Economics of agriculture
SI – 2
UDK: 637.11

MODULAR TOOL FOR DAIRY COW RATION OPTIMIZATION: SPREADSHEET BASED APPROACH

Jaka Žgajnar[1], Stane Kavčič[2]

Abstract

Paper presents developed spreadsheet tool for dairy cow ration formulation. It is constructed on the basis of two linked modules in MS Excel platform, merging common linear programming and weighted goal programming model with penalty functions. The first module estimates the least-cost magnitude that might be expected. Obtained result enters into the second module as goal that should be met as close as possible. The tool was tested at two different values of preferential weights for dairy cow with 20 kg daily milk yield. Obtained results confirm benefits of applied methodology since one is enabled to formulate least-cost ration and simultaneously overcome major drawbacks of LP approach. Besides fine tuning of set goals rational violence is enabled through penalty function system. As result calculated ration is more efficient both from economic and nutritive point of view.
Key words: *linear programming, weighted goal programming, penalty function, spreadsheet ration optimization, dairy economics*

Introduction

Many external factors (e.g. milk quota abolition, CAP reforms, fodder price fluctuations, climate changes) have significant impact on economic indicators in dairy production. Since forage costs already present up to 55 % of total variable cost, ration formulation is becoming the fundamental lever in daily dairy management. With increasing volatility of fodder prices this is even more important.

It is extremely complex and time consuming process to formulate an efficient ration that take into consideration nutritional, economic and also environmental factors. In the case that it is done by trial - error method (by hand), particularly non-nutritional facts (economics and environment) might be neglected. Both issues deteriorate also diets' efficiency.

1 Jaka Žgajnar, Assistant, B.Sc., University of Ljubljana, Biotehnical Faculty, Dept. of Animal Science, Groblje 3, SI-1230 Domžale, Slovenia, jaka.zgajnar@bf.uni-lj.si

2 Stane Kavčič, Assoc. Prof., Ph.D., same address, stane.kavcic@bf.uni-lj.si

Literature review

In the literature one could find numerous examples of utilizing operation research techniques for solving nutrition management problems. The most common are least cost ration optimization based on linear programming, starting with Waugh (1951). Even though LP approach is suitable for solving nutrition management problems, it has some drawbacks and might therefore be deficient method for ration formulation (Rehman and Romero, 1984; 1987). This is especially true when it is used as an 'engine' in an end-user application.

The two basic concepts of LP are single objective function and fixed (rigid) constraints, defined by right hand side (RHS) of equation and matrix specification. These means that only one objective might be optimized at once (e.g. cost minimization). However, ration formulation is quite complex process and reduction of several objectives into only one - cost minimization objective - is too rigid assumption. Nutrition management is one of business problems demanding multi objective consideration (Lara and Romero, 1994).

Fact that all nutrient requirements are estimated on the basis of numerous equations, points out the second basic LP assumption. It means that no constraints' violence is allowed at all, irrespective of deviation level (Rehman and Romero, 1984). In many real situations this might manifest in fact that LP model has no feasible solution. However, relatively small relaxation in RHS would not seriously affect animal welfare, but would result in a feasible solution (Rehman and Romero, 1987; Lara and Romero, 1994). Another problem concerning RHS is also the fact that constraints are usually defined only in one direction. This could reflect in rise of prime-cost or, what is lately becoming even more important, increase pollution with surplus elements and green house gas (GHG) emissions (Brink et al., 2001) due to unbalanced ration at different stages.

When ration optimization is the case, mentioned drawbacks might be reduced by multi criteria decision making (MCDM) concept (Rehman and Romero, 1984). The most pragmatic and commonly used method within MCDM techniques is weighted goal programming (WGP) (Tamiz et al. 1998). Its mathematical framework is familiar with LP, which enables simplex algorithm utilization (Rehman and Romero, 1993).

WGP technique enables one to optimize several objectives at once. Crucial objectives that are usually in contradiction might be converted into goals and the rest of objectives can be considered as constraints. Theoretically goals could be satisfied either completely, partly or in some extreme cases some of them might also not be met. This violence is enabled through deviation variables. They are measured using positive and negative deviation variables that are defined for each goal separately and present over- or under-achievement of the goal. This is also the main difference between LP and WGP, as objective function in WGP paradigm minimizes the undesirable deviations from the target goal values and does not minimize or maximize goals themselves (Ferguson et al., 2006).

Quality of obtained results is strongly dependent on selection of preferential weights. Since any deviation is undesired, the relative importance of each deviation variable is determined by belonging weights. They can be set either by expert estimation or with analysis of shadow prices. To reduce bias of obtained result also alternative technique to define weights could be used, as for example Saaty's Analytic Hierarchy Process (AHP) (Gass, 1987).

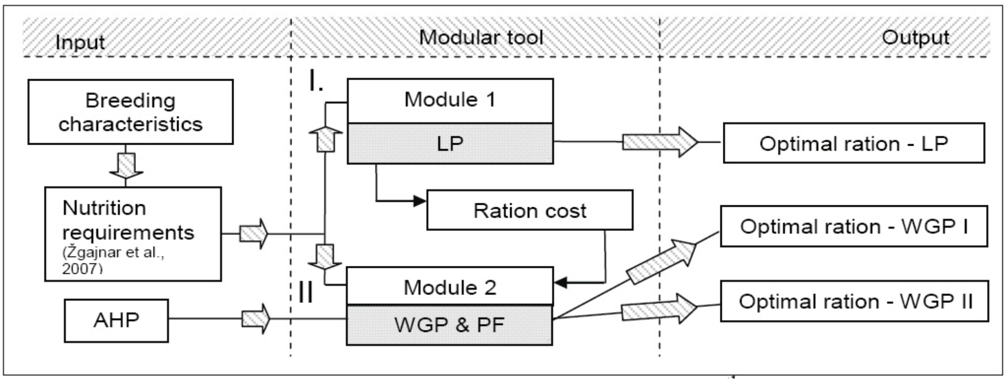
One of main drawback of WGP is concerning marginal changes. Namely, within one goal all changes are of equal importance (constant penalty) no matter how distant they are from the target value (Rehman and Romero, 1987). This addresses another new issue in ration formulation. In some situations too big deviation might lead to fail animal's requirements within nutrition desirable limits, and obtained solution is useless. To keep deviations within desired limits and to distinguish between different levels of deviations, system of penalty functions (PF) might be used to support WGP (Rehman and Romero, 1984). PF enable one fine tuning of positive and negative deviation intervals for each goal separately.

Material and methods

The paper presents an attempt of mathematical programming techniques that could be applied in daily management tasks in dairy sector. To be user friendly and available to end users, it is developed in MS Excel framework.

The modular tool is based on LP and WGP supported with PF. The first module is a classical example of least cost ration formulation. Its purpose is to get rough estimate of the ration cost, required in the second module (Figure 1)[3]. Presented tool is developed as an open system, which means that all input data are recalculated for analysed case. This is enabled with another already developed model (Žgajnar et al., 2007) that calculates animals' daily requirements and is linked with presented tool (Figure 1).

Figure 1 - Scheme of optimization tool



The tool was tested for a 600 kg dairy cow in the 120th day of lactation (presumed lactation milk yield was 5,000 kg) with a daily milk yield of 20 kg and nutritional requirements for 60th day of pregnancy. The most important constraints and goals for analysed case are presented in Table 1.

3 Approach with mathematical description of models (LP and WGP+PF) is precisely described by Žgajnar et al. (2010); the main difference is that the models are there applied for beef ration formulation.

Table 1 - Daily requirements for dairy cow with 20 kg milk yield at 60^{th} day of pregnancy, presented as constraints (LP) or set of goals (WGP)

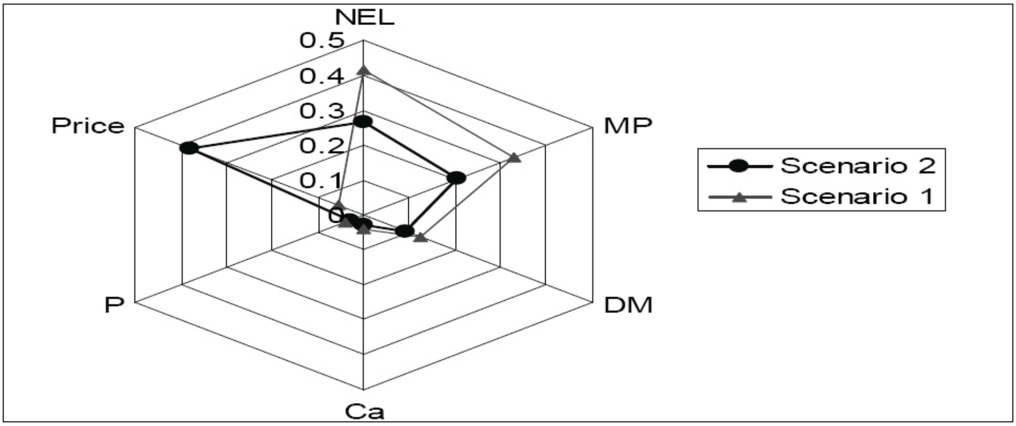
		Daily requirements			Penalty function				
		Summer/winter			Interval 1			Interval2	
		LP	WGP I / II		s1-	s1+		s2-	s2+
NEL	(MJ)	>102.1	102.1		0.5%	0.5%		1%	1%
MP	(g)	>1,219.3	1,219.30		0.5%	0.5%		1%	1%
DM	(kg)	<16.4	16.4		5%	0%		15%	0%
CF min	(kg)	>3.0							
CF max	(kg)	<4.3							
Ca	(g)	>86.5	86.5		5%	10%		27%	27%
P	(g)	>57.7	57.7		5%	10%		27%	27%
Ca:P	(%)	(1.5-2):1							
K:Na	(%)	(5.5-10):1							
Price	(cent)		*C1*		∞	10%		∞	20%

Basic set of constraints is in both models (LP and WGP, supported by PF) more or less the same. Nutritional constraints presented in Table 1 differ only in mathematical sign when nutrient requirements are transformed into goals. In the case when least cost criterion is considered (LP) only the most important (non-conflicting) minimum or maximum constraints must be met. This might manifest in 'unreasonable' ration. Anyhow, this simplification has been applied since LP module is utilised only to give rough estimation of the lowest possible diet cost.

In everyday ration formulation process one has to consider also constraints concerning quantities of feed that must or might be included into the ration. In our case study we assumed that ration should include at least 3 kg of hay and its quantity should not exceed 5 kg. Both modules should also not exceed the maximum quantity of grass and maize silage (30 kg/day).

Initial version of WGP model involves six goals supported by PF (Table 1). Relative importance of each goal is defined by belonging weights, summing to one. Weights have been estimated with AHP approach, based on pair wise comparisons. As it is apparent from Figure 2, two different scenarios have been tested with the crucial difference in preferences of cost goal. In the first scenario cost of obtained ration (WGP I) was of minor importance (0.05), while in the second scenario (WGP II) its importance was increased (0.38). In both scenarios deviation intervals remain the same (+10 % and +20 %). The most important goals to be met were satisfaction of energy (NEL) and protein (MP) requirements. In both cases deviation intervals are very restricted, since only 0.5 % positive and negative deviations are allowed in the first scenario and 1 % in the second one. Much lower weight is foreseen for the dry matter intake that presents consumption capacity. In this case deviation intervals are defined only for underachievement of the goal, while overachievement is for practical reasons (consumption capacity) not allowed. Besides that, additional constraint is included to ensure that proportion of dry matter derived from voluminous forage does not exceed 14 kg.

Figure 2 - Relative weights of six goals



The ingredients assumed to be available for formulating the rations and their characteristics are given in Table 2. Grass might be included only in summer ration. We assumed that all voluminous forage (hay, maize silage, grass silage and grass) is produced on the farm. Since these forages are usually not tradable, we estimate total cost of their production on the basis of 'model calculations' (KIS, 2007). All other forage and mineral-vitamin components on disposal could be purchased at market prices (Table 2).

Table 2 - Nutritive value of feed on disposal

	DM	NEL	MP**	CF	Ca	P	Mg	Na	K	Price or TC*
	(g/kg)	(MJ/kg DM)	(g/kg DM)							(cent/kg)
Feed on disposal										
Hay	860	5,90	85,00	270	5,70	3,50	2,00	0,35	18,25	15,30
Maize silage	320	6,50	45,00	200	7,06	6,00	1,91	0,12	10,76	3,70
Grass silage	350	5,60	62,00	260	6,00	3,51	2,20	0,35	21,30	6,14
Grass	160	7,10	121,00	205	6,00	2,60	2,00	0,10	10,50	1,50
Maize	880	8,50	83,00		0,23	4,09	1,25	0,23	3,75	30,00
Wheat	880	8,60	88,00		0,57	3,86	1,59	0,45	5,00	32,00
K-18***	880	7,61	136,74		10,23	5,68	2,84	3,98	10,23	27,67
K-19***	880	7,61	146,51		10,23	5,68	2,84	5,11	10,23	30,00
Mineral and vitamin components										
Limestone	950				400					16,40
MVM1****	930				160	100	36	120		67,56
MVM2****	930				210	70		135		58,08
Salt	950							400		50,00

* *Total cost for voluminous forage*

** *The minimal values of metabolisable proteins*

*** *Commercial names of dairy cows feed containing different % of metabolisable proteins*

**** *Commercial name of mineral- vitamin mixtures are Bovisal summer and Bovisal winter*

Results

The tool has been tested on a practical everyday example in dairy production. Formulated daily rations for both scenarios are presented in Table 3, including LP solutions. The latter serves only for estimation the diet least-cost possible (Figure 1) and might not be really applicable.

There is a significant difference between winter and summer rations and also between rations in each season (Table 3). The first one is self-explanatory with grass on disposal only in summer, while the second difference manifests scenarios' assumptions with different preferential weights and PF in place.

In winter rations (WGP I and WGP II) protein requirements are mainly covered with grass silage and purchased fodder K-19 (WGP I) and K-18 (WGP II). It is obvious that prices play significant role as more restricted cost conditions (WGP II) have significant impact on inclusion of (expensive) grass silage. This is even more obvious in summer season, where the main source of proteins is much cheaper grass (both WGP I and WGP II). Grass is therefore the crucial trigger for the difference between summer and winter rations composition.

Table 3 - Obtained daily rations formulated with LP and cost penalty function scenarios

	Daily ration					
	winter			summer		
	LP	WGP I	WGP II	LP	WGP I	WGP II
Feed used (kg/day)						
Hay	5.00	5.00	5.00	3.00	3.00	3.00
Maize silage	27.98	3.89	13.23		18.44	18.80
Grass silage		16.94	13.58			
Grass				71.38	33.50	33.77
Maize		3.26	0.30		1.26	1.12
K-18	1.03		2.88	0.86		
K-19	2.54	1.49				
Mineral components used (g/day)						
Limestone		25.0			13.9	12.3
Bovisal Summer				153.9	29.6	30.8
Bovisal Winter		14.0				
Salt	8.3	30.0	30.0		30.0	30.0
Price (EUR/day)	2.85	3.40	2.99	1.87	2.06	2.03
Price deviation (%)	0.0	19.3	4.9	0.0	10.0	8.7
Requirements deviations (%)						
NEL	5.3	-1.0	-1.0	0.0	-1.0	-1.0
MP	0.0	0.0	0.0	39.8	0.5	0.5
Total deviation*	94.9	25.8	55.3	80.6	38.3	39.5
Physical ration attribute						
CF (%)	18	19	20	20	20	20
DM (kg/day)	16.4	15.7	16.1	14.9	15.0	15.1

Total sum of deviations (including mineral deviations not presented in the table)

Penalty system enables one to control deviations from set target values (goals). More severe cost penalty system in the second scenario (through higher relative importance *w=0.38*) has in both seasons significant impact from nutrition quality aspect. More balanced WGP I ration is in summer season for 10 % more expensive in comparison with LP, while in the winter season the difference is close to 20 %. Difference between WGP II and LP is smaller and WGP II rations seems acceptable also from quality aspect.

Energy and protein requirements are fully met only in LP. Therefore at first glance least cost ration seems best solutions. However, if one considers also the sum of total deviation as measure of the 'quality' of obtained results, it is obvious that WGP rations are better. It is clear that LP neglects some nutrition objectives. This could be explained as competition between nutrition quality and economics. Also environmental impact is not negligible.

Conclusions

Paper presents a simple modulator tool that can support dairy cow ration formulation. Applied approach, combining different mathematical programming methods, proves as useful 'engine' in end-user application. It enables one to formulate close to least cost ration not taking too much risk of worsening the ration's nutritive value that is the main common drawback of LP. Rations might be additionally improved with fine tuning enabled through PF that differs between deviation sizes for each goal separately. This significantly proves in obtained rations, especially in winter season. If only least cost criterion is considered, there is almost 40 % surplus of proteins in the summer ration, which might seriously affect animals' health. In spite of cost increase, total efficiency could be improved through numerous factors.

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