumption is the growth in Gross Domestic Products (GDP) and population. In Jordan and Saudi Arabia, growth in GDP was higher than in Syria, in spite the fact that the total consumption in Syria is higher than in Saudi Arabia.

There is a clear variation in the volume of milk delivered to dairy factories in 2007. In Syria, modern processing plants process only 5% of the produced milk, the rest is processed on-farm using traditional methods. Usually it is processed into yogurt, cheese, laban and labneh (FAO 2003a) see table 2.2 for typical dairy products explanations. In Jordan and Saudi Arabia milk delivered to dairy processing plants account for 94% and 95%, respectively, from the total milk produced. Unlike in Saudi Arabia and Jordan, dairy farming in Syria is predominantly driven by small-scale production systems with high on-farm consumption, meaning that milk production is mainly for subsistence. According to the International Trade Center (ITC 2008), both imports and exports are growing in all three countries in terms of volume and value in different rates.

Milk production from small ruminants in Syria and Jordan

Milk production from sheep and goats is also growing in Syria and Jordan. In 2007 it was estimated at 873 and 96 thousand tons, respectively and was greatly lower in Jordan (20 - 32 thousand tons) due to the lower sheep and goat population (MOA 2007).

Cattle breeds in Syria and Jordan

Based on the FAO statistics (FAO 2003a) there are several cattle breeds used for milk production in Syria. The Friesian, local improved, local Akshi and local Shami cattle made up 15.4%, 66.07%, 17.4% and 1.1% of the total number of cattle and produce 25.8%, 67.6%, 5.6% and 0.9% of the total milk volume, respectively. The indigenous livestock breeds of Syria are well adapted to the arid conditions in the degraded steppe vegetation of the country (Bourn 2003)

There are two indigenous local breeds found in Jordan in addition to crossbred, Shami and Akashi (NCARE 2002). In 2007, local cows comprised only 4% of the total dairy cattle in Jordan (MOA 2007); farmers have replaced their local cows with high yielding Holstein Friesian cows.

2.3. Growth in milk production

In line with the rapid growth in population, there is an increasing demand for milk and milk products. Total milk produced in 2007 was estimated at 2.63, 0.28, and 1.34 million tons in Syria, Jordan and Saudi Arabia respectively (FAO 2008; Hemme 2008; MEP 2007). For Syria, self-sufficiency levels changed from 88% during the period of 1999-2003 reaching 93 % in 2006 (AOAD 2008). In Jordan, self-sufficiency has changed significantly from 35%, in 1980 to 57% in 2006 (MOA 1993; MOA 2006). In Saudi Arabia, the self-sufficiency was 53% in 2007 (Hemme 2008).

In Syria, dairy farms are scattered all over the country. About 60% of cow milk is delivered to urban markets by small-scale farms located in semi-urban areas. Milk transportation is done by a series of trailers. In Jordan and Saudi Arabia, most dairy farms are concentrated in one region and are highly capital intensive. In Syria, about 95% of dairy farms belong to small-scale extensive or mixed farming systems, while large farms only represent 5% of the total farms in the country, where the government owns 3% and the rest is owned by the private sector.

In the case of Jordan, currently, Holstein Friesian cows represent 96% of the total population of dairy cows in the country (MOA 2007). Milk is basically produced by intensive or semi-intensive dairy farming systems owned by private farms. About 52% of milk is produced by intensive dairy farms located in the Al-dhulel region of the eastern desert. In Jordan, there are only 605 dairy farms. The number of cows has also changed in Jordan; in 1981, Friesian dairy cows were 6.000 and by 2006, there were 50.000 dairy cows (MOA 2006).

Saudi milk production has increased from 165 thousand tons in 1970 to 1 million tons in 1999 reaching 1.34 million tons in 2007, with an annual growth rate of 4.9%. There are very few dairy farms in Saudi Arabia compared to Syria and Jordan, though the number of cows per farm is very big. Literature shows that the biggest dairy farm in the world named Al-Safi is located in Saudi Arabia (AL-Otaibi and Robenson 2002). Growth in milk yield per cow is highest in Saudi Arabia (3.3%) compared to Syria (1.2%) while this growth was negative (-0.1%) in Jordan.

The recent Saudi statistics show that there are only 30 big dairy farms in the country and most are large dairy cattle operations using modern capital intensive production and processing technology (MEP 2006). Many farms are located in Al-kharj area, near to the capital Riyadh. This area has a less humid climate which is more conducive for cattle rearing.

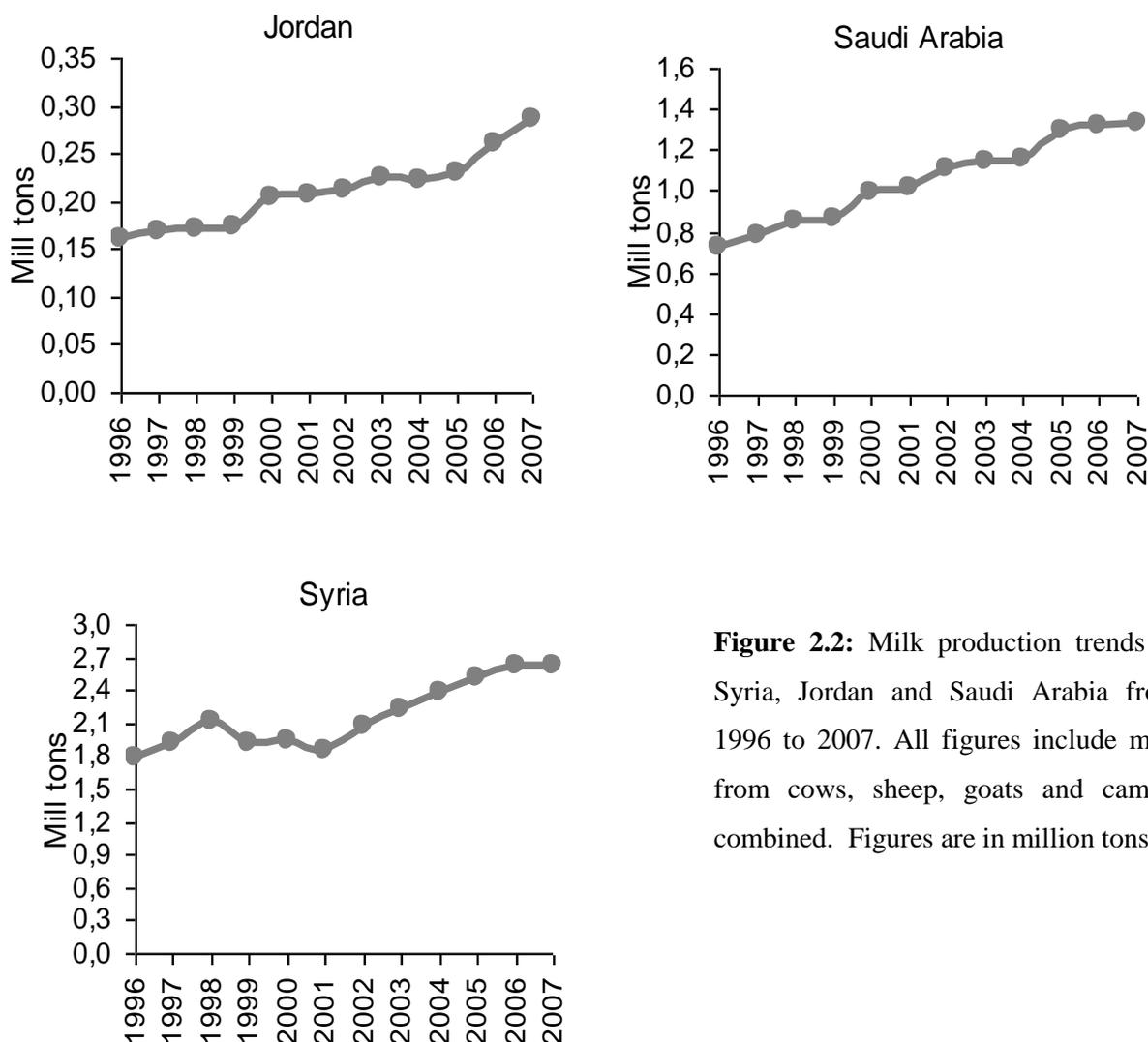


Figure 2.2: Milk production trends in Syria, Jordan and Saudi Arabia from 1996 to 2007. All figures include milk from cows, sheep, goats and camels combined. Figures are in million tons

2.4 The dairy industry

The industrial production of liquid milk has developed processing milk in the past two decades in Syria. There are two types of dairy processors: the public and the private dairy processors. There are 41 private dairy factories which are basically found in Damascus and Aleppo. With a total production capacity of 94.263 tonnes of milk per year, the production capacity of these dairies is about 30% of the total cow and goat milk production in Syria (Grad 2000; FAO 2003a; AOAD 2003). The country has three public dairy processors located in Damascus, Homs and Aleppo, having a production capacity of 44.500 tonnes milk per year (GOFI 2008). Their processing volumes are lower than their potential capacity (Grad 2000), though they are still using relatively old technologies. Milk in public dairies is processed to sterilized and pasteurized milk, ghee, butter, fruit-flavoured milk, Kashkaval cheese, Akawi cheese, other processed cheese and yogurt. In winter, when the supply of milk decreases, the dairy factories shift to use imported powdered milk in order to meet the market needs and to keep producing continuously during the year.

Table 2.1: Annual changes in the dairy sectors in Syria, Jordan and Saudi Arabia from 2002 to 2007

Item	Syria	Jordan	Saudi Arabia
Milk production (%)	6.6	5.4	4.9
Cow number (%)	5.4	5.5	1.5
Milk yield per cow (%)	1.2	-0.1	3.3
Total consumption (%)	4.7	9.5	2.8
Population (%)	2.5	3.5	2.9
GDP per capita (%)	2.72	4.97	4.08
Per capita consumption (%)	1.9	6.7	0.3
Milk delivered to dairy in 2007 (%)	5.0	94	95
Per capita milk consumption (Kg/year/capita)	117	78	55.1
Self sufficiency in milk production in 2007 (%)	93	57	53
Population (million people)	19.7	5.8	24.3
Exports million US\$ in 2006	124	62.3	403
Imports million US\$ in 2006	113	123	1.020

Adapted from Hemme (2008)

The leading private processing companies are: Karam, Syrian Finish Company, Al Mourouje, and Syrian-Saudi Company. These companies produce cheese, sterilized and pasteurized milk, yogurt, labneh and other products.

Unlike in Syria, the Jordanian modern dairy factories use both fresh and powdered milk. About 95% of produced milk is delivered to dairy factories of which 52% is provided by the Dairy Breeders Association located in the eastern part of the country. In Jordan, there are 21 modern dairy factories, which are located mostly in the regions of milk production and the surrounding of the big cities. These

factories process fresh milk, which comes from dairy farms as well as powdered milk into yogurt, laban, labaneh, cream, Baladi cheese, flavoured-yogurt, ice cream, pasteurized milk, butter and Jameed (see Table 2.2). The three biggest companies processing milk in Jordan are Hammodeh dairy, Danish-Jordanian dairy, and Teeba (Alqaisi et al 2009).

From national statistics, it is clear that the informal sector is playing an important role in milk production and processing in Syria. The dairy processing plants in both Saudi Arabia and Jordan process most of the milk produced in the country. A very little quantity of milk is consumed on the farms or by the producing families. In Saudi Arabia, the dairy industry is more capital intensive than in Syria and Jordan. Most of the dairy companies have their own plants and distributing systems. The full range of pasteurized fresh dairy products of the Western countries is equally available in Saudi Arabia (Fishwick 2004). In Saudi Arabia, the three major producers of liquid milk are Almarai, Al-Safi and NADEC. These companies account for almost all the sales of fresh, pasteurized milk, and have nearly 90% of the market of Laban and 94% of the market of yogurt (AL-Otaibi and Robenson, 2002). They produce their own fresh milk and have their own dairy farms, while other milk producers such as Jamjoom import large quantities of powdered milk. There are other factories which collect raw milk from farms scattered throughout the country. There are approximately 16 dairy factories in the Riyadh province, 14 in the eastern province and eight in the western region. The rest are scattered throughout other parts of the country.

Dairy imports

The Consumption of milk and dairy products has been increasing during the last years in all countries. In Syria the increase in demand has led to an increase in the importation of dairy products. In terms of volume, Syrian imports of dairy products changed from 19.000 tons in 2000 increasing up to 45.000 tons in 2006. Syrian imports of dairy products traditionally consist of powdered milk, butter, and cheese. Syria imports milk powder from France, New Zealand, the Netherlands, Poland, Maldives and Belgium. Jordan imported 21.363 tons of different dairy products in 2006. Jameed demand is growing tremendously as it is used in social activities and has a high consumer preference. Jameed industry has also developed recently in Jordan in the solid and liquid forms. Jordanian imports of Jameed and cheese are expected to grow from 2008 onwards. The growth rate of dairy imports to Jordan has increased by 4% throughout the period 1996 – 2006. In 2006, dairy import volumes decreased by 3% in Jordan, and by 9% in Saudi Arabia.

Growth in Saudi domestic market demand is tremendously higher than in Syria and Jordan. Saudi Arabia is a relatively open destination for international trade in dairy products and is traditionally a net importer of dairy products. In terms of volume, dairy imports increased to 98% from 179.000 tons in 1999 to 354.000 tons in 2005, with an average growth rate of 10.3 % between 1999 and 2005.

It is also observed that there were no yogurt imports to Saudi Arabia in 2005. There is a trend towards self-sufficiency for yogurt production and probably exportation.

In terms of value, Syrian imports of dairy products rose from US\$ 49 million in 2003 to US\$ 113 million in 2006 (AOAD 2008; ITC 2008). The Saudi imports expanded almost threefold in the last ten years to 2003 (NCB 2004). Imports rose by 110% from US\$ 453 million in 1999 to US\$ 1.02 billion in 2006 (ITC 2008). NCB (2006) reported that in 2006, dairy import value grew up by 15% and estimated that for 2008, dairy imports will reach US\$ 1.3 billion. The imports were much lower in Jordan as compared to Saudi Arabia where imports were US\$123 million in 2006, and having an estimated growth rate of 15%.

Dairy exports

Dairy exports also grew considerably in all countries. Syrian exports of dairy products have slowly expanded in the last years in both monetary terms (US-\$) and in volume as well. In terms of volume, exports increased from 5.000 tons in 2000 to 16.000 tons in 2006. Major exported dairy products are Jammed and white cultured cheese. The level of exports is still very low compared to Saudi Arabia where dairy exports are increasing at a higher rate. This might be because of the small quantities that are processed by the public and private dairy factories in Syria with moderate infrastructure and technology and higher on-farm consumption levels, with lower percentage of milk delivered to dairy. In Saudi Arabia, the processing units are more developed and sophisticated technology is used with higher percentage of milk delivered to dairy. Jordanian exports of dairy products are increasing steadily. The most common dairy products exported from Jordan are Jameed and white cheese.

Saudi exports of dairy products have noticed a rapid expansion between 1995 and 2006 in terms of volume and value. The most common dairy products exported are unsweetened milk, cream, sweetened milk, yogurt, laban, other milk cream, fresh cheese, fresh fermented cheese, solid and semi-solid cheese, low-fat solid milk and other cheese. The main destinations of these exports are the neighbouring gulf countries, Iraq, Jordan, Lebanon, Yemen and selected African markets.

In terms of volume, Saudi exports of dairy products expanded nearly six-fold during the period of 1992 - 2002 (NCB 2004). It is reported that there was an increase in the Saudi dairy exports by 26.4%, reaching 112.000 tons in 2004 (NCB 2006). Saudi export of dairy products was estimated at 119.000 tons in 2005. There are indications that the export market for Saudi dairy products will spread geographically and exports to places such as Iraq and Kuwait will continue as reported by Sadi and Henderson (2007).

In terms of monetary value, Syrian exports also increased from US\$ 6.87 million in 1999 to US\$ 124 million in 2006 due to an increase in production and export of concentrated and sweetened milk. In the same

year the Jordanian exports were estimated at US\$ 62.3 million. The main destinations of Jordanian exports are Saudi Arabia and United Arab Emirates. Saudi exports have increased from US\$ 115 million in 1998 to US\$ 403 million in 2006 and grew faster than Jordan and Syria. In 2006, the Saudi exports of dairy products grew up to 25% in value terms.

Largest producers in the Middle East

As explained in previous parts, the dairy industry is growing rapidly in the Middle Eastern countries. In case of Saudi Arabia, market demand is expected to grow at 5% annually until 2010. It is expected that the volume of demand for dairy products will reach 1.6 million tons in the same year (NCB 2006). The capital intensity is much more important for Saudi dairy industry than Jordan and Syrian dairy industry because two dairy farms; Almarai and Al-Safi dairy companies which are considered as the largest in the world, are located in Saudi Arabia (Al-Otaibi and Robenson 2002; Almarai 2008).

Almarai is a well known Saudi Arabian dairy company and was founded in 1976. Today this becomes the largest producer and exporter of milk and dairy products in the Middle East. Almarai has been considered as a significant contributor to the evolution of industry and commerce in the Arabian Peninsula, particularly in the development of agriculture and dairy production. The company operates across seven modern dairy farms.

Almarai has accolades including being the first dairy farm in the world to gain reputation as International Organization for Standardization (ISO) 9002 accreditation. Almarai farms have over 38,000 dairy cows and some other 27,000 female calves that are reared to join the milking herd after the birth of their first calf. Almarai intends to further expand their herd size to 100,000 cows within the period between 2008 and 2012 (Almarai 2008). The company production capacity is 1.8 million liters of milk per day with approximate annual milk packaging capacity of 500 million litres. Almarai owns 700 chilled sales vans and 40 sales depots as well as 34,000 retail outlets throughout the Gulf States. It has a market share of 40%, and has generated a consolidated net profit of US\$ 178 million in 2007, an increase of 43.6% in comparison to the same period of 2006 (Almarai 2008). It made a net profit US\$ 293 million in the first 9 months of 2008. Almarai entered the third phase of its expansion in 2006, a five-year (US\$ 1.2 billion) plan intending to purchase small or underperforming dairies. The company's total revenue through sales and acquisitions grew in 2007 by 36.7% to US\$ 1.007 billion.

The main dairy products include Laban, milk (fresh and evaporated), Trinned cheese, Labneh, Ghishta (cream), yoghurt, cheddar and processed cheese, Zabadi, butter and ghee. Zabadi is a natural set yogurt and Almarai is the third biggest product after Laban and milk. Probiotic culture Laban and milk are some of the products which contribute positively to overall health and help in maintaining a healthy digestive system (Almarai 2008). Saudi Arabia's the biggest dairy producer has finalized the

acquisition of a 75% stake in Jordan's Taiba Investment and Advanced Food Industries Company in 2008. This is the first cross-border acquisition for Almarai and it intends to expand outside its home market. About 25% of Almarai raw milk produced is pasteurized and packaged in plastic bottles and degradable paper containers of various sizes. A further 60% is fermented to make Laban (Sadi and Henderson 2007). In terms of product quality, Almarai processing plant was declared the world's best in 1998 (Arla 2003).

Al-Safi dairy company is another big company located in Saudi Arabia; Al-Safi is part of the Al Safi organization. Al-Safi dairy farm comprises of 3.500 hectares of land and having more than 36 000 Holstein Friesian cattle producing a total of 600.000 litres of milk daily. Al-Safi market share is 36% from the total dairy market in Saudi Arabia, and it is expanding in the Arabian Gulf countries (Al-Safi 2008). Danone International acquired 50.1% of the shares in Saudi Al-Safi foods, which own the Al-Safi dairy (Al-Otaibi and Robenson 2002). Al-Safi Danone main products include milk, yoghurt, Laban and fresh cream. In addition new products such as Danao, Danino, Safio milk and Rashaka were introduced. The most recent dairy products are Activia and Actimel which are fresh and healthy laban and yogurts. They have a unique pro-biotic culture, *Bifidus essensis* which facilitates digestion (Al-Safi 2008).

2.5 Current challenges and future outlook

This section will elucidate the prominent features of the dairy industry in the three countries and will give a projection for dairy production growth in the period between 2008 and 2012. Projection of growth in milk production was made by using the IFCN dairy sector model. Figure 2.3 shows the projected development in milk production per country.

Milk production is expected to grow by 6.6% for Syria, 5.4% and 4.9% for Jordan and Saudi Arabia, respectively. Syrian milk production throughout 2008 - 2012 is expected to grow. Projection has been done based on an annual growth rate of 6.6%. This trend suggests that the dairy industry in the country was productive, and has not attained self-sufficiency in many of the products but also had an excess of exports.

The small scale production system in Syria will be the major supplier for dairy industry. In terms of volume, Syria will be the biggest producer among these countries, followed by Saudi Arabia while milk production is growing in lower rate in Jordan. The major driver in milk production growth is basically the growth in national herd number by 5.4%, 5.5% and 1.5% in Syria, Jordan and Saudi Arabia, respectively. As the GDP and population rate are increasing in all countries in different rates, it is expected that the demand for dairy products will also grow.

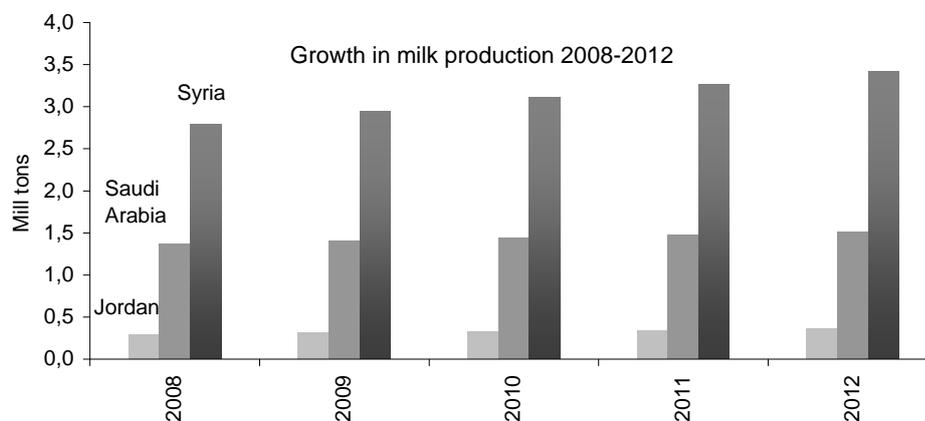
Table 2.2: Definition of some traditional dairy products in the Middle East

Product name	Description	Flavour	Fermentation	Method of preparation
Baladi cheese	White brine cheese with soft to semi-hard in texture	Acidic flavour	Fermented	Obtained by isolating the fermented cheese from the residual whey.
Danao	Combination of fresh juice flavours and milk	Sweet	Not fermented	N.A
Ghee	Yellowish liquid butter	Nutty flavour	Not fermented	Obtained by clarification of milk fat at high temperature
Ghishta	White soft cream	Creamy flavour	Not fermented	Composed of the higher-butterfat layer skimmed from the top of milk before homogenization
Jameed	Balls in form of a hard stone	Slightly salty flavour	Fermented	Produced by straining heated buttermilk in cloth mesh bags, kneading and salting the formed paste, then shaping and drying in the sun
Laban	White, liquid fermented milk similar to kefir	Slightly sour flavour	Fermented	Obtained by lactic acid fermentation
Labneh	Concentrated or strained yoghurt	Slightly sour flavour	Fermented	Produced by removing a proportion of the whey from cow's milk yogurt until fat and total solids contents of 9 to 11% and 23 to 25% respectively, are attained.
Zabadi	White to light cream in colour (yogurt)		Fermented	N.A

N.A: Not applicable (standard method)

Sources: Ganguli and Jain 1972; Tamime and Robinson 1999; Haddadin 2005; Shaker et al., 2007; Al Omari et al., 2008 ; Al-Safi 2008.

Figure 2.3: Projected milk production in Syria, Saudi Arabia and Jordan (2008 - 2012).



In 2007, total area allocated for cereal production (wheat, barley, sorghum, millet and sesame) in Saudi Arabia was estimated at 582.071 ha and produced about 2.966.953 tons. In the same year the area allocated for fodder production, estimated at 151.301 ha land produced about 2.687.791 tons of different types of fodders (MEP 2007). In Syria, total fodder production in 2006 was estimated at 9.374.000. The Syrian total fodder production (on dry matter basis) was estimated at 9.374.000 tons, with total digestible nutrients of 4.085.000 tons and 418.000 tons of digestible protein (NCAP 2008). The total deficit in all fodder resources was estimated at 2.756.000 tons. The available fodders for large animals in Jordan (excluding the agricultural by-products) were 492.000 tons only (Harb 2008).

In all countries, increasing feed prices was a major risk factor in the dairy industry. This also continues to be one of the major risk factors as all countries rely basically on imported feedstuff in feeding animals. Additionally, the availability of water resources, particularly in Saudi Arabia and Jordan will be a limiting factor in fodder production.

The dairy industries of Syria, Jordan and Saudi Arabia face major challenges which can be summarized as follows:

- Elimination of all kinds of subsidies under the World Trade Organization (WTO) rules has slashed the agricultural input subsidies and led to an increase in the cost of milk production for the local dairy industry in all the three countries. For example, slash of feed subsidies in Jordan led to increased feed prices by more than 80% (Hemme 2008).
- Fluctuation in profit margin in milk (Income over feed cost¹) due to the volatility in milk and feed prices.

¹ Income over feed cost is an indicator of the profitability of the dairy enterprise based principally on the economic efficiency.

- Shortage in water resources. This region has very low rainfall of less than 300 mm per annum and semi-arid to arid climate which make water availability very low.

Directions to industrialize dairy production in Syria will be promising in this stage of growth to improve milk quality, packaging services, marketing systems and transportation tools.

For the Syrian dairy sub-sector, there is a possible move to a more intensive production system based on the use of improved cows to improve milk production, improved feeding techniques, improved processing conditions, developed cooperation among small-scale farmers and the use of more farm-produced fodders (FAO 2003b).

Reduction of the existing risk could be possible by shifting some of the area for fodder and cereal cultivation in Saudi Arabia from high water consumption regions to lower water consumption regions and the cultivation of crops with lower water requirements and cost. The marginal cost of water is relatively high in Jordan compared to other countries of the world. In addition to water shortage, dairy production in Jordan has other constraints such as shortage of feed resources and extreme climatic conditions which hamper dairy development. More than half of the Jordanian milk is concentrated in Al-Dhuleil, which is an area that is unsuitable for fodder production, leading to high production costs from high feed prices. Adapting alternative dairy farming systems in areas where at least part of the feed could be grown on-farm would be helpful to improve existing feeding systems and reduce feed cost which represents more than 55% of total milk production (Hemme 2008). In addition, establishing a modern dairy factory by the Dairy Breeders Association in Jordan will expand the market potential for dairy producers and reduce the monopoly of big dairy factories.

There is seasonal fluctuation in demand and supply chain, as majority of dairy products consumed in Saudi Arabia like laban and labneh are fresh and very perishable and are thus more susceptible to market volatility. Secondly, the recent cut in custom duties to 5% on dairy imports in Saudi Arabia is a constraint to the dairy industry because it induces more competition from foreign suppliers. However, the Saudi dairy companies are large and strong enough and are able to compete with foreign companies. The Saudi dairy farms are now world class and their products are of international standard. Merging of small farms can also increase the competitive strength of the Saudi market. The difference between demand and supply could be minimised by producing UHT milk which has a long shelf life.

2.6 Conclusion

The dairy industry of Middle Eastern countries is growing and there is evidence that it will continue to grow in spite the lack of fodder and water resources. Growth in milk yield is driven by some factors, especially, the national GDP and population growth. The dairy industry is more capital intensive in Saudi Arabia than in Syria and Jordan. Only 5% of milk is delivered to dairy factories in Syria compared to 94% and 95% in Jordan and Saudi Arabia, respectively. Dairy exports and imports are growing faster in Saudi Arabia than in Jordan and Syria. Maintaining the growth in milk production in the Middle East can be accomplished by finding better production systems and alternative feeding programmes which could reduce the cost of milk production. Additionally, an improvement of the current agricultural policies to favour dairying and improve the sustainability of natural resources will be solicited.

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Chapter Three

Development of milk production and the dairy industry in Jordan

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Abstract

Development of the dairy industry plays an important role in the economy of Jordan. During the early 70's, Jordan established programs to promote dairy farming. Farmers imported improved dairy cows, complying with top industry operating standards, in addition to introducing the latest technology in processing, packaging and distribution. However, the previous dairy farming management programs and the lack of water and feed resources have partially hampered the dairy industry and still pose a problem due to the increasing dairy cow numbers. Jordan experienced noticeable growth in milk production and consumption during the last two decades. Milk production was growing by 5.4% between 2002 and 2007.

The objective of this article is to show the recent developments in milk production in Jordan and the diversity of dairy farming systems. It also attempts to understand the drivers for the development in milk production.

Key words: Farming systems, feed resources, milk processing

3.1 Introduction

Jordan is a small country and has a total surface area of 89.2 Km² with about 90% of this area considered as semi-arid (PRB 2008, MOA 2001, Bourn 2003). Jordan is divided into three main geographical areas with different climates: the highlands, the Jordan Valley and the eastern desert. The northern segment of the Jordan Valley, known as the Ghor, is the nation's most fertile region (UNIDO 2008). This region is several degrees warmer than the rest of the country, with an average annual rainfall fluctuating between 100 to 250 mm. The year-round agricultural climate, fertile soils, high winter rainfall and extensive summer irrigation have made the Ghor the food bowl of Jordan. Agriculture in the Jordan valley is irrigated cultivation. Dairy farming in this region is mainly at small scale, with a typical farm size ranging between one and five dairy cows. Due to the high temperatures, humidity and incidence of diseases, large scale dairy farming is not common.

The highlands of Jordan separate the Jordan Valley and its borders from the plains of the eastern desert. This region extends through the entire length of the western part of the country and hosts most of Jordan's main population centers. Dairy farming is most prominent in areas surrounding big cities like Amman, Irbid, Madaba, Jerash, where the average annual rainfall is between 300 to 200 mm. The highlands of Jordan receive Jordan's highest rainfall, and

have the richest vegetation in the country and daytime temperatures during the summer months frequently exceed 36°C and average about 32°C.

The Eastern Desert represents about 90% of the country and more than 50% of the produced milk comes from the semi-arid region that is Al-Dhulel region with very hot summers (NCARE 2002 and MOA 2008). Daytime the summer temperatures can exceed 40°C, while winter nights can be very cold, dry and windy. Average rainfall is less than 200 mm annually. Although all the regions of the Badia (or desert) are characterized by their harsh desert climate, similar vegetation types and low population densities, they vary considerably according to their underlying geology. In spite of the higher temperature and the climate conditions; intensive dairy farming in the eastern desert seems promising. The government has designated this area especially for dairy farming. Dairy farming in this region is characterized by intensive production systems and zero-grazing, due to the absence of the irrigated crop production and separated crop-dairy farming system.

About 75% of the country's cultivable land comprises of rain-fed territory to the north producing wheat, barley, lentils and chickpeas. The remaining quarter of agricultural land in the Jordan Valley and the highlands is irrigated and produces eggplants, bananas, potatoes, cucumbers, citrus fruits, tomatoes and onions (WENE 2000).

The contribution of the agricultural sector to the country's GDP was 2.5% in 2006 and currently, it employs 5.7% of the labour force in Jordan (DOS 2006 and UNIDO 2008). Although the agricultural sector's share of GDP declined in comparison with other sectors of the economy, farming remains economically important and production grows in reasonable terms.

3.2 Milk production trends

Jordanian total milk production is estimated at 260 thousand tons in 2006. of which Around 208 thousand tons are cow milk, 32 thousand tons from sheep and 20 thousand tons from goats. According to the statistics of the Ministry of Agriculture (2006), the Jordanian livestock population consists of 2 million sheep, 450 thousand goats and 50 thousand milking (dairy) cows (MOA 2006).

Jordan has experienced a rapid population growth of 2.5% annually over the last decades and an increasing demand for milk and dairy products. This has encouraged dairy farmers to

improve on production by importing high milk producing dairy cows to replace the low-yielding local Jordanian breeds (Lafi et al 1995). Currently, the Holstein Friesian cows represent 96% of the total population of dairy cows in the country (MOA 2006). In 1981, numbers of Friesian dairy cows were 6000 and by 2006 there were 50 thousand dairy cows (MOA 2006). Table 3.1 and Figure 3.1 show milk production from different livestock species in Jordan between 2000 and 2007.

Table 3.1: Total milk production in Jordan from different animals (1000 tons)

Year	Cows milk	Sheep milk	Goat milk	Total milk production
2000	162	31	11	204
2001	162	29	17	208
2002	177	23	11	211
2003	172	31	22	225
2004	169	31	22	222
2005	177	32	21	230
2006	208	32	20	260

Source: MOA 2006

The tremendous increase in dairy production is due to the increase in population growth and the increased demand for milk and dairy products. For this goal, the governments permit the imports of improved dairy cattle from Europe, USA and recently from Australia. The percentage of self-sufficiency has also changed significantly since 1980 from 35% and was 57% in 2006 (MOA 2006).

3.3 Dairy production systems

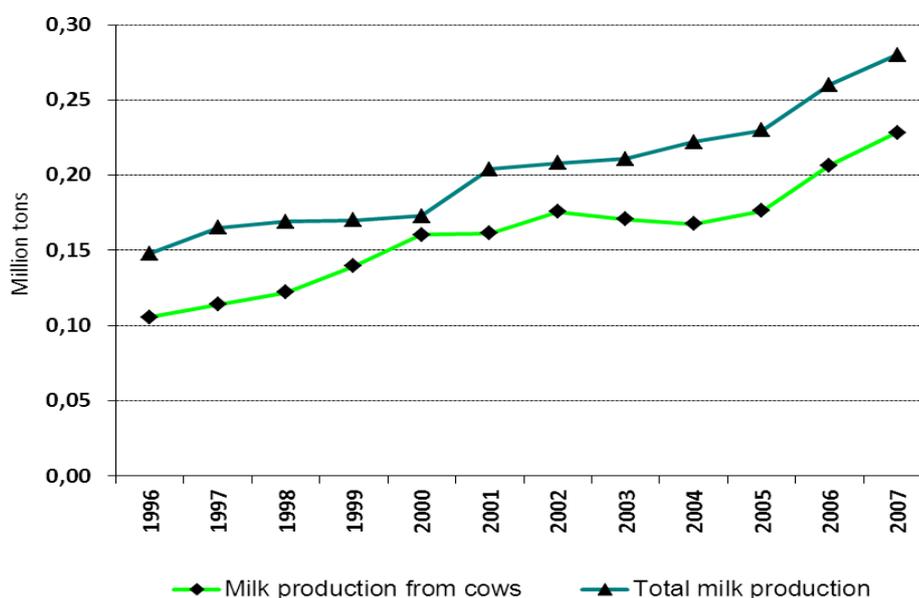
Based on the data resources from the Ministry of Agriculture in 2006, there are 605 dairy farms in Jordan. These farms are distributed into different production systems as described in the succeeding paragraphs.

The intensive production system

The intensive production system is dominant in the eastern semi-arid area of Jordan. It also exists in other large farms distributed across the country. The semi-arid area produces the largest amount of milk in the country. The area is described by high temperature in the summer time and very low temperature in winter. This system comprises of farms where the number of cows per farm exceeds 10 dairy cows. There are 605 dairy farms adopting this

system in Jordan. Two categories can be classified: the large scale farms and the average-size farms. Currently Holstein Friesian which has been imported from USA, Europe is the dominant breed reared in this system. Animals are reared in modern barns especially in those farms which have recently been established. Land size is very small and in most cases less than one hectare per farm. However, stanchion barns are still used by dairy farmers in this system.

Figure 3.1: Milk production in Jordan, *Source: MOA 2007*



The farms are attached to each other in an area specially designated to gather dairy farms called Al-Dhulel. Al-Dhulel, is considered the most intensive milk producing area, producing about 50% of the total milk produced in the country (Ghros and Heidhues 1988). In this area dairy farmers benefit from the dairy breeders association, which helps farmers in milk marketing, water support and other technical issues. Farmers use modern milking machines and equipments. Management and animal health control requirements are high if high productivity, high reproduction levels and low mortality rates are to be achieved (Ghros 1988).

Crop production is separated from dairy farming in this system. Dairy farming basically depends on concentrate feeds (maize, barley, soybeans, wheat bran). Animals also fed on wheat straw and alfalfa hay. Fresh alfalfa bought by dairy farmers is grown with (high

quality) reused treated water. Feeding systems are more developed in the large farms than the average-sized farms, where total mixed rations and advanced feeding programs are applied. Feeders are used to deliver fodder and concentrates to the barns. The average-sized farms in Al-Dhulel area is between 40-100 cows per farm. In these farms, feeding programs are not developed as in the larger farms (more than 100 cows per farm). Unbalanced rations are commonly offered to dairy cattle. Grain straw (wheat, barely) is the sole roughage given to dairy cattle on most of farms (Adib 1969). Recently, the tremendous increase in fodder prices has influenced the rations fed to animals. Straw and hay prices increased greatly, farmers feed about 700 grams of concentrate to obtain one kg of milk. Several metabolic problems develop because of unbalanced rations that are fed. Lafi et al (1995) found that the major feeds (per 1000 kg) used by dairy farmers consists of barley (500 kg), sorghum (50 kg), soybeans (240 kg), wheat bran (180 kg), NACL (14 kg), limestone dust (15 kg) and vitamins and mineral supplements (1 kg). Cows under this system produce about 6000 kg/cow/year in average. Production level differs however from one farm to another based on management practices and the available feed resources. In some big farms, milk production level is comparable to that in developed countries. In terms of productivity, cows in larger herds produce more milk than cows in average-sized herds. Consequently, the reproductive ability of the cows is not related to their yield.

Small-scale production system

Small-scale production systems exist in different regions in the country, particularly in the northern highlands, and the Jordan Valley (Ghor region). Dairy farmers in the high lands have been rearing cows a long time ago using Akshi and Shami breeds. There is no exact figures on the number of dairy farms in this system as the government usually neglects this category of farmers, focusing on the large scale production system. Farm size fluctuates from 1 to 10 dairy cows.

During the last two decades, farmers have replaced their local cows with high yielding Holstein Friesian due to its high productivity. Akshi (local breed) with a birth weight ranging between 19 and 21 kg and having a good growth rate is commonly used in this system. However, the number of local (Baladi) cows has diminished during the last few decades. In 2007, number of Baladi cows was only 4% of the total dairy cattle in Jordan (MOA 2007). Baladi cows are small, stocky and well adapted to the relatively harsh environment (HTSL 1978). The Damascus breed is sometimes crossed with Baladi cattle because of its higher

production potential for milk and meat. The Damascus red breed (known locally as Shami cattle) is still present, but its number is decreasing drastically. Baladi cows reared under this system could be pure breed (Akshi or Shami), or cross-breed of different local breeds. Baladi cows are resistant and can sustain under very poor management and environmental conditions. They are kept under poor conditions and inconsistent rangelands (Harb 1989).

Cows are housed in small traditional brick barns, with no protection against solar radiation in the hot summer, or the cold weather in winter. Less management practices than in the intensive system are observed. This system is also characterized by poor feeding resources, less health management, and no sound housing system. Farmers use both hand milking and mobile milking machines.

Small scale farming in the highlands is characterized by interdependency between crop and livestock production. A small area of the land is used for dairy farming, while the rest of the farm is used for crop production. Cows in some cases graze on crop residues (wheat and barley straw).

Cows produce lower milk than in the intensive system due to the lower quality of feedstuff offered to the animals, for example household food residues, or high lignin fiber feed stuff (i.e.: straw), and due to the poor management level. Cattle are fed on concentrate feed, agricultural by products and household food residues. A majority of small farmers depend at least partly on purchased feed, due to the reducing rainfall volume in the last few years.

Small-scale production systems in Gohr region is slightly differ from dairy farming in the highland, crops in the Gohr are irrigated and farmers produce alfalfa and other fodder crops. Farmers rear both Local and Holstein Friesian cows. Generally only small pieces of land are used to produce fodder crops. Farmers prefer to use crop by-products or commercial grazing in the short rainy period (Ghros and Heidhues 1989) They use forage and by-products from farm operations but still depend to a lesser extent, on purchased concentrate feed.

In this scale of production, natural breeding is dominant, while artificial insemination is rarely practiced. Local (Baladi) cow breeds in general produce about 1277 kg of milk per year (Tabba 2002). Friesian cows reared under this system produce about 4500 kg milk per year. The objective of rearing cows is for subsistence and for a little cash income. Milk is sometimes processed on the farm to laban, concentrated yoghurt (Labneh), yoghurt, cheese and ghee for household consumption or for marketing in village or in the surrounding markets.

The development of the herd structure shows that even for small scale farmers rearing purebred Holstein cows is more economical (Ghros and Heidhues 1988), compared to the Baladi cows. Local breeds have many disadvantages like late maturity, long calving interval, a low conception rate and a very low milk yield. The big advantage for the Friesian cows compared to the Baladi cows is the much higher yield, resulting in higher income. However, there is severing lake of resources on production characteristics, cow's performance, production constrains, in both intensive and extensive production system and further researches is required at this time.

3.4 The dairy industry

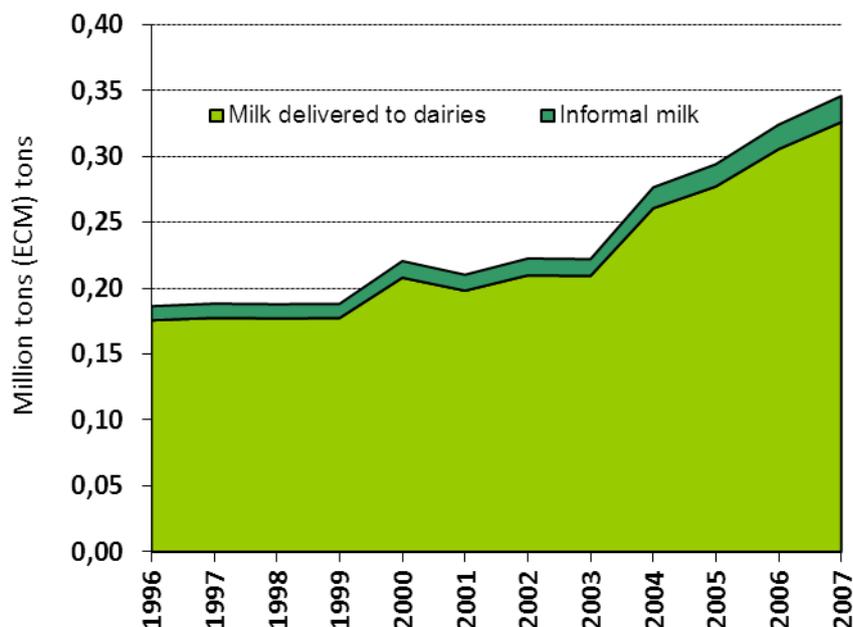
Dairying originated from the Middle East, between 7000 and 6000 BC, and from there, milk consumption spread to the Mediterranean, Europe, and Indian subcontinent and to other parts of the world (Moran 2005). Dairy products are a very important source of food in Jordan due to their nutritive value. They are also the cheapest source of animal proteins and contribute highly in subsistence of a wide number of producers and families in the peri-urban and rural areas (AOAD 2003). The production and consumption of dairy products traditionally plays an important role to the population. In the last decades, consumption of dairy products increased at extremely high rates. Currently the per capita consumption of dairy products is 78 kg in Jordan (MOA 2006). Dairy production from total animals has also increased from 204 thousand tons in 2000 to 260 thousand tons in 2006 (MOA 2006; Hemme 2007).

In Jordan, about 95% of the milk is delivered to dairy factories while the rest of the milk is informal. Informal milk in this case comprises of milk sold door to door, milk suckled by calves on-farm and milk consumed on-farm by the household (Figure 3.2). The first dairy factory was established in 1968, namely the Jordanian Dairy Company. From that time, dairy factories started processing milk from cows, sheep and goats. Currently, dairy factories can be classified into modern dairy factories, manual dairy factories, and home processing factories.

The modern dairy factories use fresh and powdered milk. In Jordan there are 21 modern dairy factories which are located mostly in the regions of milk production and surrounding the big cities. These factories process fresh milk from dairy farms in addition to the powdered milk into yogurt, laban, concentrated yoghurt (labaneh), cream, Baladi cheese, Jameed (Jameed is a fermented dairy product in the form of stone hard balls or other shapes produced by straining the heated buttermilk on cloth mesh bags, salting the formed paste by kneading, shaping and

drying in the sun), flavoured-yogurt, ice cream, pasteurized milk and butter. The biggest three companies processing milk in Jordan are Hammodeh dairy, Danish-Jordanian dairy, and the Jordanian Dairy Company. Generally; the dairy processing capacity of the modern dairy factories is already sufficient to manufacture all the fresh milk produced by farmers.

Figure 3.2: Delivered milk to the dairy industry, *Source: Hemme 2007*



The processing capacity of dairy factories in Jordan is 564 650 tons per day (Kelany 1997). About 95% of produced milk is delivered to dairy factories of which 52% is provided by the Dairy Breeders Association located in Zarqa region in the eastern part of the country and 16% comes from big dairy farms that own their dairy factories. Individual dairy farmers deliver 32% of processed milk. About 92.7% of delivered milk comes from dairy cows, while the rest comes from sheep and goats. Milk from sheep and goat is basically processed to white cultured cheese and Jameed.

The small dairy shops are a smaller size of milk processing factories (MOT 2004). They are scattered around the country, particularly in the northern and the middle of Jordan and process milk from cows, sheep and goats. Traditionally, these shops process different types of dairy products such as laban, labaneh, Jameed and white cheese which have a high preference by consumers (AAAID 2004). labneh (from Arabic laben, milk) is the name used in the Middle East and other Arabian countries for the semisolid dairy product made from set yogurt by

removal of part of its whey (Yamani and Abujaber 1994). Home production of dairy products is of regional importance. This type of processing is dominant for the small dairy farms. But it is more important for sheep and goats farmers.

Consumption, imports and exports of dairy products

The consumption of milk and dairy products increased gradually during the last two decades. Table 3.2 shows the growth in dairy products consumption between 2000 and 2006.

Table 3.2: Development in consumption of dairy products in Jordan

Year	Production, tons	Imports, tons	Dairy products consumption, tons	Self-sufficiency, %	Per capita consumption, kg
2000	204	178	382	53.4	74.4
2001	208	188	396	53.6	76.6
2002	211	128	339	62	63.6
2003	225	158	383	58.6	62
2004	222	120	342	64.8	61
2005	230	139	369	62.3	66
2006	260	205	465	57	78

Source: MOA 2006

The local production however doesn't satisfy the growth demand. To cover the market demand, big quantities of dairy products are imported. The major imported dairy products are shown in Figure 3.3.

The Jordanian self-sufficiency percentage has significantly changed from 35% in nineties up to 62% in 2006 (Qureshi 1987, MOA 2006).

The per capita consumption in Jordan has increased from 62 kg in 2003, to 78 kg in 2006. This situation is different from that in neighboring Saudi Arabia, which has lower per capita milk consumption (of 55 kg) than Jordan (Al-Otaibi and Robenson 2002). Consumption of dairy products has increased by 24% from 2005 to 2006 (Hemme 2007). While the average growth rate in domestic demand throughout the period 1996 - 2006 was 12%

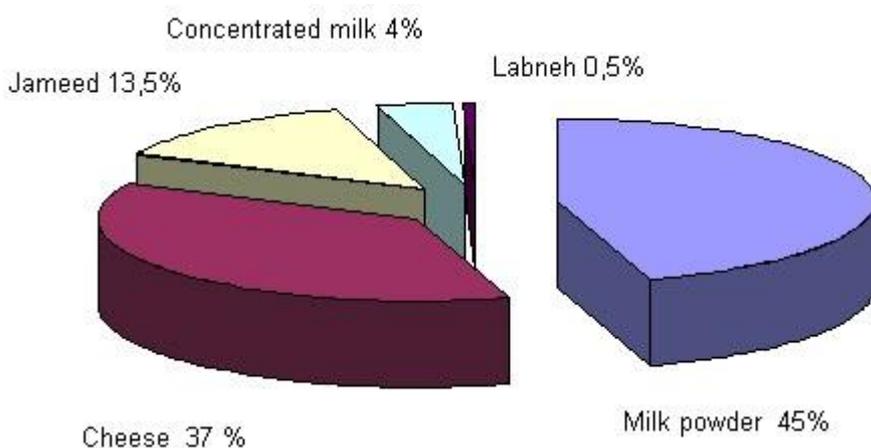
In 2006, Jordan imported 21,363 thousand tons of powdered milk with value of 61.4 million USD. There is obvious growth in Jameed consumption. Jameed is a fermented dairy product in the form of hard stone balls or other shapes produced by straining the heated buttermilk on cloth mesh bags, salting the formed paste by kneading, shaping and drying in the sun (Shaker et al 2007 and Al Omari et al 2008). Jameed however is used in social activities and it's

highly acceptable by the consumer preference. Jameed industry is also developed recently in Jordan. In 2006 the value of imported Jameed accounted to 2.5 million USD.

The large scale farms market their products directly to the factories based on day to day contracts. In Al-Duhlel region, farmers deliver their milk to dairy factories directly or via retailers. Dairy Breeders Association plays a strong role in marketing milk by finding channels between farmers and dairy factories.

The competition between dairy factories created a situation where factories sign long term contracts with farmers for milk delivery at a flexible and negotiable price which is in most cases not suitable for farmers. This competition is advantaged by extra capital, quality control, packaging, advertising and product differentiation (Mohsen 2001). Dairy processing factories are highly capitalized. Modern technology is used to process the milk. About 92.7% of the processed milk is cow milk, while the rest is from sheep and goat which is produced in spring. Based on these figures, locally produced dairy products represent nearly 55% of the total demand in 2006, while imported products comprise of the remaining 45%.

Figure 3.3: Imported dairy products for Jordan in 2006, *Source: MOA 2006*



Based on the recent statistics (DOS 2006), the total dairy products imported value has increased during the last years reaching a value of 115 million USD in 2006. The imported amounts of dairy products are shown in Table 3.3.

Jordan imports from Jameed and cheese are expected however to grow in the next years. The growth rate in imports has increased by 4% throughout the period 1996 - 2000.

Jordan exports of dairy products are increasing steadily. The most common dairy products exported from Jordan are Jameed and white Hallomi cheese. Jordan has exported cheese with value of 6.9 million USD in 2006. The main destination of Jordanian exports is the Gulf States. Exports from Jameed and the white Jordanian cheese are expected to grow in the next years. The total value for the Jordanian exports of dairy products estimated at 10.26 million USD in 2006.

Table 3.3 Annual imports and exports of selected dairy products in Jordan (in 1000 tons)

Product	Imports			Exports		
	2004	2005	2006	2004	2005	2006
Ghishta (Cream)	1.45	1.39	2.12	NA	NA	NA
Butter	1.67	1.27	1.19	NA	NA	NA
Cheese	1.68	1.27	1.32	0.82	2.18	2.80
Jameed	2.21	2.11	2.09	0.016	0.048	0.064
Milk powder	1.36	1.29	2.16	NA	NA	NA

Source: MOA 2006 NA: No available information

3.5 Feed resources

The rangelands of Jordan are not sufficient for dairy cattle grazing but have been basically used for sheep, goat and camel grazing (ACSAD 1997). Six percent of the country's area is considered as arable land with good potential for cultivation of cereals, vegetables and fruits. However, fodder production is based on rain fed production system. Under these environmental conditions dairy industry in the country is essentially depends on imported fodders.

However, fodder production only covers 25% of livestock requirement. The total feedstuff requirements for the dairy cattle sector estimated at 354 thousand tons, table 3.4 shows the available fodders for the large animals in Jordan.

Table 3.4: Available fodders for large animals

Fodder resources	Feed Unit, 1000 t	%
Natural pasture	153	31
Highlands	127	26
Green fodders	9	2
Cereals straw (Tibbin)	54	11
Grain cereals	32	7
cereals processing by-products (bran)	97	20
Other by-products	20	4
Total	492	100
<i>Source: Modified after Harb 2008</i>		

Jordan has imported about 1.8 million ton of feedstuff that is required for the livestock sector. These include barley, maize, soybean meal, concentrates, fish meal, minerals and vitamin additives (Harb 2008). Local production of grains is less than the national requirements and it fluctuate from year to year depending on rainfall and market (Al Jassim et al 1998).

Generally, feeding amounts up to 50% of the total operating expenditures on dairy cattle (Bethard 1998). Dairy cows feeding representing the largest single cost item in most of dairy operations (Myer 2005). Eventually; the cereals grains (corn, barley and soybean) are the most widely used energy feedstuffs for dairy rations in Jordan. However there is a wide range of non conventional or alternative energy feedstuffs available that can utilized for dairy feeding worldwide. These sources of protein can ensure optimal rumen fermentation leading to a more efficient production of amino acids.

By products from the feed and food industries are generally excellent sources of protein, energy and minerals for ruminants (DiCostanzo 2003). The nutrient composition of by-products frequently is different from classical grains used to feed dairy cattle (Amaral-Phillips and Hemken 2006).

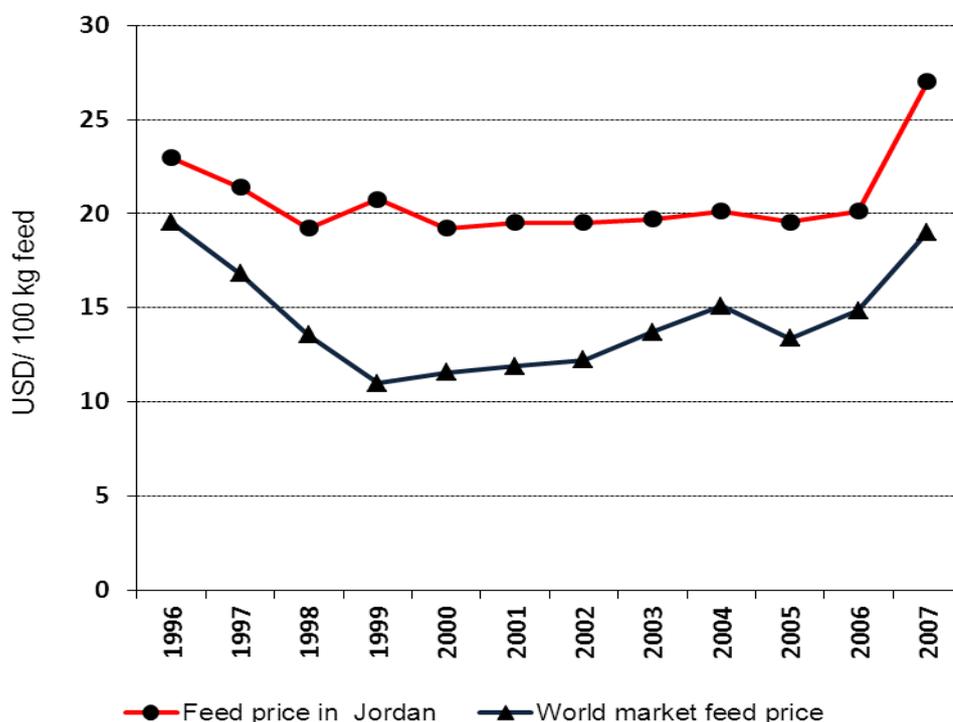
Having the fact that cows under the Jordanian conditions eat 700 gram of concentrate to produce one kg of milk could be attributed to the lower feed efficiency in the warm season than in the cold season as reported by Britt et al (2003) and Black and Custodio (1984).

In addition to the scarcity of feed resources in the country, their prices have been increasing rapidly during the last two years. Feed price has been calculated based on a price of 30% soybeans and 70% corn. The recent increase in feed price is attributed to the increase in the

world market price for feed and to the slash of feed subsidies by the government. Figure 3.4 shows the evolution of feed prices from 1996 to 2007.

The International Farm Comparison Network (IFCN) feed indicator (0.7 * corn and 0.3 * soybean meal) prices was used to compare feed prices in Jordan with world market prices. This comparison shows that feed prices in the country have always been considerably higher than world market prices showing a reduced competitiveness of dairy production from feed-intensive systems in Jordan compared to feed exporting countries. Milk-feed price ratio is shown in Figure 3.5. The milk-feed ratio is an indicator developed by the IFCN which estimates the extent to which feeding can be intensified on dairy farms on an economically sustainable basis in a country. Feed milk price ratio is designed to reflect the price of milk relative to the price of feed (Stallings 2002). In general, when this figure is above 1.5, it is said to be favorable, and feed-intensive production systems are encouraged.

Figure 3.4: Feed prices in Jordan and the world, *Source: Hemme 2007*



The milk/feed price ratio for Jordan has been favorable throughout the period 1996 – 2006 and stayed above the ratio for the world market throughout this period, except in 2001. There was an obvious change during 2006-2007, and this is attributed to the increasing in feed (corn

and soybeans) prices resulting from a slash on subsidies for imported feedstuff. Since the milk price did not react proportionately, this ration suddenly dropped to a level below the world market price. If this ratio remains stable or drops, then Jordanian dairy farmers will need to depend on local and cheaper feedstuff in order to remain sustainable.

Available agricultural by-products could play a strong role in ruminants feeding (Adib 1969, Harb 1986, Harb 1989, Harb 1999). The available agricultural by-products in the country are illustrated in Table 3.5.

There is shortage in water resources which compels a separation of dairy farming from crop production. Cereal crops and fodders are grown in the highlands and in Jordan valley area. However, growing fodders in the desert area of the country is successful if ground water used for irrigation purposes.

Figure 3.5: Milk-feed price ratio in Jordan and the world, *Source: Hemme 2007*

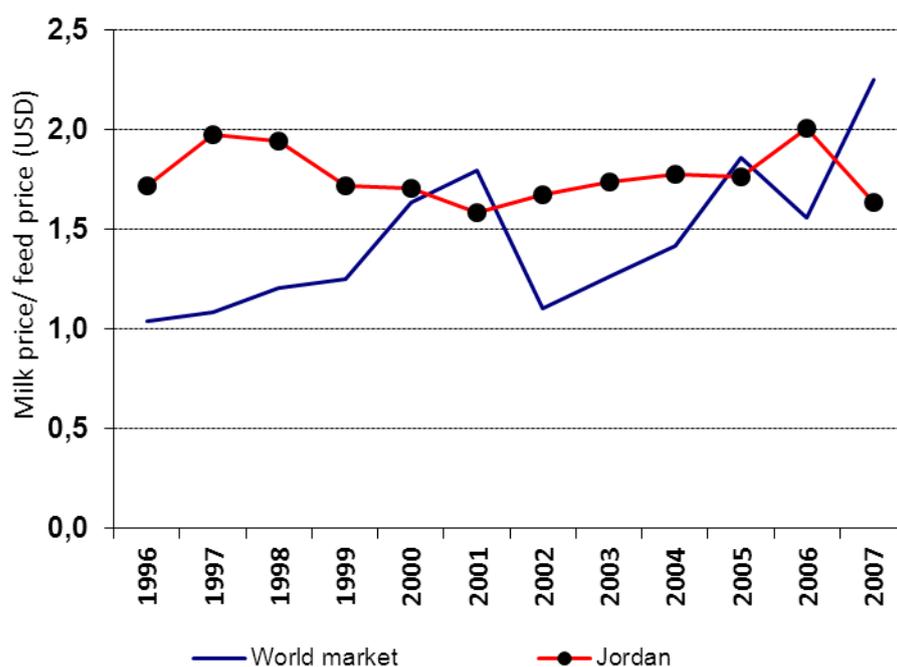


Table 3.5: Available agricultural by-products in Jordan (2008)

Feed component	Amount, 1000 t
Wheat straw	75
Barley straw	30
Legumes straw	20
Vegetables and citrus by products	20
Poultry litter	100
Olive cake	25
Olive leafs and branches	10
Bears cake Brewer's grain	1
Banana leafs	10
Tomato pomace	6
Total	297

Source: Modified after Harb 2008

Farmers buy a ready mix from the cooperative owned feed mill or from private feed mills. In large scale farms, farmers have on-farm mill and mix the feed ingredients with minerals and vitamin additives (Ghros 1989). There is shortage in roughage resources, and basically farmers depend on concentrates in feeding their cows. Straw is purchased from other cereal growing farmers after harvest in summer. While fresh alfalfa is purchased from Zarqa region or from Jordan valley.

3.6 Dairy sector analysis

The International Farm Comparison Network (IFCN) dairy sector model was used to illustrate development and the recent changes in the dairy sector in Jordan. Results are shown in Table 3.6. Milk production experienced tremendous growth at 5.4% between 2002 and 2007. The reason behind this is the growth in population and increasing number of visitors annually from the neighbouring countries, with increasing in per capita consumption of 6.7% annually.

Table 3.6. Annual changes between 2002-2007 in some parameters of the dairy sector in Jordan

Item	Amount
Milk production (%)	5.4
Cow number (%)	5.5
Milk yield per cow (%)	-0.1
Total consumption (%)	9.5
Population (%)	3.5
GDP per capita (%)	4.97
Per capita consumption (%)	6.7
Milk delivered to dairy in 2007 (%)	94
Per capita milk consumption (Kg/year/capita)	78
Self sufficiency in milk production in 2007 (%)	57
Population (million people)	5.8
Exports million US\$ in 2006	62.3
Imports million US\$ in 2006	123

Source: Adapted from Hemme (2008)

The per capita of milk consumption increased during the last years. However, the self sufficiency of 57% achieved in 2007 is still lower than in the neighbouring countries, for example Syria, where the self sufficiency is 93% (Alammouri 2006).

It is expected that milk production will continue growing in the next years. The main drivers for this development are the increase in dairy cows and total milk yield, and an increase in per capita consumption.

3.7 Conclusion

Milk production in Jordan is very important especially for milk producing families and the employees in the dairy industry. The dairy sector in Jordan has encountered several problems in feeding and management. There is an absence of a clear farm gate pricing strategy, unbalanced feed rations and scarcity of feed resources especially as zero grazing production systems are dominant.

Milk production cost is high due to the high feed prices. Shifting part of dairy farming to areas where at least part of the feed could be grown would be helpful to improve feeding systems, which are currently used. In addition, establishing a modern dairy factory by the dairy breeders association would succeed to find a new market for dairy producers and reduce the monopoly dominated by big dairy factories. It is recommended that the dairy sector should have clear strategies in milk pricing. Reducing imports of powdered milk will greatly help farmers in marketing their milk. Milk pricing should be associated with feed prices. The

practice of integrated crop-dairy production system might be essential at this time to improve management and reduce the feed cost. Finally, an improvement on feed rations and the use of high quality roughages and silage should be encouraged.

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Chapter Four

Nutritional and ecological evaluation of dairy farming systems based on concentrate feeding regimes in semi-arid environments of Jordan

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Abstract

The objective of this study was to evaluate the nutritional and ecological aspects of feeding systems practiced under semi-arid environments in Jordan. Nine dairy farms representing the different dairy farming systems were selected for this study. Feed samples (n= 58), fecal samples (n= 108), and milk samples (n=78) were collected from the farms and analysed for chemical composition. Feed samples were also analysed for metabolisable energy (ME) contents and in vitro organic matter digestibility according to Hohenheim-Feed-Test. Furthermore, fecal nitrogen concentration was determined to estimate in vivo organic matter digestibility. ME and nutrient intakes were calculated based on the farmer's estimate of dry matter intake and the analysed composition of the feed ingredients. ME and nutrient intakes were compared to recommended standard values for adequate supply of ME, utilizable crude protein, rumen undegradable crude protein (RUCP), phosphorus (P), and calcium (Ca). Technology Impact Policy Impact Calculation model complemented with a partial Life Cycle Assessment model was used to estimate greenhouse gas emissions of milk production at farm gate. The model predicts CH₄, N₂O and CO₂ gases emitted either directly and indirectly. Average daily energy corrected milk yield (ECM) was 19 kg and ranged between 11 and 27 kg. The mean of ME intake of all farms was 184 MJ/d with range between 115 and 225 MJ/d. Intake of RUCP was lower than the standard requirements in six farms ranging between 19 and 137 g/d, was higher (32 and 93 g/d) in two farms, and matched the requirements in one farm. P intake was higher than the requirements in all farms (mean oversupply= 19 g/d) and ranged between 3 and 30 g/d. Ca intake was significantly below the requirements in small scale farms. Milk nitrogen efficiency N_{eff} (milk N/intake N) varied between 19% in and 28% and was mainly driven by the level of milk yield. Total CO₂ equivalent (CO₂ eq.) emission ranged between 0.90 and 1.88 kg CO₂ /kg ECM milk, where the enteric and manure CH₄ contributed to 52% of the total CO₂ eq emissions, followed by the indirect emissions of N₂O and the direct emissions of CO₂ gases which comprised 17% and 15%, respectively, from total CO₂ eq. emissions. Emissions per kg of milk were significantly driven by the level of milk production ($r^2=0.93$) and of eDMI ($r^2=0.88$), while the total emissions were not influenced by diet composition. A difference of 16 kg ECM/d in milk yield, 9% in N_{eff} and of 0.9 kg CO₂ eq. /kg in ECM milk observed between low and high yielding animals. To improve the nutritional status of the animals, protein requirements have to be met. Furthermore, low price by-products with a low carbon credit should be included in the diets to

replace the high proportion of imported concentrate feeds and consequently improve the economic situation of dairy farms and mitigate CO₂ eq. emissions.

Key words: Dairy, feeding systems, efficiency, greenhouse gas emissions (GHGs)

4.1 Introduction

Semi-arid and arid regions are characterized by low rainfall that results in a low primary production and forage quality (Pascual et al., 2000). Grain production and grazing on pasture are limited in such areas because of the extreme shortage in water and arable land and of recurrent drought, therefore, imported and expensive feedstuffs on dairy farms have to be used as efficient as possible. Water and irrigation is considered to be a major determinant of land productivity and stability of yield (Siam, 2009). However, due to the limited access, the rangelands of Jordan are not sufficient for dairy cattle grazing but have been basically used for sheep and goat grazing (ACSAD, 1997). Six percent of the country's area is considered as arable land with good potential for cultivation of cereals, vegetables and fruits.

The absence of grassland has led to dominance in concentrate based diets for dairy cows. This has an economic impact on farm profitability due to the volatility in global prices of the major feed components which has increased the general concern about food security status of many developing countries (World Bank, 2008).

Local feed resources which are produced seasonally have delimited to minor varieties such as straw, limited amounts of grains, agricultural by-products and grass which is produced seasonally. These feeds are produced in small quantities and there is remarkable scarcity in satisfying the local dairy sector requirements. In some cases farmers allocate small area to produce corn silage on farm. In addition, there are challenges in the existing systems as the feeding rations for dairy cows are frequently not adequately formulated due to poor extension services provided for dairy farms and the knowledge in diet formulation by farmers. This has implications on energy, protein and minerals supply needed to meet the requirements of lactating animals.

Under the current feeding systems, the diets of the animals are composed of high amounts of grains which were reported to cause rumen acidosis, when roughage intake is low. Consequently, chewing activity and saliva production are reduced, which negatively affects health and productivity. The efficiency of converting feed nitrogen (N) to milk N can reach maximum level of 40% as reported by Galloway (1998). However, it range between 15 and

40% depending on the production level and the feeding practices (Calsamiglia et al., 2010). Furthermore, the accurate protein supply adapted to the animal's requirement improves the animal efficiency and accordingly reduce N excretion (Arriaga et al., 2009).

In regards to the regional fragile environment, climate change threatens to reduce the availability of water resources, increase food insecurity, and hinder economic growth (IISD, 2009). Global dairy farming activities are considered to be a source for greenhouse gas (GHG) emissions which are estimated to contribute approximately 4% of total anthropogenic GHGs (FAO, 2010). Information on the efficiency of dairy feeding systems and their ecological impacts under semi-arid conditions are lacking. Therefore the objectives of this study were to assess the nutritional status of dairy cows under concentrate feeding regimes in nine representative farms in Jordan via i) evaluation of animal diets and productivity, and ii) evaluation of nutrients use efficiency and the impact of current farming practices on GHGs emission from dairy farms.

4.2 Materials and methods

4.2.1 Dairy farms description

Nine dairy farms in Jordan (denoted A to I) which represent the range of farm sizes, livestock densities, and milk production were selected for this study. Figure 4.1 shows the farms location and a schematic illustration of data collection and analysis. These farms are representative of dairy herds typical for the country considering the large scale concentrated in the eastern part and medium scale farms which are distributed in other parts of the country. Farm visits and collection of data and samples were done in September 2008 and March 2010 for a period of four to five weeks for each time.

Data collection included location, herd size, milk production per cow, body weight, milking and feeding regimes. The types and amounts of feed offered to animals were recorded for each farm weekly. Therefore, table 4.3 represents diet composition and the estimated dry matter intake (eDMI) for a period of 4-weeks average. Fresh matter feed intake of lactating cows was taken from the farm records (farmers estimate). However, farmers did not have records for farms I and E, and the intake of barley and wheat bran were weighed at the day of the interview.

- Visited farms**
- Eastern Jordan**
Farms A,B, C, F, G
 - Jordan valley**
Farms E and I
 - Middle high lands**
Farms D and H



Nutritional evaluation

Sampling procedure:

- Feed (two samples were obtained in each period from the feed stores, each sample represent different feed types offered to lactating animals)
- Milk (two samples were obtained each week from farm milk bulk)
- Fecal (three fecal samples were collected from each farm weekly, each sample was obtained from three healthy lactating animals)

Analysis:

- Hohenheim-Feed test
- Proximate analysis for feed
- Fecal N and P analysis
- Milk N, MUN and fat analysis

- Feed composition and intake
- Feed efficiency
- Nutrients balance

Ecological evaluation

- Herd data
- Economic farm data

Model use

- TIPICAL model:
Life cycle assessment
- GHGs emission and carbon footprint

Figure 4.1: Farm locations and a schematic illustration of data collection and analysis

Since eDMI values in the current study represents the amount of feed offered to the animals, these values does not necessarily express what the animals have consumed.

Table 4.1 shows a description of dairy farms used in the study, and table 4.3 gives details on type of feeds used and their quality.

Table 4.1: Description of the analysed dairy farms

Farms	A and F	B, C, D, G, H	E and I
Location	Eastern Jordan (arid)	B, C and G in eastern Jordan (arid), D and H located in middle high land (semi-arid)	Jordan valley (semi-arid)
Land endowment (ha)	>7<10	< 1	< 0.5
Herd size	300-400	30-100	3-5
Milk yield (kg ECM/year)	A: 7625 F : 8235	B :7015 C: 6405 D: 6100 G: 6400 H: 4575	E: 3660 I : 3355
Production system	Large scale	Middle scale	Small scale
Milking system	Milking parlor	-Milking parlor -Pipeline milking	Hand milking
No. of workers involved	12	< 5 > 2	One family labour

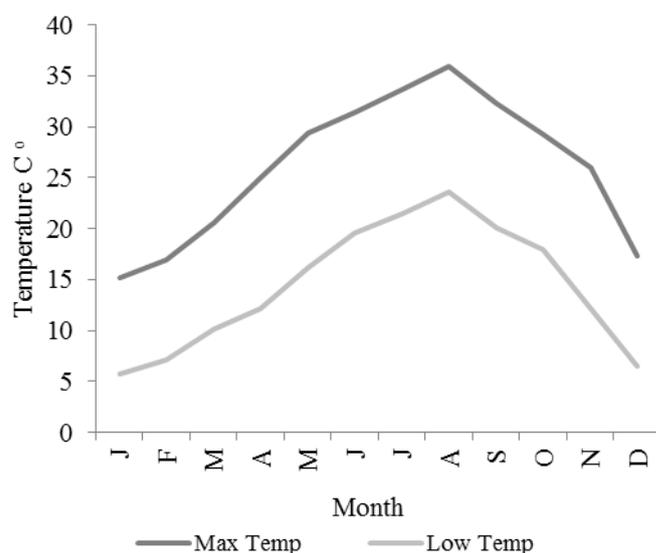
In farms A and F, lactating cows were classified to 6 groups based on their milk yield (50-60 cows per group). Cows were categorized to three levels of milk yield: ≥ 30 ; $<30 \geq 20$; < 20 kg/d with two groups for each category. Diets quality and the level of DMI offered to animals among these groups were based on animal performance. Feed offered to animals composed of concentrate and forages (such as alfalfa hay, corn silage, wheat straw, fresh alfalfa and ryegrass). All feed offered were purchased except the corn silage used in farms A and F was produced on farm.

Cows were milked using milking parlour of 24 cows each time with high hygienic standards and milk was kept in cooled containers till marketing at the same day. Manure was remained in the yard until dried and thereafter removed every two to three weeks. Sick animals were kept under quarantine till they were treated. Mortality rate of calves fluctuated between 1% and 2 % per year, respectively.

Farms B, C, D, G and H, represent the middle scale farm type. Lactating cows in these farms were divided into two groups according to milk yield. Diets offered to animals composed of alfalfa hay, wheat straw, concentrate and ryegrass. Cows were milked using milking parlour of 12 cows each time or by using pipeline milking system. Collected milk was kept in cooled

containers until marketing. Mortality rate of calves was higher than in large scale farms, which reached up to 3% per year. Manure remained on the field was removed less often than in large scale farms.

Figure 4.2: Monthly (mean) higher and lower temperatures in Jordan (2010)



Farms E and I belong to small scale family farms which are dominant in the Jordan valley and in small villages. The farms are located in the backyard of houses and managed by family members. Less management efforts were given to the cows, while raising cows was subsistence oriented. Diet was composed of wheat bran and barley. Cows were hand milked or by using small milking vacuum machines with a low hygienic standard.

Feeding cows usually occurred early in the morning and in the afternoon after milking times. Barley grains represented the highest proportion of the concentrate which exceeded 35%. Figure 4.2 shows the average higher and lower temperatures in Jordan in year 2010.

4.2.2 Chemical analysis of feed, milk and fecal samples

From each farm, milk and fecal samples from lactating cows, as well as feed used on farm, were collected in two different periods. Feed samples (n = 58) which represent the feed offered to animals were collected from each farm twice (in two weeks interval) during the study periods. Samples were obtained at the feed stores, mixed by hand and the representative sub-samples were taken. Three fecal samples were collected from each farm weekly (in total n = 108) so that an estimate on fecal characteristics and N and P contents can be presented. Furthermore, a representative fecal samples number from each farm with

different management system was important to obtain in order to evaluate the in vivo organic matter digestibility. Each fecal sample was obtained from three healthy lactating cows, mixed within animals, and the sub-samples were taken.

Since milk from all lactating animals is collected in the bulk milk, only two milk samples per farm were collected each week (in total $n = 78$). Fecal and milk samples were preserved in ice container prior to analysis at the same day.

Feed samples were analyzed for dry matter (DM), crude ash (CA), crude lipid (CL), phosphorus (P) and Calcium (Ca) according to AOAC (1995). The DM in feed and fecal samples was determined by oven-drying at 105 °C for overnight. CA content was measured by incinerating samples at 550 °C for 4 h. N content in milk and fecal samples was determined using the Kjeldahl procedure using Cu as catalyst (AOAC, 1995). The concentration of crude protein (CP) content in feed and fecal samples was calculated by multiplying the N concentration by 6.25, while CP in milk was calculated by multiplying N concentration by 6.38 (Barbano and Clark, 1990). Neutral detergent fibre (NDF) content in feed samples was determined according to Van Soest et al. (1991). Acid detergent fibre (ADF) content was determined according to Goering and Van Soest (1970).

The in vitro gas production, and the concentration of metabolizable energy (ME) and digestible organic matter (DOM) of feed samples were determined by triplicate in vitro incubation with rumen fluid for 24 h (Menke et al., 1979). Milk urea nitrogen (MUN) was analyzed using Spotchem Analyzer SP-4420 (Arkry Inc., Japan).

4.2.3 Evaluation of feed intake and determination of energy and nutrient requirements, and of nitrogen and phosphorus excretion.

Determination of DM intake and energy corrected milk

eDMI and intake of feed ingredients are shown in table 4.3. To evaluate the intake data provided by farmers, two formulas were used, first according to NRC (2001) using protein and energy corrected milk (ECM) and metabolic body weight as variables, and secondly according to Fox et al. (2003) using the ECM and body weight as variables. ECM with 4.0 % fat and 3.3 % protein was calculated according to the formula $ECM (kg) = (\text{milk production} \times (0.383 \times \% \text{ fat} + 0.242 \times \% \text{ protein} + 0.7832)) / 3.1138$ (Østergaard et al., 2003).

Determination and evaluation of DOM and ME intake and ME requirement

Two methods were used to determine and to evaluate the digestibility of organic matter (OMD) of the diets. Firstly, the contents of digestible organic matter DOM (g/kg DM) was determined according to the in vitro method of Menke and Steingass (1988) using the formula: $DOM = 14.88 + 0.889 \times \text{gas yield (ml/200mg)} + 0.045 \times CP + 0.065 \times CA$, where CP and CA concentrations expressed in g/kg DM, thereafter the measured mOMD of the diet was calculated as the ratio between measured DOM intake and the eDMI. Secondly, the estimated eOMD (%) was calculated from the fecal CP concentration (FCP, g/kg OM) according to the formula: $eOMD = 79.76 - 107.7e^{(-0.01515 \times FCP)}$ (Lukas et al., 2005).

Daily fecal excretion (kg DM/cow) was calculated as the fecal OM (kg/d) x (100/ OM% of DM). Accordingly, the measured ME (mME, MJ/kg DM) was calculated using the formula: $mME = 1.242 + 0.146 \times \text{gas yield (ml/ 200mg)} + 0.007 \times CP + 0.0224 \times CL$ where CP and CL concentration are expressed in g/kg DM (Menke et al., 1979). The estimated ME concentration from each diet (eME, MJ/kg DM) was calculated according to the formula: $eME = (-0.9 + 0.17 \times eOMD \%) \times eOMI$ (Aiple et al., 1992) where the eOMI is the estimated organic matter intake in kg. Results of mME and eME intakes (MJ/d) are presented in table 4.4.

The ME requirements were calculated as the sum of ME for lactation (ME_L), maintenance (ME_m) and pregnancy (ME_p) as follows: $ME_L \text{ (MJ/d)} = LE/0.6$, where LE is energy in milk (MJ/kg milk) calculated according to the formula: $LE = 0.38 \times \%fat + 0.21 \times \%protein + 0.95$ GfE (2001). $ME_m \text{ (MJ/d)} = 0.49 \times LW \text{ (kg)}^{0.75}$ where LW is live weight in kg. It was further assumed that ME_p is equivalent to the energy requirement for two kg of milk.

Calculation of CP and uCP supply and requirements

Concentrations of rumen degradable crude protein (RDCP) and rumen undegradable crude protein (RUCP) in feeds were taken from the feed tables of DLG (1997). The concentration of utilizable CP at the duodenum was calculated according to the formula $(uCP, \text{g/kg}) = (187.7 - (115.4 \times (RUCP/CP)) \times DOM + 1.03 \times RUCP)$ (GfE, 2001), where the intake of CP and RUCP is expressed in g/kg DM, and the DOM in percentage.

Calculation of Ca and P requirement, N and P use efficiencies

In order to evaluate Ca and P intakes of the cows, the daily requirements (g/d) were calculated according to NRC (2001) using formulas as follows: Ca requirement = $(0.0154 \times LW + 1.22 \times ECM)/0.38$ and P requirement = $(0.0143 \times LW + 0.99 \times ECM)/0.50$, while

phosphorus efficiency was calculated as $P_{\text{-eff}} (\%) = 100 \times (\text{milk P}/\text{intake P})$ where milk P (g/d) was calculated as milk yield (kg) $\times 0.9$ (Wu et al., 2000). N use efficiency was calculated as $N_{\text{-eff}} (\%) = 100 \times (\text{milk N}/\text{intake N})$. Ruminal nitrogen balance (RNB, g/kg DM) was calculated according to the formula $\text{RNB} = ((\text{CP g/kg DM} - \text{uCP g/kg DM})/6.25)$ (GfE, 2001).

4.2.4 Estimation of greenhouse gas emissions (GHGs)

The scope of the partial life cycle assessment (LCA) approach used to quantify GHGs includes the entire production process of raw milk considering direct and indirect emissions. The direct emissions include all emissions which originate at the farm level. Indirect emissions include emissions from the production of intermediate products such as fertilisers or concentrates as well as emissions from the production of farm assets (e.g. buildings and machineries). Emissions from deforestation and other land use changes are not included in the calculations. The Greenhouse gas emissions (CH_4 , N_2O and direct and indirect CO_2) from each farm were calculated using feed intake, manure nitrogen and data related to the use of fuel, electricity, chemicals (hygiene and cleaning materials) and purchased feed used on the farm. Farm data was introduced to the TIPICAL (Technology Impact Policy Impact CALculations) model. The model was developed by Hemme (2000) and has been refined to suit its applicability on a global scale. The TIPICAL model is a calculation and accounting model. The model was recently further developed and includes sub-modules for analysis on feeding systems, carbon footprints, water consumption, economic risk exposure and milk quality issues (Hemme et al., 2010).

Methane emissions

The enteric CH_4 (MJ/d) emissions was calculated according to the formula: $\text{CH}_4 = 3.41 + 0.52 \times \text{DMI (kg/d)} - 0.996 \times \text{ADF (kg/d)} + 1.15 \times \text{NDF (kg/d)}$ (Ellis et al., 2007). This formula was selected because the level of CH_4 emissions caused by fermentation in the rumen depends mainly on the composition and quantity of the diet (IPCC, 1996), which were known in the present study. Furthermore, it has a low root mean square prediction error (RMSPE) compared to other equations published in that study. CH_4 energy was converted to mass value using the conversion factors of 0.02 kg/MJ (Brouwer, 1965).

CH_4 (g/d) emissions of calves and heifers were calculated according to the formula: $\text{CH}_4 = 55 + 1.2 \times \text{LW (kg)}^{0.75}$ (Kirchgeßner et al., 1991). Live weights of heifers were estimated according to age classes (i.e., 0–12, 12–24 and >24 month) Kirchgeßner et al. (1991).

CH₄ emissions from manure were calculated according to the formula $EF = VS \times Bo \times 0.67 \text{ kg/m}^3 \times MCF \times MS\%$, (IPCC, 1996). Where EF: CH₄ emission (g/d); VS²: volatile solids excreted by animal and assumed to be 1.9 kg/cow/d according to IPCC (1996). The maximum CH₄ production capacity that can be produced from a given quantity of manure (Bo) was assumed to be 0.13 m³ CH₄ /kg VS. CH₄ volume was converted to mass by using the conversion factor of 0.67 m³/kg. MCF: methane conversion factors for each manure management system for the respective climate region. The MCF defines the portion of the methane producing potential that is achieved depending on the manure management system and was assumed here to be 0.33. MS%: manure production system in climate region (assumed to be 1). The animal manure management system is considered as drylot where animals were kept on unpaved feedlot and the manure is allowed to dry until it is periodically removed which is the case in Jordanian dairy farms.

Nitrous oxide emissions

Table 4.2 shows the emission factors used to calculate the direct (on- farm) N₂O emission which was caused by fuel use, and by manure production. Indirect N₂O emissions from the production of the fertilizers used for purchased feed production were calculated by multiplying usage of N nutrients by the N₂O emissions factor of 0.012 kg N₂O /kg N (Simon, 1998).

N₂O emission losses from manure were calculated from N excretion of cows, calves and heifers multiplied by a N₂O emission factor of 0.02 kg N₂O/kg N excreted (IPCC, 2001).

Manure N excretion of cows obtained from the current study (see table 4.5). N excretion of calves and heifers were assumed based on age clusters and according to Kirchgessner et al. (1991). Animals between the ages of 2 and 12 months were assumed to excrete 22 kg N/ year and those between 12 and 24 months, 47 kg N/year.

² To check the plausibility of the VS value, the daily VS excretion was calculated according to IPCC (2006) using the formula: $VS = [(GE \times (1-DE\%/100)) + (UE \times GE)] \times [(1-ASH/18.45)]$, where: VS = volatile solid excretion per day on a dry-organic matter basis, kg VS/d. GE = gross energy intake MJ/d. GE was determined in the current study using bomb calorimetric method (Parr Inc., USA). DE% = energy digestibility of the feed. (UE x GE) = urinary energy expressed as fraction of GE. Typically 0.04GE can be considered urinary energy excretion by most ruminants. ASH = the ash content of manure determined in our study (table 4.4). The results showed that average VS in all farms was 1.92 kg/d, therefore, the IPCC value of the VS can be accepted.

Table 4.2: Factors used to calculate GHGs emission from dairy farms

Item	Emission factor	Source
CH ₄ to CO ₂ eq.	25	IPCC, 2007
N ₂ O to CO ₂ eq.	298	IPCC, 2007
Manure N ₂ O (kg/kg N) ¹	0.02	IPCC, 2001
Purchased feed N ₂ O (kg/kg N)	0.012	Simon 1998
Fuel N ₂ O (g / l) ²	0.007	Audsley et al., 2003
Diesel (g CO ₂ /l)	2950	Audsley et al., 2003
Electricity (g CO ₂ /kWh)	202	FAO, 2010
Wheat (g CO ₂ /kg)	231	IPCC, 2001
Soybean meal(g CO ₂ /kg)	224	Nagy, 1999
Mineral and vitamin premix (g CO ₂ /kg)	111	Nagy, 1999
Bedding material (g CO ₂ /kg) ³	0.05	
Dairy chemicals (g CO ₂ /kg)	0.1	
Vehicles (kg CO ₂ /kg)	5.9	Öko-Institute, downloaded from
Implements (kg CO ₂ /kg)	5.1	Umweltbundesamt (2010)
Buildings ((kg CO ₂ /m ²)	132.4	

¹ The N₂O emission losses from manure = nitrogen excretion of cows in kg/year multiplied by an emission factor of 0.02 for drylot waste management systems dominant in Jordanian dairy farms

² N₂O emissions of fuel combustion = diesel fuel usage in kg multiplied by the N₂O emission factor of 0.007 g N₂O / L

³ CO₂ Emission from bedding materials= usage of bedding material in kg /year multiplied by 0.05 g CO₂ / kg

Emission from dairy chemicals = the quantity used in kg/year multiplied by 0.1 g CO₂ /kg.

-Quantities of fuel, dairy chemicals as well as data on vehicles and bedding materials were collected from the farms

-The CO₂ emissions from concentrate feed were calculated assuming that the concentrate feed used on a farm contains 67 % carbohydrate sources (e.g. wheat), 30 % protein sources (e.g. soybean meal) and 3 % minerals and vitamins.

Carbon dioxide emissions

The sources used to calculate CO₂ emissions in dairy farms (respiratory CO₂ was not included in the calculations) are fuel combustion, concentrate production, pesticides, machineries, buildings and other assets and input stuff e.g. bedding material and dairy chemicals. Table 4.2 shows the emission factors used for the calculations as follows: Farm assets were clustered into vehicles, implements, buildings and fences. In order to calculate the emissions from vehicles and implements, factors converting their weight into emissions were applied (table 4.2). The indirect emissions of assets were divided by the expected working life which was assumed to be 10 years for vehicles and implements and 25 years for buildings. The CO₂ emissions from concentrate feed were calculated assuming that the concentrate feed used on a farm contains 67 % carbohydrate sources (e.g. wheat), 30 % protein sources (e.g. soybean meal) and 3 % minerals and vitamins which fit to the typical ration dominant in the farms.

GHG credit

GHG credit is an allocation of emissions to co-products of milk production. These can include meat, manure, animal draught power and capital functions. In the current study only beef credits was considered as their method of estimation is generally accepted (Cederberg and Stadig, 2003; Sevenster and de Jong, 2008) and others are of minor relevance for the farms in this study. The method applied in this study is the so-called cause-effect physical ('biological') allocation (Cederberg and Stadig, 2003), whereby emission credits for the beef of culled cows are allocated based on the proportion of 40 to 60% according to KTBL (2006) which is based on energy intake allocation between beef and milk. This proportion seems reasonable since milk yield in the studied farms is lower than the typical production level in Europe which indicate higher proportion of GHG are caused by beef production, compared to the allocation factors are used in Europe. It is further assumed that male calves are sold at the age of two weeks.

For computation of the beef credit, all animals of a farm (cows, heifers and female calves) are first converted via their live weight into livestock units (LU)³ and the total number of animals sold (cows, heifers and bull calves) is given in terms of LU. In a second step, farm's total emissions are divided by the total LU per farm in order to obtain an estimate of emissions per LU. The emission credits for culled cows are then computed by multiplying the number of culled cows (in terms of LU) by the total emission per LU weighted by 40 % (allocation factor). Beef credits for culled heifers and bull calves are computed by multiplying the animals sold, in terms of LU, by total farm emissions per LU.

³ 1 Livestock unit (LU) = 650 kg live weight (Kirchgeßner et al. 1991)

4.3 Results

4.3.1 Diet composition, energy and nutrient intake of the cows

Table 4.3 shows the feeds, their chemical composition and the eDMI of the used feed in each farm. In the large and middle scale farms, quality of concentrate and roughage feed were higher than those in small scale farms.

CP content in concentrate feeds varied between farms in different regions and was the highest in farms A and F with 182 and 207 g/kg DM and the ME content ranged between 11.9 and 13.7 MJ/kg DM in farm D and C, respectively. Similarly, CP in Alfalfa hay varied between 160 and 203 g/kg DM with ME contents ranging between 8.6 MJ/kg DM and 10.3 MJ/kg DM and its DOM content ranged between 643 and 737 g/kg DM. Corn silage was offered on farms A and G with ME contents of 7.4 and 9.8 MJ/kg DM, respectively. CP concentration in wheat straw was in the range of 30-50 g/kg DM and ME varied between 5.5 and 7.6 MJ/kg DM. It was offered in most of the farms and possessed low DOM content with range between 450-600 g/kg DM. Feeds in small scale farms E and I possessed lower CP and ME than concentrate feeds in other farm types. The eDMI was a result of farmers interview, therefore; to assess the accuracy of eDMI, two prediction (DMI_1 and DMI_2) formulas were used (table 4.4) and compared with eDMI.

When considering all farms, mean DMI_1 was 17.3 kg/d, this is 1.1 kg higher than the mean eDMI. The largest and smallest difference between DMI_1 and eDMI ranged between 0.1 in farm B and 4 kg in farm E. Likewise, mean DMI_2 was 15.6, this is -0.6 kg/d lower than eDMI with a difference ranging between -1.8 kg in farm B and 2.5 kg in farm E. The fact that eDMI in the current study remains between the two predictions (DMI_1 and DMI_2), may support the validity of eDMI. However, eDMI in farm E is exceptionally low. The negative energy balance of -14 MJ ME indicates as well that eDMI was at least 1.3 kg underestimated, and therefore the results of this farm need to be carefully interpreted.

eDMI and intake of feed ingredients are shown in table 4.4. eDMI was 10 % and 44 % higher in large scale farms compared to middle and small scale farm types, accordingly milk yield was higher by 13 % and 54 % respectively.

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Table 4.3: Intake, chemical composition, in vitro gas yield and calculated metabolizable energy (ME), net energy for lactation (NEL), digestible organic matter contents (DOM) of feed used on the farms

Farm code	Feedstuff	eDMI*	DM	CP	RDCP	CA	CL	NDF	ADF	P	Ca	In vitro			
												- gas yield	ME	NEL	DOM
		Kg/d	%	g/kg DM	% of CP	g/kg DM	ml/200 mg DM	MJ/kg DM	MJ/kg DM	g/kg DM					
A	Concentrate	13.7	93	182	72	54	17	200	60	5.2	4.5	65.1	12.4	7.4	844
	Corn silage	2.5	39	77	75	105	15	370	200	1.9	6.3	36.0	7.4	4.4	572
	Wheat straw	1.4	93	50	70	115	7	690	420	0.7	3.0	37.4	7.3	4.4	582
	Alfalfa hay	1.8	93	160	70	81	15	430	310	2.7	12.4	42.8	8.9	5.4	654
B	Concentrate	13.4	89	160	72	60	22	160	60	6.0	5.5	62.6	12.0	7.2	817
	Alfalfa hay	2.7	93	140	70	110	22	490	320	3.5	5.8	40.0	8.6	5.2	643
	Wheat straw	2.6	92	45	70	85	7	610	420	0.7	2.8	26.2	5.5	3.3	458
C	Concentrate	13.2	88	169	72	75	24	250	50	5.0	7.5	66.7	12.7	7.6	866
	Wheat straw	1.7	93	40	70	93	5	620	420	2.2	5.4	27.7	5.7	3.4	475
	Whole-plant corn fresh	1.5	29	140	75	83	19	560	280	4.0	2.1	58.5	11.2	6.7	785
	Alfalfa hay	1.4	93	139	70	99	21	370	250	2.8	11.2	45.2	9.3	5.6	678
D	Concentrate	13.5	90	140	72	72	5	190	100	3.9	7.0	66.0	11.9	7.2	843
	Wheat straw	1.4	94	32	70	77	7	770	460	0.5	2.1	28.4	5.8	3.5	466
	Alfalfa hay	2.7	89	160	70	132	29	490	310	1.9	11.5	43.6	9.4	5.6	697
E	Barley	2.0	89	110	70	43	36	190	50	8.1	2.0	59.7	11.5	6.9	754
	wheat bran	8.0	88	160	75	39	34	350	100	3.3	0.9	56.0	11.5	6.9	743
F	Concentrate	13.3	89	207	73	69	48	203	71	5.1	6.8	60.4	12.6	7.5	824
	Ryegrass fresh	3.3	11	216	70	161	60	453	243	6.0	7.5	49.8	11.4	6.8	793
	Wheat straw	1.4	90	42	70	57	27	832	495	0.8	4.5	37.6	7.6	4.6	539
	Alfalfa hay	0.9	87	203	70	141	43	418	270	2.2	15.0	45.6	10.3	6.2	737
G	Concentrate	12.4	89	200	72	55	40	236	78	5.2	6.4	60.7	12.4	7.5	817
	Ryegrass fresh	1.4	10	251	85	151	88	460	235	6.4	6.3	46.0	11.7	7.0	769
	Corn silage	1.1	31	79	75	67	56	503	277	2.5	5.0	46.2	9.8	5.9	639
	Wheat straw	2.7	89	35	70	68	36	830	470	0.6	3.5	30.7	6.8	4.1	482
H	Concentrate	10.6	89	168	72	41	68	255	81	5.4	5.3	66.8	13.7	8.2	845
	Fresh alfalfa	2.0	39	187	75	141	43	418	270	2.9	27.5	42.3	9.7	5.8	701
	Wheat straw	1.7	85	36	70	80	38	813	455	0.7	4.5	36.0	7.6	4.6	537
I	Wheat bran	7.9	87	163	75	45	46	354	110	3.9	1.2	51.5	11.0	6.6	710
	Barley	3.6	89	115	70	44	36	204	70	8.3	2.5	58.0	11.3	6.8	745

eDM intake* : data represent the farmers estimated amounts of feed offered to animals.

DOM = 14.88 + 0.889 x gas yield (ml/200mg) + 0.045 x CP (g/kg DM) + 0.065 x CA (g/kg DM) (Menke and Steingass, 1988).

ME = 1.242 + 0.146 x gas yield (ml/200mg) + 0.007 x CP (g/kg DM) + 0.0224 x CL (g/kg DM) (Menke et al., 1979).

NEL = 0.6 x (1 + 0.004 x (9.57)) x ME.

Proportion of RDCP for each feed were taken from feed tables for ruminants (DLG, 1997).

The higher eDMI in large scale farms was also associated with higher mME and CP daily intake at rates of 41% and 47% respectively compared to small scale farms E and I. Since management differed between farming systems (animals grouping, feed availability), accordingly, milk yield varied between 11 and 27 kg ECM/d. Similar to eDMI, trends were observed for the intakes of OM, CP, NDF and RUCP.

For the complete diets, the concentration of mME, per kg DM differed between farms and was in the range of 10.6 and 12.4 MJ/kg DM, while CP concentration varied between 148 and 196 g/kg DM in farms I and F, respectively. Similarly, and due to the differences in forage quality between farms, NDF content varied between 270 g/kg DM in farm B and 360 g/kg DM in farm G. Due to the small variation in NDF concentration across farms, there was no impact of NDF content in the diet on milk fat and protein concentrations. Likewise, the concentration of mME and CP of feed had no effect on milk yield and composition.

CP intake was lower than the requirements in seven farms; three farms (B, C and D) had a deficiency level of more than 10%, while four farms with slight deficiency level ranged between 4% and 9%.

For all farms, mean CP intake was with 115 g (or 4%) lower than the requirements, however varied between oversupply of 11% in farm F and deficit of 17% in farm D. Likewise, RUCP intake was lower than the requirements in six farms. Three farms (B, C and D) had a deficiency level of more than 10%, while in three farms were between 5 and 8% below the requirements. Although CP was in deficit in several farms, MUN was unexpectedly not depressed and varied between 15 and 36 mg/dl.

MUN was higher in summer time (in farms A to E) compared to spring time (F to I). The average MUN in the current study was 25 mg/dl, with an average RNB of -1.2 g/kg DM, while average CP intake was 157 g/kg DM. The daily CP intake differed between farms and accordingly the RNB ranged between 3.2 g/kg DM in farm F and -4.4 g/kg DM in farm D. In general, RNB was negative in all farms except in farms F and G.

mME intakes were similar to the requirements in all farms except in farm E where the intake was 7% lower than the requirements, and consequently ME balance was negative for this farm.

There was wide variation in mOMD between farms; it ranged between 72% in farm I and 81% in farm C, with average of 77% for all farms. The eOMD results (table 4.4) were lower than the mOMD and ranged between 77% in farm G and 69% in farm H with a mean of 73% for all farms. A mean difference between mOMD and eOMD of 4% was observed. The eME

intake was the lowest in farm E (109 MJ/d) and the highest in farm A (206 MJ/d). Considering all farms, the mean difference between eME and mME was 10 MJ/d with higher values observed for the mME.

P intake was above the requirements in all farms with range of 5% in farm D and 71% in farm I in relation to the requirements. In average, P intake was 35% above than the requirements. Deficiency in Ca intake was observed in small scale farm E and I. A deficiency of 79% in farm E and a surplus of 69% in farm H were notified in relation to the requirements. For all farms, mean Ca intake was 11% above than the requirements.

4.3.2 Nitrogen and Phosphorus balance

N and P balances of animals in the studied farms are displayed in table 4.5. The intake of N was mainly driven by the level of eDMI and varied between low intake of 240 g/d in farm E and high intake of 485 g/d in farm A with mean of 406 g/d for all farms. In percentage terms, at higher levels of eDMI the proportion of fecal N was lower. The N_{eff} ranged between low (19%) in farm I and high efficiency (28%) in farm A, with average of 24% for all farms. Furthermore, due to the high eDMI in high yielding cows, a higher proportion of N was secreted in milk and consequently N_{eff} was higher. Similarly, the P_{eff} improved at higher eDMI levels, accordingly; P_{eff} (average 24%) ranged between 15% in farm I and 31% in farm D. The results show that 61 % of P intake was excreted in feces with range between 30% in farm H and 87% in farm A.

Table 4.4: Energy and nutrient intake and requirement, milk yield and composition and fecal excretion of lactating cows

Farm	A	B	C	D	E	F	G	H	I	Mean
Intake										
eDMI kg/d	19.3	18.6	17.8	17.6	10.0	18.9	17.6	14.3	11.4	16.2
¹ eOMI kg/d	18.0	17.3	16.4	16.1	9.6	17.2	16.5	13.5	10.9	15.0
² eDOMI kg/d	14.9	13.8	14.3	13.9	7.5	15.0	13.2	11.3	8.2	12.5
CP g/d	3030	2639	2697	2362	1500	3707	3023	2211	1690	2577
RDCP g/d	2180	1890	1943	1691	1114	2785	2224	1601	1247	1852
RUCP g/d	849	749	754	671	386	922	799	609	460	688
NDF g/d	5433	5012	5706	4992	3180	5699	6357	4920	3505	4978
ADF g/d	2420	2656	2186	2849	892	2654	2867	2167	1115	2201
P g/d	81	91	89	59	43	91	77	64	60	73
Ca g/d	103	96	127	128	12	134	103	118	19	93
MEI MJ/d										
eME intake	206	200	190	185	109	203	200	147	123	174
³ mME intake	214	197	207	194	115	225	200	178	126	184
⁴ ME balance	11	5	23	18	-14	14	19	30	5	12
Milk yield and composition										
Milk yield kg/d	25	23	22	20	11	25	22	15	10	19
Energy corrected milk kg/d	25	23	21	20	12	27	21	15	11	19
Milk protein %	3.4	3.4	3.3	3.4	3.4	3.5	3.3	3.2	3.3	3.4
Milk fat %	3.2	3.6	3.1	3.3	4.1	3.7	3.1	3.3	3.6	3.4
MUN mg/dl	30	28	32	36	34	15	19	18	10	25
OMD %										
mOMD	77	74	81	79	75	79	75	79	72	77
⁵ eOMD	73	73	74	73	72	75	77	69	72	73
Fecal										
DM%	21	17	15	18	21	17	16	19	17	18
Ash kg/kg DM	124	179	141	179	190	130	150	80	81	139
CP, g/kg OM	178	186	188	180	176	203	236	155	171	186
⁶ Fecal DM kg/d	3.5	4.3	2.4	2.7	2.5	2.6	3.8	2.4	2.9	3.0
Predicted DMI and energy and nutrient requirements										
⁷ DMI ₁ kg/d	19,5	18,7	18,4	17,6	14,0	20,1	18,0	15,8	13,5	17,3
DMI ₂ kg/d	17.5	16.8	16.7	15.9	12.5	18.0	16.1	14.3	12.2	15.6
uCP g/d	3192	2905	3006	2844	1575	3333	2903	2386	1752	2655
RDCP g/d	2297	2081	2165	2036	1170	2504	2136	1728	1293	1934
RUCP g/d	895	824	841	808	405	829	767	658	459	721
ME MJ/d	196	187	178	171	123	205	176	142	116	166
P g/d	65	62	59	56	37	70	57	45	35	54
Ca g/d	102	97	92	87	58	110	90	70	54	84

¹eOMI: estimated organic matter intake. ²eDOMI: estimated digestible organic matter intake.

³For each feed, the mME, MJ/kg DM was calculated according to the formula mME= 1.242+0.146 x gas yield (ml/ 200mg) + 0.007 x CP (g/kg DM) +0.0224 x CL (g/kg DM) (Menke et al., 1979).

⁴Calculated from the mME according to the equation: ME balance= mME intake – MEI -ME_m -ME_p, assuming requirement equivalent of 2 kg of milk for pregnancy.

⁵eOMD = 79.76 – 107.7e^(-0.01515 x FCP) (Lukas et al., 2005), FCP =Fecal crude protein expressed in g/kg OM.

ME_m =0.49 x LW^{0.75}. RNB g/kg DM = ((CP g/kg DM –uCP g/kg DM)/6.25) (GfE, 2001).⁶Based on eDMI and mOMD.

⁷DMI₁ calculated according to NRC (2001), DMI₂ calculated according to Fox et al., (2003).

Table 4.5: Nitrogen and phosphorus balance

	A	B	C	D	E	F	G	H	I	Mean
N use efficiency										
N intake g/d	485	422	432	378	240	593	484	354	270	406
N % of intake										
Fecal N ¹	18	25	14	17	25	12	25	15	27	20
Urinary N ²	54	47	60	55	51	65	52	63	54	56
Milk N	28	28	26	28	24	23	23	21	19	24
RNB g/kg DM	-1.3	-2.4	-2.8	-4.4	-1.2	3.2	1.1	-2.0	-0.9	-1.2
P use efficiency										
P intake g/d	81	91	89	56	43	91	77	64	60	73
P % of intake										
Fecal P	87	74	68	79	69	36	61	30	47	61
Absorbed and urinary P ³	-15	3	10	-10	9	39	14	49	38	15
Milk P	28	22	22	31	22	25	26	21	15	24

¹Daily fecal excretion of N (g/d) = N concentration per kg fresh matter faeces/(DM% x kg DM faeces excreted per day).

²Urinary N g/d calculated as N intake- Fecal N- Milk N.

³ Absorbed and urinary P calculated as P intake – Fecal P-Milk P.

4.3.3 GHGs emission

Table 4.6 shows the estimated GHGs emission per cow and per kg ECM produced in different farm types. The daily enteric CH₄ emission was significantly driven by the level of eDMI, accordingly, emissions per cow were the highest in farm A and F and were 31% higher than those in farms E and I.

Depending on the level of milk yield, CH₄ emission per kg ECM produced was the lowest in farm F of 14g/kg ECM compared to 26 g/kg ECM in farm I.

In order to find out the main drivers for emissions per kg ECM milk produced, the relationship between both eDMI and ECM milk and the total GHG emissions (in CO₂ eq.) were evaluated. Figure 4.3 illustrates the relationship between the total CO₂ eq. and the eDMI described by the following function ($y = -89x + 2673$. with $R^2 = 0.88$ and S.E=120), where y represents the CO₂ eq. (g/kg ECM) and x is the eDMI (kg/d). The effect of the daily ECM milk on CO₂ eq. was more pronounced than that of eDMI. Furthermore, the relationship between CO₂ eq. and ECM milk yield is illustrated in figure 4.4 which resulted in the following function ($y = 3.51x^2 - 180x + 3307$. with $R^2 = 0.93$ and S.E= 125) where y represents CO₂ eq. per kg ECM and x is the milk yield in ECM (kg/d). For both regression equations all coefficients were highly significant (p-value <0.001).

CH₄ (enteric and manure) represented 52% of total GHG emissions (in CO₂ eq.). In general, per kg of milk, high yielding cows in farms A and F emitted lower CO₂ eq. (20% and 88% in relative terms) compared to middle and small scale farm types.

Table 4.6: Estimated GHGs emission

Farms	A	B	C	D	E	F	G	H	I	Mean
Estimated gas emission/ cow/d										
Enteric CH ₄ g/cow/d	346	324	341	309	228	343	341	287	245	307
Enteric CH ₄ g/kg DM intake	18	17	19	18	23	18	19	20	22	19
Enteric CH ₄ g/kg ECM milk	15	15	17	17	21	14	18	21	26	18
CH ₄ from manure g/d	61	27	61	47	34	70	47	67	59	55
N ₂ O from manure g/d	5	5	4	3	2	6	5	4	3	4
Whole farm emissions (CO ₂ eq. g/kg ECM milk)										
CH ₄	503	470	574	650	810	481	617	714	984	645
Direct N ₂ O	109	156	131	171	362	154	222	218	383	212
Indirect N ₂ O	144	184	216	127	177	176	135	127	182	163
Direct CO ₂	15	26	16	20	61	24	37	21	58	31
Indirect CO ₂	132	197	220	145	263	156	137	144	271	185
Total CO ₂ eq. emissions g/kg ECM milk	903	1032	1157	1114	1673	991	1147	1224	1879	1235

CH₄ (MJ/d) estimated according to the formula $CH_4 = 3.41 + 0.52 \times DMI - 0.996 \times ADF \text{ kg/d} + 1.15 \times NDF \text{ kg/d}$ (Ellis et al., 2007).
 Whole farm Estimated CH₄ emission includes emissions from cows, heifers, calves and from manure.
 Direct N₂O includes also emissions from manure.
 Direct and indirect emission factors used to calculate CO₂ emissions are shown in table 4.2.

Figure 4.3: Relationship between CO₂ eq. emission and daily eDMI intake.

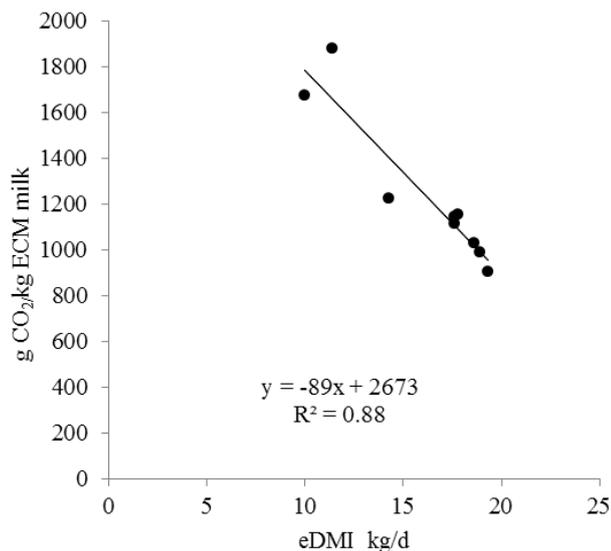
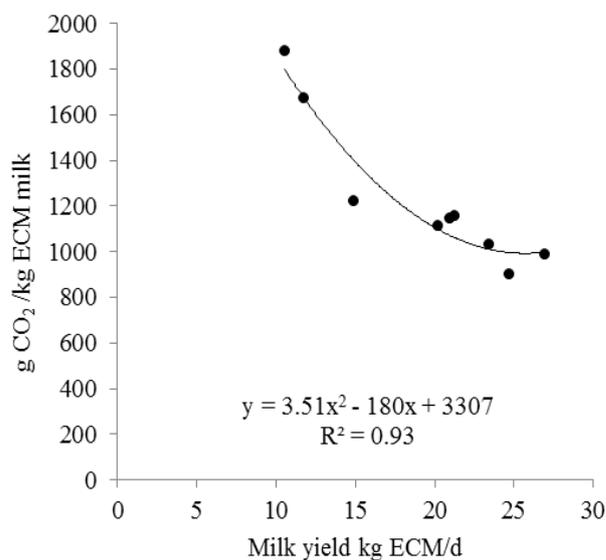


Figure 4.4: Relationship between CO₂ eq. emission and daily ECM milk yield.



4.4. Discussions

4.4.1 Energy and nutrient supply and requirement of the cows

Mean values for chemical composition of concentrates, alfalfa hay, wheat bran, wheat straw feed used on farms (Table 4.3) were similar to those reported in other studies (Seker, 2002; Iantcheva, 1999; NRC, 2001; Abas et al., 2005). Using similar feed on dairy farms indicates that the opportunity for dairy farmers to choose different feed types was limited. This usually depends on farm location, feed availability in the market and their prices, for example feeding ryegrass was accessible only in two farms located near a plant production enterprise.

The eDMI in the current study represent the average amount of feed offered to the lactating cows during the study period and not precisely what the animals have ingested. Accordingly, there could be small discrepancy in the daily intake of ingredients provided in table 4.3 and 4.4, particularly in farm E where eDMI obviously seems to be underestimated. Since it was not possible to precisely measure DMI, the discrepancy in the ingredients intake could not be avoided. However, since eDMI on other farms ranged between two DMI predictions, this might supports the plausibility of the estimated DMI used in this study.

The variations in milk yield across farms were mainly caused by the differences in eDMI (Table 4.4). In large and middle scale farm types, dairy farmers improved feed management by means of inclusion high quality and quantity of concentrate and forage feed compared to small scale farms. On small scale farms, feed availability was limited and farmers could not afford additional quantities due to economic reasons. There was no relationship between milk fat percentage and either NDF or ADF concentration in the diet. Average NDF content in the current study was 30%, which is lower than the standard requirements (34% NDF) when the diet is based on barley grains (Beauchemin, 1991). The current results of NDF percent and the associated milk fat are similar to those reported by Mustafa et al. (2000).

Furthermore, a large proportion of NDF was provided by non-forage sources which are less effective in maintaining milk fat percentage. According to the NRC (2001), 16% NDF in the diet should originate from forage. This was not attained in the studied farms. Likewise, the dietary concentration of physically effective NDF (peNDF) was below the requirements (20% of the diet) due to the high proportion of concentrate intake, consequently, one would speculate that ruminal pH is reduced (Zebeli et al., 2008) and has affected milk fat percentage. The small proportion of forage in diets is due to the fact that the transportation costs for forage feeds are high due to their bulky structure. Dairy farmers prefer to import high density concentrate feeds which require less space during transportation from overseas. Furthermore,

forages are not available year round in the neighboring countries which eliminate the use of fiber in animal's diet from imported sources.

Since availability of forage is a main constraint for dairy farmers to improve diet structure, alternatively, they may need to utilize available by-products which are rich in physically effective fiber such as barley and wheat straws.

Milk protein percentage was not influenced by the level of mME intake across the studied farms. This could be attributed to the dilution of milk protein percentage caused by the increase in milk yield. At higher energy supply, microbial protein synthesis increased (Mackle et al., 2000) and consequently has affected the total milk protein yield, however not protein percentage, since milk yield has increased too as response to higher energy supply. Furthermore, large quantity of starch was available in the rumen and in the intestine that have provided more propionate for glucose synthesis and more glucose for absorption in the intestine (Yang and Beauchemin, 2007) which caused an increase in milk yield.

Comparing CP intakes with CP requirements, a remarkable deficiency occurred in two farms which could have affected productive performance of the animals.

When comparing farms at similar eDMI, N_{eff} of animals with high ME/CP ratio in farm A was improved and one would speculate that more available energy in the rumen to capture ruminal ammonia which have provided microbial growth and outflow from the rumen compared to farm F with lower ME/CP ratio.

Average RUCP was only slightly lower (4%) than the requirements which indicates that RUCP supply was not limiting the productive performance of animals in farms B, C, D and H. Since CP is provided to a great proportion by expensive soybean meal rich in RDCP, alternatively; available by-products rich in RUCP (as % of CP) such as: corn gluten meals (63%) and brewer's grains (54%) should be considered as alternatives when RUCP is greatly deficient in diets where CP supply was largely below the requirements, higher CP intake can be realized by feeding feed with highly degradable CP or by supplementing urea to reduce the gap.

MUN concentrations were within the recommended values (12-18 mg/dl) in farms F, G, H and I which were visited in spring time, but were higher in farms A, B, C, D and E which were visited in summer time irrespective from CP intake and concentration in the diet. The high values of MUN could be caused in part by the intake of RUCP above the requirements in farms F and G which might have also contributed to an increased urea synthesis (Nousiainen et al., 2004). The lack of a consistent relationship between MUN and RNB in the current study suggests that other reasons may have caused an increase on MUN values. Cows were

raised under semi-arid environments with higher temperatures (figure 4.2) than those in moderate climates. The higher MUN values in summer time compared to spring time are confirmed by observations of Mishra et al. (1970) who reported an increase in rumen ammonia and lactic acid levels in cows in heat stress. It seems evident that MUN values were greatly influenced by the season, therefore, the average recommended values determined in moderate climate regions seem to be not valid for hot climate regions. As a conclusion, MUN can be used to compare diets within a region and in the same time. Further research is needed to confirm our results which need to consider the physiological changes might occur to animals raised under hot climate conditions.

The absolute difference between mOMD and eOMD was 4% (table 4.4). Several authors have reported differences between both values (Fanchone, 2009; Schlecht and Susenbeth, 2006; Lukas, 2005). Several factors could have caused this divergence. The fecal N per unit of OM excreted is affected by the ingredients of concentrates (Herrera-Saldana et al., 1990), the proportion of concentrate in the diet (Lukas et al., 2005), and the level of feeding (Schlecht and Susenbeth, 2006). Furthermore, multiple intakes above the maintenance reduce the digestibility which was reflected in eOMD, however not the mOMD which is related to feeding at maintenance level. Feeding level between two and four times above maintenance which is the case in the studied farms, results in digestibility reduction of 3 to 4% (Vandehaar, 1998) which is in good agreement with the difference between both approaches. Schlecht and Susenbeth (2006) found that the Lucas's equation overestimate the digestibility of their diets probably due to higher undigested feed N or endogenous N losses. Despite the uncertainty due to the small difference between the two methods, eOMD has an advantage of being less laborious and expensive than the mOMD method. This method seems, therefore, to be feasible for predicting the OMD of lactating cow's diets under the Jordanian conditions.

the difference between mME intake and ME requirements for lactation, maintenance and reproduction was positive in several farms. However, when it was re-calculated from the eME intake values, the difference between intake and the requirements was reduced, except in farm E where the eDMI was obviously underestimated. This suggests that the eME may provide a more realistic estimate of the actual ME consumed by animals than the mME. The higher energy intake compared to requirements for maintenance and lactation might be due to the increasing costs for thermoregulation and physical activity.

Ca intake was deficient in farms I and E by more than 10% while other farms had a surplus between 22 and 69%. However, the intake of 12 g/d in farm E is unrealistic low due the underestimated eDMI. Nevertheless, small farmers claimed that their animals grazed a low

quality pasture (farmers had no idea about the grass type) during spring time, as well animals ate the residues of the household food (mixture of tea, peels of potato, tomato and beans) which did not exceed 1 kg DM/d. Therefore, we speculate that these feeds probably provided some additional minerals which are not taken into account in table 4.4. Since the deficiency was found in small scale farms, additional supplements of Ca source to the diets are essential. In contrast to Ca, P intakes were above the requirements between 5 and 71%. Furthermore, since manure is frequently sold to other enterprises, this also reduces its environmental impacts. It seems evident that feed costs can be lowered by reducing expensive P supplementation in the concentrates.

4.4.2 Efficiency of nitrogen and phosphorus utilization

N_{eff} was significantly driven by the level of milk yield and correlated with the level of eDMI ($r = 0.88$). It is evident that the proportion of maintenance requirement is reduced at high levels of eDMI, allowing more protein to be used for milk production. N_{eff} was 19% in low yielding to 28% in high yielding cows. Furthermore, in relative terms, CP requirements increase at lower rate as milk yield increases (NRC, 2001), thereby improving N_{eff} for milk production. The effect of dietary CP and energy content on animal's N_{eff} was observed between individual farms. For example, at high ME/CP ratio in farm D, N_{eff} was higher in farm C where the ratio was lower. Although, the adequate energy supply associated with oversupply of CP (the case in farms F and G) resulted in positive RNB has not improved the N_{eff} compared to an adequate energy supply and low CP feeding in farm A. These results agree with Wu and Satter (2000) and Kebreab et al. (2001). Therefore, it seems evident that grouping animals in large scale farms based on their level of milk production may improve N_{eff} .

The low P_{eff} is attributed to the high P supply above the requirements. At an adequate intake, P_{eff} is about 33%. The high P content in the diets indicates that the rations were not proper formulated toward the required levels of minerals.

Since the amount of inorganic P which was added to the concentrates is unknown, the extent of a possible P reduction could not be quantified. Compared to the requirements; the current results suggest that in average 35% of the dietary P could be reduced.

4.4.3 GHG emission

Emission data for arid and semi-arid regions are very scarce. Therefore, the current results were compared with those from other regions. Predicted mean enteric CH₄ emission for all farms was 307 g/cow/d. These results were lower than those reported by Mills et al. (2003) who found that enteric CH₄ emission varied between 323 and 414 g/cow/d which could be attributed to the differences in the used diets, their composition and the level of eDMI between Mills's study and the current study. The high proportion of concentrates and the low roughage intake might be the main factor. However, which is of greater importance, emissions per unit of eDMI and milk decreases with increasing eDMI and milk yield, respectively.

In farms A, B where eDMI was high, CH₄ emission varied between 18 and 17 g/kg DM, while at low eDMI in farms E and I, CH₄ emission was 23 and 22 g/kg DM, respectively, and were similar to those reported by Hindrichsen et al. (2006) and Holter and Young (1992). The reduced CH₄ emission per kg eDMI with increasing feed intake is caused by higher passage rate (Yan et al., 2000). Furthermore, a large proportion of propionic acid was observed at high DMI (Benchaar et al., 2001). Since diets in different farms were similar in their NDF and ADF contents, diet composition might have had a small impact on CH₄ emission.

Mean CH₄ emission from manure was estimated at 11% of total CH₄ emissions. Hindrichsen et al. (2005) reported similar proportions of slurry-derived CH₄ emission which varied between 10–27%. The variation between CH₄ emissions from manure on farms could be related to the fecal composition (DM and NDF), volatile solids production, the way for manure storage on farm, and due to the ambient temperature. In order to evaluate the plausibility of enteric CH₄ emission values, further equations were used. Data on dry matter, NDF and ADF intakes were used to predict CH₄ emissions by two linear regression models developed by Ellis et al. (2007)⁴ which showed that the estimated values might probably by 10-11% underestimated. In spite the fact that Ellis's model was developed under different conditions, it has an advantage of being simple and required available dietary information. Since the estimated enteric CH₄ fall within the range of other studies based on concentrate diets (Kebreab et al., 2008), it can be probably concluded that the used equation provided a reasonable prediction.

CH₄ (enteric and manure) emission represented the highest proportion (52%) of the total CO₂ eq. Since no land was used to produce feed, the direct emissions of CO₂ and N₂O accounted

⁴ The equations used: CH₄ (MJ/d) = 2.16 + 0.493 x DMI - 1.36 x ADF + 1.97 x NDF ((RMSPE 28.2%), CH₄ (MJ/d) = 3.272 + 0.736 x DMI (RMSPE = 28.2%)

for a small magnitude. These were caused mainly by farm management practices and manure excretion from animals. Daily N₂O emission from manure was driven significantly by the daily CP intake and its concentration in the diet. However, N₂O emission (in CO₂ eq.) per kg ECM milk produced was lowest in large farms compared to small farms and caused by the level of milk yield. The composition of the diet had no influence on the total CO₂ eq. emission, while the impact of feeding level (figure 4.3) was more pronounced. For example in farm A, at 4x maintenance energy intake of 214 MJ/d, the total CO₂ eq. were lower by 51% than in farm I where energy intake was 2x maintenance of 124 MJ/d.

The relationship between daily total GHG emissions (in CO₂ eq./kg ECM) and the ECM milk produced are illustrated in figure 4.4. CO₂ eq. emission were lower when animals produced higher amounts of milk, similar results were reported by Rotz et al. (2010) and by Hagemann et al. (2011).

In spite the fact that farming systems greatly differ between regions, it is worth to compare our results with data available from Europe. EU dairy farming systems producing between 7000-9000 kg milk per cow and year are intensive with variable proportions of grass in the diet. Inorganic fertilizers as well as manure are applied on farm. According to De Vries and Boer (2010), CO₂ emissions ranges between 1.04 and 1.20 kg CO₂ eq./kg ECM milk. Despite the differences in feeding regimes, the current results agree well with those of Casey and Holden (2005) who found that emission was 1.3 kg CO₂ eq./kg ECM milk produced due to two facts that high emissions are caused by energy and fertilizers used in the EU farming systems and by the high level of milk yield leading to a reduction per kg ECM. The current results from small scale farming can not be compared with those from Europe since milk yield was much lower. Nevertheless, they agree with Bartl et al. (2011) who reported that emission of small scale farms in the coastal areas of Peru was 1.74 kg CO₂ eq. /kg ECM milk.

The significant relationship between CO₂ eq. emission and the level of milk yield implies a remarkable mitigation potential in CO₂ emissions, in particular for small scale farming.

4.5 Conclusion

This study evaluated the productive performance, lactating cow's diets and the ecological impact of dairy farming systems in semi-arid environments of Jordan.

It is evident that the level of eDMI is the main driver for the wide variations in productive performance and efficiency between animals. Small farmers will probably not be able to improve on animal performance without institutional support and resource allocation for their farms. Since global feed prices are increasing, alternative feeding systems at low concentrate levels need to be developed. To improve the nutritional status of the animals, protein requirements have to be met. Furthermore, low price by-products with a low carbon credit should be included in the diets to replace the high proportion of imported concentrate feeds and consequently improve the economic situation of dairy farms and mitigate CO₂ eq. emissions.

In the context of animal improvement, performance drivers other than diet related factors such as the environmental conditions and their impact on animal efficiency need to be further investigated. Further studies on alternative feeding strategies under semi-arid climate conditions are needed.

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Chapter Five

Evaluating the use of food industry by-products as feed to improve the economic performance and mitigate GHG emissions of dairy farming systems in semi-arid areas: the case of Jordan

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Abstract

Dairy feeding systems in Jordan are based on imported concentrates and forages. This has economic and ecological implications due to the increase in global feed prices and the GHG emissions from land use change. Therefore alternative feeding systems which reduce the reliance on imported concentrates should be developed. The objectives of this study are to i) evaluate the availability of food industry by-products and their nutritional value, ii) assess the economic impact of alternative feeding scenarios and iii) estimate the degree of GHGs mitigation by using these by-products as potential feeds in the Jordanian dairy farming systems. Feed samples from eleven food industry by-products and ten conventional feeds were collected from food factories and from three typical dairy farms, representing the typical large, medium and small scale farm types, respectively. Feed samples were analysed for their chemical composition and metabolisable energy (ME) contents. Additionally, economic and production farm data were collected and introduced to a model for ecological and economic evaluation. The model is a production and accounting model which includes sub-modules for analysis of feed, carbon footprints, water consumption, and economic risk exposure. The model is complemented with a partial life cycle assessment model for estimating GHGs emissions of milk production at the farm gate. Four feeding scenarios (AD: Actual diets that are typically used on dairy farms; ID: Improved diet based on actual feeds used on the farm; AB: Diet including few available by-products; DL: Diet with no limitation for feed availability) were developed and evaluated for their nutritional, ecological, and economic impacts. Food industry by-products used in the study were sesame meal, potato chips, raw potato, poultry litter (layer and broiler), potato peels, sesame hulls, tomato pomace, olive cake, brewers grains, and anise extract. Compared to the AD scenario, concentrate feeding was reduced by 50, 60 and 70% in the ID, AB and the DL scenarios respectively and replaced by forages or by-products. Consequently, diet composition changed across the developed scenarios. ME content turned out to be at the lower bound (10 MJ/ kg DM) in the DL and the ID scenarios, which is 10% lower than its contents in the AD scenario. The utilizable crude protein content increases when more by-products are included in the diets, reaching the highest value of 254 g/kg DM in the DL scenario, which is 54% above the typical value in the AD scenario. While the neutral detergent fiber increased and reached the highest value in the DL scenario at 36%, which is 8% higher than in the AD scenario. The economic evaluation of three typical dairy farms (status-quo) showed that cost of milk production is 21% (in relative

terms) lower in the small scale farm type compared to large scale farm type which was associated with lower capital, labour and purchased inputs.

When the ID, AB and the DL scenarios were applied on the 400 cow farm, cost of milk production was reduced by 5%, 9%, 14% respectively. Cost reduction was driven by lowering the amount of concentrates used. Furthermore, increasing concentrate prices by 22% had a limited impact on the diets change but had a considerable impact on cost of milk production. Nevertheless, the DL scenario remained profitable when the concentrate price changed.

The ecological evaluation of the scenarios showed that GHG emissions expressed in CO₂ equivalent (CO₂ eq.) were reduced by 21% relatively in the DL scenario compared to the AD. Overall, the total mitigation of CO₂ eq. emission ranged between 70 and 290 g CO₂ eq./kg ECM as a result of inclusion of by-product feeds.

The developed alternative feeding scenarios suggest several choices for dairy farmers to incorporate food industry by-products into rations to replace imported concentrate and consequently reduce the cost of milk production and mitigate GHG emissions.

Key words: Feeding scenarios, Food by-products, Economic indicators, Dairy farms, GHGs mitigation, Models

5.1 Introduction

In arid and semi-arid zones, commercial dairy farming systems are based on imported feeds due to the shortage of local resources such as water or cultivated land. Feed cost is the most important factor affecting the profitability of dairy farms. The global increase in feed prices along with the governmental slashes of feed subsidies was associated with an increase in cost of milk production. In spite of the resource limitations and stark fluctuations in milk and feed prices, Jordan's milk production grew by 5.4 % during the period from 2000 to 2007 (DOS, 2008). Only six per cent of the country's area is considered as arable land with good potential for cultivation of cereals crops (MOA, 2008). In 2008, Jordan imported about 1.8 million tons of feedstuff for its livestock sector. These include *inter alia* barley, maize, soybean meal, compound feeds, roughages, fish meal, mineral feed and vitamins (Harb, 2008). Currently, cereals (corn and barley) are the most widely used energy-rich feedstuffs in dairy rations. The rangelands in the country are not suitable for dairy cattle grazing and have been basically used for small ruminant grazing (ACSAD, 1997). To cover the increasing demand for milk and dairy products, farm size has been growing towards large-scale intensive production systems with no land allocated for crop production located on semi-arid lands in the eastern part of the country. As in many developing countries, proper utilization of non-conventional feed resources, notably food industry by-products, which don't compete with human nutrition, is imperative in meeting the projected increasing demand for livestock products (Maghsoud et al., 2008). Despite lower quality and handling problems (transportation and preservation), food industry by-products can contribute to reducing milk production costs and mitigating greenhouse gas (GHGs) emission associated with milk production (Vellinga et al., 2011; Vasta et al., 2008). Replacing imported commercial feeds with food industry by-products can save energy in transportation and reduce the environmental impact of burning or landfilling food wastes (Cao et al., 2009). Several by-products do not require processing but may face limitations in handling, storage and feeding. Food industry by-products such as sesame meal, tomato pomace and olive cake have been used as alternative feeds for ruminants without compromising animal performance (Obeidat et al., 2009; Abbeddou et al., 2011; Al-Masri, 2003). However, the potential of by-products as ingredients of ruminant rations requires careful planning and evaluation. Furthermore, many by-products show high variations in quality depending on the method of production.

The objectives of this study are to i) evaluate the availability of food industry by-products and their nutritional value, ii) assess the economic impact of alternative improved feeding

scenarios and iii) estimate the degree of GHGs mitigation by using these by-products as potential feeds in the Jordanian dairy farming systems.

5.2 Materials and methods

5.2.1 The model farms

Farms analyzed in this study were selected following the typical farm concept. This concept allows the analyst to assess the farms' present economic situation and to simulate the impact of technological, market or policy changes on their economic performance. The analysis in this paper is based on three typical dairy farms representing the main dairy farming systems in Jordan. These farms (JO-400, JO-80, JO-5)⁵ were devised for three different geographical regions, covering the area from the semi-arid desert in the east, to the Jordan valley environment in the west of Jordan. Using this limited number of farms allows presenting a detailed analysis on the impact of alternative dairy feeding systems.

JO-400: represents a **large-sized typical farm** of the eastern semi-arid area of Al-Duhlel. The region receives 100-150 mm precipitation per annum with rainfall probability peaking in January to March. This type of farm is characterized by intensive farming. Feeding is mainly based on imported concentrates, alfalfa hay, corn silage and locally produced ryegrass. Cows breed is Holstein Friesian, milked three times a day using a milking parlour with an average milk yield of 7625 kg energy corrected milk (ECM) per cow and year.

JO-80: represents an **average-sized farm** located in the eastern semi-arid area of Al-Duhlel (same location as for JO-400 farm). The farm is characterized by intensive farming with feeding rations based on imported concentrates, wheat straw, corn silage and ryegrass. The breed of cows is Holstein Friesian, milked twice a day in a milking parlour, producing 6400 kg ECM per year.

JO-5: represents a **small sized farm** located in the Jordan valley, a region which receives 100 - 200 mm precipitation per annum with rainfall probability peaking in January to March. The dominant breed is Holstein Friesian cows; however, other local breeds (Akshi, Damascus cows or cross breeds) are sometimes used in this type of farms. Cows are milked by hand or by small vacuum milking machines two times per day, producing 3355 kg ECM per year. The

⁵ The abbreviation JO-400: indicates the country name: Jordan, while the number indicates the number of lactating cows in the farm chosen.

feeding system is based on grains composed of barley and wheat bran. In all farm types, land size is small and there is no opportunity to graze the cows.

A wide variety of farm data were collected from these typical farms which represent the year 2010 on the following parameters: dairy herd structure, annual milk yield, milk price and quality (fat and protein content), purchased feeds, land and labour use and prices, capital

Table 5.1: Overview of three typical dairy farms in Jordan

Farms	JO-400	JO-80	JO-5
Location	Eastern Jordan	Eastern Jordan	Jordan valley
Land endowment (ha)	> 7	< 1	< 0.5
Milk yield kg (ECM)	7625	6400	3355
Production system	Large scale	Medium scale	Small scale
Milking system	Milking parlor	Pipeline	Hand milking
Labour units (FTE)	12	< 4 > 2	Only family labour
Feed intake (kg DM/day)			
Alfalfa hay	1.8		
Barley grains			3.6
Concentrate	13.7	12.4	
Corn silage	2.5	1.1	
Grass	1.4	1.4	
Wheat straw		2.7	
Wheat bran			7.9

DM: dry matter, minerals and vitamins are added to the concentrate mix.

(liabilities), machinery and building used, dairy and crop farm expenses, input prices (feedstuffs, fertilizers, energy, etc), opportunity cost of farm-owned factors of production (family labour, own land, own capital). Data from each typical farm was validated with a panel of local dairy experts (dairy consultant, veterinary doctor) to ensure that the farm represents the typical farm type. The typical farms are not representative of their country or region in the statistical sense; they rather represent the farm types that account for the bulk of milk production in the respective region. Table 5.1 provides an overview of these farms used in this study.

5.2.2 Feedstuff and analysis

Feed samples, eleven by-products and ten conventional feeds, were collected in March 2010. All concentrate feeds, alfalfa fresh and hay, fresh ryegrass, wheat straw, wheat bran, barley and corn silage samples were collected from the farms. On delivery, purchased concentrate feed was preserved in containers. Typically, concentrate feed is composed of a mixture of grains and by-products, i.e.: barley grains, corn grains, wheat bran, soybean meal, vitamins and mineral feeds. Roughage samples were taken from the farm's roughage store. By-

products samples were collected from the food factories located in the northern part of Amman and in Zarqa provinces.

Two samples (sample weight ranged between 0.5 and 2 kg fresh weight) from each by-product were collected. All feed samples were analysed for dry matter (DM), nitrogen (N), crude ash (CA), crude lipid (CL), acid detergent fiber (ADF) and neutral detergent fiber (NDF). The DM in feed samples was determined by overnight oven-drying at 105 °C. The ash content was determined by incinerating samples at 550 °C for 4 h (ISO, 2002). Total N content in feed samples was determined using the Kjeldahl procedure using Cu as catalyst (AOAC, 1995).

Neutral detergent fibre (NDF) content in feed samples was determined according to Van Soest et al. (1991) and acid detergent fibre (ADF) content according to Goering and Van Soest (1970).

The *in vitro* gas production and the calculations of digestible organic matter (DOM) and the ME were determined following the procedure of Menke et al. (1979) using the following equations:

$$\text{DOM} = 14.88 + 0.889 \times \text{Gp} + 0.045 \times \text{CP} + 0.065 \times \text{CA}$$

$$\text{ME} = 1.242 + 0.146 \times \text{Gp} + 0.007 \times \text{CP} + 0.0224 \times \text{CL}$$

The utilizable crude protein (uCP) content from each feed was calculated according to GfE (2001) as follows:

$$\text{uCP} = [187.7 - (115.4 \times (\text{RUCP} / \text{CP}))] \times \text{DOM} + 1.03 \times \text{RUCP}$$

Where:

DOM = digestible organic matter concentration in % in DM

ME= metabolizable energy concentration in MJ/ kg DM

Gp= gas production in ml after incubation of 200 mg sample DM for 24 h

CA= crude ash concentration of the sample in g/kg DM

CL= concentration of crude lipid of the sample in g/kg DM

CP= concentration of crude protein of the sample in g/kg DM

uCP= utilizable crude protein at the duodenum g/kg DM

RDCP= rumen degradable CP concentration in g/kg DM

RUCP= rumen undegradable CP concentration in g/ kg DM CP fraction of rumen undegradable protein (RUCP) for each feed was taken from feed tables (DLG, 1997; NRC, 2001) as well as the sources listed in table 5.3.

Table 5.2 shows the chemical composition of different feeds analysed in this study. The following food industry by-product were analysed:

- Sesame meal: the residue which remains after the mechanical oil extraction of sesame seeds; rich in protein and energy, possess 37.7 % CP and 14.4 MJ ME/kg DM, and 26.8% CL DM
- Sesame hulls: the results of mechanical separation of the hulls from sesame kernels, low in in CP (6.4%) and energy of 7.6 MJ ME/kg DM and contain 37.2% CA.
- Potato peels from peeling raw potatoes: possess 10.5 % CP, 15.2 MJ ME/kg DM and DOM of 98.4% (in vitro).
- Raw potato: consisting of cull or whole potatoes discarded because of size; contains of 10.2 % CP and 15 MJ ME/kg DM, low in fiber and high in DOM of 96.2% (in vitro).
- Potato chips: undesirable product from exposing potato slices to boiling oil; low in CP (8.8 %), 17.7 MJ ME/kg DM, low in fiber and rich in CL (32.1%) and has DOM of 73.8%.
- Olive cake: the residue which remains after pressing of green olives, containing hulls and kernels; possess 8.5 % CP and 8 MJ ME/kg DM, NDF of 50%, 12% CL and DOM of 42.1%.
- Tomato pomace: a heat-treated waste product of tomato paste processing, containing peel and seeds; it possess 23.2 % CP, 9.6 MJ ME/kg DM, 55.1%NDF and 42.2% ADF and is low in DOM (51.8%)
- Poultry litter (broiler): resulting from the removal of the poultry litter, containing excreta, bedding, wasted feed and feathers; this by-product possesses 25.4 % CP ,7.4 MJ ME/kg DM, NDF of 40.6%, ADF of 21.5% and DOM of 58.3%
- Brewers grain: the residue of barley and maize grains fermentation, contains 24.2 % CP, 10.9 MJ ME/kg DM, NDF of 48.6% and DOM level of 65.4%
- Anise by-product: the residue which remains after oil extraction using the absorption method; contains 24.1 % CP and 11 MJ ME/kg DM, NDF of 61.2%, and DOM of 62.1%.

Although food industry by-products can be implemented in rations of dairy cows, there are several limitations of using them in animal diets. These are associated with the chemical composition of the feed and feed forms (liquid vs bulky). Table 5.3 shows the

Evaluating the use of food by-products to optimize the economic performance and mitigate GHGs

Table 5.2: Chemical composition, in vitro gas production and metabolizable energy (ME), net energy for lactation (NEL) and digestible organic matter (DOM) of food industry by-product and conventional feeds used in the study

By-product feeds	DM %	CA %	CL %	NDF %	peNDF* g/kg DM	ADF %	CP %	Gp ml/200 mg DM	ME MJ/kg DM	NEL MJ/kg DM	DOM % of DM	Price US-\$ /kg DM (2010)
Sesame meal	90.8	10.2	26.8	16.1	64	10.2	37.7	31	14.4	8.7	66.3	0.294
Potato chips	97.6	3	32.1	4.3	42	2.1	8.8	60	17.7	10.6	73.8	0.144
Raw potato	24.6	4.6	3.5	5.7	56	2.3	10.2	84	15	9	^a 96.9	0.570
Layer litter	89.8	27.2	2.7	22.9	91	9.5	27.7	29	8.1	4.8	71.2	0.156
Potato peels	20.9	4.4	3.4	9.8	98	5.3	10.5	85	15.2	9.1	^a 98.4	0.671
Sesame hulls	90.5	37.2	3.2	20.1	80	12.6	6.4	36	7.6	4.6	73.5	0.186
Tomato pomace	93.6	9	14.7	55.1	220	42.2	23.2	23	9.6	5.7	51.8	0.194
Olive cake	92.3	3.3	12	50.0	199	31.2	8.5	24	8	4.8	42.1	0.228
Brewers grains	18.5	3	8	48.6	87	16	24.2	42	10.9	6.5	65.4	0.529
Anise extract	26.6	5.8	12.2	61.2	244	36.7	24.1	37	11	6.6	62.1	0.289
Broiler litter	88.7	15	3.1	40.6	162	21.5	25.4	25	7.4	4.4	58.3	0.158
Compound feed 1	88.9	6.9	4.8	20.3	81	7.1	20.7	60	12.6	7.6	82.4	0.362
Compound feed 2	88.7	4.1	6.8	25.5	102	8.1	16.8	66	13.7	8.2	84.5	0.347
Compound feed 3	90	7.2	0.5	19.3	70	10.2	14	66	11.9	7.2	84.3	0.327
Alfalfa hay 1	87.2	14.1	4.3	41.8	376	27	20.3	46	10.3	6.2	73.7	0.352
Alfalfa hay 2	92.6	8.1	1.5	43.3	389	30.8	16	43	8.9	5.4	65.4	0.326
Wheat straw	85.4	8	3.8	81.3	812	45.5	3.6	36	7.6	4.6	53.7	0.336
Corn silage	31.4	6.8	5.6	50	427	27.7	7.9	46	9.8	5.9	^b 63.9	0.332
Wheat bran	87.3	4.5	4.6	35.4	60	11	16.3	52	11	6.6	71.0	0.224
Barley grains	88.8	4.4	3.6	20.4	76	7	11.5	58	11.3	6.8	74.5	0.243
Ryegrass	11	16.1	6	45.3	453	24.3	21.6	50	11.4	6.8	79.3	0.714

DM: dry matter; CA: crude ash; CL: crude lipid; NDF: neutral detergent fiber; ADF: acid detergent fiber; peNDF: physically effective NDF; CP: crude protein; Gp: gas production; ME: metabolizable energy; NEL: net energy for lactation; DOM: digestible organic matter. * Sources: peNDF for each feed calculated as the proportion of DM retained by a 1.8 mm screen multiplied by dietary NDF. The proportion of DM retained (physical effective factors (pef)) value for anise by-product (assumed to have a similar structure as for sunflower meal) was obtained from Mertens (1997). For sesame meal, sesame hulls, brewer grains by-products and concentrate feeds were obtained according to Mertens (1997). For potato by-products, assumption was given as 100% due to its large particles structure; therefore peNDF is equal to NDF. According to GfE, (2001), the peNDF of wheat straw assumed to be 100 % of NDF. peNDF value of ryegrass assumed to be 100% of NDF, scorn silage 85%, alfalfa hay 90% of NDF content (Mertens, 2002). ^a : DOM% was calculated from the measured gas production; ^b: low quality corn silage, seems lower than its comparable digestibility values in the literature.

different by-products and the limits when included in the diet of ruminants. For some by-products rich in oil (i.e. potato chips), the high crude fat content (32.1%) can be a limiting factor for the intake by animals as well as for the on-farm long-term preservation (Dickey, 1971). Furthermore, rich oil by-products contain considerable amounts of unsaturated fatty acids that reduce fiber digestion in the rumen. Other by-products such as olive cake and tomato pomace may cause refusal, therefore these should be included in the diet only in small quantities. Weiss et al. (1997) reported that tomato pomace possesses high lignin compounds. In Olive cake around 71% of the nitrogen is associated with the cell walls and is therefore not available for digestion (Molina-Alcaide et al., 2003). Additionally, several authors (Fegeros et al., 1995; Martin Garcia et al., 2003; Yanez Ruiz et al., 2004) found variable amounts of total condensed tannins which are able to bind and precipitate proteins (Hagerman et al., 1992) and depress digestibility (Silanikove et al., 1994). Moreover, the seasonal production of olive cake and its use in animal feeding throughout the year requires preservation and storage. The deep stacking of olive cake near the processing plants can result in a considerable deterioration (mould formation) of the material and in wastage of nutrients (Hadjipanayiotou, 1994)

5.2.3 Feeding scenarios

Four feeding scenarios were developed and tested in this analysis with the objective of putting together least-cost diets for lactating dairy cows by replacing concentrate feed by locally produced by-products. These scenarios were evaluated for their nutritional, economic and ecological aspects. All feeds used were assumed to be imported except ryegrass and the food by-products. Data on estimated dry matter intake (eDMI) in the three farm types were obtained from Alqaisi et al. (2013). The scenarios were defined as follows:

1. Actual diet (AD): this scenario represents the actual feeding systems practised on the typical dairy farms. The scenario thus represents the status-quo of the feed rations used, the cost of milk production and the CO₂ eq. emissions, and serves as a benchmark for the following feeding scenarios.
2. Improved diet (ID): in a previous study on nutritional and ecological evaluation of dairy farming systems in Jordan, Alqaisi et al. (2013) revealed that several farms fed imbalanced diets to lactating cows. Therefore, this scenario is based on actual feedstuffs in use that were formulated to fulfil animal requirements.

3. Diet including available food industry by-products (AB): this scenario is based on the assumption that a limited number of by-products (layer litter, sesame meal and anise extract) were used due to their availability.
4. Diet with no limitation for feeds availability (DL): all common feeds and by-products shown in table 5.2 were assumed to be available to dairy farmers.

The constraints used to formulate the diets are shown in the bottom panel of table 5.3. The nutrient composition of by-product feeds was taken from table 5.2. Requirements for the energy and nutrients were set as constraints for feed ingredients formulation in a linear programming (LP) model: metabolizable energy (ME) ≥ 10 MJ/kg DM; utilizable CP (uCP) ≥ 137 g/kg DM; rumen undegradable protein RUCP $\geq 30\%$ of uCP; physically effective neutral detergent fiber (peNDF) ≥ 220 g/kg DM (Mertens, 1997).

Feeding scenarios were established based on 2010 feed prices shown in table 5.2; in view of the current feed price trends, it was essential to know to what extent changes in feed prices affect the feeding systems and the cost of milk production. We thus also simulated the four scenarios with prices of 2011 (an increase of 22% over 2010 levels).

Sensitivity analyses were carried out to assess possible negative effects of feeding by-products on DM or energy intake, since feeding by-products may reduce palatability of the diet or the energy value might be reduced due to the high variability of their composition. Therefore, two additional scenarios were calculated: one in which feed intake is reduced by 10% and the other in which diet energy concentration is reduced by 0.5 MJ ME/ kg DM. The effect on milk yields was calculated and taken into account based on i) the difference between energy intake in the DL scenario and the two calculated scenarios, and ii) based on the assumption that animals require 5.2 MJ ME for each kg of milk (at 4% fat) produced. Thereafter, the results were inserted into the farm model TIPICAL⁶ (using the JO-400 farm data) to calculate cost of milk production and CO₂ eq. emissions.

5.2.4 Model used and parameters estimated

The methodology applied for data collection, economic analysis and results validation was developed by the International Farm Comparison Network (IFCN) and utilises the TIPICAL (Technology Impact Policy Impact CALculations) model. This model was developed by

⁶ The TIPICAL model will be described in the following section.

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Table 5.3: Review of the literature on the effect and limitations of food industry by-products in ruminant diets

Food by-product	Usage in the diet of the study on DM basis	Feeding description	Experimental diet	Effect	Maximum proportion recommended	Source
Sesame meal	20% in concentrate mix	Feeding 20% sesame meal as a part of concentrate in growing cattle consuming fresh cut forage. Concentrate feeding at 40% of the total DM intake.	Fresh forage based diet supplemented with concentrate which composed of: maize meal by-product, Sesame meal, urea, fish meal, Brewers grains and additives.	Compared to the inclusion of highly degradable protein sources, live weight gain was higher but non-significantly increased.	8%	Reaño et al. (1992)
	10% in concentrate mix	Feeding 10% of sesame cake in concentrate mixture	Ad libitum rice straw supplemented with 3 kg concentrate mix composed of: broken rice, cotton seed cake, sesame cake, wheat bran, screening gram, gram husk and additives	Compared to treatments with treated and non-treated rice straw, there were non-significant differences in milk yield and composition	5%	Ko et al. (2008)
Raw potato	Several proportions	Feeding 0, 12, 24 and 36% potato chipping and corn by-products to lactating dairy cows on DM basis	Corn silage, concentrate, by-product and protein supplement, minerals and feed additives	As inclusion of by-product increased, dry matter intake decreased significantly, in addition, no significant differences among treatments for milk production.	12%	Brown et al. (1983)
	Several proportions	Inclusion 0, 10, 15 or 20% of potato waste by-product to lactating cows ration on DM basis	Corn silage, haylage, high moisture corn, protein supplement and minerals and feed additives	Milk yield was highest at the highest inclusion of by-product. Milk fat percentage tended to decrease when inclusion of by-products increased.	20%	Onwubuemeli et al.(1985)
Potato peels	Several proportions	Inclusion 10%, 20%, 30% and 40% in finishing beef diets on DM basis	Dry-rolled corn, potato -processing waste, alfalfa hay, concentrated separated by-product(desugared molasses), sunflower meal and feed additives	DM intake decreased when increasing by-product from 10% to 40%. Body weight decreased with 10% to 30%.	10%	Radunz et al. (2003)
Poultry litter	Several proportions	Feeding 0, 10, 20, and 30% of dry poultry waste for lactating cows on DM basis	Cotton seed hulls, citrus pulp, ground corn, soybean meal, cane molasses, urea and feed additives	Milk yield declined by 2.9% when by-product included at 10%, but progressively lower (19.4 and 34.5%) when inclusion of by-products was at rates of 20 and 30%.	10%	Silva et al. (1976)
Sesame hulls	12.5 and 25%	Inclusion 12.5 and 25% of sesame hulls into Awassi lambs ration on DM basis	Barley, soybean meal, sesame hulls, wheat hay, urea and feed additives	Compared to only concentrate diet, DM intake increased; there was no significant effect on daily gain change.	25%	Obeidat and Aloqaily, (2010)
Tomato pomace	12%	Tomato pomace of 12% was ensiled with whole corn plants. Feeding corn and tomato pomace silage (mixture) 60% of DMI	Corn silage, corn plus pomace silage, soybean meal, ground ear corn, rolled corn, alfalfa meal, distillers grain, molasses, urea and feed additives	Milk production and composition, nutrients digestibility and nitrogen balance were not affected by addition of tomato pomace	12%	Weiss et al. (1997)
	30% mixture of ensiled tomato and apple pomace	Inclusion 15 and 30% of ensiled tomato and apple pomace of total mixed ration (proportion of 50:50 on DM basis) for lactating cows diet	Alfalfa hay, soybean meal, barley, wheat bran and feed additives.	Reduction of chewing activity, slightly lower rumen pH, higher DM and organic matter digestibility of the whole diet.	15%	Abdollahzadeh et al. 2010
Olive cake	15%	Feeding cows 15% of olive cake silage to lactating cows on DM basis	Barley grains, soybean meal, wheat bran, hay and straw and feed additives	Compared to the control diet, milk yield did not differ significantly.	15%	Hadjipanayiotou, (1999)
	10 and 20%	Feeding dairy cows with proportions of 10 and 20 % of olive cake mixed with concentrate	Concentrate, roughage and feed additives	No significant differences in milk production and composition between low and high inclusion of olive cake by-products	10%	Belibasakis, (1982)
Brewers grains	15% wet or dry form	Feeding 15% of wet or dry brewers' grain for Holstein-Friesian dairy cows diets on DM basis	Alfalfa hay, corn silage, dried or wet brewers' grain, steam rolled corn, soybean meal, cotton seed whole linted, dehydrated beet pulp, sugar beet molasses and feed additives.	No influence on feed intake, milk yield or on milk composition	15%	Dhiman et al. (2003)
	15 and 30%	Feeding dairy cows with proportions between 15 and 30 % of wet brewers grains on DM basis	Ground corn, soybean meal, soybean hulls, wet brewers grains, corn silage, alfalfa silage and feed additives.	No significant difference in DM intake between the control and the tested diets. Milk yield was greater when by-product included at 30% on DM basis	30%	West, (1994)

DM: dry matter, DMI: dry matter intake, Constrains limits (proportion in the diet on DM basis) used in the LP model of the feed items were as follow : Seasm meal \leq 0.10, potato chips \leq 0.05, Raw potato \leq 0.05, Layer litter \leq 0.10, Potato peels \leq 0.05 (as three types of potato were used here, the proportion of each type was set at 0.05 to produce an average value between the above mentioned studies), Seasm hulls \leq 0.10, Tomato pomace \leq 0.15, Olive cake \leq 0.05, Brewers grain \leq 0.10, Anise \leq 0.01, Broiler litter \leq 0.10, Compound feed \leq 0.35, Wheat straw \leq 0.05, Corn silage \leq 0., Ray grass fresh \leq 0.05. In some cases, no specific limitations on including compound feed in the diet, the constrains for compound feed were set with objective to reduce their inclusion in the diet and replace them by equivalent energy and protein feeds from by-products., Limit of wheat straw inclusion was set based on the typical inclusion proportion included on farms (i.e. in JO-400 farm, similar proportion of wheat straw in the diet was used). Furthermore wheat straw, corn silage and raygrass are expensive feeds compared to their comparable dietary fiber sources in by-products, therefore they were limited to their constrains.

Hemme (2000) and has been refined to suit its applicability on a global scale. The TYPICAL model is a production and accounting model. The model was recently extended to include sub-modules for the analysis of alternative feeding systems, carbon footprints, water consumption, economic risk exposure and milk quality issues (Hemme, 2010).

The economic performance of farms both in the status-quo and the alternative feeding scenarios were characterized by the following indicators: cost of milk production, share of feed cost in total cost, margin over total feed cost, entrepreneurs profit and the return on investment (ROI).

In a first step; and for each of the ID, AB, and DL scenarios, feed items, feed composition (table 5.2) and feed prices were introduced to a standard LP model. The LP model combines feed ingredients such that the required nutrient quantities are supplied at least cost (Tozer, 2000). The LP model has the following form:

$$\begin{aligned} \text{Minimize } T &= \sum_{j=1}^n c_j x_j \\ \text{Subject to } \sum_{j=1}^n a_{ij} x_j &\leq (\geq =) b_i \\ &x_j \geq 0 \end{aligned}$$

with

T = total cost of ration

c_j = per-unit cost of feed ingredient j

x_j = quantity of feed ingredient j in the ration

a_{ij} = quantity of nutrient i in ingredient j

b_i = required amount of nutrient i in the ration.

The direction of the relation sign for the b_i 's depends on the nutrient or the nutrient balance required in the ration.

In a second step, farm data from the three typical farms, which represent the year 2010, were entered into the TYPICAL model. The calculation of the indicators used for the economic evaluation was as follows:

- Cost of milk production: the difference between the total costs of the dairy enterprise and the non-milk returns.

- Share of feed cost in total costs: calculated using the Activity-Based Costing method (ABC)⁷. The share of feed cost was given as the ratio of feed costs (in US-\$/100 kg ECM milk) and total costs of milk production per 100 kg ECM milk.
- Margin over feed cost: the difference between milk price and total feed cost
- Entrepreneurs profit: the difference between milk price and the total cost of milk production
- Return on investment (ROI): the sum of ROI of total farm operation and farm asset appreciation

5.2.5 Estimation of GHG emission

The ecological evaluation of the dairy farms and the developed feeding scenarios was assessed through a partial life cycle assessment (LCA) model which estimates greenhouse gas (GHG) emissions (Hagemann et al., 2011). The boundary of the LCA emissions is from 'cradle to farm gate'. This includes both direct and indirect emissions caused by the production of inputs used in dairy production. Emissions which occur beyond the farm gate (e.g. transport, processing, and packaging of milk) are thus not included in the analysis. The direct emissions include all emissions which originate at the farm level. Indirect emissions include emissions from the production of intermediate inputs such as fertilisers or concentrates as well as emissions from the production of farm assets (e.g. buildings and machineries). Emissions from deforestation and carbon sequestration are not included in the calculations. Emissions are estimated as follows:

Methane emissions

Enteric methane emissions are calculated according to the formula by Ellis et al. (2007):

$$\text{CH}_4 \text{ (MJ/d)} = 3.41 + 0.52 \times \text{DMI (kg/d)} - 0.996 \times \text{ADF (kg/d)} + 1.15 \times \text{NDF (kg/d)}.$$

This formula was selected because the level of CH₄ emissions caused by the digestion in the rumen depends basically on the composition and quantity of the feed (IPCC, 1996) as there are detailed feed data available in the current study. For calculating the CH₄ emissions of calves and heifers, the following equation from Kirchgessner et al. (1991) was applied:

$$\text{CH}_4 \text{ (g/d)} = 55 + 1.2 \times \text{live weight (kg)}^{0.75}.$$

⁷ The ABC is a method to allocate costs of milk production into different activities. The method allocates labour cost, machinery cost, fuel cost, electricity cost and water costs to the following activities: home grown feed production, feeding and manure handling cost, milking, cow handling and finally the farm management. In some cases, allocation was 100% for feed (the case of purchased feeds), other cost such as labour cost for feeding and manure handling was allocated at 50% for feeding while 25% of the machinery cost allocated for feeding,...etc. The sum per farm is divided by the quantity of ECM produced on farm to yield an average cost figure.

Live weights of heifers were estimated according to their age classes (i.e., 0–12, 12–24 and >24 months) following Kirchgessner et al. (1991).

CH₄ emissions from manure were calculated according to the IPCC (2006) formula:

$$EF = (VS \times Bo \times 0.67 \text{ kg/m}^3 \times MCF \times MS\%) / 365 / 1000$$

With EF: emission factor (g/d); VS: volatile solids excreted by animal (kg/d) for animal; Bo: maximum methane producing capacity (m³/kg of VS) for manure produced by animal; MCF: methane conversion factors for each manure management system by climate region; and MS%: fraction of animal type manure handled using manure system in climate region. The VS⁸ (the biodegradable and non-biodegradable fractions of the manure) production assumed to be 1.9 kg/cow/d) according to IPCC (2006). The maximum CH₄ production capacity that can be produced from a given quantity of manure (Bo) assumed to be 0.13 m³ CH₄/kg VS. MCF defines the portion of the methane producing potential that is achieved depending on the manure management system and was assumed to be 0.33. The animal manure management system is considered as drylot where animals were kept on unpaved feedlot and the manure is allowed to dry until it is periodically removed which is the case on the Jordanian dairy farms.

Nitrous Oxide emissions

Direct N₂O emissions originate from on-farm fuel combustion and manure production. N₂O emission losses from manure were calculated from N excretion of cows, calves and heifers multiplied by a N₂O emission factor of 0.02 kg N₂O /kg N excreted (IPCC, 2001). N excretion of the cows in the AD scenario was determined by Alqaisi et al. (2013), whereas N excretion in the ID, AB, and DL scenarios was calculated as the difference between N intake and milk N. The percentage of CP in milk was obtained from Alqaisi (2013). Milk protein values of 3.4% for farm JO-400; and 3.3 % for farms JO-80 and JO-5 were converted to N by dividing by 6.38. N excretion of calves and heifers were assumed based on age clusters according to Kirchgessner et al. (1991). Animals between the ages of 2 and 12 months were assumed to excrete 22 kg N/year and those between 12 and 24 months, 47 kg N/year (Kirchgessner et al., 1991). Indirect N₂O emissions from the production of the fertilizers used from purchased feed production were computed by multiplying usage of N nutrients by the N₂O emissions factor of 0.012 kg N₂O / kg N (Simon, 1998).

⁸ The IPCC value for VS production of 1.9 kg/cow/d proved to be accurate according to Alqaisi et al. (2013).

Carbon dioxide emissions

The sources used to calculate CO₂ emissions in dairy farms (respiratory and fermentative CO₂ was not included in the calculations) are fuel combustion; concentrate production, pesticides, machineries, buildings and other assets and input stuff e.g. bedding material and dairy chemicals. The bottom line of table 5.5 shows the emission factors used for the calculations as follows: farm assets were clustered into vehicles, implements, buildings and fences. The indirect emissions of assets were divided by the expected working life which was assumed to be 10 years for vehicles and implements and 25 years for buildings. The CO₂ emissions from concentrate feed were calculated assuming that the concentrate feed used on a farm contains 67 % carbohydrate sources (e.g. wheat), 30 % protein sources (e.g. soybean meal) and 3 % minerals and vitamins which fit to the typical ration dominant in the farms.

GHG credit

GHG credit is an allocation of emissions to co-products of milk production. These can include meat, manure, animal draught power and capital functions. In the present study, only beef credits are considered as their method of estimation is generally accepted (Cederberg and Stadig, 2003; Sevenster and de Jong, 2008) and others are of minor relevance for the farms in this study. The method applied in this study is the so-called cause-effect physical ('biological') allocation (Cederberg and Stadig, 2003), whereby emission credits for the beef of culled cows are allocated based on the proportion of the dairy cow's feed intake that is needed for maintenance and body growth. It is assumed in accordance with KTBL (2006) that this proportion is 40% of metabolizable energy (ME) intake, leaving 60% of ME intake for milk production. It is further assumed that male calves are sold at the age of two weeks.

For computation of the beef credit, all animals of a farm are first converted via their live weight into livestock units (LU)⁹ and the total number of animals sold (cows, heifers and bull calves) is determined in terms of LU. In a second step, a farm's total emissions are divided by the total LU per farm in order to obtain an estimate of total farm emissions per LU. The emission credits for culled cows are then computed by multiplying the number of culled cows (in terms of LU) by the total emission per LU weighted by 40 % (allocation factor). Beef credits for culled heifers and bull calves are computed by multiplying the animals sold, in terms of LU, by total farm emissions per LU.

⁹ 1 Livestock unit (LU) = 650 kg live weight (Kirchgeßner et al. 1991)

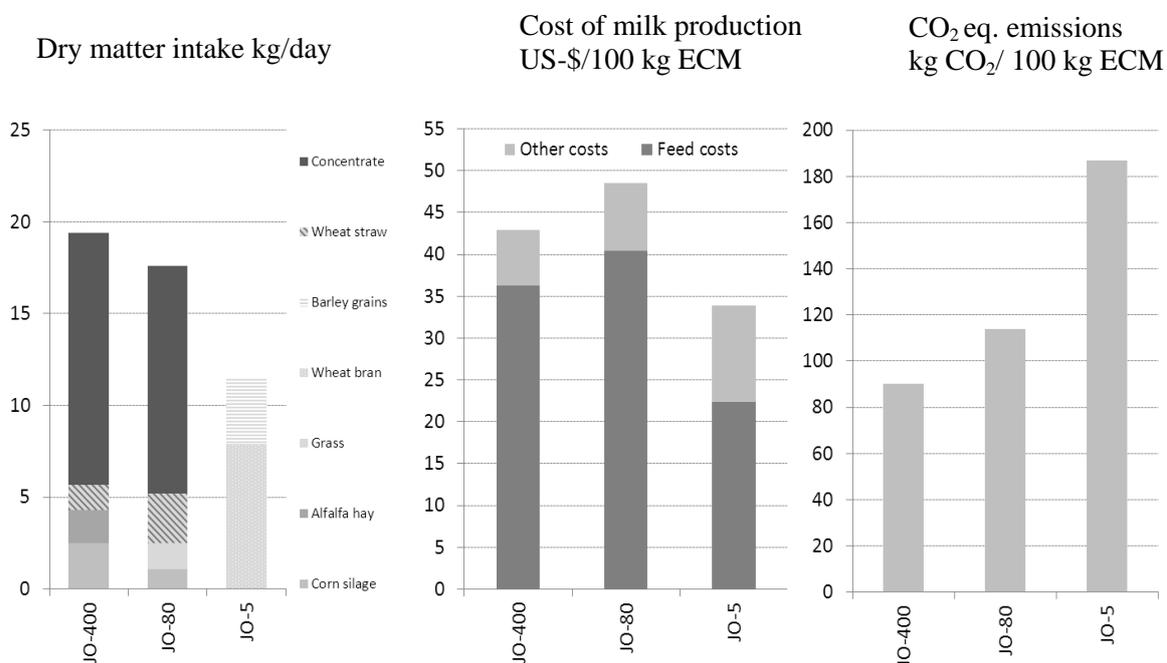
5.3 Results

5.3.1 Nutritional evaluation of scenarios

The actual diets used in the AD scenario are shown in figure 5.1. In the two large farms (JO-400 and JO-80) concentrate feed accounts for more than 70% of the diet. In the small-scale farm type (JO-5), barley grains and wheat bran are the main feeds used, however seasonal grazing on pasture is available during spring time.

Table 5.4 shows the impact of the feeding scenarios on the composition of the diets. In the AD scenario, uCP content is the lowest (165 g/kg DM). The uCP content increases when more by-products are included in the diet, reaching the highest value of 254 g/kg DM in the DL scenario. This is associated as well with an increase in RUCP content in the diet, reaching the highest level in the DL scenario at 102 g/kg DM. In all scenarios, the uCP content lies above the required minimum of 137 g/kg DM (GfE, 2001). Inclusion of food industry by-products has a considerable impact on ME content of the diets. In the AD scenario, the ME content is the highest (11 MJ/kg DM). The energy content turned out to be at the lower bound (10 MJ/kg DM) in the DL scenario.

Figure 5.1: Selected performance figures of dairy farming systems in Jordan –status quo



Although concentrate feed was not replaced with food industry by-products, the ME level fell to 10 MJ/kg DM in the ID scenario. Since forages and by-products possessed lower energy value compared to concentrate, the ME contents in the ID, and the DL diets is reduced,

consequently the daily intake of ME is reduced by 10 MJ and by 23 MJ compared to the AB and the AD diets.

Compared to the AD scenario, inclusion of large amounts of by-products in the diets reduced the DOM to 71% and 66% in the AB and DL scenarios, respectively. At the same time, the peNDF level in the AB and the DL scenario is lowered as the share of by-products included in the diets increases, reaching the limit of 220 g/kg DM in the DL scenario.

The **ID scenario** is composed of conventional feeds with 65% of alfalfa hay and 35% concentrate feed on the JO-400 farm. Concentrate inclusion is reduced by 50% compared to the AD scenario. In the JO-5 farm, (figure 5.4) wheat bran inclusion is lowered by 20% relatively to the AD scenario. In this scenario, the diet is characterized by lower ME (10 MJ/kg DM) content compared to the AD scenario, while the uCP content is higher by 45 g/kg DM, and the diet contains 6% higher (in absolute term) NDF compared to the AD scenario, and consequently the peNDF was the highest (272 g/kg DM) across all scenarios.

The **AB scenario** includes 21% of food industry by-products (sesame meal and hulls, layer litter, the remainder is composed of conventional feeds of concentrate, alfalfa and corn silage at levels of 30, 30 and 19% on DM basis. Compared to the AD scenario, concentrate feeding is reduced by 60 %. In JO-5 farm, the AB scenario features 50% less wheat bran and was replaced by olive cake and poultry litter as by-products. The main changes compared to the AD scenario are a reduction in the ME content to 10.5 MJ/kg DM, an increase of the uCP content by 62 g/kg DM and an increase in peNDF contents by 26 g/kg DM.

The **DL scenario** in the different farm types is presented in figures 5.2, 5.3 and 5.4. Food industry by-products are included at a level of 60% of the total diet, while the remainder is composed of actual feeds of alfalfa hay and concentrate. Poultry litter, tomato pomace, potato by-products, wheat straw, olive cake and sesame meal were selected by the model to formulate the diet. Compared to the AD scenario, concentrate in this scenario is reduced by 70%. In the JO-5 farm (figure 5.4), this scenario includes 80% food industry by-product and 20% wheat bran, inclusion of wheat bran in the diet is reduced by 70% relative to the AD scenario. Including more by-products in this scenario increases peNDF by 18 g/kg DM compared to AD. Likewise, uCP is the highest across all scenarios and increases by 90 g/kg DM compared to the AD scenario.

Assuming the higher feed prices of 2011, the biggest change, compared to the 2010 rations, occurs in the rations of the DL scenario. These changes can be attributed mainly to a reduction in the share of concentrates in the diet.

5.3.2 Economic evaluation of the scenarios

The economic result of the AD scenario is shown in figure 5.1. The cost of milk production varies between farms and was highest in the medium-scale farm (JO-80) at 49 US-\$/ 100 kg ECM produced and lowest in small-scale farm (JO-5) at 34 US-\$/ 100 kg ECM. The cost of milk production in the large-scale farm type (JO-400) takes a middle ground at 43 US-\$/ 100 kg ECM produced. Table 5.5 shows the results of the economic evaluation of all scenarios for all farm types. In JO-5 farm, the proportion of feed cost was 13% lower than in JO-400. The share of feed cost in total costs was highest in the AD scenario and reached 81% in JO-80 farm.

When concentrate feed is replaced by less expensive alfalfa hay in the **ID scenario**, no significant reduction in the cost of milk production is observed compared to AD. The greatest cost reduction in the ID scenario (at 5%) occurs in the JO-400 farm. This reduction, however, is small compared to the other scenarios which include by-products in the diet and consequently, the margin over feed cost increases by 16%. In the **AB scenario**, the maximum cost reduction (by 7%) is achieved in the JO-400 farm. This is caused by replacing concentrates with food industry by-products of lower prices. The associated increase in the margin over feed cost is 25% and that in entrepreneur's profit 20% compared to the AD scenario. When including more by-product feeds in the **DL scenario**, the cost of milk production declines by 13% in the JO-80 farm due to the reduction in feed cost. This change in the cost of milk production causes an increase in the margin over feed cost by 30% compared to the AD scenario and an increase in entrepreneur's profit by 26%. Within the DL scenario, the highest ROI is achieved in the JO-400 farm (55%). In sum, greater inclusion of by-products leads to reduced cost of milk production in all scenarios. Furthermore, the increase of margin of over feed cost is positively associated with the share by-products in the diet.

Figure 5.2: Impact of alternative feeding scenarios in the large-scale farm type (JO-400)

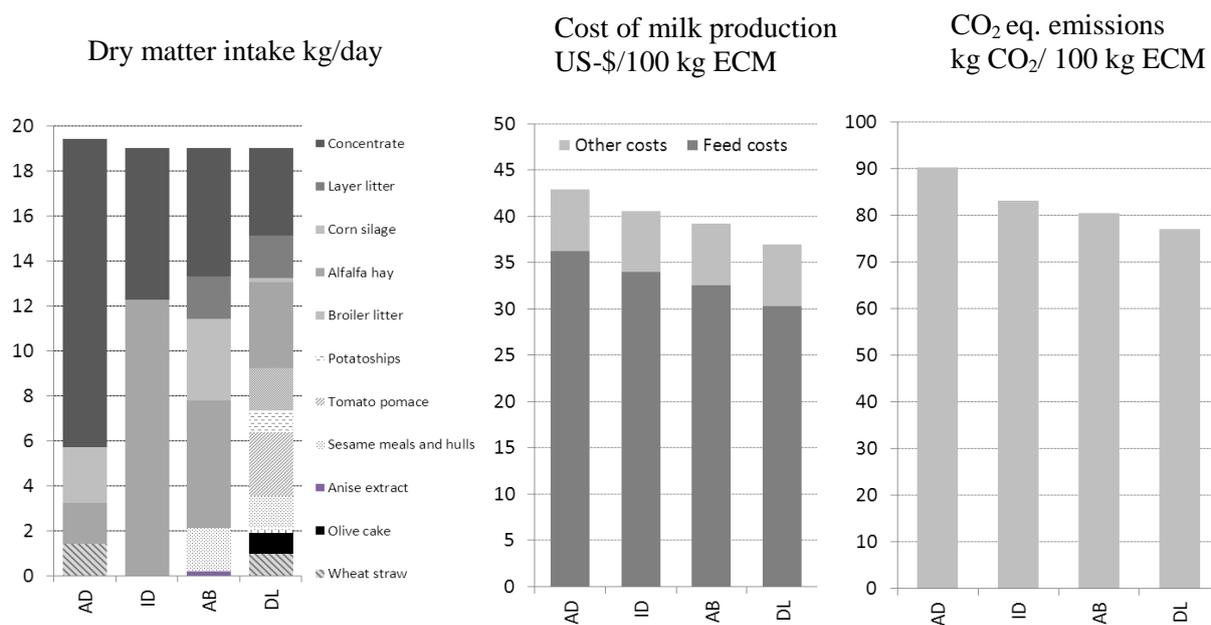


Table 5.5 also shows the impact of rising feed prices on the economic performance of the scenarios. An increase in feed prices by 22% as witnessed between 2010 and 2011 raises the cost of milk production in all scenarios – as one would have expected. This increase is most pronounced in the **AD scenario** due to the large proportion of purchased concentrates in the system. The cost of milk production rises by 13% and 14% in JO-400 and JO-80 farms, respectively, compared to the status-quo, reaching levels of 49 and 55 US-\$/ 100 kg ECM respectively. The cost of milk production in JO-5 appears to be more robust to changes in feed prices, increasing by only 8% relative to 2010 levels.

In the **ID and AB scenarios**, the increase in the cost of milk production between 2010 and 2011 is only 7% and 2%, respectively in JO-400 farm, indicating that the ID and AB diets are more robust to feed price changes than the AD diets.

To evaluate the effect of feed price change on cost of milk production of the developed scenarios, the DL scenario was compared to the AD scenario. Although feed prices increased in 2011, the **DL scenario** still has a competitive advantage in lower cost of milk production of 7, 8 and 6% (in relative terms) in JO-400, JO-80 and JO-5 farms respectively compared to their costs in the AD scenario.

The impact of the ME or DM intake change on the cost of milk production is shown in figure 5.6. The sensitivity analysis reveals that the cost of milk production falls by 0.8 US-\$/100 kg ECM when the ME content of the feed is reduced by 0.5 MJ/kg DM. It shows as well that the

cost will increase by 1 US-\$/100 kg ECM at 10% less DM intake compared to the DL scenario.

Figure 5.3: Impact of alternative feeding scenarios in the medium-scale farm type (JO-80)

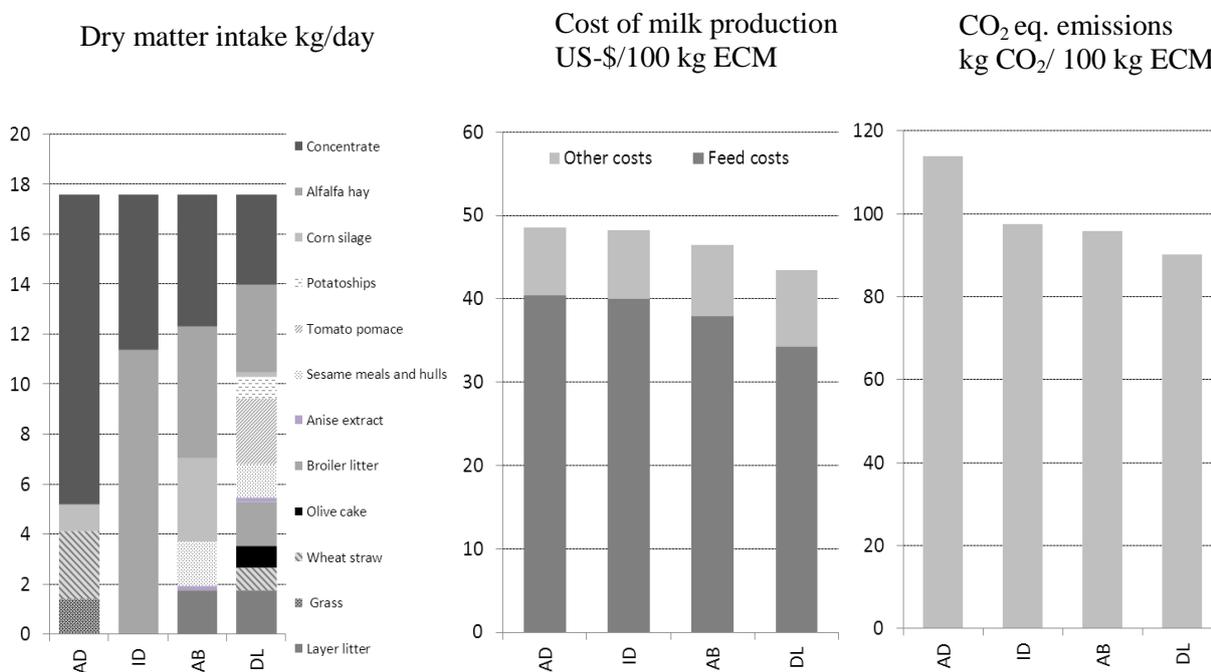


Figure 5.4: Impact of alternative feeding scenarios in the small-scale farm type (JO-5)

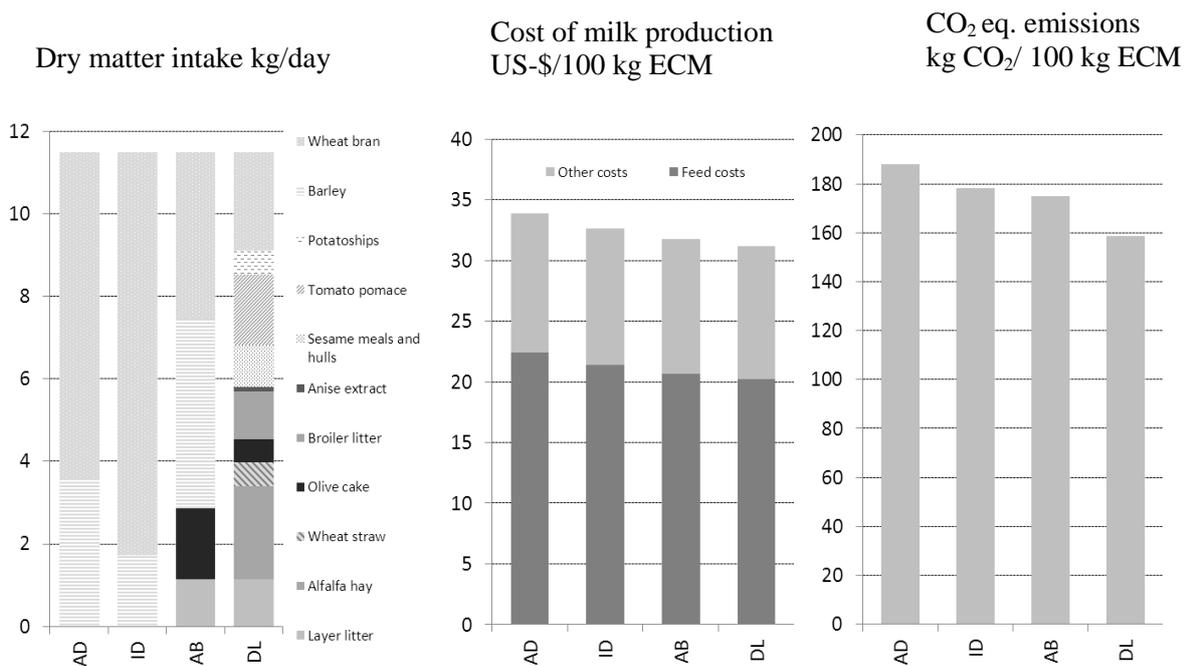
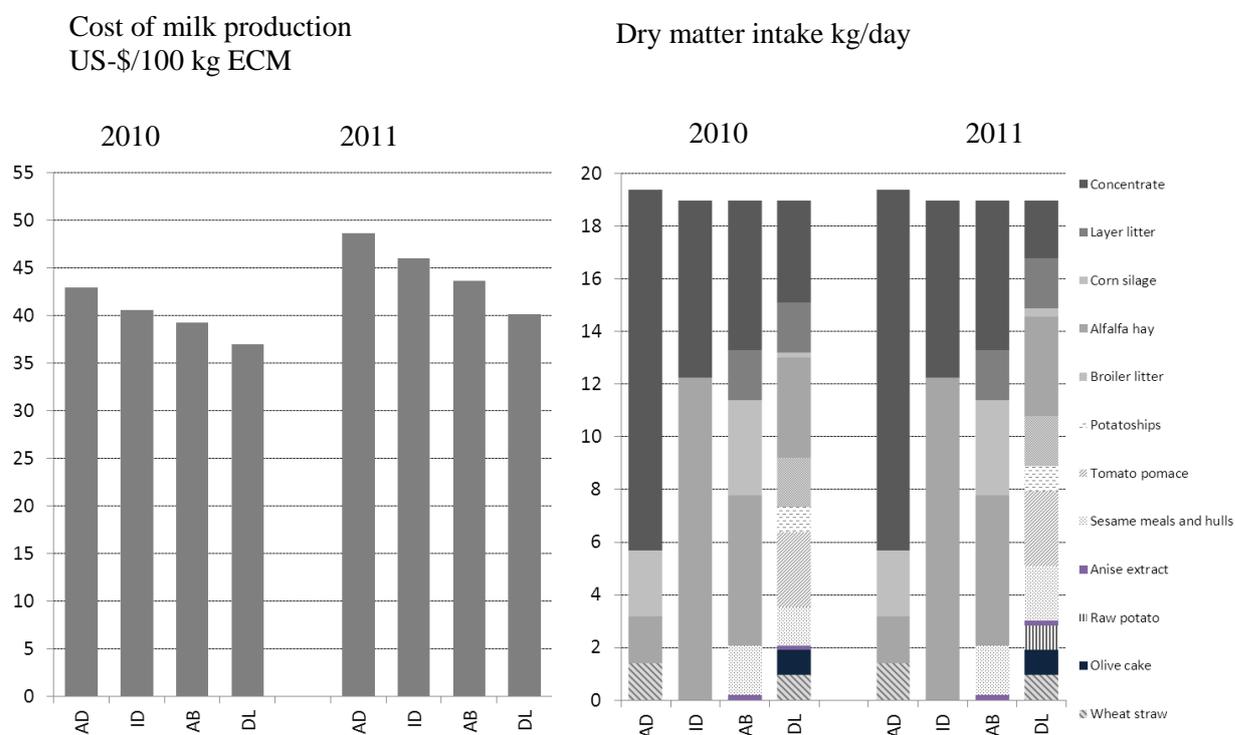


Figure 5.5: Impact of a 22% increase in feed prices on diet composition and milk production costs in the large-scale farm type (JO-400) under alternative feeding scenarios. Note: the price change occurred from 2010 to 2011.



5.3.3 Ecological evaluation of scenarios

The main indicator used for the ecological evaluation of feeding scenarios is the GHG emissions expressed in CO₂ eq. The status-quo emissions in the **AD scenario** are shown in figure 5.1. CO₂ eq. emissions vary between the farming systems under consideration. The highest emissions of 188 kg CO₂ eq./100 kg ECM are observed in the small-scale farm, while the JO-400 farm has the lowest emissions estimated at 90 kg CO₂ eq./100 kg ECM.

Total CO₂ eq. emissions are reduced gradually when replacing purchased concentrate by locally-produced by-products. Likewise, the reduction in emissions in the ID scenario without using by-products in the diet indicates the importance of diet formulation in mitigating GHG emissions.

Of all scenarios, DL offers the highest GHG mitigation. A maximum mitigation of 15% is achieved in the JO-400 farm under the DL scenario. In the same scenario, more mitigation is achieved in the JO-80 farm at an estimated maximum of 21%. For the small-scale farm (JO-5), CO₂ eq. emissions are lowered by 16% under the DL scenario compared to AD. This is

due to replacing the purchased concentrate with by-products which contribute less to indirect CO₂ emissions.

Given that DMI and milk yield are assumed to be constant in the various scenarios, the variations in CO₂ eq. emissions between the scenarios within each farm type can be attributed to different diet components. In particular, a reduction in the share of purchased concentrates and an increase in locally produced by-products results in less indirect N₂O and CO₂ emissions. The differences in total CO₂ eq. emissions per kg ECM between farm types are related to the variations in milk yield: with higher milk yield in JO-400 farm, total CO₂ eq. emissions are significantly lower than in JO-5 farm with its lower yield level. The sensitivity analysis shows that CO₂ eq. emissions increase by 10% and by 16%, respectively, as a response to lower ME content and DM intake in the DL scenario.

5.4. Discussions

5.4.1 Nutritional assessment of by-products and the feeding scenarios

The objectives of the present study were to: evaluate the nutritional value of food industry by-products as animal feed; assess the economic impact of using alternative improved feeding scenarios; and estimate the degree of GHG mitigation by using feed by-products in the Jordanian dairy farming systems. The evaluation of the formulated scenarios is based on the chemical composition of by-product feeds, the level of dry matter intake of conventional and by-product feeds as well as the nutritional requirements to produce a certain amount of milk. Furthermore, maximum dietary inclusion values of by-product feeds from previous researches (shown in table 5.3) were used in diets formulation.

The chemical composition of by-products analysed in this study was similar to that found in other studies (Abbeddou et al., 2011; Onwubuemeli et al., 1985; Abdollahzadeh et al., 2010; Silva et al., 1976; Dhiman et al., 2003). The high ME content and low level of uCP in the AD scenario is caused by inclusion of high amounts of concentrates. These are higher in energy but lower in uCP content than some by-products in the other scenarios. In the AD scenario, ME content does not appear as a limiting factor for milk production and animal efficiency. However, in other scenarios, the ME content of the formulated diets declines by between 0.5 and 1 MJ/kg DM due to the low energy content in by-products feeds. Consequently, the lower daily energy intake in the ID and DL scenarios could have slightly affected milk production and animal efficiency. However, this effect was not considered in the analysis, and therefore, the economic and the ecological results particularly in these two scenarios could have been overestimated by 5-7%.

The NDF level was the lowest in the AD scenario and may suggest that peNDF was neglected when the diets were formulated by farmers. Furthermore, the AD scenario reflects the real situation where farmers are using few varieties of roughages (alfalfa hay and corn silage). Therefore, it becomes essential to incorporate non-conventional fibrous feed sources in order to optimize the use of expensive concentrate feed. It was therefore important to add a constraint to the model which considers ruminal fermentation in the developed scenarios.

The ID scenario uses the same feeds typically used on farms. The changes in diet composition are caused by replacing concentrate feed by alfalfa hay which is characterized by a higher CP content. Furthermore, the advantage of this diet is that it possesses high levels of peNDF and meets the requirements compared to the AD scenario. However, the total ME intake from concentrate feed is reduced by 51% compared to the AD scenario, consequently ME appears

to be a limiting factor. The ME content was reduced by 1 MJ/kg DM due to the low concentrate content in the diet and therefore one would speculate that milk yield and animal efficiency could be reduced under this scenario.

In spite the fact that the inclusion of forage has improved fiber contents in the diet, a slight reduction in milk yield would be expected. Nevertheless, this scenario can be useful for dairy farmers who wish to reduce the share of concentrate feed in the diet. In this regard, recent changes in Jordan allowing the use of treated water resources have made fodder production more accessible to dairy farmers. Therefore, this scenario can be seen as a realistic improvement of the diets.

Likewise, the main changes in the AB scenario compared to AD are due to the inclusion of sesame meal (which possesses a high ME but low peNDF content) and poultry litter (characterized by a high CP content). The consequences of including limited amounts of by-products in this scenario are obvious in increasing (although slightly) the ME content compared to the ID scenario. However, compared to the AD scenario, the ME content is slightly lower in AB, whilst peNDF content is higher and meets the requirements.

Obeidat et al. (2010) find that feeding sesame hulls in small ruminant diets improves feed intake with no major effects on daily gain. The use of this by-product leads to an economic advantage when it replaces barley and soybean meal in the ration. Furthermore, total ME intake from concentrate feed is reduced by 58% compared to the AD scenario. The formulated diet indicates that sesame meal can be used as an energy source while layer litter can be introduced as a rich source for CP.

From the current analysis, and due to the wide variations in energy contents of the used by-products, it seems evident that incorporating by-products in the animal's diets will reduce ME contents, and therefore might slightly affect milk yield and animal efficiency.

Table 5.4: Impact of feeding scenarios and the changes in concentrate price on ingredients composition of diets in the JO-400 farm

JO-400 farm	Unit	2010 feed prices				2011 feed prices			
		AD	ID	AB	DL	ID	AB	DL	*DL-9.5
CA	%	6.7	7.8	9.7	11.0	7.8	9.7	11.8	13.0
CL	%	NA	11.2	4.7	7.2	11.2	4.7	7.4	6.0
NDF	%	28.0	34.8	32.8	36.4	34.8	32.8	35.9	36.5
peNDF	g/kg DM	203	272.2	228.5	220.0	272.2	228.5	220.0	220.0
ADF	%	12.4	23.5	19.9	23.1	23.5	19.9	22.9	23.2
UDCP	g/kg DM	44.0	44.8	65.4	102.1	44.9	65.4	105.0	97.4
uCP	g/kg DM	165.0	209.7	227.3	254.1	209.1	227.3	253.0	248.3
ME	MJ/kg DM	11.0	10.0	10.5	10.0	10.0	10.5	10.0	9.5
DOM	%	77.0	72.1	71.4	66.0	72.1	71.4	66.1	66.1
Proportion of DM feed intake									
Concentrate		0.71	0.35	0.30	0.20	0.35	0.30	0.12	0.18
Layer litter		0.00	0.00	0.10	0.10	0.00	0.10	0.10	0.10
Corn silage		0.13	0.00	0.19	0.01	0.00	0.19	0.02	0.01
Alfalfa hay		0.09	0.65	0.30	0.20	0.65	0.30	0.20	0.20
Grass		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wheat straw		0.07	0.00	0.00	0.05	0.00	0.00	0.05	0.05
Olive cake		0.00	0.00	0.00	0.05	0.00	0.00	0.05	0.05
Raw potato		0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00
Anise extract		0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.01
Sesame meal and hulls		0.00	0.00	0.10	0.08	0.00	0.10	0.11	0.10
Tomato pomace		0.00	0.00	0.00	0.15	0.00	0.00	0.15	0.15
Potato chips		0.00	0.00	0.00	0.05	0.00	0.00	0.05	0.05
Broiler litter		0.00	0.00	0.00	0.10	0.00	0.00	0.10	0.10

* Sensitivity analysis scenario: the same feeds and constrains in the DL scenario was used here; the only change was due to reducing the energy content constrain to 9.5 MJ/kg DM.

-DM: dry matter; CA: crude ash; EE: ether extract; NDF: neutral detergent fiber; ADF: acid detergent fiber; peNDF: physically effective NDF; CP: crude protein; uCP: utilizable CP, RUCP: undegradable crude protein, ME: metabolizable energy; DOM: digestible organic matter.

-The defined ingredients constrains were set at the following levels: ME \geq 10 MJ/kg DM; uCP \geq 137 g/kg DM; UDCP \geq 30% of uCP; peNDF \geq 220 g/kg DM. Whereas ADF and NDF, CA, CL and DOM are shown as a result of the diet formulation Scenarios are defined as follow: AD: Actual diets that are typically used on dairy farms; ID: Improved diet based on actual feeds used on the farm; AB: Diet including few available by-products; DL: Diet with no limitation for feed availability.

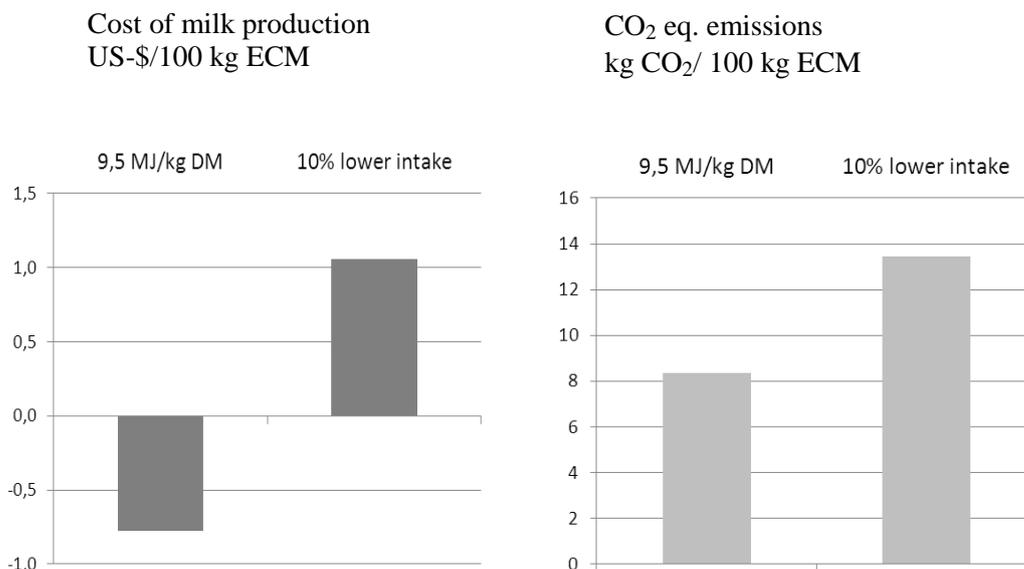
Despite the fact that layer litter is produced in large quantities, farmers do not prefer to include this by-product in the diet, probably due to the fear of harmful pathogens or the accumulation of copper in the litter. These considerations have limited its utilization as an animal feed. Muia et al, (2001), however, shows that including poultry litter in the diet up to 3.65 kg DM/day does not affect animal performance. Nevertheless, treatment of this by-product might be needed before feeding. Possible techniques such as steam heating, air drying or roasting methods can be used to eliminate possible pathogenic effects at different efficiency levels (Ghaly and MacDonald, 2012). This might be however associated with additional costs, therefore an economic evaluation of this by-product is required in this case.

Compared to the AD scenario, considering all by-products are available in the DL scenario has reduced the ME content of the diet, increased peNDF and uCP owing to the inclusion of tomato pomace, olive cake, layer litter and wheat straw feeds which are characterized by high NDF content compared to concentrate feeds. Tomato pomace in lactating cows' diets is reported to make up 30% of the diet when mixed with apple pomace (Abdollahzadeh et al., 2010). In the current study, tomato pomace comprised 15% of the total DL formulated diet. Furthermore, total ME intake from concentrate was reduced by 72% compared to the AD scenario. This could lead to lower animal efficiency and consequently lower milk yield would be expected.

Compared to the ID and the AB scenarios, the reduction in the peNDF level in the DL scenario was caused by replacing corn silage and alfalfa hay with less effective fiber in the tomato pomace and broiler litter. These are rich in NDF but possess low effective fiber due to their physical structure. However the critical value for peNDF could be reached. Application of the DL scenario might be challenged by the availability of several by-products on-farm. This requires additional investments to preserve by-products and consequently it might lose its competitiveness compared to conventional feeds. Therefore the focus on few by-products as such in the AB scenario seems to be more realistic for dairy farmers. Nevertheless, this scenario may certainly be suitable for large-scale dairy farms where the investment is already well established.

Brewer's grain has considerable potential as a feed for lactating cows; however it was not selected as food by-product in the least-cost procedure for the developed scenarios because of its high price compared to other by-products with similar nutrient composition.

Figure 5.6: Impact of DM or energy intake reduction on the cost of milk production and total CO₂ eq. emissions in the large-scale farm type (sensitivity analysis)



Generally, the uCP content increased through the use of food by-products. The negative impact of oversupply of protein can result in a decline in nitrogen (N) use efficiency and excessive urinary N excretion (Varel et al. 1999). It can further affect animal health and reduce cow fertility (Mitchell et al., 2005). Since some of the used by-products are rich in both energy and protein, reducing the CP content to a required level would also be associated with reducing ME contents. The higher uCP content through the feeding of by-products suggests that the by-products are an important source for CP in animal diets.

Since some by-products, particularly olive by-products and tomato pomace, may be partly refused by the animals due to their low digestibility and palatability, one would anticipate that this might affect the level of milk production and consequently the calculated costs and CO₂ eq. emissions. Therefore a sensitivity analysis was performed. This analysis shows no significant changes in the cost of milk production and other calculated economic figures.

To assess the effect of an increase in concentrate prices on the composition of diets, all scenarios were formulated with concentrate prices inflated by 22%. A significant change in diet composition was only observed in the DL scenario where concentrate feed is reduced by 8% and replaced to a larger extent by sesame hulls and raw potato. This relatively small impact suggests that changes in feed prices will only have minor effects on diet composition.

5.4.2 Economic assessment

The economic impacts of using alternative feeding scenarios were assessed and estimated by comparing costs of milk production under different scenarios.

Figure 5.1 shows the cost of milk production in the three typical dairy farms for the status-quo scenario. The low cost of milk production in small-scale farming systems (20% lower than the large-scale farm) is attributable to low input of capital, labour and land. In JO-5, the opportunity cost was higher than in JO-400 and JO-80 because JO-5 is managed solely by family labour, whereas the other two farms hire most of their labourers. Furthermore, land in the JO-5 is inherited by the household, while in the larger farms land is purchased. The additional costs of land, labour and infrastructure have contributed to an increase in the cost of milk production in the two larger farm types. Nevertheless, the cost of milk production is mainly driven by the high feed costs which account for around 80% of total cost in JO-80 and JO-400). Differences in feed cost between the three farms types are caused by differences in the prices and quantities of purchased feed and by differences in milk yields. The analysis of milk production costs suggests that small-scale farming systems have a competitive advantage over the large and medium-scale farms.

In the ID scenario, the lower cost is associated with replacing the expensive concentrates with much cheaper alfalfa hay. The further reduction in the cost of milk production in the DL scenario is caused by the lower feed cost associated with low prices of food industry by-products. Similar results were reported by Grasser et al. (1995). The potential for cost reduction in large-scale farms is higher than in the other farm types. This is due to the initially high shares of purchased feeds being replaced by food industry by-products with lower prices.

Of all scenarios studied, the AD scenario is most sensitive to an increase in feed prices. This is due to the large proportion of purchased concentrates. By contrast, the DL scenario is most robust to feed price fluctuations and remains the most competitive scenario.

The slight reduction in cost of 0.8 US-\$/100 kg ECM when the ME content of the feed is reduced by 0.5 MJ/kg DM in the sensitivity analysis is due to the minor replacement of concentrate with sesame meal, which resulted in lower feed cost. Furthermore, the value of the reduced milk output is compensated for by the reduction in feed cost.

The cost increase by 1 US-\$/100 kg ECM at 10% less DM intake compared to the DL scenario is driven by the reduced milk yield. Furthermore, a potential reduction in DM intake has more pronounced effects on milk yield than reducing the level of ME content per kg DM,

consequently higher cost of milk production would be expected. It seems evident that by-product feeds are not priced based on their energy contents.

Under the on-going farming system intensification in Jordan, the results of this study indicate that locally available food industry by-products could be instrumental in maintaining the profitability and competitiveness cost of milk production.

Evaluating the use of food by-products to optimize the economic performance and mitigate GHGs

Table 5.5: Cost of milk production and total CO₂ eq. emissions on dairy farms under alternative feeding systems and price levels

Item	Unit	2010				2011			
		AD	ID	AB	DL	AD	ID	AB	DL
400-cow farm									
<i>GHGs emissions</i>									
Total CO ₂ eq. emissions*	kg CO ₂ /100 kg ECM	90	83	81	77	90	83	81	71
<i>Economic indicators</i>									
Cost of milk production	US-\$/100 kg ECM	43	41	39	37	49	46	44	40
Feed cost on total cost	%	79	78	77	76	81	80	80	78
Margin over total feed cost	US-\$/100 kg ECM	18	21	24	26	13	15	16	23
Enterpreneurs profit	US-\$/100 kg ECM	19	21	24	26	13	15	16	23
ROI total	%	40	45	50	55	29	34	34	48
80-cow farm									
<i>GHGs emissions</i>									
Total CO ₂ eq. emissions	kg CO ₂ /100 kg ECM	114	97	96	90	114	97	96	89
<i>Economic indicators</i>									
Cost of milk production	US-\$/100 kg ECM	49	48	46	42	55	51	53	45
Feed cost on total cost	%	81	81	80	79	83	82	83	80
Margin over total feed cost	US-\$/100 kg ECM	16	16	19	22	9	14	11	19
Enterpreneurs profit	US-\$/100 kg ECM	13	13	16	19	6	11	8	16
ROI total	%	11	12	15	20	2	9	5	16
5-cow-farm									
<i>GHGs emissions</i>									
Total CO ₂ eq. emissions	kg CO ₂ /100 kg ECM	188	178	175	159	188	178	175	165
<i>Economic indicators</i>									
Cost of milk production		34	33	32	31	37	36	36	32
Feed cost on total cost	%	66	66	65	65	68	67	67	65
Margin over total feed cost	US-\$/100 kg ECM	4	5	6	7	1	2	2	6
Enterpreneurs profit	US-\$/100 kg ECM	12	13	14	14	9	9	10	13
ROI total	%	24	26	27	28	19	20	21	26

Scenarios are defined as follow: AD: Actual diets that are typically used on dairy farms; ID: Improved diet based on actual feeds used on the farm; AB: Diet including few available by-products; DL: Diet with no limitation for feed availability.

-Emission factors used to calculate total CO₂ eq were: **N₂O emission** from fertilizers used to produce the purchased feed: 0.012 kg/kg N, (Simon, 1998), Fuel N₂O: 0.007 g / l (Audsley et al., 2003); Manure N₂O: 0.02 kg/kg N (IPCC, 2001). **CO₂ emissions:** fuel combustion 2950 g CO₂/l (Audsley et al., 2003); concentrate production (Soybean 224 g CO₂/kg, corn: 445 g CO₂/kg; Mineral and vitamin premix: 111 g CO₂/kg (Nagy, 1999), machineries: 5.9 kg CO₂/kg, buildings 132.4 kg CO₂/m², bedding material: 0.05 g CO₂/kg and dairy chemicals :0.1 g CO₂/kg.

-The N₂O emission losses from manure = nitrogen excretion of cows in kg/year multiplied by an emission factor of 0.02 for drylot waste management systems dominant in Jordanian dairy farms.

N₂O emissions of fuel combustion = diesel fuel usage in kg multiplied by the N₂O emission factor of 0.007 g N₂O / L.

-Enteric CH₄ emission (g/cow/d) = CH₄= 3.41+ 0.52 x DMI - 0.996 x ADF kg/d + 1.15 x NDF kg/d (Ellis et al., 2007).

-Total CO₂ eq. emission considering the global warming potential of CH₄ and N₂O to be 25 and 298 times that of CO₂, respectively.

5.4.3 Ecological assessment

Mitigation of GHG emissions from farming systems must be studied at the farm scale using a system approach (e.g. Schils et al., 2007). Both LCA models and GHG emission data from arid and semi-arid environments are lacking. Our analysis thus had to draw on models developed for European production systems. Modifications on the data used in the model were thus necessary. For instance, in order to assess the impact of feeding protein-rich by-product on the direct N₂O emission, N excretion of the cows in the AD scenario was determined by Alqaisi et al. (2013), whereas N excretion in the ID, AB, and DL scenarios was calculated as the difference between N intake and milk N in order to better estimate N₂O emission. Furthermore, direct emissions from energy use on farm were computed based on emission factors from the region.

Given the similarity of the diets on the three model farms, CO₂ eq. emissions per cow are of a similar order of magnitude. The two main drivers of GHG emissions per kg milk are the level of DMI and the milk yield. The milk yield has more impact, with higher yield being associated with significantly less CO₂ eq./kg ECM milk. Therefore, yield performance is responsible for much of the variation in total CO₂ eq. emissions between large and small-scale farms. With up to 53% of total GHG emissions, CH₄ is the single most important greenhouse gas in Jordanian milk production. Interestingly, the share of CH₄ gas increases slightly with the inclusion of food industry by-products in the diet. This is caused by a reduction in the other two greenhouse gases, CO₂ and N₂O. As a result of the higher intake of by-products across the scenarios, CP intake increases and consequently direct emissions of N₂O from manure follow suit. This effect is counteracted by reductions in indirect emissions are reduced due to the reduced amounts of concentrate included in the diets. The latter effect outweighs the increased direct N₂O emission. Similar results were reported by Cederberg and Mattsson (2000) who recommended the use of domestic or regional by-products as opposed to ingredients imported from other countries to reduce the direct emissions of CO₂ and N₂O gases.

Our analysis has shown that CO₂ eq. emissions per 100 kg ECM in JO-5 are roughly twice the emissions in JO-400. Similar results are reported by Rotz et al. (2010) and by Hagemann et al. (2011). The higher ecological performance of JO-400 is the combined effect of better diets in and higher milk yields. Compared to other farming systems in semi-arid environments,

emissions from JO-5 are similar to those reported for small-scale coastal farming systems in Peru (Bartl et al. 2011).

Incorporating food industry by-products under the DL scenario reduces the CO₂ eq. emissions per 100 kg ECM by 14% in JO-400 and by 16% in JO-5. Given that milk production is assumed to be constant across the scenarios, the lower emissions in the DL and AB scenarios compared to AD are associated with a reduction of indirect emissions caused by feed production due to fertilizer and energy use. Food industry by-products are often criticised for possessing higher CP contents with the consequence of higher N contents in manure. Our analysis of GHG emissions suggests that feeding CP-rich diets does indeed increase the direct emission of N₂O but that this effect is more than offset by reductions in indirect emissions associated with feeding concentrates. Vellinga et al. (2011) report similar results: total GHG emissions were reduced by 10% (or 50 g per kg milk) when agricultural by-products were used to replace concentrate feed. However, this is less than the reduction estimated in the current study. The difference can be attributed to the higher proportion of by-product feeds in the formulated diets. In the present study, the mitigation potential amounts to a maximum of 290 g/kg ECM in JO-5 farm.

The sensitivity analysis shows that reducing the level of DM intake will have a more pronounced impact on CO₂ eq. emissions than reducing the ME concentration in the diet. This is related to the fact that at lower DM intake, milk yield is reduced more sharply, and therefore CO₂ eq. emissions per kg milk are higher than that when the ME contents per kg DM is reduced.

5.5 Conclusion

Alternative dairy feeding systems in Jordanian agriculture were explored by evaluating their nutritional, ecological and economic consequences at the farm level. The systems under investigation varied in their share of food industry by-products and were compared against the current concentrate-based feeding systems. The analysis was carried out for small, medium and large-scale dairy farms typical of production systems in the arid and semi-arid environments of Jordan.

The results suggest that inclusion of food industry by-products in the rations of milk cows in such production systems can be a promising option for reducing production costs and mitigating GHG emissions. Feeding regimes which include by-products thus have the potential to kill two birds with one stone: increase the competitiveness of the farms and contribute to GHG mitigation efforts. The degree to which these benefits can be reaped depends on the level of inclusion of by-product feeds in the lactating cows' diets and the response of milk production to diet change. More research is needed to test the limits by exploring potential adverse effects on animal health and yields that may result from too high shares of by-products. Also, further research is needed to explore to what extent the results from this study extend to similar dairy production systems under arid or semi-arid conditions in countries outside Jordan. Finally, the benefit of improved feeding systems can only be reaped if farmers are willing to adopt the improved technology. This requires an examination of the potential obstacles to the adoption of this innovation and a study of the incentives needed to aid its diffusion.

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Chapter six

6 General discussions

This study analysed dairy developments in three countries in the Middle East (Jordan, Syria and Saudi Arabia). Stronger emphasis was made on the Jordanian dairy farming systems. The study reviews the recent trends in dairy development in the Middle East and shows the drivers for growth in milk demand and production. It analysed nutritional, ecological and the economic aspects of milk production systems in semi-arid environments of Jordan. It further assessed the impact of alternative feeding systems on the economic performance and potential mitigation of GHGs from dairy farming systems. This chapter summarises the key findings and draws conclusions and implications for dairy farming, and also identifies future research needs.

6.1 Summary of results and implications

In this section the results obtained from the individual chapters which shape this thesis are summarised. The overarching objective of the thesis was to assess options for improving the nutritional, ecological, and economic situation of dairy production systems in the Middle East region.

The specific objectives were to:

1. assess the state-of-the-art of dairy farming systems in the Middle East and to analyse dairy sector developments in the region;
2. analyse the drivers of dairy development in Jordan;
3. evaluate the nutritional and ecological aspects of dairy feeding systems in Jordan;

4. assess the ecological and the economic impact of feeding alternative feed resources under different feeding scenarios in the Jordanian dairy farming systems.

Chapter 2 reviewed literature on dairy farming systems and analysed dairy development in three countries in the Middle East. The key highlights from this review are incorporated in the discussions that follow in this chapter.

The drivers for dairy development in Jordan were discussed in **Chapter 3**. The chapter elaborated on the availability of feed resources in the country and the development in milk and feed prices between 1996 and 2007. The total feedstuff requirements for the dairy cattle sector in Jordan was estimated at 354 thousand dry matter tons per year. Two farming systems typical of the region were evaluated and discussed: intensive and extensive farming systems. The milk-feed price ratio (calculated by dividing the milk price by the feed price) was used as a profitability indicator. Based on this indicator, it was concluded that concentrate based rations were favorable throughout the period 1996–2006. During that period, feed prices (calculated based on corn and soybeans meal) were 25% higher than world market feed prices. In 2007, feed subsidies were slashed and feed prices increased by 40% compared to the world market feed price. In spite of the shortages in resource availability, milk production grew in Jordan by 5.4% between 2002 and 2007. Growth in milk production was mainly driven by growth in per capita consumption.

An evaluation of the nutritional and ecological aspects of dairy farming systems and feeding regimes was elaborated in **chapter 4**. The study compared nutrient intake of lactating cows with standard tabulated values to evaluate the diets and animal performance. In vitro and in vivo methodologies were used and applied on nine dairy farms from Jordan. The variations in the use of feed resources were discussed for the different farming systems analysed. The differences in productive performance across farms were related to the quality of feeds and the level of feeding. Deficiencies in crude protein were observed in the diets of several farms. Small scale farms emit 88% more CO₂ eq. per kg of milk compared to small scale farms. The enteric and manure CH₄ gas comprised the highest proportion of CO₂ eq. (52%). The level of dry matter intake and the daily milk yield were the main drivers for the variation in greenhouse gas emissions per cow across different farming systems. A comparison between low and high yielding animals revealed differences of 16 kg ECM/d in milk yield, 85 g/d in milk nitrogen and 900 g CO₂ eq. /kg ECM in

mitigation. The study concluded that there is a huge economic and environmental potential by the use of available rich protein and energy by-products which are cheap and emit less GHGs. Further research on alternative feeding systems with low concentrate feed inputs should be evaluated in the near future.

Chapter 5 discusses the nutritional, ecological and economic impacts of including food industry by-products in the diets of the animals. Eleven by-products were evaluated for their chemical composition and metabolisable energy contents. Four feeding scenarios which fulfil the requirements of lactating cows were developed. Technology Impact Policy Impact Calculation model (TIPI-CAL), in addition to a basic linear programming model were used in the study. The results showed that cost of milk production can be reduced by 2 US-\$/100 kg ECM when the diet formulated from typical feeds is optimised. A potential reduction of 4 and 6 US-\$/100 kg ECM was observed when food industry by-products were included at different levels. Furthermore, the inclusion of by-products resulted in mitigation in CO₂ eq. emissions which ranged from 70 to 290 g CO₂ eq. /kg ECM. The study showed that when feed prices increased by 22%, the cost of milk production increased by 10%, but the composition of the diet was not greatly influenced. Since intensification of farming system leads to higher production costs per kg milk produced, food industry by-products can play an important role in improving the competitiveness and reducing the carbon footprint of milk production.

Since climate, geography and resource availability are similar for dairy farming systems in the Middle East countries, the results of this study can be used in several ways to further develop dairy farming systems in the region.

Currently, many countries in the region are moving toward **intensified** production systems which are capital intensive and are practised with good access to transportation and cooling facilities. These systems are characterized by high inputs and high outputs associated with high costs of milk production. The intensification has increased the pressure on land and water resources used for improving the grazing system and pasture. However, improvements in pasture management are hindered by water availability. As a result, the current intensification is based on imported concentrates so as to cut down on local consumption of water.

As shown in chapter 5, the extensive dairy farming system practised in small scale farms have an advantage due to their lower cost of milk production by 20% compared to large scale farming. These results are important for the future development of dairy farming systems in the region due to the fact that reasonable quantities of milk are produced by small scale farmers. Small scale farms are subsistence oriented and operate with low feed inputs compared to large scale farms. These farms are business oriented and have a higher interest in improving on feed management; this was reflected in the productive performance of the animals. However, improvement on productive performance in small scale farms may require additional resources and might influence the economic advantage of these farms.

The impact of current farming systems on **GHG** emissions was evaluated in this study. Including this part of the study was of importance to understand the patterns of GHGs emission and their drivers under semi-arid environmental conditions. Beside the nutritional importance of the diets which were stressed in this study, the association between both levels of milk production, and level of dry matter intake and the CO₂ eq. emissions indicated that reducing CO₂ can be achieved by improving the productive performance of animals. With total CO₂ emission per kg ECM milk in small scale farms being about twice as high as in large scale farms, there is an opportunity for small scale farms to mitigate their emissions by considering alternative feed resources. Other strategies to mitigate emissions that apply to small and large scale dairy farming will be via increasing the culling rate and designing selection criteria targeting higher yielding animals which utilize their genetic potential and are known for high efficiency. Furthermore, the possibility to mitigate total CO₂ emissions without scarifying cost of milk production was discussed in this study and has proved to improve the ecological and economic situation on farms.

Feeding systems differ between countries within the region, but they are common in using imported concentrates. For example, feeding systems in the dominant small scale farming system of Syria are based on crop residues and concentrate feeds. In Algeria, feeding systems in small scale farms are based on imported concentrate in addition to grass produced locally. In Egypt, feeding is based on alfalfa hay and concentrate. In contrast, dairy farming systems in Saudi Arabia are dominated by large farms and intensive production system. Concentrate and fodders are

produced on improved pastures whilst animals under this production system are more efficient in converting feed into milk compared to farming systems in other countries.

The importance of food industry **by-products** and crop residues and particularly those from cereals crops in arid and semi-arid regions for dairy feeding is beyond question. In terms of quality, by-products which are energy-rich and protein-rich (sesame meal, tomato pomace and brewers grains) can play a substantial role in replacing concentrate feeds. Since some of the available feeds are of low quality, they may require certain practices and techniques to maintain and improve their feeding value (Kebreab et al, 2005). They require correct handling and storage (Owen and Aboud 1988). Several methods were suggested to improve by-product quality. Nitrogen treatment via adding urea (Balch, 1967) reported to improve the daily milk yield (Mpofu, 2005) and has been used to replace alfalfa hay in some diets (Topps and Oliver 1993). Consequently this type of treatment has reduced the cost of feeding. Furthermore, the chemical treatments by sodium hydroxide (Homb, 1984) have improved the digestibility of plant cell wall. Nevertheless, integration of these techniques requires intervention from extension services as well as financial support to dairy farmers.

Due to the regional scarcity of **water** resources, an alternative source of water namely treated wastewater can make a significant contribution to the limited irrigation water supply; treated wastewater can be used for fodder production (Carr et al., 2011). The advantage of this system is a reduced water price for irrigation. This is important for replacing imported fodders by locally produced roughages such as alfalfa and ryegrass. On-station trials should be performed to study the impacts on animal performance. The successful application of the above mentioned options is associated with the willingness of dairy farmers in the region to change and adopt new techniques aiming at improving the efficiency of the system. The support of policy and decision makers and extension service providers will also be of great significance.

Although this multidisciplinary research has covered several aspects of farming systems, this can be seen as one step for future research aiming at developing dairy farming in Jordan and the region.

6.2 Methodology

In this thesis, several evaluation methods and approaches were used. The nutritional evaluation of animal's diet was based on data for the estimated dry matter intake obtained from nine dairy farms. Based on the data estimated by dairy farmers, nutrient intake and efficiency was calculated. Although, the estimated intake was within the range in several farms, it was noticed that the animal efficiency in smaller farms might have been overestimated as they were far below the requirements.

When small scale farmers were interviewed, they indicated that cows were seasonally fed on low quality pasture in spring time. However, it was not possible to precisely estimate the grass intake from pasture since the type of grass and grazing time was not known.

It was also not possible to compare the current estimation with previous studies from the region due to the paucity of such studies in literature. Alternatively, precise measures of estimated dry matter intake and feed residue on a limited number of animals from each farm could have improved the results.

Including more farms in the study could have definitely improved the results and would have allowed the use of statistical analysis, consequently more robust results and improved conclusions. However, it was not possible to include more farms due to financial and time limitations. Furthermore, the used approach focused on frequent visits to few dairy farms with more detailed data collection per farm during a limited time period. Data collection covered a period of four to five weeks each time. The results could also be improved if longer periods are considered and precise parameters on measuring/estimating dry matter intake were applied.

Since days in milk is an essential indicator also for measuring animal efficiency and the reproductive performance, including this indicator could improve evaluation of the systems. Nevertheless, it was not possible since this value was not recorded in several farms.

Furthermore, an important aspect for arid and semi-arid regions which was not considered in this thesis is the effect of climate on feed intake and animal performance. If this factor would have been evaluated, the output of the study could be improved and some aspects such as high MUN values in summer time could be better explained and evaluated. Furthermore, the predicted formula used to evaluate the estimated dry matter intake did not consider the ambient temperature

and therefore, considering this parameter would have produced a better prediction for the daily intake.

In spite of the above mentioned challenges and limitations in data collection and evaluation, the results obtained in the current study appear reliable in several aspects. For example, when the digestibility of the diets was evaluated using the *in vitro* measured organic matter digestibility and *in vivo* estimated organic matter digestibility methods, they showed a similar trend. Furthermore, the estimated organic matter digestibility results confirm the validity of fecal N estimation. Likewise, the results of chemical composition of feed data were within the range found in the literature.

The LCA model used to estimate GHG emission was developed on the basis of European standards and the level of accuracy was not calculated. Emission factors from desert, arid, and semi- arid regions are lacking. Therefore the emission factors used in the LCA model were partly replaced (based on the availability of data) by factors that are representative of the region, providing more reasonable estimates of total emissions per unit kg of milk. It was difficult to compare the results with those from the regions due the paucity of studies on GHGs in the Middle East. However, when compared with recent findings from other parts of the world under similar environmental conditions from Peru (Bartl et al., 2011), the results obtained in this study can be considered reliable and within the expected range. The economic evaluation of farming systems is based on three typical farms. Description of farming systems followed the IFCN approach using the TIPI-CAL model. The use of this approach is debatable since a single farm is supposed to represent farming systems in the respective region, especially if the definition of the typical farm is wrongly perceived. However, it was necessary to use the typical farm approach since the evaluation of alternative feeding systems required the use of whole farm data. Furthermore, the advantage of this method is that it enables status quo analyses of production costs as well as projections of the farm under different strategies and scenarios (Deblitz, 2005). Nevertheless, the panel approach (group of dairy farming experts which includes expert farmers, consultant and veterinarians) for data collection has proved to be an appropriate tool to evaluate and judge field data quality (Ndambi and Hemme, 2009). Furthermore, the economic results were reviewed and discussed with the panel until confirmed. However, future scenarios of alternative feeding systems were limited to four. Including more scenarios in the analysis would have explored more

options than what was produced. Furthermore, evaluation of feeding systems based on changing the proportion of single by-products in the diet was not performed and could have produced different results.

6.3 Outlook and research priorities

In spite of the existing challenges from climate and resources availability, there is potential for dairy industry development in the Middle East for the following reasons:

1. The continuous growth of demand for locally produced and imported milk
2. Available technologies in marketing, milk collection and processing of milk and dairy products
3. The availability of alternative local feed resources and agro-industrial by-products which could be used as animal feed
4. Availability of alternative water resources which can mitigate the shortage of fodders and fresh water
5. Local policies in support of dairying which make the sector attractive for future investment

On the basis of the preceding discussions, some feeding aspects need to be further examined. For example, it would be essential to understand whether formulating diets with low energy contents and consequently lower milk yield is more profitable than formulating high energy diets that fulfil animal requirements at high milk yields. Previous regional research on feeding systems was dedicated to small ruminant (sheep and goat) including pasture development and feed resources. Very little research has focused on improving the efficiency of dairy cows under arid and semi-arid conditions. Therefore, the current study can be extended to better evaluate dairy farming systems in arid and semi-arid conditions. The dimensions of future research need to concentrate on the following aspects:

- The potential and the capacity of producing green fodder from treated wastewater reuse and the farmers preferences for feeding animals on such type of fodder.
- Assessing the impact of alternative feed resources on animal efficiency and also to assessing the possibility of improving low quality agricultural by-products via introducing treatment techniques for dairy farms.

- Studying the impact of heat stress on animal performance and developing techniques which mitigate its effect on productive and reproductive performance.
- Economic and ecological evaluation of future alternative farming/feeding systems which ensure profitability under different farm management scenarios.
- Evaluating the adaptability of imported breeds to local conditions in comparison with native and cross breeds and setting breeding programs suitable to cattle raised under semi-arid and desert climates.
- Studying the impact of animal diets and climatic conditions on the reproductive performance of lactating cows and their health need to be investigated.
- Assessing the current agricultural policies and their impact on the developments of dairy farming systems as well as searching alternative policies which favour the support to dairy farmers is needed.
- Developing education and training programs that target academics, institutional advisory services and farmers.

6.4 Conclusions

Regional milk production in the Middle East is growing beyond the available resources of land and water. Due to the growing demand on milk and dairy products, self sufficiency of milk is not attained, consequently; the gap between supply and demand is increasing. With more emphasis on dairy farming systems in Jordan; the main challenges encountered by the dairy farmers are the availability of feed resources from concentrate and forages, and the volatility of imported feed prices. These challenges are therefore a threat to the development of competitive milk production systems. The lack of possibilities to grow pasture and to plant legumes and grasses has reduced their use as an essential dietary component. These challenges were more evident for the extensive farming system, which was reflected in their productive performance. Consequently, animal efficiency was lower in the extensive system, associated with higher greenhouse gas emissions compared to the intensive farming system. As an alternative to traditional feeding practices, available food industry by-products can be used in animal diets. Replacing current feeding systems with ones that use more alternative by-products shows a good development potential for dairy farming. Simultaneously, the pronounced ecological and economic impact of current feeding systems might be avoided. Dairy farmers most likely will accept changing the current feeding systems if the available alternatives would assure a similar or higher milk yield without additional economic inputs. Small farmers will probably not be able to improve animal performance without institutional support and resource allocation for their farms. Given that some alternative choices are available, it depends on the farmers' willingness to adapt new techniques and/ feeding systems which reduce the reliance on expensive concentrate. As potential future scenarios, these options need to be further investigated for their suitability for dairy farming systems in Jordan. Since global feed prices are increasing, the long term sustainability and the economic impact of intensifying farming systems based on imported concentrates feed needs to be evaluated. Maintaining the growth in milk production in the semi-arid environments of the Middle East can be accomplished by improving the current agricultural policies to favour dairying and improve the sustainability of natural resources. The current study used several approaches which can serve as a base-line for future follow-up studies.

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7 Summary

Arid and semi-arid regions have limited arable land and water resources. As a result, production of grain and forage is often insufficient to fulfil the requirements of lactating animals. The absence of grassland has led to the dominance of grains based diets imported from overseas. This has an ecological impact due to the emissions of greenhouse gases (GHGs) from land change activities. In addition, the prices of these grains are increasing. Therefore, the objectives of this thesis were to evaluate the nutritional and ecological aspects of the dairy farming systems and feeding strategies dominant under semi-arid environmental conditions in Jordan, and to evaluate how dairy production systems will respond to future changes in feed items and feed prices. The framework of the ecological, nutritional and economic assessment of dairy farming system consisted of several steps: **1)** data on dairy development and its drivers in three countries in the Middle East were collected and analysed, **2)** the nutritional and ecological analysis is based on nine dairy farms of different farm size and management schemes. Feed, milk and fecal samples as well as data on estimated dry matter intake (eDMI), animal performance, herd structure were collected and analysed, **3)** feed samples (traditional feed collected from farms and food industry by-products collected from food manufactories (n=69)), fecal samples (n=108) and milk samples (n=78) were collected from the farms and analysed for their chemical composition. All feed and food by-product samples were analysed for their metabolisable energy (ME) contents and organic matter digestibility (mOMD) in vitro according to Hohenheim-Feed-Test. Furthermore, fecal nitrogen concentration was determined to estimate in vivo organic matter digestibility (eOMD). Based on the farmer's estimate of DMI and the analysed composition of the feed ingredients, ME and nutrient intakes were compared to recommended standard values for adequate supply of ME, utilizable crude protein (uCP), rumen undegradable crude protein (RUCP), phosphorus (P), and calcium (Ca). **4)** greenhouse gas emissions (GHGs) were calculated using the Technology Impact Policy Impact Calculation model (TIPI-CAL) complemented with a partial Life Cycle Assessment model for estimating GHG emissions of milk production at the farm gate, the results are converted to CO₂ equivalents (CO₂ eq.). The model takes into account CH₄, N₂O, and CO₂ gases emitted directly and indirectly. **5)** to investigate what could be the ecological and economic consequence of using alternative feed resources, four feeding scenarios (AD: Actual diet, feeding diets that are typically used by dairy farmers; ID: Improved diet based on actual feedstuffs used

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on the farm; AB: Diet including few available by-products; DL: Diet with no limitation for feeds availability). The scenarios were developed and evaluated for their nutritional, economic and ecological impacts using different optimization and calculation models. All scenarios fulfilled the animal's nutrients and energy requirement. Results of the nutritional and ecological evaluation revealed that average daily energy corrected milk yield (ECM) was 19 kg/d and ranged between 11 and 27 kg. Diet evaluation showed that the mean of ME intake of all farms was 184 MJ/d with range between 115 and 225 MJ/d in low and high yielding cows, respectively. Intake of RUCP was lower than the requirements, which ranged between 19 and 137 g/d in six farms. On the other hand, it was higher (32 and 93 g/d) in two farms, and matched the requirements in one farm. P intake was higher than the requirements in all farms (mean oversupply= 19g/d) and ranged between 3 and 30 g/d. Milk nitrogen efficiency (milk N/intake N) varied between 19% in low producing animals and 28% in high producing animals, with mean of 24% in all farms. Total (CO₂ eq.) emission ranged between 0.90 and 1.80 kg CO₂ eq./ kg ECM milk. Where the enteric and manure CH₄ gas comprised (52%) the highest proportion of CO₂ eq. emissions. Followed by the indirect emissions of N₂O and CO₂ gases which comprised 28% from total CO₂ eq. emissions. Emissions per cow were significantly driven by the level of milk production ($r^2=0.93$) and by the level of eDMI ($r^2=0.88$), while the total emissions were not influenced by diet composition. A different of 16 kg ECM/d in milk yield, 85 g/d in milk nitrogen and mitigation of 900 g CO₂ eq./kg in ECM milk observed between low and high yielding animals. The status-quo analysis of three typical farm types showed that cost of milk production is 21% lower in the small scale farm type compared to large scale farm type. Model application of alternative feeding scenarios revealed that the cost of milk production in the large scale farm can be reduced by 6 US-\$/ 100 kg ECM when applying the DL scenario compared to the actual scenario. Similarly, when applying the DL scenario (high inclusion of food by-products in the diet), GHGs emissions (in CO₂ eq.) were reduced by 15% and was driven by lower concentrate feeding of 70% in the diet compared to the actual feeding scenario. Overall, a total mitigation of CO₂ eq. emission between 70 and 290 g/kg ECM produced is achievable. Alternative feeding management scenarios need to be considered for future developments of dairy farming systems. These include the development of low input concentrate feeding systems which insure profitability and reduce ecological impacts of farming systems.

8 Zusammenfassung

In ariden und semi-ariden Regionen sind Ackerland und Wasserangebot begrenzt. Die Produktion von Getreide und Grundfutter ist daher häufig nicht ausreichend, um den Bedarf der Milchkühe zu decken. Der Mangel an Grünland führte zu Kraftfutter-basierten Rationen, deren Komponenten aus Übersee importiert werden. Der Wechsel der Landnutzung führte zu Umweltbelastungen durch die Emission von Treibhausgasen (GHGs). Zusätzlich stiegen die Kraftfutterpreise in den vergangenen Jahren.

Das Ziel dieser Arbeit war daher die Evaluierung der Fütterungs- und Umwelteffekte von Milchproduktionssystemen und Fütterungsstrategien unter semiariden Umweltbedingungen in Jordanien sowie die Bewertung von Milchproduktionssystemen hinsichtlich ihrer künftigen Entwicklung bezüglich verfügbarer Futtermittel und deren Preisentwicklung.

Die ökologische, ernährungsphysiologische und wirtschaftliche Bewertung der Milchproduktionssysteme bestand aus mehreren Schritten: 1) Daten zur Entwicklung der Milchwirtschaft und deren Einflüsse wurden in drei Ländern im Nahen Osten gesammelt und analysiert. 2) Die Fütterungs- und Umweltanalyse basierte auf neun Milchviehbetrieben unterschiedlicher Betriebsgröße und Management. Futtermittel-, Milch- und Kotproben wurden analysiert, die Trockenmasse-Aufnahme geschätzt (eDMI), und tierische Leistungen und Herdenstruktur erfasst. 3) Futtermittelproben (aus landwirtschaftlicher Produktion und Nebenprodukte aus der Lebensmittelindustrie (n = 69)), Kotproben (n = 108) und Milchproben (n = 78) wurden auf den Betrieben gesammelt und ihre chemische Zusammensetzung bestimmt. Die Futtermittel und Nebenprodukte der Lebensmittelindustrie wurden auf ihren Gehalt an umsetzbarer Energie (ME) und ihre Verdaulichkeit der organischen Substanz (mOMD) in vitro mit dem Hohenheimer-Futterwert-Test untersucht. Darüber hinaus wurde die Stickstoff-Konzentration im Kot bestimmt, um die in vivo Verdaulichkeit der organischen Substanz (eOMD) zu schätzen. Basierend auf der Schätzung der DMI des Landwirtes und der analysierten Zusammensetzung der Futtermittel wurde die jeweilige Aufnahme mit Empfehlungen für eine ausreichende Versorgung mit ME, nutzbarem Rohprotein (uCP), Pansen unabgebauten Rohprotein (RUCP), Phosphor (P) und Kalzium (Ca) verglichen. 4) Die Treibhausgasemissionen (GHGs) wurden unter Verwendung des „Technology Impact Policy Impact Calculation“-Modell

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(TIPI-CAL) mit einem partiellen „Life Cycle Assessment“-Modell ab Hof berechnet. Die Ergebnisse wurden in CO₂-Äquivalente umgerechnet (CO₂ eq.). Das Modell berücksichtigt CH₄, N₂O sowie direkte und indirekte CO₂ Mengen. 5) Untersuchung der ökologischen und ökonomischen Konsequenzen bei Verwendung alternativer Futtermittel; hierbei wurden vier Fütterungsszenarien geprüft (AD: aktuelle Ration, die typischerweise von Landwirten verwendet werden; ID: verbesserte Ration basierend auf aktuell verwendeten Futtermitteln auf dem Betrieb; AB: Ration einschließlich einiger verfügbarer Nebenprodukte; DL: Ration ohne Einschränkung bei der Verfügbarkeit von Futtermitteln). Die Szenarien wurden entwickelt, um die ernährungsphysiologischen, ökonomischen und ökologischen Auswirkungen verschiedener Berechnungsmodelle zu evaluieren. Alle Szenarien erfüllen den Nährstoff- und Energiebedarf der Milchkuh. Die Ergebnisse der Futter- und Umweltbewertung ergab, dass die durchschnittliche tägliche Energie-korrigierte Milchmenge (ECM) bei 19 kg/d und zwischen 11 und 27 kg lag. Rationsauswertungen ergaben, dass im Mittel von allen Betrieben die ME-Aufnahme 184 MJ/d betrug. Die ME-Aufnahme lag im Bereich zwischen 115 und 225 MJ/d bei Kühen von niedriger bis hoher Leistung. Die RUCP-Aufnahmen waren in sechs Betrieben um 19 und 137 g/d niedriger als die Bedarfsanforderungen. In zwei Betrieben waren die RUCP-Aufnahmen höher als die Bedarfsanforderungen (32 und 93 g/d). Die P-Aufnahme lag mit 3 bis 30 g/d über den Anforderungen (mittleres Überangebot 19 g/d). Die Stickstoff-Effizienz (Milch N/ Aufnahme N) variierte zwischen 19% bei Kühen mit niedrigen Leistungen und 28% bei Kühen mit hohen Leistungen. Die durchschnittliche Stickstoff-Effizienz in allen Betrieben lag bei 24%. Die gesamten Emissionen lagen zwischen 0.90 und 1.80 kg CO₂ eq. /kg ECM. Das CH₄-Gas aus Verdauungsvorgängen und Gülle erbrachte den höchsten Anteil an CO₂ eq. Emissionen (52%). Die indirekten Emissionen von N₂O- und CO₂-Gasen betrugen zusammen 28% der Gesamt-CO₂ eq. Emissionen. Die Emissionen pro Kuh wurden deutlich von der Höhe der Milchproduktion ($r^2 = 0.93$) und die Höhe der eDMI ($r^2 = 0.88$) bestimmt, während die Gesamtemissionen nicht durch die Rationszusammensetzung beeinflusst wurde. Milchkuhe mit niedriger Leistung wiesen eine um 0.90 kg CO₂ eq./kg ECM höhere Emission auf. Die Status-Quo-Analyse von drei typischen landwirtschaftlichen Betrieben zeigte, dass die Kosten für die Milchproduktion in kleinen Betrieben um 21% niedriger als in großen Betrieben ausfiel. Modellierung alternativer Fütterungsszenarien zeigten, dass die Kosten der Milcherzeugung in größeren Betriebstypen um

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6 US-\$ / 100 kg ECM durch der Anwendung des DL-Szenario im Vergleich zur aktuellen Situation reduziert werden können. Bei der Anwendung des DL-Szenarios (hohe Aufnahme von Nebenprodukte der Lebensmittelindustrie in der Ration) wurden auch die GHG-Emissionen (in CO₂ eq.) um 15% durch niedrigere Kraftfuttermengen reduziert.

Eine Verringerung der CO₂ eq. Emission um 70 bis 290 g/kg ECM ist daher möglich.

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