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FULL LENGTH ARTICLE

Comparing methane emissions from different sheep-keeping systems in semiarid regions: A case study of Syria

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Abstract Sheep husbandry represents a significant source of methane (CH_4) in semiarid grassland regions such as Syria. However, the contribution of sheep to CH_4 emissions in Syria is still unknown. This study was designed to quantify CH_4 emissions and identify possible mitigation strategies for their reduction. Methodology developed by the Intergovernmental Panel on Climate Change (IPCC) was used to estimate CH_4 emissions. A survey was conducted on 64 farms from different locations in Syria in 2009. Data were collected concerning sheep-keeping systems (SKSs), body mass, milk and wool yield, farm locations, feed rations, periods of grazing on the Steppe, the duration of pasturing on agricultural residuals and time periods when sheep were kept in stables. Using a linear statistical model, the influence of SKS, geographical region and sheep body mass on emitted CH_4 were analysed. The results showed that the geographical region, SKS and sheep body mass had significant effects ($P < 0.05$) on CH_4 emissions. According to the model, the mean values of estimated CH_4 emissions from extensive, semi-intensive and intensive SKSs were 26 ± 0.9, 22.5 ± 1.3 and 13.5 ± 1.7 kg/sheep year, respectively. In comparing differences between the least square means of CH_4 emissions, the extensive and semi-intensive SKSs produced 92% and 66% higher CH_4 emissions compared to intensive SKS. The differences in CH_4 emissions within the distinct SKSs were attributed to dietary composition. Extensive SKS used a less concentrated

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feeding regime (98 ± 17 day/year) than semi-intensive SKS (114 ± 47 day/year), and intensive SKS employed concentrated feeding year round. Furthermore, it was observed that sheep with the same body mass produced higher CH_4 emissions in extensive SKS than in semi-intensive and intensive SKSs. Moreover, the semi-intensive SKS occupied more natural pastures than extensive SKS, which caused an overuse of the Steppe. Therefore, an effective mitigation strategy involves the use of more digestible feed, which would be accomplished by increasing the quantity of concentrated feed. Owing to unfavourable farming conditions, low-cost nonconventional feeds such as the residuals of wheat and cotton should be used to improve sheep management practices to reduce Steppe overgrazing in the extensive and semi-intensive SKSs of Syria and other semiarid areas.

1. Introduction

The rangelands of the Arabian Steppe, which amount to half of Syria's land mass, are the main source of feed for domestic livestock, especially sheep and goats. In Syria, as in many other semiarid landscapes, rearing small ruminants is often the only possible enterprise for sedentary and nomadic populations because of the relatively unfavourable climatic conditions (Rahman, 2008). The Steppe is possible only to use as fed source for sheep husbandry. Ruminant livestock accounts for 35–40% of global anthropogenic methane (CH_4) emissions, which result from enteric fermentation and manure (Steinfeld et al., 2006). Methane is a potent greenhouse gas (GHG) with a global warming potential that is 25 times that of CO_2 on the basis of weight (Solomon et al., 2007).

Syrian flocks are mainly composed of multipurpose (milk, meat, and wool) Awassi sheep, a hardy, fat-tailed breed that is well adapted to local climatic conditions (Shomo et al., 2010). Sheep-keeping systems (SKSs) in Syria were classified as extensive, semi-intensive and intensive (Cummins, 2000). Extensive SKS are characterised by long-distance movement for grazing the rangeland of the Steppe. In addition to grazing, sheep are provided with concentrate feed within the semi-intensive SKS. The main purpose of intensive SKS is lamb fattening, where concentrate feed is mainly used. The major feeds in Syria are barley, maize, and cotton seed cake (Cummins, 2000). In 2005, sheep comprised approximately 75% of the meat and 25% of the milk supply in Syria (ACSAD, 2005). An increasing demand for these livestock products has resulted in higher flock sizes and rising CH_4 emissions (Aw-Hassen et al., 2008), while crop development has primarily occurred on marginal lands with low rainfall (Louhaichi et al., 2009). These practices have led to lower grain production for human consumption, animal feed deficits and the overgrazing-induced degradation of Steppe rangelands (Salkini et al., 2008). With respect to CH_4 emissions, Aluwong et al. (2011) reported considerable variation in values per tropical livestock unit (TLU, 250 kg body weight), between 21 and 40 kg of CH_4 per TLU per year. An enteric CH_4 emission represents an economic loss to the farmer in which feed is converted into CH_4 rather than into product output (Pelchen and Peters, 1998). Thus, improved productive efficiency in sheep husbandry should be achieved by changing feed utilisation and dietary supplements (Aluwong et al., 2011; Waghorn and Hegarty, 2011). Several CH_4 mitigation options for ruminants are summarised in a review by Martin et al. (2010) in which one option is breeding animals with lower enteric CH_4 emissions (Pinares-Patiño et al., 2011). Furthermore, various authors have indicated that using best management practices could significantly reduce CH_4 emissions per animal (Wiedemann Hartwell et al., 2010; Sejian et al., 2011). The level of CH_4 emission from enteric fermentation can be reduced by increasing dry matter intake in the form of high-grain feed, good quality forage and a carefully tailored roughage-to-concentrate ratio (Sejian et al., 2011; Zervas and Tsiplakou, 2012). Additionally, Grainger et al. (2008) reported that whole cottonseed appears to be a promising dietary supplement for CH_4 emission mitigation. However, grain needs for human consumption and the resulting competition with concentrate feed grain production should be considered.

The aim of this study was to compare different Syrian SKSs and their respective enteric CH_4 emission factors (EF) kg CH_4/sheep year, the difference of EF is because of the different GE intakes in each SKS which change according to animal needs. To estimate the CH_4 emissions it was applied recommendations from the Intergovernmental Panel on Climate Change (IPCC, 2006) (Tier 2) to specific farm management data that were obtained from a regional survey of 64 farms. Understanding the relationships between the sheep diets of different SKSs to enteric CH_4 production is essential for identifying viable reduction strategies. Moreover, it is important to produce definitive advice for enhancing rangeland management and minimising negative environmental impacts. Following these conclusions will make it possible to optimise land use and to balance the needs of humans and animals.

2. Materials and methods

2.1. Site description

This study was conducted at various farms across Syria (Fig. 1). The Syrian Ministry for Agriculture and Agrarian Reform (MAAR) divided Syria into five settlement zones according to agricultural activities and the amount of annual precipitation. The sizes of the five zones, along with their respective amounts of precipitation, are as follows: (1) 27,036 km^2: 350 mm/year; (2) 24,628 km^2: 250–350 mm/year; (3) 13,147 km^2: 250 mm/year; (4) 18,332 km^2: 200–250 mm/year; and (5) 102,034 km^2: 100–150 mm/year (MAAR, 2009). Settlement zone 5 is defined as the Steppe, which is located in the eastern part of Syria, represents 55% of the national territory and is the main region for sheep production. Zones 1 and 2 are wheat production areas, whereas barley is the dominant crop in zones 3 and 4 (Shomo et al., 2010). A total of 64 farms with different SKSs were surveyed in various Syrian governorates, and they are each marked with a sheep in Fig. 1. These farms were located within the governorates of

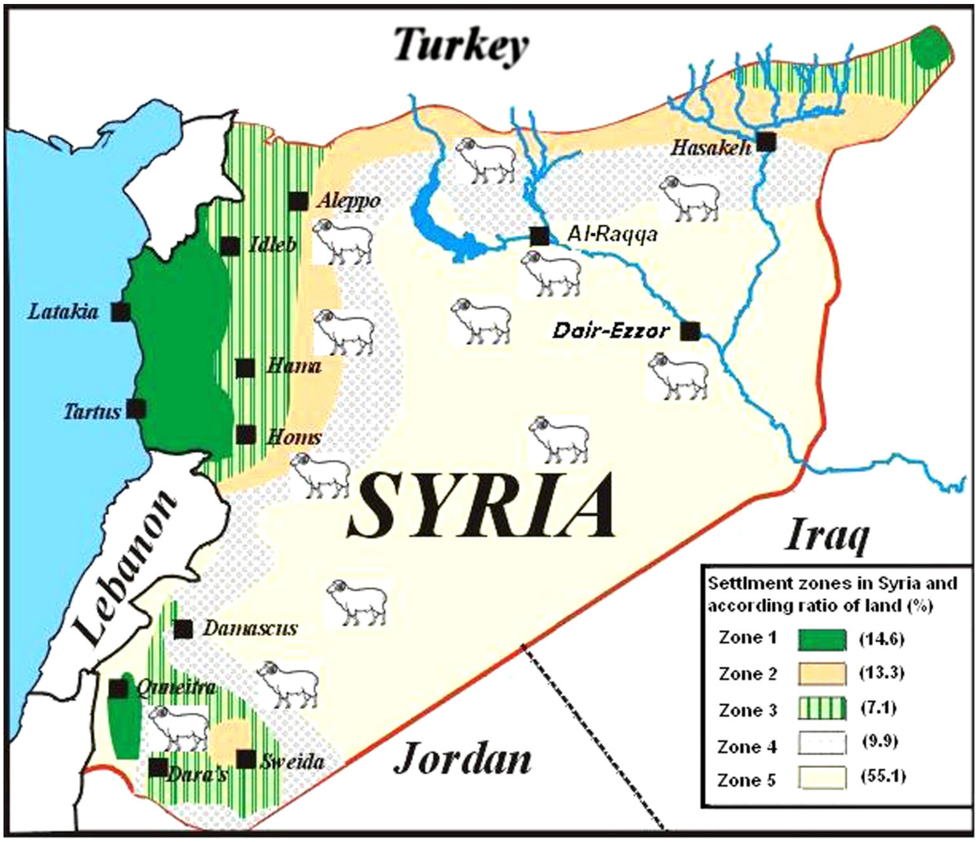

Figure 1 Map of Syria with settlement zones and marked regions (sheep) where farm data were collected (modified after MAAR, 2009).

Aleppo and Idleb in the north; Damascus, Sweida, Daraa and Quneitra in the south; Al-Raqqa, Hasakeh and Dair Ezzor in the east; and Homs and Hama in the west.

2.2. Data enquiry

Data from 64 farms with different SKSs are collected from September to November of 2009. The specific number of farms in each SKS is shown in Table 1. The best method for gathering animal performance data was to prepare a custom questionnaire that collected information on sheep production, including the number of animals, their body mass, milk and wool yield. Furthermore, general information about the SKSs and farm locations were recorded, including yearly feed rations, period of time spent grazing on Steppe rangeland, duration of pasturing on agricultural residuals and periods of time when sheep were kept in stables.

2.3. Feed composition within SKS

The SKSs in Syria differed according to the yearly amount of feed that is given to sheep during the time they are kept in stables, the type of stables, land use and grazing management. Depending on the aforementioned differences, the SKSs in this study are categorised into three groups: extensive, semi-intensive and intensive, according to Cummins (2000). Concentrate feed is mainly a mix of barely, wheat, corn and soya. They are bought from the Syrian Public Institution for feed. The feed composition used in each SKS is summarised in Table 1.

2.3.1. The extensive SKS

The extensive SKS is characterised by grazing through migratory movement on the Steppe. Herds graze natural pasture during the spring and move to crop areas after the harvest to graze crop stubble (residual cotton and wheat). This is considered to be the most common form of SKS in Syria and has been used by the Bedouins for ages. There is no closed stable in the extensive SKS except a tent that is installed in a place near the grass. By roaming the Steppe and looking for grass, the Bedouins take part in a pasture circulatory system, in which the herds are brought at regular intervals from the east to the west and the other way around.

Table 1 Number of farms and summary of feed composition used in SKSs during a year.

SKS	Number of farms	Concentrate feed	Rangelands of the Steppe	Cotton residual	Wheat residual
		Months	Months	Months	Months
Extensive	46	2–5	4–9	1	1–4
Semi-intensive	16	2–7	4–10	–	1–4
Intensive	2	12	–	–	–

2.3.2. The semi-intensive SKS

Within the semi-intensive SKS, there is also rangeland grazing, and producers provide their sheep with concentrate feed at locations near settlements. The sheep are kept in small herds in closed stables. They are intended mainly for home consumption and to generate additional income.

2.3.3. The intensive SKS

In this system, sheep are kept in closed stables and provided with concentrate feed (up to 85% of their diet) for more than 10 months of the year. The intensive SKS is found in semi-urban areas or areas near main urban centres, and they target both local and export markets. The main purpose of intensive SKS is lamb fattening, which is performed between two and four times during the year. The intensive SKS is rare in Syria. Most farms work with extensive or semi-intensive keeping-systems. Therefore, during the data collection it is surveyed only two intensive farms. Both of them were research centres, and they were associated with the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) and Damascus University.

2.4. Estimation of enteric CH_4 emissions

The animal performance data in the questionnaire (input data) are used to estimate Tier 2 CH_4 emission factors from enteric fermentation for sheep in different SKSs according to the approach of the IPCC (2006), as shown in Fig. 2. This process included the following four steps: (1) calculation of net energy (NE) requirements (maintenance, lactation, pregnancy and growth) which was calculated according of input data in each farm; (2) conversion of NE into gross energy requirements (GE) which presented in Eq. (1) is the amount of energy (MJ/day) an animal needs to perform activities such as growth, lactation, and pregnancy; (3) calculation of CH_4 energy output that is expressed as a proportion of GE intake; and (4) calculation of CH_4 energy lost to CH_4 emission according to GE and Methane conversion factor (Y_m), percent of GE in feed converted into CH_4 as presented in Eq. (2).

GE requirement is derived based on the summed net energy requirements and the energy availability characteristics of the feed (Fig. 2), are estimated using the following Eq. (1) (IPCC, 2006):

$$GE = \left[\frac{\left(\frac{NEm+NEa+NEl+NEp}{REM}\right) + \left(\frac{NEg+NEwool}{REG}\right)}{\frac{DE\%}{100}} \right] \quad (1)$$

where GE, Gross energy, MJ/day; NE_m, Net energy required by the animal for maintenance, MJ/day; NE_a, Net energy for animal activity, MJ/day; NE_l, Net energy for lactation, MJ/day; NE_{work}, Net energy for work, MJ/day; NE_p, Net energy required for pregnancy, MJ/day; REM, Ratio of net energy available in a diet for maintenance to digestible energy consumed; NE_g, Net energy needed for growth, MJ/day; NE_{wool}, Net energy required to produce a year of wool, MJ/day; REG, Ratio of net energy available for growth in a diet to digestible energy consumed; $DE\%$, Digestible energy expressed as a percentage of gross energy.

Emission factor is estimated using the following Eq. (2) (IPCC, 2006).

$$\mathrm{EF} = \frac{GE \times \left(\frac{Ym}{100}\right) \times 365}{55.65} \quad (2)$$

where EF, Emission factor, kg CH_4/sheep year; GE, Gross energy intake, MJ/sheep day; Y_m, Methane conversion factor, per cent of gross energy in feed converted into CH_4, according to IPCC, 2006 (6.5% ± 1.0%).

2.5. Statistical analysis

A statistical analysis was performed to evaluate the influence of the following factors on emitted CH_4 per sheep: SKS, region and body mass. Therefore, a linear model expressed in Eq. (3) was created. The main factors of SKS (a_i) and region (d_j) are tested.

$$E_{ijk} = \mu + a_i + d_j + f_k + wy + e_{ijk} \quad (3)$$

where E_{ijk} represents the calculated emissions of CH_4, μ signifies the general mean of CH_4 emissions, and a_i, and d_j account for the fixed effects of the SKS and the region, respectively. Furthermore, the random effects of each farm are expressed by f_k. The influence of the body mass of sheep (y in kg) is given

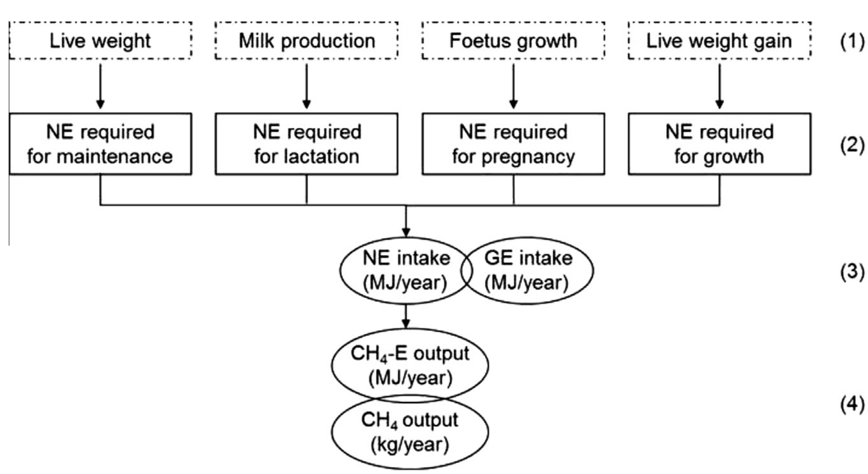

Figure 2 Flow chart presenting the calculation of enteric CH_4 emission factors for SKSs according to steps (1) through (4) from Tier 2 of the IPCC (2006) approach (modified after Aljaloud et al., 2011). The dotted and solid lines show the input and calculated data, respectively.

by the estimated covariable w, and e_{ijk} represents the independent normally distributed residual. This model was used to test the differences in emission data gathered from 64 farms at a significance level of $\alpha = 0.05$. The linear mixed model was applied using the MIXED procedure from SAS 9.2 statistical software (SAS, 2010). When testing differences between factor levels in pairwise t-tests, the SIMULATE option in the LSMEANS statement was used to adjust P-values for multiple testing to keep the global significance level. To some extent the number of sheep per farm will be covered by the random farm effect that is already included in the statistical model Eq. (3).

3. Results

3.1. Effects of SKS on CH_4 emission

The results of the linear model depicted in Eq. (3) showed that the types of SKS had significant effects ($P < 0.05$) on CH_4 emissions. The extensive and semi-intensive SKSs produced 92% and 66.2% higher CH_4 emissions than intensive SKS, respectively. The mean values of estimated CH_4 emissions from the linear model (Eq. (3)) in extensive, semi-intensive and intensive SKSs are presented in (Table 2). Table 3 presents the differences in the least squares means (LSM) of CH_4 emissions between different SKSs and clarifies that the CH_4 emissions of intensive SKS differed significantly ($P < 0.05$) from the extensive as well as the semi-intensive SKS. There is no significant difference ($P = 0.2$) between semi-intensive and extensive SKSs as shown in (Table 3).

Methane emissions varied greatly within the same SKS. The CH_4 emissions in extensive SKS varied from 15.9 to 31.9 kg/sheep year. In contrast, semi-intensive SKS ranged from 16.8 to 38.1 kg/sheep year, whereas the intensive SKS showed CH_4 emissions from 13.8 to 16.1 kg/sheep year (Fig. 3).

3.2. Effects of different feedstuff components on CH_4 emissions

Fig. 4 depicts the ranges of each SKS and their corresponding feedstuff components. The different of NE requirements in the SKSs drived to have different GE and EF. The result implied that for the extensive SKS, 1 kg of feed from Steppe rangelands, and from residuals of wheat and cotton produced 0.07, 0.08 and 0.06 kg CH_4/sheep day on average, respectively. In contrast, within the semi-intensive SKS, 1 kg of feed from the rangelands of the Steppe and from wheat residual produced 0.08 and 0.04 kg CH_4/sheep day on average, respectively. Concentrate feed from all SKSs (extensive, semi-intensive and intensive) resulted in CH_4 emissions of 0.04 kg/sheep day.

Table 2 Least squares means for CH_4 emissions in different SKSs.

SKS	Estimate (kg CH_4/sheep year)	Standard error	DF[a]	t Value	$Pr > \|t\|$
Extensive	26	0.94	42.8	27.47	< .0001
Semi-intensive	22.45	1.28	29.2	17.53	< .0001
Intensive	13.5	1.61	50	8.36	< .0001

[a] DF: degree of freedom.

3.3. Effects of different regions on CH_4 emissions

The results of Eq. (3) revealed that regions had a significant influence on CH_4 emissions ($P < 0.05$). This study showed that regions indirectly affect CH_4 emission as a result of their feedstuff components. The estimated CH_4 emissions from the region of Aleppo differed significantly in relation to Hassake, Homs and Sweida ($P < 0.05$). The LSM differences between Aleppo vs. Hassake, Aleppo vs. Homs and Aleppo vs. Sweida were 4.09 ± 1.05, 4.16 ± 1.07, and 5.52 ± 1.31 kg CH_4/sheep year, respectively the CH_4 emissions in each region were presented in (Table 4).

3.4. Effect of body mass on CH_4 emissions

The results of Eq. (3) revealed that body mass has a significant effect on CH_4 emissions ($P < 0.05$). Eq. (3) showed that each 1 kg of body mass increased CH_4 emission to 0.5 ± 0.05 kg/sheep year (Fig. 5). In each SKS, the CH_4 emissions grew as a consequence of increasing body mass. Fig. 5 showed that CH_4 emissions in the intensive SKS were lower than the other two SKSs, but the body mass was higher during the same time.

4. Discussion

4.1. Different SKSs and feedstuff components in relation to CH_4 emissions

This study builds on IPCC methodology Tier 2. Calculating CH_4 emissions from sheep using the IPCC methodology depends on the energy loss via CH_4 (Y_m) and gross energy intake in MJ/sheep year. In this study, the Y_m was 6.5 ± 1.0% (IPCC, 2006). However, the exact Y_m for the calculations in Syria is unknown and should be measured for more accurate results. Murray et al. (1978), Kempton and Leng (1979) and Johnson (1992) reported that energy loss via CH_4 emission ranged between 3.5% and 9.7%. Pelchen and Peters (1998) found that Y_m averaged 7.2%.

The CH_4 emissions that are associated with keeping sheep in extensive, semi-intensive and intensive SKS were 26 ± 0.9,

Table 3 Differences in LSM of CH_4 emissions between different SKSs.

Differences of LSM between SKS	Estimate (kg CH_4/sheep year)	Standard error	DF[a]	t Value	Adj P
Extensive vs. semi-intensive	3.54	2.01	38.6	1.76	0.2020
Extensive vs. intensive	12.49	2.23	50	5.59	< 0.0001
Semi-intensive vs. intensive	8.95	1.55	48.7	5.79	< 0.0001

[a] DF: degree of freedom.

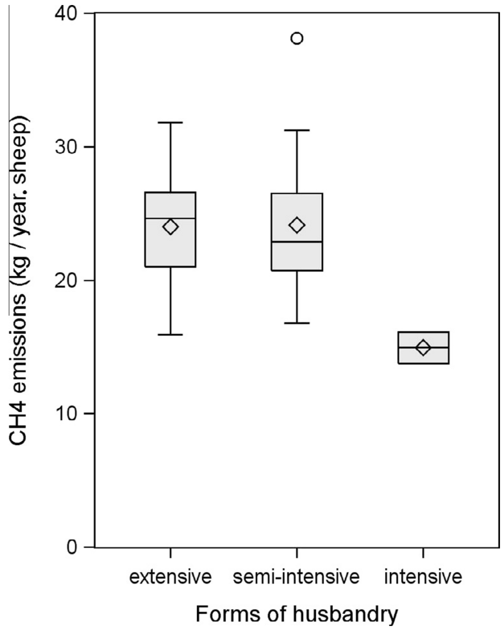

Figure 3 Box-and-whisker plot* of CH_4 emissions within the different SKSs. *Definition of box-and-whisker plot: (bottom: 25th percentile; top: 75th percentile; middle: 50th percentile median; diamond: mean value).

22.5 ± 1.3 and 13.5 ± 1.7 kg/sheep year, respectively. Other published studies showed that CH_4 emissions were 7.4 kg/sheep year (Dengel et al., 2011); 22.1 g/sheep day = 7.9 kg/sheep year (Pelchen and Peters, 1998); 21.8 g/sheep day = 7.8 kg/sheep year when the sheep fed on corn; 38.3 g/sheep day = 13.8 kg/sheep year when the sheep fed on barley (Yurtseven and Öztürk, 2009); 22.7 g/sheep day from grass, and 18.6 g/sheep day from feed pellets (Pinares-Patiño et al., 2011). Emissions of CH_4 from sheep in developed countries were 21.9 g/sheep day = 7.8 kg/sheep year; in developing countries, there were 13.7 g/sheep day = 4.9 kg/sheep year (Sejian et al., 2011).

The CH_4 emissions in this study were higher than other published studies, which could be explained by the default IPCC value of Y_m which was used to calculate CH_4 emissions.

The extensive SKS caused greater CH_4 emissions compared to semi-intensive and intensive SKSs (Table 2). The CH_4 difference from the extensive SKS was attributed to the varying components of the sheep diets. Extensive SKS used less concentrate feed with 98 ± 17 day/year compared to semi-intensive SKS with 114 ± 47 day/year and intensive SKS, which used concentrate feed year-round. This finding is consistent with the results of other authors (Yurtseven et al., 2009; Yurtseven and Öztürk, 2009) who found that Awassi ewes that consumed a diet containing a lower concentrate feed ration produced more CH_4 per sheep than the ewes that ate a diet containing more concentrate rations. Using more concentrate feed in the SKSs produced lower CH_4 emissions (Rowlinson, 2008). Sejian et al. (2011) found that ruminant CH_4 emissions differed among developed and developing countries, depending on factors such as dietary composition and amounts of concentrate feed, which agrees with our result showing that a diet with a lower concentrate feed ration produced more CH_4 emissions.

Not all sheep studies showed decreasing CH_4 emissions with greater amounts of concentrate feed within the diet. Moss and Givens (2002) noticed that the amount of energy lost as CH_4 emissions increased when there was a decreasing proportion of soya beans in the grass silage. The difference in CH_4 emissions from the same feed combination in a different SKS (Fig. 4) could be explained by different consumptions by the sheep on each farm.

Low CH_4 emissions from concentrate feed could be explained by its higher digestibility relative to other feeds. This

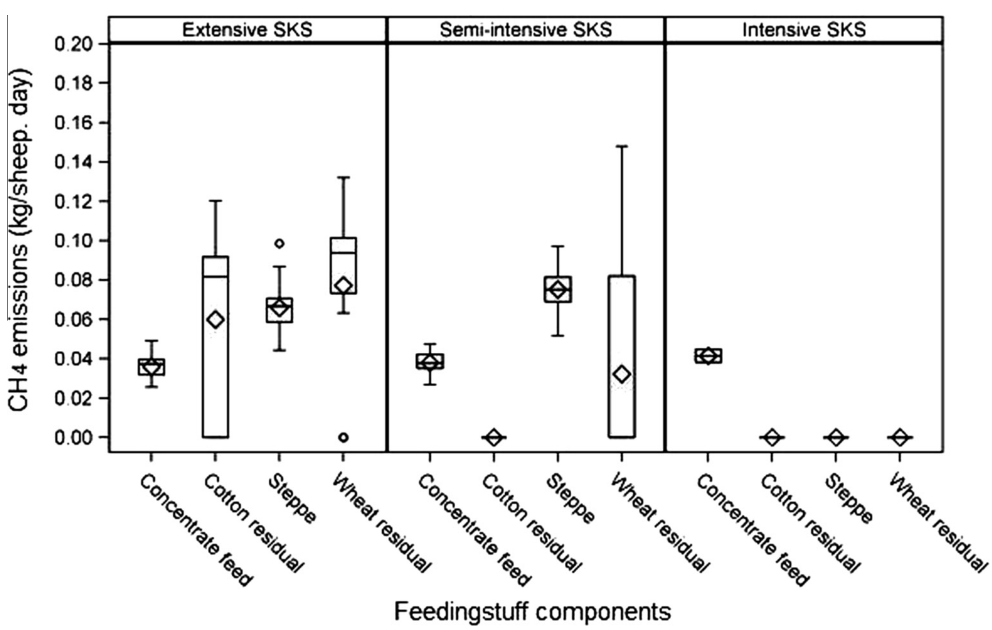

Figure 4 Box-and-whisker plot* of CH_4 emissions from sheep that are supplied with different feedstuff components within the SKSs. *Definition of box-and-whisker plot: (bottom: 25th percentile; top: 75th percentile; middle: 50th percentile median; diamond: mean value).

Table 4 Least squares means for CH_4 emissions in different regions.

Region	Estimate (kg CH_4/sheep year)	Standard error	DF[a]	*t* Value	$Pr > \|t\|$
Aleppo	23	1.54	50	14.84	< .0001
Damascus	18.7	0.83	50	22.49	< .0001
Daraa	18.7	1.55	50	12.02	< .0001
Dair Ezzor	20	1.41	50	14.19	< .0001
Idleb	23.1	2.04	12.2	11.35	< .0001
Hama	28.8	3.28	11.2	8.76	< .0001
Hasakeh	18.8	1.42	50	13.25	< .0001
Homs	18.8	1.43	50	13.09	< .0001
Quneitra	17.9	2.02	11.9	8.90	< .0001
Al-Raqqa	22.1	1.71	50	12.91	< .0001
Sweida	17.4	1.6	50	10.90	< .0001

[a] DF: degree of freedom.

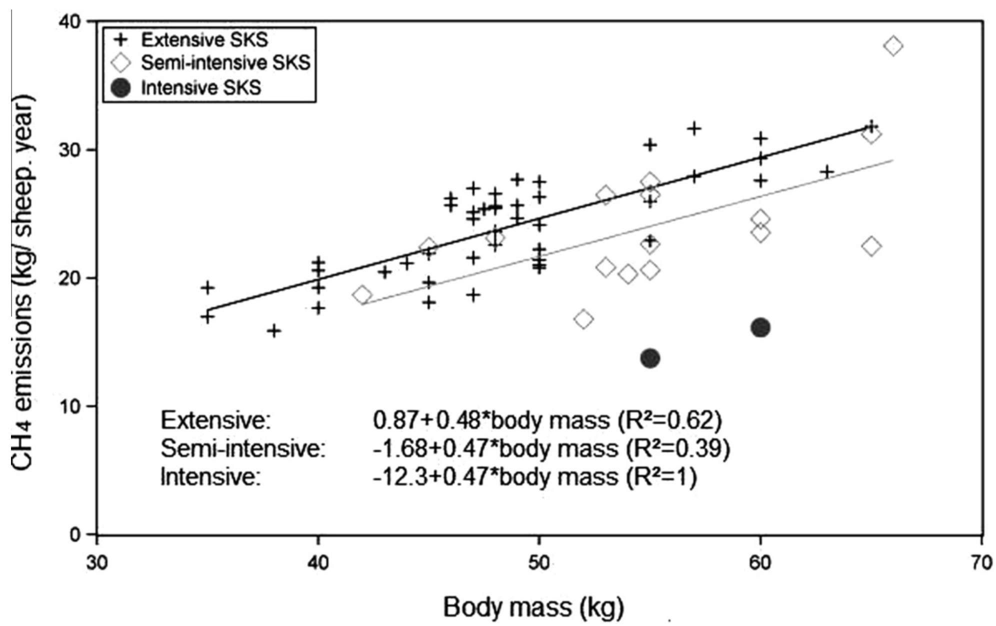

Figure 5 Body mass effect on CH_4 emissions in different SKSs.

finding agreed with Waghorn et al. (2002), Hammond et al. (2011), who reported that high digestibility contributes to low CH_4 emissions. The descending orders of digestibility of the different feedstuff components are as follows: soya with 84%; barley with 76%, cotton seed cake with 73%, corn with 71%, wheat shells with 65%, rangeland of the Steppe with 50%, cotton residuals with 45% and wheat residual with 44% (ACSAD, 2008). Pinares-Patiño et al. (2003), Hart et al. (2009) and Yan et al. (2010) stated that there is a consensus about the association of increased feed intake and reduced CH_4 yield (g/kg dry matter intake) that could be supported by the results of this study when the feed has high digestibility, as with soya and barley.

4.2. Regional effect on CH_4 emissions

The 64 surveyed farms are located in 11 different regions. Overall, the eastern parts of Syria experienced less precipitation (90–140 mm/year). The Hama region had the highest CH_4 emissions in Syria with 28.8 ± 3.3 kg/sheep year (Table 4). This finding can be explained by the lower amount of concentrate feed that was used in this area. In the Hama area, concentrate feed was used for only two months of the year.

In the Aleppo region, significantly higher CH_4 emissions were produced compared to the regions of Hassake, Homs and Sweida (Table 4). This increase might be a result of the lower weight gain of sheep in Aleppo between birth and one year of age.

The different regions of Syria vary by air temperature and precipitation. Ruminants increase their intake of concentrate feed and reduce their intake of roughage to minimise the heat increment in their bodies under high environmental air temperature when concentrate feed and roughage are freely available (Yurtseven and Görgülü, 2004, 2007).

It is demonstrated in (ACSAD, 2008) that the digestibility of soya at 84%, barley at 76%, and cotton seed cake at 73% w higher than the different feedstuff components (cotton residual, wheat residual and rangelands of the Steppe). Feed digestibility for sheep living on farms in all regions should be improved by using feed with high digestibility and low cost.

In this study cotton seed cake which is highly digestible at 73% and inexpensive had reduced CH_4 emissions, so it could be used to mitigate the CH_4 emissions. This suggestion agreed with the results of Grainger et al. (2008), who reported that whole cotton seed cake appears to be a promising dietary supplement in CH_4 emission mitigation. Alternatively, soya could also be used as an additional feed, which improves digestibility by reducing CH_4 emissions. This suggestion did not represent a viable strategy because it was an expensive feed under relatively unfavourable conditions of the human populations.

4.3. Effect of body mass on CH_4 emissions

The CH_4 emissions were greater with increased live weights ($P < 0.05$) (Fig. 5). This can be explained by an increased feed intake caused by growing body mass. This finding agreed with Pelchen and Peters (1998), who found that CH_4 emissions increased ($P < 0.05$) with increasing live weights. It is clearly shown in Fig. 5 that sheep with the same body mass in extensive SKS produced higher CH_4 emissions compared to the semi-intensive and intensive SKSs. This could be explained by the feedstuff components from each SKS. It is possible to produce sheep with high body mass and lower CH_4 emissions when the feedstuff components have a high digestibility.

4.4. Mitigation strategies to reduce CH_4 production

Lowering CH_4 emissions is important for the reduction of anthropogenic GHG emissions (Buddle et al., 2011). Any reduction strategy must fit a general framework that included factors such as the development priority, product demand, infrastructure, livestock resources and local resources.

Increasing concentrate feed could be considered an accessible strategy for mitigating CH_4 emissions. Adding more components such as soya, corn and barley to existing concentrate feed should reduce CH_4 emissions. Any increase of concentrate feed should be directed to the Bedouins because most of them earn low incomes and therefore try to obtain inexpensive feed for their sheep. To enhance rangeland management, farmers should use available nonconventional feedstuff such as cotton seed cake and integrate it into sheep diets. Hilali et al. (2011) found that using cotton seed cake could reduce feed costs and CH_4 emissions, which supports the results in this study.

The semi-intensive SKS in terms of time depends more on rangeland of the Steppe than extensive SKS (Table 1), which caused an overuse of the Steppe. Alternative use of residuals from wheat, cotton and soya as feeds will help to improve sheep management practices in the extensive and semi-intensive SKSs.

5. Conclusions

Emissions of CH_4 from sheep enteric fermentation in Syria are calculated using the Tier 2 default CH_4 emission factors of the IPCC (2006). The findings in this study could be used in many countries in semiarid zones with climates similar to those of Syria. The varying components of sheep diets have been identified as a reason for CH_4 emission differences among the different SKSs. Higher feed ration digestibility would lead to less overall CH_4 emissions. It was possible to produce sheep with high body masses and lower CH_4 emissions when the feedstuff components are highly digestible. The results of this study suggested that cotton seed cake was one example of an affordable solution. The overuse of the Steppe could be reduced by including the alternative use of wheat and cotton residuals in the extensive and semi-intensive SKSs.

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