Journal of Agriculture and Environment for International Development - JAEID 2017, 111 (1): 225-243
DOI: 10.12895/jaeid.20171.606

Productive, economic and environmental effects of optimised feeding strategies in small-scale dairy farms in the Highlands of Mexico

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Submitted on 2017, 15 March; accepted on 2017, 15 May. Section: Research Paper

Abstract: Since most dairy production in developing countries comes from small farms, there is scope to reduce their contribution to greenhouse gas (GHG) emissions. In the highlands of Mexico, the limitations in these systems are high feeding costs. This paper assessed the production, economics and estimated methane emissions from traditional feeding strategies (TFS) in 22 small-scale dairy farms compared to optimised feeding strategies (OFS) evaluated through on-farm research in eight participating farms in ~~the~~ dry (DS) and rainy (RS) seasons. Results were analysed with a completely randomized design. There were no differences (P>0.05) in milk fat, body condition score (BCS) or live weight between TFS and OFS, but there was higher (P<0.05) milk yield (17.99 vs 14.01 kg/cow/d), energy corrected milk (ECM) (16.77 vs 12.93 kg/cow/d) and milk protein (32.1 vs 30.9 g/kg milk) in OFS than TFS. Profit margin/cow/day was higher (P<0.05) (US$4.42 vs US$2.74) with a lower (P<0.05) feeding cost (US$0.18 vs US$0.22/kg) in OFS than TFS. Environmentally, the calculated enteric CH_4 emission intensities were lower (P<0.05) in OFS (19.8 g CH_4/kg milk) than TFS (25.3 g CH_4/kg milk). Optimized feeding strategies in small-scale dairy farms increase milk yields, reduce feeding costs, increase incomes, and reduce enteric CH_4 emission per kg of milk.

Keywords: *Small-scale dairy systems; feeding strategies; milk yields; feeding costs; enteric CH_4 emissions.*

Introduction

Small-scale dairy systems are an option for rural development and the amelioration of poverty (FAO, 2010a). In the highlands of central Mexico, they enable farming families to overcome poverty indices (Espinoza-Ortega *et al.,* 2007); and overall these systems represent over 78% of specialised dairy farms (Pincay-Figueroa *et al.,* 2016), and contribute around 37% of the national milk supply (Hemme *et al.,* 2007).

These systems are small farms with herds between 3 and 35 milking cows plus replacements that rely on family labour for running the farm and are linked to local markets (Fadul-Pacheco *et al.,* 2013).

The assessment of the sustainability of these small-scale dairy farms that manage traditional feeding strategies (TFS) in the highlands of central Mexico showed a high dependence of external bought-in inputs like commercial concentrates (Fadul-Pacheco *et al.*, 2013; Martínez-García *et al.,* 2015).

High costs are also due to the fact that farmers do not make use of home-grown feed resources when quality is better, like pastures and cereals, whether in terms of grain, fresh herbage, or as conserved forage (silage) for the dry season when they tend to rely on low quality straws (Alfonso-Ávila *et al.,* 2012; Martínez-García *et al.*, 2015).

Environmentally, global dairy production, including replacements, contributes to 4% of greenhouse gases from human origin (FAO, 2010a), and within the agricultural sector, cattle are responsible for 40% of greenhouse gas (GHG) emissions mostly in the form of enteric methane (FAO 2014).

Small-scale dairy systems are the majority in developing countries as in Mexico, and are an option to ameliorate rural poverty and enhance food security (FAO 2010b); representing as well an opportunity and a need to reduce the emission of GHG.

The importance of ruminant production both in contributing to the farming systems and communities development, and their role in reducing enteric methane (CH_4) production is highlighted by the project *"Reducing Enteric Methane for improving food security and livelihoods"* launched by FAO. It is a global initiative implemented in countries of four regions (South America, East and West Africa, and South Asia), with the aim to "*identify system specific technologies and interventions to increase ruminant productivity and reduce the emissions intensity of enteric methane*" (FAO, 2017).

The FAO project recognizes the higher intensity of enteric CH_4 emissions (emissions per unit of product) in livestock systems in developing countries, coupled to the need to improve the productivity and efficiency of these systems as a key to improve rural livelihoods. The project proposes to identify areas of high potential for intervention, in order to implement cost effective technologies that improve productivity that translate into better livelihoods for farmers and reduce GHG emissions (FAO, 2017).

Small-scale dairy systems in the highlands of central Mexico therefore face the need to reduce feeding costs to improve productivity and their profitability for better livelihoods and thus enhance their sustainability; and to reduce the intensity of GHG emissions.

One way to meet these challenges is by optimising feeding strategies (OFS) making better and more efficient use of the available feed resources on the farm, thus reducing the dependence on external inputs by improving the quality of home-grown forage (Martínez-García *et al.,* 2015).

The objective of the work herein reported was to evaluate the effect of optimised feeding strategies (OFS) in comparison to traditional feeding strategies (TFS) in small-scale dairy systems of the highlands of central Mexico. The analysis was in variables of productive performance (milk yields and milk protein and fat contents), economic terms (feeding costs and returns from the sale of milk), and in environmental terms by means of the estimation of enteric CH_4 emissions.

Material and methods

The work undertook a comparative comprehensive analysis of data from work of on-going projects on the assessment of the sustainability of small-scale dairy systems in the central highlands of Mexico that includes the identification and appraisal of traditional feeding strategies and the development and evaluation through on-farm research of optimised feeding strategies.

Alfonso-Ávila *et al. (*2012) for the dry season and Martínez-García *et al. (*2015) for the rainy season have published some results on the identification and analysis of traditional feeding strategies, identifying four main feeding strategies for each season, resulting in eight strategies for the whole year.

The analysis for optimised feeding strategies draws on data from the work by and Pincay-Figueroa *et al. (*2016) and Jaimez-García *et al. (*in press*)*, who evaluated two feeding strategies in each experiment (four strategies) during the dry season.

Pincay-Figueroa *et al.* (2016) compared cut-and-carry pasture against intensive grazing of pastures, complemented with maize silage and concentrates. Jaimez-García *et al. (*in press) compared maize silage as only source of forage plus a high protein home-made concentrate, against intensive grazing complemented with maize silage and commercial compound concentrate.

Velarde-Guillén *et al.* (2016) in the rainy season evaluated four feeding strategies combining cut-and-carry or intensive grazing of pastures, plus to supplementation treatments, commercial concentrates or ground maize grain.

Therefore, there were also eight optimized feeding strategies for the whole year. The eight TFS and eight OFS evaluated in the work herein reported are described in Tables 2 and 3.

In this analysis, the nutrient composition of diets was included as well as the calculations of methane emissions as new data generated for the analysis. Also hypothetical future scenarios with changes in the feeding costs and price of milk were analysed.

The analysis was comprehensive in the comparison of results from TFS and OFS in both the dry and the rainy season in terms of variables for productive performance, feeding costs and margins, and the calculated emission of methane as an important GHG. No estimation of methane emissions was done before in the works that preceded this current analysis.

Study area

The projects take place in the municipality of Aculco, in the northwest of the State of Mexico (that surrounds Mexico City), at an altitude of 2440 m and a sub-humid temperate climate with a mean temperature of 13.2 °C. There are two well defined seasons: the rainy season (RS) from May to October, and the dry season (DS) from November to April. Mean annual rainfall is around 800 mm.

The region is characterised by small-scale dairy farms, with herds between 3 and 35 cows plus replacements of up-graded Holstein breed. Average farm size is 6.5 ha (Alfonso-Ávila *et al.*, 2012). Cows are milked twice daily mostly by hand, and 80% of milk produced is sold for artisan cheese makers.

Model for optimised feeding strategies

The model developed by Castelán-Ortega *et al.* (2016) to optimise net income in small-scale dairy systems from central Mexico was utilised. The linear programming model is composed of four sub-models: output sale activities, forage crops and pasture production, fertilizer application, and diets for dairy cows and heifers.

In the present study, the fourth sub-model (diets for dairy cows and heifers) was modified and the equation for the estimation of methane emissions of Ellis *et al.* (2007) was incorporated as a restriction, in order to limit the use of ingredients that theoretically generate large amounts of methane during fermentation in the rumen.

Ingredients, feeding strategy and animal response

The analysis of the TFS was done from data collected from 22 small-scale dairy farms (Alfonso-Ávila *et al.*, 2012; Martínez-García *et al.*, 2015), grouped in four main strategies for the dry season and four for the rainy season, giving a total of eight feeding strategies for TFS. The analysis of OFS (in eight small-scale dairy farms) was done on data from Pincay-Figueroa *et al.* (2016) and Jaimez-García *et al.* (in press), in simultaneous on-farm experiments for the dry season (four feeding strategies), and from Velarde-Guillén *et al.* (2016) for the rainy season also evaluating four feeding strategies, totaling eight OFS.

OFS were evaluated through on-farm participatory experiments undertaken with eight small-scale dairy farmers. Data includes the feeds used and their chemical composition. The equations for Relative Feed Value (RFV) (Jeranyama and Garcia, 2004) were used to estimate dry matter (DM) digestibility and metabolisable energy content:

$$\%DMD=88.9-(0.779\times\%ADF)$$

$$ME=3.61\times DMD\times 4.184$$

Where: DMD= Dry matter digestibility; ADF= Acid detergent fibre; ME= Metabolisable energy (MJ/kg DM).

The classification of ingredients for TFS and OFS were pastures, conserved forages (hays and silages), straws, and supplements (concentrates). Collected data included milk yields (MY) and milk composition (protein and milk fat), as well as feeding costs. Energy corrected milk (ECM) was calculated using the equation proposed by Auldist *et al.* (2013; 2014): ECM (kg/cow/d)= milk yield (kg) x (376 x fat% + 209 x protein% + 948)/3,138 which corrects milk to an energy value of milk containing 4.0% milk fat and 3.3% milk protein.

Estimation of enteric methane

Enteric methane production was estimated with the following the equation from Ellis *et al.* (2007), since it is based on the proportion of forage in the diet. The objective of the OFS was to increase the proportion of quality forages in the feeding of milking cows:

$$eCH_4\ (MJ/d)=8.56+0.139*F$$

Where:
eCH_4 = Estimated methane production
F= Forage in the ration (%)

The methane conversion rate (MCR) was calculated as follows: MCR (%GE intake) = (CH_4 MJ/d * 100)/GE intake MJ/d, where GE is the gross energy intake in MJ /d (Castelán-Ortega *et al.*, 2014).

Feeding costs

Calculation of feeding costs and margins was from partial budgets as has been done in previous work (Alfonso-Ávila *et al.*, 2012; Martínez-García *et al.*, 2015). The feeding costs and prices of sold milk for TFS and OFS were deflated. The mean price of milk paid to farmers was US$0.42/kg. Feeding cost per kg of milk (FC) profit margin, and profit margin per day/cow (PMD) by season and feeding strategy were analysed.

Statistical analysis

As mentioned above, eight feeding strategies per season were evaluated, four traditional and four optimised strategies per season; resulting in a total of 16 evaluated feeding strategies over the whole year.

The four traditional feeding strategies per season and eight over the whole year were grouped as TFS. Samewise, the four optimized feeding strategies per season and eight over the whole year were grouped as OFS. Comparison was between TFS vs. OFS.

The four TFS in the dry season were (Martínez-García *et al.*, 2015): LFC = Low feeding cost, OR = Own resources, HFC = High feeding cost, BS = Based on straws. The four OFS for the dry season were (Pincay-Figueroa *et al.*, 2016): C = Based on cut and carry pasture, G = based on grazed pasture (plus maize silage and commercial concentrates, and (Jaimez-García *et al.*, in press): MS+SM+GM = maize silage + soyabean meal + ground maize, G+MS+CC = grazing + maize silage + commercial concentrate.

There were also four TFS in in the rainy season (Alfonso-Ávila *et al.*, 2012). Eighteen feedstuffs were grouped in: HNH feeds = high in neutral detergent fibre (NDF) and in DM, HNL feeds = high in NDF but low in DM, HCh feeds = high in non-fibrous carbohydrates, and HCP feeds = high in crude protein. The feeding strategies were: Strategy 1 (S1) uses HND, HNL and HCP, Strategy 2 (S2) uses HND, HNL, HCh and HCP, Strategy 3 (S3) is based on HNH and HCP, and Strategy 4 (S4) utilises HNL and HCh (Table 3).

The four OFS for the rainy season were (Velarde-Guillén et al, 2016): G+CC= grazing + oat hay + commercial concentrate, G+GM= grazing + oat hay + ground maize, C+CC= cut and carry pasture + oat hay + commercial concentrate, and C+GM= cut and carry pasture + oat hay + ground maize (Table 3).

Data were analysed as an unbalanced completely randomized design (Montgomery, 2001) to take into account 22 farms (observations) under TFS and 8 farms (observations) for OFS, comparing TFS against OFS, with the following analysis of variance model:

Y_i=μ+T_i+e

Where:

μ= Population mean;

T= effect of feeding strategies (TFS vs. OFS) per season and per year (i=1,2);

e= Experimental error.

Completely randomised designs are widely used in animal feeding experiments as reported by Grala *et al.* (2011) and Venderwerff *et al.* (2015).

In each feeding strategy, data from each farm were used in the statistical analysis that compared variables for TFS vs. OFS by season and over the whole year (Table 4). Stroup *et al.* (1993) mention the difficulties of undertaking participatory rural research on farm, and explain the valid use in the statistical analysis of farm data as single replicates.

Results

Ingredients and rations

Table 1 shows the ingredients used both in TFS as in OFS. Grazing and soybean meal are not used in TFS, but were included for the OFS. Table 2 and Table 3 show that OFS, in both seasons, do not include straws, prioritizing the use of quality forages (pastures and conserved forages) which represent up to 67% of diets over the whole year, 69% in the dry season (DS), and 65% in the rainy season (RS). In the dry season, conserved forages are more important, while cultivated pastures are more important during the rainy season.

Compared to this, quality forages in TFS only represent an average of 38% in diets (37% in DS and 38% in RS); whereas supplements represent 33% of diets both for TFS and OFS over the whole year.

Table 2 and Table 3 show the characteristics of TFS and OFS for DS and RS. In general, TFS contain 9.8% more crude protein (CP), but less DMD (8.5%) and ME (8.4%) than OFS. In relation to the proportion of forage in the diet, in both strategies, the proportion is above 60% in both seasons.

Forages comprise up to 70% of the rations in DS and 72% in RS for TFS, but pasture is used in TFS as cut and carry herbage and only constitutes 23% of the ration (32% of forage) in RS and 7% (10% of forage) in DS. Together with conserved forages, this means that quality forages in TFS only constitute 38% of the diet in DS, and 42% in RS. This results in low MY for both seasons for TFS (13.4 kg milk/cow/day in DS and 14.6 kg milk/cow/day in RS).

Forages in OFS constitute 71% of the ration in dry season and 64% in the rainy season, respectively. Quality forages constituted all of the forage provided in the dry season (with 13% represented by pasture and 87% conserved forage), and 64% in the rainy season (68% pasture and 32% conserved forage) which resulted in higher milk yields of 18.5 and 17.5 kg milk/cow/day for the dry and rainy seasons.

Milk yields, ECM, milk composition (protein and fat), live weight and body condition score are shown in Table 4.

Table 1 - Ingredients and chemical composition in traditional (TFS) and optimized feeding strategies (OFS).

Group	Ingredient	DM	Ash	CP	FND	FAD	DDM	eEM
Conserved: Hays and Silages	Alfalfa Silage (d and r)	410	120	164	404	253	69.19	10.45
	Maize Silage (d* and r)	339	70	68	541	197	73.56	11.11
	Alfalfa Hay (d and r)	880	110	170	504	306	65.06	9.83
	Oat Hay (d and r*)	867	84	61	564	314	64.43	9.73
	Chopped Maize Forage (r)	260	70	90	573	294	66.00	9.97
	Reeds (r)	280	80	103	686	403	57.51	8.69
	Weeds (r)	360	120	106	570	346	61.95	9.36
Straw	Oat Straw (d and r)	880	100	48	727	437	54.86	8.29
	Barley Straw (d)	880	95	42	740	460	53.07	8.02
	Maize straw (d and r)	860	80	61	706	401	57.66	8.71
	Sorghum straw (d and r)	820	100	56	682	369	60.15	9.09
	Wheat Straw (d)	826	90	107	574	278	67.22	10.15
	Ground Maize Straw (d)	849	107	60	738	509	49.25	7.44
Grass	Cut and Carry Pasture (d* and r*)	225	129	132	506	197	73.57	11.11
	Grazed Pasture (d* and r*)	203	131	209	458	166	75.94	11.47
Supplement	Soybean Hulls (r)	900	53	122	618	436	54.94	8.30
	Commercial Concentrate (d* and r*)	925	98	186	276	86	82.18	12.41
	Poultry Manure (r)	300	190	220	370	190	74.10	11.19
	Distillers Grains (r)	500	100	200	440	120	79.55	12.02
	Ground Maize (d* and r*)	910	34	83	207	39	85.87	12.97
	Rolled Maize (r)	900	18	107	293	35	86.17	13.02
	Maize bran (r)	470	94	193	474	127	79.01	11.93
	Soybean Meal (d*)	950	68	439	222	70	83.48	12.61
	Pears (r)	200	34	32	320	230	70.98	10.72
	Wheat Bran (r)	885	99	152	442	156	76.79	11.60
	Maize Bran (d)	873	103	106	491	214	72.20	10.90

d: ingredient used in the dry season; r: ingredient used in the rainy season; *: ingredients used in the optimized feeding strategy; DM: dry matter; CP: crude protein; NDF: Neutral detergent fibre; ADF: Acid detergent fibre; DDM: Digestibility of the dry matter; eME: Estimated Metabolisable energy (MJ/kg DM). Adapted from Alfonso-Ávila *et al.* (2012), Martínez-García *et al.* (2015), Pincay-Figueroa *et al.* (2016), Jaimez-García *et al.* (in press) and Velarde-Guillén *et al.* (2016).

Table 2 - Dry matter offered (kg/cow/day) and characteristics of feeding strategies during the dry season.

	Traditional				Optimized			
Ingredient (kg DM)	LFC	OR	HFC	BS	C	G	MS+SM+GM	G+MS+CC
Alfalfa Silage	0.30		0.08	0.57				
Maize Silage	0.45	1.32	0.99		6.40	6.40	14.29	10.39
Alfalfa Hay	0.26	0.98	4.33	0.20				
Oat Hay	0.11		0.26					
Pasture: Cut and carry	3.56	3.48	3.14	3.52	2.52			
Pasture: Grazing						0.74		1.00
Commercial Concentrate	3.01	4.12	4.11	3.46	4.80	4.80		4.85
Ground Maize	0.15	0.76		0.08			0.93	
Farm Mix	0.71	1.48						
Soyabean Meal							2.38	
Wheat Bran			0.52	0.34				
Oat Straw	0.28	0.46	0.06					
Barley Straw		0.36	0.21	0.83				
Wheat Straw	0.28	0.10						
Maize Straw		1.53	5.90	5.29				
Ground Maize Straw	2.37	0.70	0.76					
Sorghum Straw	0.63		0.12					
Total	12.11	15.29	20.48	14.29	13.72	11.94	17.59	16.24
% Forage	48.47	53.83	73.68	72.85	65.01	59.80	81.22	70.14
DM g/kg FM	443	534	615	558	371	401	482	490
CP g/kg DM	149	131	124	118	120	125	127	116
NDF g/kg DM	483	482	544	550	426	421	438	414
ADF g/kg DM	215	196	265	254	152	144	158	148
Digestibility g/kg DM	722	736	683	691	771	777	766	774
MJ/kg DM	10.90	11.12	10.31	10.44	11.64	11.73	11.57	11.69

Adapted from Martínez-García *et al.* (2015), Pincay-Figueroa *et al.* (2016) and Jaimez-García *et al.* (in press). LFC: Low feeding cost; OR: Own resources; HFC: High feeding cost; BS: Based on straws; C: Based on cut and carry pasture; G: based on grazed pasture; MS+SM+GM: maize silage + soyabean meal + ground maize; G+MS+CC: Grazing + maize silage + commercial concentrate; Farmer Mix: commercial concentrate, ground maize and wheat bran

Table 3 - Dry matter offered (kg/cow/day) and characteristics of feeding strategies during the rainy season.

	Traditional				Optimized			
Ingredient (kg DM)	S1	S2	S3	S4	G+CC	G+GM	C+CC	C+GM
HNH	3.24	3.23	8.83					
HNL	5.65	4.73		7.13				
HCh		0.96						
HCP	4.23	3.42	5.21	5.20				
Oat Hay					2.54	2.54	2.54	2.54
Pasture: Cut and Carry	1.13	0.95		1.43			6.54	5.37
Pasture: Grazing					5.95	4.85		
Commercial Concentrate					4.51		4.51	
Ground Maize						4.50		4.50
Total	14.25	13.29	14.04	13.75	13.00	11.89	13.59	12.41
% Forage	66.45	62.91	52.20	62.18	65.31	62.15	66.81	63.74
DM g/kg FM	428	448	716	371	322	346	319	341
CP g/kg DM	136	130	139	145	156	106	137	92
NDF g/kg DM	515	503	521	488	439	379	455	397
ADF g/kg DM	274	266	274	253	199	169	222	191
Digestibility g/kg DM	676	682	676	692	734	757	716	740
EM MJ/kg DM	10.20	10.30	10.20	10.45	11.09	11.44	10.82	11.18

Adapted from Alfonso-Ávila *et al.* (2012) and Velarde-Guillén *et al.* (2016). S1: strategy 1; S2: strategy 2; S3: strategy 3; S4: strategy 4; G+CC: grazing + oat hay + commercial concentrate; G+GM: grazing + oat hay + ground maize; C+CC: cut and carry pasture + oat hay + commercial concentrate; C+GM: cut and carry pasture + oat hay + ground maize; HNH: soya husk, wheat bran, oats straw, alfalfa hay, maize straw, sorghum straw; HNL: alfalfa silage, maize silage, reeds, chopped green maize forage, weeds; HCh: rolled maize grain, ground maize, pears; HCP: commercial concentrate, poultry manure, distillers grains.

Estimation of enteric CH_4

Table 5 shows the estimated methane emissions calculated from Ellis *et al.* (2007). There were no significant differences (P>0.05) for methane emission in g/cow per day or in g/kg of DM intake (DMI) or expressed as MJ/cow/day or as the proportion of gross energy intake (GEI) lost as methane (MCR).

Table 4 - Milk yield (MY), energy corrected milk (ECM) fat and protein in milk (MF and MP), live weight (LW), body condition score (BCS), feeding cost per kg of milk (FC) and profit margin and per day/cow (PMD) by season and feeding strategy.

Item	Dry season			Rainy Season			General		
	TFS	OFS	P	TFS	OFS	P	TFS	OFS	P
MY (kg/cow/d)	13.44	18.50	*	14.58	17.47	NS	14.01	17.99	*
ECM (kg/cow/d)	12.51	17.25	*	13.35	16.29	*	12.93	16.77	*
MF (g/kg milk)	35.3	34.9	NS	34.1	34.9	NS	34.7	34.9	NS
MP (g/kg milk)	30.8	32.1	*	31.0	32.1	*	30.9	32.1	*
LW (kg)	500	493	NS	500	493	NS	500	493	NS
BCS	NA	1.80	---	NA	1.95	---	NA	1.88	---
FC (US$/kg milk)	0.26	0.18	*	0.19	0.18	NS	0.22	0.18	*
PMD (US$/day/cow)	2.17	4.53	*	3.31	4.31	*	2.74	4.42	*

TFS: Traditional feeding strategies; OFS: Optimized feeding strategies. MY = Milk yield, ECM = Energy Corrected Milk, MF = Milk fat content, MP = Milk protein content, LW = Live-weight, BCS = Body Condition Score, FC = Feeding costs, PMD = Profit margin per day.
P = Probability NS = P>0.05 * P<0.05 NA: Not available.

Table 5 - Methane emission by season and feeding strategy (from Ellis et al.*, 2007).*

	Dry season			Rainy season			General		
	TFS	OFS	P	TFS	OFS	P	TFS	OFS	P
CH_4 in g/cow/d	324	335	NS	324	335	NS	324	335	NS
CH_4 in g/kg DMI	21.57	22.74	NS	23.48	26.29	NS	22.52	24.52	NS
CH_4 in g/kg milk	24.82	18.22	*	22.55	19.22	*	23.68	18.72	*
CH_4 in MJ/cow/d	18.07	18.64	NS	18.07	18.64	NS	18.07	18.64	NS
CH_4 in % of GEI (MCR)	6.52	6.87	NS	7.09	7.94	NS	6.8	7.41	NS

NS P>0.05; * P<0.05
MCR = Methane conversion rate

Discussion and Conclusion

Milk production

Milk yield results are encouraging in terms of possible achievements in small-scale dairy systems by prioritizing quality forages in diets, with differences in higher milk yield with OFS compared to TFS. This is different from reports by Aguerre *et al.* (2011) from work in Wisconsin (USA) with high yielding intensive systems where an increase of quality forage in the diet did not affect MY.

However, for small-scale systems, results are in line with Albarrán *et al.* (2012) who stated that it is feasible to sustain or increase milk yields by decreasing concentrates in diets of milking cows in small-scale dairy systems as the proportion of quality forages in the diet increases.

Since concentrates are the input with the highest cost in TFS diets, they do not allow higher profit margins than diets with a limited use of concentrates in small-scale systems (Martínez-García *et al.*, 2015). Sehested *et al.* (2003) reported that including 20% of commercial concentrate in the diet of an organic dairy system resulted in a higher efficiency in kg of milk/ kg of DMI than with concentrates comprising 40% of the diet.

In the work herein reported, TFS contained 29% of supplements of which 87% were commercial concentrate, such that 25% of the total diets were commercial concentrates. In comparison, in OFS supplements represented 32% of diets, of which 63% were commercial concentrates, such that only 20% of the diet as commercial concentrates.

Albarrán *et al.* (2012) reported lower feeding costs as the proportion of grazed pasture in the diet increased compared to diets in which grazed pasture was not the main forage source, enabling higher profits per kg of milk produced.

This is similar to reports by Tozer *et al.* (2003), in Pennsylvania in the USA, where a study comparing grazing, grazing plus a total mixed ration, or a total mixed ration in confinement, showed that although higher milk yields with the total mixed ration in confinement were obtained, it represented the highest feeding costs.

Results of milk protein content are in line with Brun-Lafleur *et al.* (2010) who report in multiparous cows an milk protein content of 32 g/kg milk and 31 g/kg milk in two treatments with the same content of CP in the diet, but the second one with less metabolisable energy content in the diet, as is the case for TFS.

The use of straws, mainly maize straw, in these systems is common. Hellin *et al.* (2013) reported on the widespread use of maize straw as feed for cattle in three different regions of Mexico. In the study area, farmers usually harvest and store maize straw in stacks after the grain harvest (Hellin *et al.*, 2013).

The main restriction on the use of maize straw for feeding dairy cows is its low nutritive value. A radically different situation if the maize crop is used as silage which besides being superior in terms of metabolisable energy content, has economic benefits by harvesting the whole crop at once, rather than one harvest for the grain and one harvest for the straw.

Maize silage has been shown to be a feasible option for small scale dairy systems in securing a good quality forage at a low cost (Albarrán *et al.*, 2012). In the OFS maize straw was substituted in the dry season for maize silage (Jaimez-García *et al.*, in press), which among other advantages reduces the need for pasture herbage.

Milk yields (MY) in OFS are higher than in TFS ($P<0.05$), with 4.0 kg milk/cow/day above than in TFS over the whole year, with a larger gap in the dry season (5.1 kg/cow/day) that is reduced in the rainy season to 2.9 kg/cow/day.

The energy corrected milk (ECM) yields were also significantly different ($P<0.05$), 3.8 kg ECM/cow/d higher in OFS than in TFS along the year, with a larger gap in the dry season (4.7 kg/cow/d) and a smaller gap in the rainy season (2.9 kg/cow/d). Milk fat is slightly higher in OFS (0.14 g/kg milk) as well as milk protein content (1.22 g/kg milk) ($P<0.05$) when compared with TFS.

The milk protein (MP) content in OFS, with diets that have a mean of 122 g of CP/kg DM and an estimated 11.37 MJ EM/kg DM, represent 4% higher MP than TFS, with diets with 134g of CP/ kg DM, but less estimated metabolisable energy (10.49 MJ/kg DM).

Cows in the dry season lost a 2% and a 0% of their initial live weight for the TFS and OFS, respectively; whereas in the rainy season, the TFS lost 2% and the OFS gained 7% of the initial LW.

Feeding costs

Table 4 shows feeding costs for each feeding strategy. OFS are economically more efficient and profitable than TFS since feeding costs in OFS were 18% lower than TFS ($P<0.05$), which is reflected in larger profits per kg of milk sold, and profit margins over feeding costs /cow per day were over 60% higher in OFS ($P<0.05$). In terms of season of the year, milk production in the rainy season (RS) is more profitable than in the dry season (DS) due to lower feeding costs.

In the rainy season, when there is an abundance of good quality feeds mostly in terms of pasture growth, milk production is up to 53% more profitable than in the dry season.

The increase in the availability of quality forage from the dry to the rainy brings about a decrease in feeding costs in TFS, increasing margins by 40% in relation to the dry season. In OFS the contribution of quality forages decreased by 10% (because a buffer forage was included in the OFS trial in the rainy season, and it came out to be low quality oat straw), which represented an increase in profit margins brought about by the higher use of pasture in the rainy season compared to the dry season.

Pasture, particularly grazed pasture is the feed resource in these systems with the lowest cost of production. Optimising the use of pasture by changing from cut and carry to intensive grazing results in substantial reductions in feeding costs, since cut and carry represents feeding costs up to 29% higher than when pastures are utilised by grazing (Pincay-Figueroa *et al.*, 2016).

Results show that by optimizing home-grown forage resources of farms they may obtain higher incomes. International milk price volatility from the 1980's, coupled with price increases in feeds for dairy cattle as from 2008 (FAO, 2010b), makes maximising the use of quality forages a viable strategy to improve the economic performance of small-scale dairy farms.

These results are in agreement with Tozer *et al.* (2003), who report that the grazing strategy showed higher profits in scenarios with low prices for milk and high costs for feeds.

Future scenarios for the dry season may reduce the availability of water for irrigation. Under this situation, the use of maize silage in the OFS showed higher profits and economic performance than TFS; which have a high reliance on external inputs of straws and supplements. In Australia, Browne *et al.* (2013) reported that the changes in the rain patterns have greater effects on farm profitability than other factors; finding higher profitability in farms that were less dependent or had alternative strategies to reduce irrigation water needs.

CH_4 emissions

Estimated methane production in TFS and OFS were not significantly different for measures expressed per cow per day, per kg of DMI whether in g or in MJ, or when expressed as the proportion of GE lost as methane (MCR). However, there were significant differences ($P<0.05$) with TFS producing 26.6% more methane per kg of milk than OFS, due to the significantly higher milk yield. On a per season basis, methane emissions during the rainy seasons are higher than in the dry season.

In both seasons, feeding strategies have estimated methane emissions within the range between 2% - 12% of Metabolisable Energy Intake (MEI) lost as CH_4 (Beauchemin and McGinn 2005), and under 10% of lost energy as methane reported for Mexico by Castelán-Ortega *et al.* (2014). Mean estimated CH4 emissions are within the normal range of 77– 447 g CH4/cow/day reported by Ellis *et al. (*2007).

Estimated CH_4 emissions in this study, both for TFS as for OFS, are similar to those reported by Legesse *et al. (*2011) (347 g CH_4/cow/d); but lower than those reported by Hymøller *et al. (*2014) (430 g CH4/cow/day), Vellinga and Hoving (2011) (507 g CH_4/cow/day), and Aguerre *et al.* (2011) (538 – 648 g CH4/cow/day).

Aguerre *et al.* (2011) reported that the increase in the proportion of forage in the diet of high yielding Holstein cows from 47% to 68% increased CH_4. Similarly, in the work herein reported, OFS diets with a higher percentage of quality forage yielded an estimated higher CH_4 emission than TFS diets that included straw, but

OFS diets increased MY, becoming more efficient as the emission of CH_4 decreased when expressed as g CH_4/kg milk produced.

This demonstrates that it is possible to reduce methane emissions per kg of milk produced from small-scale dairy systems, with improved feeding strategies based on a majority of home-grown inputs, mainly good quality forages, without negative effects on production.

Methane emission per kg of milk produced is less in the OFS. Results are lower than reports by Vellinga *et al.* (2011) (19.80 g CH_4/kg in OFS vs 21.12 g CH_4/kg milk) in the Netherlands from work undertaken in 24 farms with the objective of reducing enteric methane emissions (dairying represents 50% of GHG emissions from farms). This was achieved by devising increased efficiency in feeding strategies, prioritizing their own resources and increasing milk yields per kg of DMI, as is the case in the work herein reported.

Replacing commercial concentrates with other supplements reduces methane emissions by 0.4-0.8 g CH_4/kg milk. The use of maize silage may reduce emissions by 0.2-0.4 g CH_4/kg milk, as long as farmers keep cultivating maize in their fields for at least three years (as is usual practice). Otherwise, with an annual rotation with pastures, the emission of CO_2 and N_2O is higher than the Carbon Dioxide equivalent (CO_2eq.) reduced from implementing maize silage (Vellinga and Hoving, 2011).

Combining maize silage in conjunction with grazing associated grass-legume pastures is a profitable and sustainable option for dairy production (Albarrán *et al.*, 2012) in these systems. This strategy reduces CH_4 emissions by 2% when utilising associated ryegrass (*Lolium perenne* L.) – white clover (*Trifolium repens* L.) compared to grass only pastures (Enriquez-Hidalgo *et al.*, 2014)

These actions may reduce in 25 – 30% the emission of CO_2eq. (Vellinga *et al.*, 2011), similar to the reduction of 26.5% in the emission of g CH_4/kg milk observed between the optimised feeding strategies (OFS) and the traditional feeding strategies (TFS), with 23% in the dry season and 32% in the rainy season, in this study.

As conclusion, results from the work herein reported show that parallel to increased milk yields and lower feeding costs, which result in improved profit margins by implementing OFS, there may be an enhanced sustainability not only in the economic scale, but also in the social scale from better incomes, and in the environmental scale from lower GHG emissions.

The work herein reported draws on data collected entirely on-farm from participatory research work with promising results applicable by farmers in their productive conditions.

Acknowledgements
Authors express their gratitude to the farmers and their families, who have been participating in the project to which this work belongs, for their enthusiasm, kindness and commitment with the project. This work was undertaken thanks to funding by the Spanish Agency of

International Cooperation for Development (*Agencia Española de Cooperación Internacional para el Desarrollo*) through project AECID 11-CAP2-1526, the Mexican National Council for Science and Technology (*Consejo Nacional de Ciencia y Tecnología CONACYT*) through the grant 129449 CB-2009, and the Higher Education – Enterprise Foundation (*Fundación Educación Superior Empresa, A.C.- FESE*) from Mexico through grant UAEM 3300/2012E. Our gratitude also to *CONACYT* for the postgraduate studies grant.

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