

Analysis of feeding strategies for small-scale dairy systems in central Mexico using linear programming*

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ABSTRACT

A limitation of small-scale dairy systems in central Mexico is that traditional feeding strategies are less effective when nutrient availability varies through the year. In the present work, a linear programming (LP) model that maximizes income over feed cost was developed, and used to evaluate two strategies: the traditional one used by the small-scale dairy producers in Michoacan State, based on fresh lucerne, maize grain and maize straw; and an alternative strategy proposed by the LP model, based on ryegrass hay, maize silage and maize grain. Biological and economic efficiency for both strategies were evaluated. Results obtained with the traditional strategy agree with previously published work. The alternative strategy did not improve upon the performance of the traditional strategy because of low metabolizable protein content of the maize silage considered by the model. However, the study recommends improvement of forage quality to increase the efficiency of small-scale dairy systems, rather than looking for concentrate supplementation.

KEY WORDS: small-scale dairy systems, linear programming, forage quality

INTRODUCTION

Mexican small-scale dairy enterprises are the major provider of domestic milk (around 45%). They also enhance rural livelihoods as an important source of income and employment, and give dynamism to regional agricultural markets

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(Arriaga et al., 1997). A typical small-scale dairy enterprise in Michoacan State is family owned and operated, with limited land surface, and herd size of about 13 cows plus replacements. The feeding strategy is usually based on fresh cut lucerne, maize grain and maize straw, commercial concentrates, with average milk production of 15 litres per cow per day (Tzintzun et al., 1997; Salas, 1998). Studies carried out on small-scale dairy herds in central Mexico by Melendez and Alonso (2001) found that feed has the highest proportion within the cost structure (51-94%). A previous study, which used linear programming (LP) and partial budgeting to select an optimal forage production strategy, suggested that forage strategies with higher net incomes were the traditional strategy utilized by the farmers (fresh cut lucerne plus maize grain and straw) and alternative strategies that utilized maize silage, fresh ryegrass and oat hay as forage sources (Val-Arreola et al., 2004b). However, the study considered the optimum forage combination that needs to be cultivated rather than production performance of the cows.

Linear programming is the principal tool for formulating dairy cattle rations when profit maximization is the objective, considering cost, nutritional composition of feedstuffs and animal performance as a function of nutrient intake; obtaining as a result the optimum feeding strategy when availability of resources is constrained (Reyes et al., 1981; Church and Varela-Alvarez, 1991). The objective of this study is to analyse the effectiveness, in terms of animal performance, of the traditional feeding strategy used in small-scale dairy farms, and an alternative strategy based on ryegrass hay, maize silage and maize grain by constructing and applying a LP model.

MODEL DESCRIPTION

The model seeks to represent relationships between nutrients and responses in the dairy cow. The model is developed for a single month of lactation and then replicated over remaining months. As nutritional requirements change during lactation, the requirements of an average small-scale system dairy cow for each month of lactation were calculated at the outset. The model formulates the optimum daily ration to maximize profit and provides an insight into the most appropriate milk production level without acutely underfeeding the cow. The model considered three basic elements: a. response of milk production to energy intake; b. specification of minimum amounts of nutrients such as metabolizable protein (MP), calcium (Ca), phosphorus (P) and neutral detergent fibre (NDF); and c. a minimum level of maize straw or maize silage according to feeding strategy.

Milk production and energy requirements

When the producer's goal is to maximize profit rather than production, the relationship between nutrients consumed and resulting performance becomes important. Church and Varela-Alvarez (1991) proposed a method to formulate rations based on cost and nutritional composition of the ingredients, animal performance as a function of nutrients, and total production. By assuming milk production response to energy is quadratic, they incorporated a curvilinear response into a LP model by representing it as several small linear segments. A high producing cow converts feed into milk more efficiently than a low producing one because a lower proportion of feed intake is utilized to meet maintenance requirements (Bath, 1985). Our approach was to estimate daily metabolizable energy (ME) requirement for maintenance, milk production, pregnancy and liveweight in each month of lactation according to the recommendations of AFRC (1993). A cow weighing 600 kg and yielding 17 kg of milk per day and in the first month of lactation was taken as starting point. Daily requirement for maintenance depends on liveweight of the cow, which changes over lactation. The beginning of lactation is normally characterized by a gradual decrease in liveweight, followed by a steady increase in mid lactation as milk yield diminishes. This weight change pattern was represented using the equation of France et al. (1982), which was used to calculate the corresponding ME requirement for liveweight change from one month to the next, and discounting or adding these values to the right hand side (RHS) values accordingly. Similarly, the energy requirements for milk production reflect the shape of the lactation curve. The lactation curve of the dairy cow was represented using the equation of Dijkstra et al. (1997) which was found to be the most appropriate equation for cows reared under small-scale systems in central Mexico (Val-Arreola et al., 2004a).

Protein and mineral requirements

The MP system by AFRC (1993) was used in this study. MP requirements for maintenance, pregnancy, liveweight change and production were calculated. Newbold (1994) pointed out that response to increased intake of protein is likely to be curvilinear. A similar procedure to that for ME was used to calculate MP requirements.

Ca and P requirements were calculated using the equations of AFRC (1991). For small-scale dairy herds, estimation of these elements is critical because such cattle are commonly fed native forages or crop by-products that often do not meet mineral needs (Dominguez, 1997). Ca and P requirements for milk production were estimated using the same procedure used for ME requirements.

Dry matter intake

Sniffen et al. (1993) and Poppi et al. (1994) reviewed factors affecting dry matter intake (DMI) by cattle in both the short and the long term, such as energy level, physical digestive capacity of the animal, intrinsic nature of the feed consumed, milk yield and lactation stage. However, Arriaga (1996) pointed out that in small-scale dairy systems the applicability of methods to estimate DMI are limited by availability of information. He suggested intake capacity as one of the primary factors affecting DMI in small-scale dairy herds. The equation of Vladivelloo and Holmes (1979) for predicting DMI is recommended for general use by AFRC (1993) and was used in this study.

Feed coefficients

Empirical relationships for feed nutritive values, feed intakes and metabolic efficiencies developed in temperate climates are often used to predict nutritional outcomes and performance for tropical cattle. Nicholson et al. (1994) showed that differences in nutritive values between temperate and tropical regions can result in inaccurate prediction of animal performance under tropical conditions. Nevertheless, feed composition tables from temperate countries are used in developing countries for practical purposes, as information on specific nutrients or feeds is commonly not available (Nittis, 1983; AFRC, 1993). Nutritive values and feed parameters used in the LP model, as shown in Table 1, for dry matter (DM), ME, CP, ether extract (EE), Ca and P were taken from Kearl (1982). These are within the ranges reported by Jimenez (1989) for feedstuffs used for livestock in Mexico. Table 1 also shows the parameters used to calculate feed MP supply suggested by AFRC (1993). Local information on protein degradability, acid detergent insoluble nitrogen (ADIN), digestibility of undegradable dietary protein (UDP) in the small intestine as a decimal (dsi) and fermentable metabolizable energy (FME) of Mexican feeds were not found. Therefore, these values were taken from AFRC (1993). Neutral detergent fibre was obtained from NRC (1988) in which a minimum level of 28% of the DMI was assumed. The procedure given by AFRC (1993) for estimating MP supplied by the diet when FME is non-limiting was used. Optimal solutions were checked to verify this assumption.

Minimum inclusion levels of 0, 1, 2, 3, 4 and 5 kg DM were considered for rations utilizing maize straw, and levels of 0, 10, 20, 30 and 40% of DMI were considered for rations utilizing maize silage. To implement such a restriction, a coefficient of 1.0 was assigned to maize straw and to maize silage, depending on the ration formulated.

TABLE 1

Nutritive values per unit of forages and feeds used in the LP model

Item	g/kg DM ¹				ME MJ/kg DM ¹	Means values for N degradability parameters ²						FME MJ/kg DM ²	NDF g/kg DM ³	
	DM g/kg FM ¹	CP	EE	Ca		P	a	b	c	u	ADIN g/kgDM			dsi
Fresh lucerne	250	173	24	15.50	2.6	10.00	0.24	0.67	0.12	0.09	1.2	0.75	9.3 ⁴	450
Lucerne hay	870	199	34	18.90	3.4	9.12	0.20	0.65	0.29	0.15	2.0	0.75	8.1	450
Maize grain	880	100	52	0.08	3.6	13.97	0.47	0.48	0.27	0.05	0.4	0.95	12.4	90
Maize straw	850	59	17	4.70	1.6	7.44	0.30	0.50	0.12	0.20	1.0	0.70	5.9	670
Fresh ryegrass	200	100	49	4.40	3.4	11.00	0.24	0.67	0.12	0.09	1.2	0.75	10.6	650
Ryegrass hay	860	86	13	6.50	3.2	10.00	0.22	0.60	0.08	0.18	1.2	0.70	8.6	640
Oat hay	900	115	26	0.80	4.8	7.99	0.22	0.60	0.08	0.18	1.2	0.70	7.0	560
Maize silage	290	59	28	3.80	3.1	10.37	0.69	0.20	0.10	0.10	2.2	0.70	9.0	530
Commercial concentrate	880	180	6	0.03	2.9	8.85	0.47	0.48	0.27	0.05	0.4	0.95	7.8	100
Phosphate rock	1000			350.0	130.0									

¹ Kearl (1982)

² a = cold water extractable N as decimal of total N (by dacroon bag); b = slowly degradable N as decimal of total N; c = rate constant for fraction

u = undegradable N as decimal of total N (= 1 - a - b); dsi = digestibility in small intestine of UDP as decimal (AFRC, 1993)

³ NRC (1988)

⁴ FME was estimated by considering that in most of fresh forages FME value represents the 93% of ME content (AFRC, 1993)

MATHEMATICAL STATEMENT

The LP model is of maximize profit type, in which nutritional requirements, animal performance, feed costs and composition are considered through the mathematical statement:

$$\text{maximize } z = plq - \sum_{j=1}^n c_j x_j$$

subject to:

$$\sum_{j=1}^n a_{ij} x_j - n_i q \geq b_i \quad (i=1, \dots, m-2)$$

$$\text{MP}_{\text{supp}} - n_m q \geq \text{MP}_{\text{mpw}}$$

$$\text{MP}_{\text{supp}} = 0.6375 * \text{MCP} * \sum_{j=1}^n \text{FME}_j x_j + \sum_{j=1}^n \text{DUP}_j x_j$$

$$q \geq 0$$

$$x_j \geq 0 \quad (j=1, \dots, n)$$

where:

a_{ij} = density of nutrient i in ingredient j (MJ/kg DM or g/kg DM)

b_i = requirement for nutrient i per cow for maintenance, pregnancy and liveweight change (MJ/day or g/day)

c_j = cost of the ingredient j (M\$/kg DM)

l = level of milk production per cow (kg/day)

n_i = requirement for nutrient i per cow for milk production (MJ/day or g/day)

n_m = requirement of MP for milk production (g/day)

p = price of milk (M\$/kg)

q = proportion of milk production level achieved

x_j = amount of ingredient j fed per cow (kg DM/day)

z = margin of income over feed costs per cow (M\$/day)

DUP_j = digestible undegraded feed protein content of ingredient j (g/kg DM)

FME_j = fermentable metabolizable energy content of ingredient j (MJ/kg DM)

MCP = microbial crude protein yield (g/MJ FME)

MP_{mpw} = MP for maintenance, pregnancy and liveweight change per cow (g/day)

MP_{supp} = MP supplied by all ingredients per cow (g/day)

The index m represents the number of nutrients and n represents the number of ingredients (ration components) considered by the model.

Three further restrictions were added to the model. The first limits DMI:

$$\sum_{j=1}^n x_j \leq \text{DMI}$$

where:

DMI = dry matter intake per cow, according to potential milk production and liveweight (kg/day).

The second and third establish the level of maize straw or maize silage (according to strategy) and the minimum NDF level, respectively:

$$\sum_{j=1}^n r_j x_j \geq t$$

$$\sum_{j=1}^n \text{NDF}_j x_j \geq \text{NDF}_{\min}$$

where:

r_j = coefficient for ingredient j (= 1.0 maize straw and maize silage, = 0 otherwise)

t = minimum level of maize straw or maize silage inclusion per cow (kg DM/day)

NDF_j = NDF content of the ingredient j (kg/kg DM)

NDF_{\min} = minimum level of NDF per cow (kg/day).

The model was solved in Microsoft Excel 2003 using the Solver tool, which utilizes the simplex method with bounds on the variables for ordinary linear programming. To illustrate the model, the detached matrix form is shown in Table 2, in which the ingredients fresh lucerne, maize grain or commercial concentrate, maize straw and phosphate rock are used to formulate a ration for a cow in her first month of lactation.

FEEDING STRATEGIES

A number of versions of the LP model was developed to assess different ration formulations throughout lactation. The rations were formulated for a dairy cow with a liveweight of 600 kg at calving and average milk yield of 17 kg/day in the first month of lactation, assuming a milk fat production of 35 g/kg of milk.

Rations for cattle in small-scale dairy systems vary according to perceptions of the producer, climatic characteristics of the region and availability of feedstuffs (Dominguez, 1997). In Michoacan State, studies have been conducted describing feeding strategies practiced by dairy enterprises of this type. Urzua et al. (1998) reported that in the northeast of the state, a typical ration for dairy cattle is based on a fresh legume such as lucerne or vetch, maize straw, and maize grain or commercial concentrate, and stressed the importance of sun dried forages in the feeding strategy of such farms. In the central part of Michoacan State, most producers use diets based on fresh lucerne and maize straw supplemented with maize grain or commercial concentrate according to availability and price. These studies also reported that alternative ingredients are used for feeding dairy cattle by some producers, such as oat hay, maize silage, fresh ryegrass or hay made with the fresh forages mentioned above. The degree of inclusion of these ingredients in the diet depends on the

TABLE 2
LP model matrix for a ration of fresh lucerne, maize grain or commercial concentrate, maize straw and phosphate rock for a small-scale systems dairy cow in the first month of lactation, considering 1kg DM of maize straw

Item	Decision variables						Restrictions		
	fresh lucerne	maize grain	maize straw	commercial concentrate	phosphate rock	milk sold	requirements for milk production	type	value
Objective function, M\$/kg DM	1.00	1.70	0.59	2.18	0.0665	-3.00	M\$/kg		
ME, MJ/kg DM	10.00	13.97	7.44	8.85				≥	48.36 MJ/d
MP _{supp} , g/kg DM								≥	204.97 g/d
FME, MJ/kg DM	9.30	12.4	5.9	7.78					
DUP, g/kgDM	0.044	0.011	0.014	0.021					
Ca, g/kgDM	0.0155	0.0008	0.0047	0.0003	0.35			≥	23.79 g/d
P, g/kg DM	0.0026	0.0036	0.0016	0.0029	0.13			≥	28.07 g/d
Dry matter, kg/kg FM	0.25	0.88	0.85	0.88	1.00			≤	12.26 kg/d
Minimum level of maize straw, kg DM			1.00					≥	1.00 kg/d
NDF, kg/kg DM	0.45	0.09	0.67	0.10				≥	3.43 kg/d

producer's knowledge, feed preferences, feed availability and cost (Mendez et al., 2000). A traditional diet with ingredients more commonly used by small-scale dairy enterprises in Michoacan State (fresh lucerne, maize grain or commercial concentrate, maize straw) was modelled. In order to evaluate the effects of different levels of maize straw the rations were formulated by considering supplementing minimum levels of 0, 1, 2, 3, 4 and 5 kg on a DM basis of maize straw at first month of lactation (early lactation), fifth month of lactation (middle lactation) and tenth month of lactation (late lactation). An alternative diet was also modelled, considering the results obtained by Val-Arreola et al. (2004b), utilizing ryegrass hay, maize grain and small quantities of maize silage as ingredients. These authors pointed out that the forage production strategy with higher profits was obtained when maize silage was considered in the forage production strategy. Then, rations were formulated in which the maize silage was evaluated at different levels as a percentage of the total DMI (0, 10, 20, 30 and 40%) during early, middle and late lactation. A milk price of M\$3.0/kg was assumed (US\$1.00 = M\$9.50).

RESULTS

Traditional diet

Model solutions meet the nutritional requirements for maintenance, pregnancy and weight change, with remaining nutrients directed towards milk production (e.g., ME_{milk} for energy and MP_{milk} for protein). Table 3 shows the effects of different levels of maize straw inclusion on milk production for early lactation. For each kilogram added to the ration, the quantity of fresh lucerne decreased by 0.75 kg. Higher milk production, and higher margins were achieved when maize straw was not included. The ration becomes cheaper when higher amounts were added (Table 3). When milk production per MJ of ME was evaluated there were no differences between the inclusion levels. Similar results were obtained when MP efficiency was evaluated. When economic efficiency was evaluated, almost no differences were observed in terms of margins obtained per MJ of ME_{milk} and per gram of MP_{milk} (Table 3).

For mid lactation, higher milk production was obtained with rations without maize straw (Table 4). Although daily ME and MP supply were higher than for early lactation due to higher DMI, the content of ME/kg DM was almost the same but MP/kg DM was lower. The ration cost became cheaper when higher quantities of straw were added, but no economic advantage was achieved with higher levels of inclusion.

For late lactation, as in the previous cases, higher milk production was achieved with no maize straw included in the ration (Table 5). ME supply was also higher at zero inclusion with a steady decrease thereafter. Although ration

TABLE 3

Effects of maize straw inclusion for the traditional diet on milk production in early lactation

Item	Minimum of level of maize straw inclusion considered by the model, kg DM					
	0	1	2	3	4	5
Fresh lucerne, kg DM/d	8.69	7.95	7.21	6.46	5.72	4.97
Maize grain, kg DM/d	2.70	2.45	2.21	1.96	1.71	1.46
Maize straw, kg DM/d	0.00	1.00	2.00	3.00	4.00	5.00
Commercial concentrate, kg DM/d	0.00	0.00	0.00	0.00	0.00	0.00
Phosphate rock, kg DM/d	0.86	0.85	0.85	0.84	0.83	0.83
Milk yield, kg/d	15.27	14.57	13.86	13.15	12.44	11.73
ME supply, MJ/d	117.06	114.23	111.40	108.57	105.74	102.91
MP supply, g/d	799.09	768.34	737.60	706.85	676.11	645.37
ME content, MJ/kg DM	9.55	9.32	9.09	8.86	8.62	8.39
MP content, g/kg DM	65.18	62.67	60.16	57.65	55.15	52.64
Income over ration cost, M\$/d	31.95	30.41	28.87	27.33	25.79	24.25
Ration cost, M\$/d	13.88	13.29	12.70	12.12	11.53	10.95
Milk per MJ of ME _{milk} , kg	0.21	0.21	0.21	0.21	0.21	0.21
Margin per MJ of ME _{milk} , M\$	0.44	0.44	0.44	0.44	0.44	0.44
Milk per g of MP _{milk} , kg	0.02	0.02	0.02	0.02	0.2	0.02
Margin per g of MP _{milk} , M\$	0.05	0.05	0.05	0.05	0.05	0.05

TABLE 4

Effects of maize straw inclusion for the traditional diet on milk production in mid lactation

Item	Minimum of level of maize straw inclusion considered by the model, kg DM					
	0	1	2	3	4	5
Fresh lucerne, kg DM/d	9.49	8.75	8.00	7.26	6.51	5.77
Maize grain, kg DM/d	3.21	2.96	2.74	2.47	2.22	1.98
Maize straw, kg DM/d	0.00	1.00	2.00	3.00	4.00	5.00
Commercial concentrate, kg DM/d	0.00	0.00	0.00	0.00	0.00	0.00
Phosphate rock, kg DM/d	0.73	0.72	0.71	0.70	0.70	0.69
Milk yield, kg/d	11.14	10.45	9.77	9.08	8.40	7.71
ME supply, MJ/d	131.43	128.65	125.84	123.04	120.25	117.45
MP supply, g/d	870.60	840.84	811.09	781.33	751.58	721.82
ME content, MJ/kg DM	9.79	9.58	9.37	9.16	8.95	8.75
MP content, g/kg DM	64.83	62.61	60.39	58.18	55.96	53.75
Income over ration cost, M\$/d	17.97	16.50	15.02	13.55	12.08	10.60
Ration cost, M\$/d	15.45	14.87	14.29	13.70	13.12	12.54
Milk per MJ of ME _{milk} , kg	0.21	0.21	0.21	0.21	0.21	0.21
Margin per MJ of ME _{milk} , M\$	0.34	0.33	0.33	0.32	0.30	0.29
Milk per g of MP _{milk} , kg	0.02	0.02	0.02	0.02	0.02	0.02
Margin per g of MP _{milk} , M\$	0.04	0.04	0.04	0.03	0.03	0.03

TABLE 5

Effects of maize straw inclusion for the traditional diet on milk production in late lactation

Item	Minimum of level of maize straw inclusion considered by the model, kg DM					
	0	1	2	3	4	5
Fresh lucerne, kg DM/d	8.95	8.20	7.46	6.72	5.97	5.23
Maize grain, kg DM/d	3.05	2.80	2.56	2.31	2.02	1.82
Maize straw, kg DM/d	0.00	1.00	2.00	3.00	4.00	5.00
Commercial concentrate, kg DM/d	0.00	0.00	0.00	0.00	0.00	0.00
Phosphate rock, kg DM/d	0.67	0.66	0.65	0.64	0.63	0.62
Milk yield, kg/d	6.78	6.15	5.51	4.87	4.24	3.60
ME supply, MJ/d	124.20	121.43	118.65	115.87	113.10	110.32
MP supply, g/d	767.52	739.86	712.19	684.53	656.86	629.20
ME content, MJ/kg DM	9.80	9.59	9.36	9.15	8.93	8.71
MP content, g/kg DM	60.58	58.39	56.21	54.03	51.84	49.66
Income over ration cost, M\$/d	5.76	4.43	3.10	1.77	0.44	-0.89
Ration cost, M\$/d	14.59	14.01	13.43	12.85	12.27	11.69
Milk per MJ of ME _{milk} , kg	0.21	0.21	0.21	0.21	0.21	0.21
Margin per MJ of ME _{milk} , M\$	0.18	0.15	0.12	0.08	0.02	-0.05
Milk per g of MP _{milk} , kg	0.02	0.02	0.02	0.02	0.02	0.02
Margin per g of MP _{milk} , M\$	0.02	0.02	0.01	0.01	0.002	-0.006

costs were cheaper when higher quantities were added, the profits were lower due to lower production of milk. The biological and economic efficiencies for MP did not show any differences with level of inclusion.

Alternative diet

Results obtained for early lactation are shown in Table 6. The quantities of ryegrass hay diminished as silage level and milk production increased. Cost of the ration increased when higher quantities of the silage were included, which resulted in a slight profit increase. Both ME and MP supplies increased with higher levels of inclusion. Milk production increased at higher levels of maize silage, perhaps, as a consequence of a higher MP content of the ration.

Table 7 shows the effects for mid lactation of increasing maize silage levels in the ration. As with early lactation, predicted milk production increased with level of maize silage inclusion. Although ration cost increased, it seems not to have affected economic efficiency due to higher milk production. An increase in MP supply as the level of maize silage increased was observed (Table 7).

In late lactation, ration costs were similar to those for early lactation, but with lower milk production (Table 8). However, both biological and economic efficiencies of ME and MP were similar to those obtained for early and mid lactation rations.

TABLE 6

Effects of maize silage inclusion for the alternative diet on milk production in early lactation¹

Item	Minimum of level of maize silage inclusion considered by the model, % of total DM intake				
	0	10	20	30	40
Maize silage, kg DM/d	0.00	1.23	2.45	3.68	4.90
Ryegrass hay, kg DM/d	5.97	4.62	3.27	1.93	0.58
Maize grain, kg DM/d	5.66	5.78	5.90	6.01	6.13
Phosphate rock, kg DM/d	0.63	0.64	0.64	0.64	0.65
Milk yield, kg/d	13.84	13.97	14.11	14.25	14.39
ME supply, MJ/d	138.72	140.26	141.79	143.32	144.86
MP supply, g/d	805.64	811.60	817.57	823.54	829.51
ME content, MJ/kg DM	11.31	11.44	11.06	11.69	11.82
MP content, g/kg DM	65.71	66.20	66.69	67.17	67.66
Income over ration cost, M\$/d	25.54	25.64	25.75	25.85	25.96
Ration cost, M\$/d	15.96	18.43	20.89	23.36	25.82
Milk per MJ of ME _{milk} , kg	0.21	0.21	0.21	0.21	0.21
Margin per MJ of ME _{milk} , M\$	0.39	0.39	0.39	0.38	0.38
Milk per g of MP _{milk} , kg	0.02	0.02	0.02	0.02	0.02
Margin per g of MP _{milk} , M\$	0.04	0.04	0.04	0.04	0.04

¹lucerne hay, oat hay and commercial concentrates were not included

TABLE 7

Effects of maize silage inclusion for the alternative diet on milk production in mid lactation¹

Item	Minimum of level of maize silage inclusion considered by the model, % of total DM intake				
	0	10	20	30	40
Maize silage, kg DM/d	0.00	1.34	2.68	4.03	5.37
Ryegrass hay, kg DM/d	7.05	5.58	4.11	2.65	1.18
Maize grain, kg DM/d	5.72	5.84	5.96	6.08	6.20
Phosphate rock, kg DM/d	0.66	0.67	0.67	0.68	0.68
Milk yield, kg/d	10.66	10.80	10.94	11.08	11.22
ME supply, MJ/d	150.41	152.05	153.68	155.32	156.95
MP supply, g/d	849.89	855.97	862.04	868.13	874.20
ME content, MJ/kg DM	11.20	11.32	10.93	11.57	16.69
MP content, g/kg DM	63.28	63.74	64.19	64.64	65.09
Income over ration cost, M\$/d	14.83	19.85	15.01	15.10	15.19
Ration cost, M\$/d	17.16	19.85	22.55	25.24	27.93
Milk per MJ of ME _{milk} , kg	0.21	0.21	0.21	0.21	0.21
Margin per MJ of ME _{milk} , M\$	0.29	0.29	0.29	0.29	0.29
Milk per g of MP _{milk} , kg	0.02	0.02	0.02	0.02	0.02
Margin per g of MP _{milk} , M\$	0.03	0.03	0.03	0.03	0.03

¹lucerne hay, oat hay and commercial concentrates were not included

TABLE 8

Effects of maize silage inclusion for the alternative diet on milk production in late lactation¹

Item	Minimum of level of maize silage inclusion considered by the model, % of total DM intake				
	0	10	20	30	40
Maize silage, kg DM/d	0.00	1.27	2.53	3.80	5.07
Ryegrass hay, kg DM/d	6.65	5.26	3.88	2.50	1.11
Maize grain, kg DM/d	5.42	5.23	5.64	5.75	5.86
Phosphate rock, kg DM/d	0.61	0.62	0.62	0.62	0.63
Milk yield, kg/d	6.37	6.49	6.61	6.73	6.86
ME supply, MJ/d	142.12	143.66	145.19	146.70	148.27
MP supply, g/d	749.35	754.68	760.09	765.34	770.66
ME content, MJ/kg DM	11.22	11.34	11.46	11.58	11.70
MP content, g/kg DM	59.14	59.56	59.99	60.41	60.83
Income over ration cost, M\$/d	2.89	2.95	3.01	3.06	3.12
Ration cost, M\$/d	16.21	18.75	21.29	23.83	26.37
Milk per MJ of ME _{milk} , kg	0.21	0.21	0.21	0.21	0.21
Margin per MJ of ME _{milk} , M\$	0.10	0.10	0.10	0.10	0.10
Milk per g of MP _{milk} , kg	0.02	0.02	0.02	0.02	0.02
Margin per g of MP _{milk} , M\$	0.01	0.01	0.01	0.01	0.01

¹ lucerne hay, oat hay and commercial concentrates were not included

DISCUSSION

Previous studies of small-scale dairy farms in central Mexico suggested that the decision to adopt any strategy for feeding dairy cattle depends on the producers' attitude towards risk. Basically, this is related to acceptance of some profit forfeited by choosing a different alternative in order to reduce variation in net returns over the year. Previous work has shown the need to propose nutritional strategies based on strategic use of high quality forages with limited use of concentrates or feed supplements (Castelán et al., 2001; Arriaga et al., 2002). Other studies have mentioned factors such as: i. cattle being kept as an investment (then to be maintained with minimum inputs), ii. opportunity cost of feed sources (choosing feeds according to their potential demand in regional markets) and, iii. perception of management and use requirements when a particular strategy is adopted (Fleury et al., 1996; Bennison et al., 1997). However, we agree with Castelán et al. (2001) and Arriaga et al. (2002) who stated the decision to adopt a particular feeding strategy would be influenced by response of the cattle to a particular ration in terms of efficiency, biological or economic. In our case, efficiency was the ratio output/input given in a variety of units, and it can be affected by several factors (Ostergaard et al., 1990).

Traditional diet

Several workers have cited fresh cut lucerne, maize grain and maize straw as a common feeding strategy among small-scale producers in Michoacan State (Val-Arreola, 1998; Méndez et al., 2000). Higher milk yields were obtained when maize straw was excluded from the ration, which is in agreement with the LP model. Arriaga et al. (2002) pointed to quality of forage as the main factor limiting response to feeding in small-scale systems, which explains cases of lower milk production when higher quantities of maize straw were added (Table 4).

Alternative diet

Traditional feeding strategies involving maize straw can affect economic efficiency of small-scale dairy farms, where milk sales are the main source of income (Arriaga et al., 1999). Several studies have evaluated feeding strategies that utilize maize silage as a forage supplement (Martinez and Améndola, 1998; Arriaga et al., 2002) and found better economic performance with higher availability of forage over the year and less dependence on commercial concentrates, thus reducing the effect of critical periods of forage shortage. With our model, performance of the alternative strategy suggested lower economic efficiency than the traditional strategy, which can be explained by lower protein efficiency estimated by the model (Tables 6, 7 and 8), suggesting protein as the limiting nutrient as energy efficiencies are similar in both strategies. Our model did not show differences in energy efficiency over lactation, disagreeing with Stockdale (1995) who, when analysing response to different levels of maize silage supplement, observed differences between early and late lactation. With regard to energy efficiency, this author found 0.38 kg milk/MJ of ME in early lactation and 0.26 kg milk/MJ of ME in late lactation; both cases are higher than the efficiency obtained by our model.

Borton et al. (1997) found higher profits when lucerne was the only forage source, in comparing the merits of maize silage and lucerne. Results of these authors disagree with our LP model, though differences in margin are small in the model. Ensiling is a way of preserving nutrients and maintaining forage quality. Results of our model show with the traditional strategy milk production diminishes at higher levels of maize straw inclusion, whilst with the alternative strategy milk production is maintained or even increased at higher levels of maize silage. Martinez and Amendola (1998) tried to reduce the effect of forage shortage by supplementing grazing lactating cows. They found that on an individual basis highest milk production was obtained with no maize silage supplementation, but at a herd level milk production increased due to increased stocking rate, which agrees with previous work (Val-Arreola et al., 2004b).

Economic considerations

The higher performance obtained at higher levels of maize silage inclusion compared to maize straw can be explained by cost of each nutrient and nutrient density provided by each ingredient. Borton et al. (1997) found that net return obtained by systems based on maize silage can be affected by deficiencies in protein and low DM density of the silage. Another factor that has been described, which affects economic margins, is quantity of grain in the rations and response of the cow to increasing quantities of grain. Smith (1975) suggested that optimum economic performance can be obtained at about 4.0-9.8 kg/cow/day according to quantity of forage, which is in agreement with the predictions of our model. The traditional strategy suggests quantities of about 3 kg/cow/day, which agrees with the findings of Arriaga et al. (2001) when they evaluated the feeding strategies in small farms.

Studies carried out in Mexico have pointed out that, despite improved forage quality, the farmer's perception plays an important role when adopting a new strategy. This perception is related to issues such savings generation, security and assets protection. Schilizzi and Boulier (1997) found that the farmers on the western coast of Mexico prefer cultivating maize instead of increasing the grazing area, because they could use part of the maize harvest to feed the animals and sell the other part. They also found the alternative forage strategy proposed reduced monetary inflow by 10%, even though farm profit increased by 20%.

The results obtained by our model are consistent with results of previous studies carried out on small-scale dairy farms in Mexico. The use of a LP model to explore the importance of forage quality to both biological and economic efficiency of feeding strategies has shown that protein content in the case of the maize silage is a critical factor limiting performance of lactating cows. The benefit of adopting a strategy based on maize silage would be to reduce the possibility of forage shortages, as pointed out by previous workers (Val-Arreola et al., 2004b). However work needs to be done to analyse the relationship between forage production strategy and feeding strategy using an integrated approach.

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STRESZCZENIE

Analiza strategii żywienia dla małych farm mlecznych w centralnym Meksyku przy zastosowaniu programowania liniowego

Ograniczenia w systemach stosowanych w małych mlecznych farmach w centralnym Meksyku wynikają z tradycyjnej strategii żywienia, która jest mniej efektywna przy zmiennej dostępności składników pokarmowych (paszy) w ciągu roku. W pracy przedstawiono model programowania liniowego (LP), pozwalający na zwiększenie dochodów poprzez koszt paszy. Użyto go do oceny dwóch sposobów postępowania: tradycyjnego używanego przez drobnych producentów mleka w Stanie Michoacan, opartego na stosowaniu w żywieniu krów świeżej lucerny, ziarna kukurydzy i słomy kukurydzianej oraz alternatywnego, proponowanego przez LP model i opartego na stosowaniu siana z rajgrasu, kiszonki z kukurydzy i ziarna kukurydzianego. Oceniono biologiczną i ekonomiczną efektywność obydwóch sposobów postępowania. Zastosowanie alternatywnej strategii nie poprawiło wyników postępowania tradycyjnego z powodu niskiej zawartości białka metabolicznego w kiszonce z kukurydzy, którą zastosowano w modelu. Jednakże uzyskane wyniki pozwalają na zalecenie poprawy jakości pasz objętościowych zielonych celem zwiększenia efektywności produkcji w małych farmach mlecznych, raczej niż na uzupełnianiu dawek paszami treściwymi.