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SPREADSHEET TOOL FOR LEAST-COST AND NUTRITION BALANCED BEEF RATION FORMULATION

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ABSTRACT

This paper points out some facts that might improve economic outcome of livestock production in the sense of diet formulation. A spreadsheet tool from two linked modules based on MS Excel platform was constructed, merging different mathematical deterministic programming techniques. The first module utilizes linear program for least-cost ration formulation, aiming to obtain rough estimate what magnitude of the costs might be expected. Resulting value is then considered as target value of cost goal in the second module. It is based on weighted goal programming with penalty function. Obtained results confirm benefits of applied approach. It enables formulation of least-cost ration not taking too much risk of worsening the ration's nutritive value and balance between nutrients. This is especially important when improved economic and nutritive efficiency is the primal and common aim of optimization tool.

Key words: cattle / bulls / spreadsheet tools / beef economics / beef ration optimization / linear programming / weighted goal programming / penalty function

ORODJE ZA NAČRTOVANJE NAJCENEJŠIH IN PREHRANSKO IZRAVNANIH OBROKOV ZA PITANCE

IZVLEČEK

Prispevek izpostavlja nekatere dejavnike, ki z vidika sestavljanja krmnih obrokov lahko izboljšajo gospodarnost živinoreje. V Excelovem okolju je bilo v obliki elektronskih preglednic razvito modularno orodje, ki združuje različne tehnike determinističnega matematičnega modeliranja. Prvi modul vključuje tehniko linearnega programiranja in služi za oceno najcenejšega možnega krmnega obroka. Dobljeni rezultat kot ciljna vrednost vstopa v drugi modul, ki temelji na tehtanem ciljnem programiranju, nadgrajenem s kazensko funkcijo. Pridobljeni rezultati potrjujejo prednosti uporabljenega pristopa, ki omogoča sestavljanje najcenejših krmnih obrokov, ne da bi ob tem tvegali močnejše poslabšanje hranilne vrednosti in razmerja hranil. To je posebej pomembno, kadar je izboljšanje ekonomske in prehranske učinkovitosti temeljni cilj optimizacijskega orodja.

Ključne besede: govedo / biki / pitanje / elektronsko orodje / ekonomika / optimiranje prehrane / linearno programiranje / tehtano ciljno programiranje / kazenska funkcija

INTRODUCTION

Due to changing economic and political environment, the beef sector is becoming one of the most sensible agricultural sectors in the European Union. Its economic position is mostly dependent on the efficiency of each agricultural holding production structure, with the crucial role playing the economy of scale. However, at the moment poor economics position of beef sector could be significantly imposed with progressive abolition of previous Common Agricultural Policy (CAP) production coupled support and increasing environmental and other public demands – in addition to World Trade Organization (WTO) pressures, which have led to rapid market fluctuations. Together with direct consequences on the beef market, there are indirect influences that are going to present an increasing economic challenge for beef farmers, especially through higher input prices. Since ration costs might present 40 to 70% of total variable costs, it follows that livestock ration formulation is becoming an increasingly important task also in management of beef sector. It is the fundamental lever in technological improvement that manifests in economic as also ecological terms. In order to help breeders to deal with these challenges many tools have been developed.

The most frequent technique applied is deterministic linear programming (LP). It is a classical approach to formulate animal diets and also appropriate tool to optimize human nutrition (Darmon *et al*., 2002). When focusing only on livestock diets, one can find out that the most frequent manner of utilizing LP technique is least-cost ration formulation, for the first time used by Waugh (1951). As any optimisation technique also LP has some drawbacks.

Common to all LP problems is single objective function as its basic concept. It means that one try to get the optimal solution in minimizing or maximizing desired objective within set of constraints imposed. From this point of view LP could be deficient method for ration formulation, since it exclusively relies on one objective (cost function) as the only and the most important decision criteria (Rehman and Romero, 1984; 1987). Lara and Romero (1994) are stressing that in practice decision maker never formulates ration only on the basis of a single objective, but rather on the basis of several different objectives, where economic issue is only one of many.

Another drawback of pure LP is also mathematical rigidity of constraints (right hand side – RHS), which usually results in fact that set of equations does not have a feasible solution (Rehman and Romero, 1984). This means that no constraints' (e.g. given nutrition requirements) violence is allowed at all, irrespective of deviation level. However, relatively small deviations in RHS would not seriously affect animal welfare, but would result in a feasible solution (Lara and Romero, 1994).

The most appropriate and commonly used method that partly overcomes listed problems of LP paradigm is weighted goal programming (WGP) (Tamiz *et al*., 1998). It is a pragmatic and flexible methodology for resolving multiple criteria decision making problems what ration formulation definitely is. Its advantage is also in familiarity with LP, since simplex algorithm is utilized to find the solution (Rehman and Romero, 1993).

The aim of this paper is to present developed spreadsheet tool, utilizing mathematical modelling techniques. In the first part a brief overview of WGP and penalty function is given. It is followed by a short description of the optimization tool. Then, the basic characteristics of the analysed case are presented, followed by the results and discussion. Brief conclusions are given in the last section.

MATERIAL AND METHODS

Weighted goal programming with penalty function

Weighted goal programming's formulation is expressed as mathematical model with a single objective (achievement) function (weighted sum of the deviations variables). Hence, the objective function in WGP model minimizes the undesirable deviations from the target goal levels and does not minimize or maximize goals themselves (Ferguson *et al*., 2006). In most cases obtained solution is compromise between contradictory goals, enabled with positive and negative deviation variables. Negative deviation variables are included in the objective function for goals that are of type "more is better" and positive deviations variables are included in the objective function for goals of type “less is better”. Since any deviation is undesired, the relative importance of each deviation variable is determined by belonging weights.

Since the goals are measured in different units and have different numerical values, the deviations are scaled with normalisation techniques (Tamiz *et al.*, 1998). With this process incommensurability is prevented and all deviations are expressed as ratio difference (i.e. (desired – actual)/desired) = (deviation)/desired)).

Rehman and Romero (1987) are pointing on the main drawback of WGP that is concerning the marginal changes. Namely, the method does not distinct between marginal changes within one observed goal; all changes (deviations) are of equal importance. This addresses another new issue in ration formulation example. Namely, 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, penalty function (PF) might be introduced into the WGP model (Rehman and Romero, 1984).

Our approach enables one to define allowed positive and negative deviation intervals in more stages for each goal separately. Dependant on goal’s characteristics (nature and importance of 100% matching) these intervals might be different. Sensitivity is dependant on number and size of defined intervals and the penalty scale utilised (s_i; for i = 1 to n). Penalty system is coupled with achievement function (WGP) through penalty coefficients.

Toll for two-phase beef ration formulation

The aim of the paper is to present a simple optimization tool for beef ration formulation, developed in MS Excel framework. It is designed as two phase approach (modules) based on mathematical programming techniques (LP and WGP with PF).

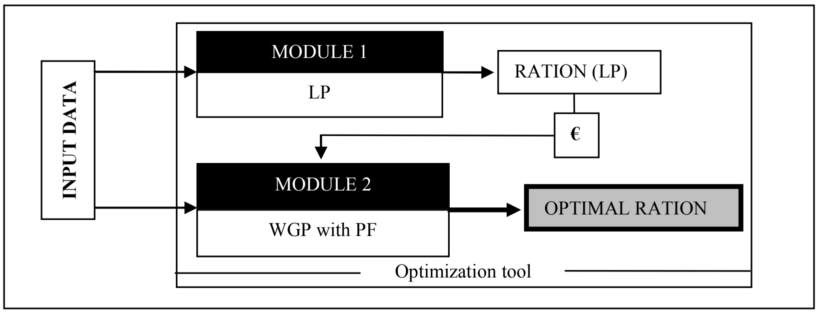

Figure 1. Scheme of the optimization tool.

The first module (Fig. 1) is based on LP paradigm and is an example of least-cost ration formulation. On the basis of the most important non-competitive constraints it searches for the roughly balanced ration at the least possible cost. On the solution obtained an estimate of cost magnitude expected might be made. Therefore the first module (LP) is as simple as possible (on constraints side), intended just to get crude cost estimation. Through cost function it is linked to the second module based on weighted goal program (WGP) with PF.

Mathematical formulation of the first and the second module

The first module (LP) is formulated as shown in equations (1), (4) and (7). It mostly relays on economic (cost) function (C) and satisfies only the most important nutrition requirements coefficients (b_i), known also as right hand side (RHS). In the first optimization phase one is searching for the ration at the lowest possible cost. Except minimum requirements (b_i) that should be met, prices (c_j) are the most important factor that dictates the level of *j*th feed (X_j) included into the ration.

$$\min C = \sum_{j=1}^{n} c_j * X_j \quad \text{such that} \tag{1}$$

$$\min Z = s_1 \sum_{i=1}^{k} w_i \frac{d_{i1}^- + d_{i1}^+}{g_i} + s_2 \sum_{i=1}^{k} w_i \frac{d_{i2}^- + d_{i2}^+}{g_i} \quad \text{such that} \tag{2}$$

$$\sum_{j=1}^{n} a_{ij} X_j + d_{i1}^- + d_{i2}^- - d_{i1}^+ - d_{i2}^+ = g_i \quad \text{for all } i = 1 \text{ to r and } g_i \neq 0 \tag{3}$$

$$\sum_{j=1}^{n} a_{ij} X_j \leq b_i \quad \text{for all } i = 1 \text{ to m} \tag{4}$$

$$d_{i1}^- \leq g_i - p_{i1}^{\min} g_i \quad \text{for all } i = 1 \text{ to r} \tag{5a}$$

$$d_{i1}^- + d_{i2}^- \leq g_i - p_{i2}^{\min} g_i \quad \text{for all } i = 1 \text{ to r} \tag{5b}$$

$$d_{i1}^+ \leq p_{i1}^{\max} g_i - g_i \quad \text{for all } i = 1 \text{ to r} \tag{6a}$$

$$d_{i1}^+ + d_{i2}^+ \leq p_{i2}^{\max} g_i - g_i \quad \text{for all } i = 1 \text{ do r} \tag{6b}$$

$$d_{i1}^+, d_{i1}^-, d_{i2}^+, d_{i2}^-, X_j \geq 0 \tag{7}$$

The second module (WGP with PF) is formulated as shown in equations (2) to (7). The achievement function (*Z*), expressed in equation (2) is defined as weighted sum of undesired deviation variables (d_{i1}^+, d_{i1}^-, d_{i2}^+, d_{i2}^-) from observed goals (g_i), multiplied with belonging penalty coefficients (s_1 and s_2). Obtained sum-product is subject of minimization (2). The relative importance of each goal is represented by weights (w_i) associated with the corresponding positive or negative deviations. To control deviations (5a, 5b, 6a, 6b) for each goal in WGP, penalty intervals (p_{i1}^{min}, p_{i1}^{max}, p_{i2}^{min}, p_{i2}^{max}) are in place. Because of the normalization process, only goals that have nonzero target values (3) could be relaxed with positive and negative deviations.

Obtained target value (*C*) in the first module enters into the second module (WGP with PF) as cost goal (3) that should be met as close as possible. This is also the only case where negative deviation is not penalised and also not restricted with intervals. All other constraints that do not have defined target value or do not have priority attribute are considered in equation (4). One of the main assumptions of the LP paradigm is also non-negativity that is considered for both models in equation (7).

Case analysis

The tool has been tested on a hypothetical case. It was presumed that beef fattening starts at 200 kg of live weight and stops at 600 kg. For the reason of more precise ration formulation, whole fattening period has been split into four breeding periods (100 kg weight gains) with different average daily gains. In the first period bulls gained 0.9 kg per day, while in the second and the third period the average daily weight gain is the same (1.1 kg). The last quarter last 100 day which means that average daily weight gain was 1 kg.

All nutritional requirements have been assessed with the spreadsheet model for ruminants' nutritional requirements estimation (Žgajnar *et al*., 2007). The most important constraints and goals are presented in Table 1. Basic set of constraints in both modules (LP and WGP with PF) is more or less the same; they differ only in mathematical sign when they are transformed into goals.

In the process of ration formulation one should also consider other 'non-nutrition' constraints. In our hypothetical case study we assume quite frequent example that might be met on Slovene beef farms. Because of our climate characteristics, the first or second grass mowing is usually conserved as hay and from rest the grass silages are prepared. This is why the amount of hay in the diet is restricted and in all four periods maximal amount of hay is set to 2 kg per day (Table 1).

Table 1. Nutrition requirements divided into four breeding periods, presented as constraints (LP) and set of goals in WGP

		Fattening period							
		200–300 kg		300–400 kg		400–500 kg		500–600 kg	
		LP	WGP I / II	LP	WGP I / II	LP	WGP I / II	LP	WGP I / II
ME	(MJ)	>6 311	6 311	>6 574	6 574	>7 547	7 547	>9 105	9 105
MP	(g)	>46 880	46 880	>45 228	45 228	>48 114	48 114	>54 260	54 260
DM	(kg)	<632	632	<718	718	<920	920	<936	936
CF min	(kg)	>114		>129		>166		>168	
CF max	(kg)	<164		<187		<239		<243	
Ca	(g)	>4 152	4 152	>4 368	4 368	>4 462	4 462	>5 200	5 200
P	(g)	>2 358	2 358	>2 596	2 596	>2 958	2 958	>3 300	3 300
Price	(cent)		*C1*		*C2*		*C3*		*C4*
Hay	(kg/day)	<2		<2		<2		<2	

LP = constraints for the first module (both scenarios); WGP I / II = constraints for the second module (both scenarios)

Initial version of WGP model involves six goals (Table 2). Importance of each goal is defined with weights (w_i) ranging between 0 and 100. For energy and protein requirements deviation intervals are very restricted, while for the rest of the goals deviations are more relaxed. For the dry matter intake that presents consumption capacity deviation intervals are defined only for underachievement of the goal, while overachievement is for practical reasons (consumption capacity) not allowed.

Table 2. Weights of defined goals and penalty function intervals for two scenarios

		Penalty function intervals								Goal weights
Goal		Interval 1				Interval 2				(w_i)
		p_{i1}^{-}		p_{i1}^{+}		p_{i2}^{-}		p_{i2}^{+}		
	Unit/scenario	SI	SII	SI	SII	SI	SII	SI	SII	
ME	(MJ)	1%		1%		5%		10%		70
MP	(g)	1%		1%		5%		10%		100
DM	(kg)	2%		0%		20%		0%		33
Ca and P	(g)	2%		5%		20%		30%		5
Price	(cent)	∞		4%	10%	∞		10%	15%	90

SI / SII = first/ second scenario; p_{i1}^{-}, p_{i1}^{+}, p_{i2}^{-}, p_{i2}^{+} = penalty intervals at the first and the second stage

Mineral appropriateness of the ration (preventing deficits as also toxic concentration) is assured through several safety nets (classical minimal and maximal constraints). This is also the reason why only two minerals (Ca and P) are considered as goals. Besides, their ratio should range between (1.1–1.5):1 in both modules to obtain solution. Applied approach of WGP with PF has been tested with varying extensions of cost deviation intervals (PF), which manifests in two scenarios (Table 2). In the first scenario price of obtained ration (WGP I) might deviate from set target value for the most 4% to be penalised within the first stage (s_1) and at maximum 10% within the second stage (s_2). In the second scenario (WGP II) both margins are relaxed (10% and 15%), while the penalty coefficients remain the same ($s_1 = 1$ and $s_2 = 5$).

In analyzed hypothetical case seven different feed (Table 3) and four different mineral-vitamin components were on disposal.

We assumed that all forage (hay, grass silage and maize silage) is prepared on the farm. Since these forages are usually not tradable, we estimate full cost of their production on the basis of 'model calculations' prepared by Agricultural institute of Slovenia (KIS, 2007). All other forage on disposal could be purchased at market prices (Table 3).

Table 3. Nutritive value of assumed feed

	DM	ME	MP	CF	Ca	P	Mg	Na	K	Price or FC*
	(g/kg)	(MJ/kg DM)	(g/kg DM)							(cent/kg)
Feed on disposal										
Hay	860	9.93	85.00	270	5.70	3.50	2.00	0.35	18.25	15.30
Maize silage	320	10.76	45.00	200	7.06	6.00	1.91	0.12	10.76	3.70
Grass silage	350	9.50	62.00	260	6.00	3.51	2.20	0.35	21.30	6.14
Grain maize	880	13.42	83.00	0.00	0.23	4.09	1.25	0.23	3.75	30.00
Wheat	880	13.47	88.00	0.00	0.57	3.86	1.59	0.45	5.00	32.00
Rapeseed cake	900	12.31	125.00	0.00	2.89	7.00	2.78	2.22	10.00	37.00
Soya meal	880	13.19	215.00	0.00	3.41	7.84	2.61	1.14	20.00	46.00

*Full cost approach

RESULTS AND DISCUSSION

A hypothetical case has been chosen to test developed spreadsheet tool. Formulated rations for all four fattening periods are presented in Table 4. Between three analysed cases (LP, WGP I and WGP II) there is a significant difference in formulated rations, but in all three cases they are quite simple. The major differences occur as result of allowed deviations in WGP with PF compared to LP and because of the changes in penalty intervals between both WGP analyses (scenario I and II). The difference manifests in quantities of maize silage, grass silage and soya meal, dependant on economic parameters, while the hay quantities are the same in all three cases and are at the highest level allowed (2 kg/day).

From obtained results it is obvious that soya meal and grass silage are substitutes for proteins. It is interesting that soya meal is included in the ration when prices are more important (LP and WGP I). With regard to Slovene circumstances one would expect the opposite situation. This fact could be explained with 'economies of scale' where costs for home produced forage (grass silage) are mostly dependant on tillage and quantity of yields. Due to high importance of cost goal (Scenario 1), deviations never exceed defined goals that much to be in the second interval of overachievement, nor in the second scenario where intervals are extended. This is not the case in other goals (dry matter intake, Ca and P), where also the second (s_2) penalty interval operates.

From nutrition quality aspect we can conclude that WGP supported by PF yields more balanced ration as LP. These confirm also absolute sums of total relative deviations from nutritional requirements (as one of those parameters that measure the 'quality' of obtained results). This is significantly manifested in the second and third fattening period (WGP I and especially WGP II), where penalty system reduces energy surpluses. Even though WGP I rations are more balanced in all four breeding periods, they are for only 4% more expensive as least-cost ration (LP). This fact is emphasised in the second scenario, where intervals for cost deviation are relaxed. As result they increase in comparison to the first scenario for 0.6 to 3.2%, but total deviations (as quality parameter) improve for 0.6 up to 9.8%, respectively. This could be understood as contradiction between nutrition quality and economics. However, when rations are not balanced – even if individual parameter requirements are fulfilled – one can not expect to achieve anticipated daily gains, resulting in higher per unit production costs.

Table 4. Obtained results and daily rations formulated with spreadsheet tool and cost penalty function scenarios

	Fattening period, daily ration												Whole period, 394 days 200–600 kg		
	200–300 kg			300–400 kg			400–500 kg			500–600 kg					
	LP	WGP I	WGP II	LP	WGP I	WGP II	LP	WGP I	WGP II	LP	WGP I	WGP II	LP	WGP I	WGP II
Duration, days	112			91			91			100			394		
Feed used, kg/day															
Hay	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	788	788	788
Maize silage	8.81	4.05	3.99	14.93	7.06	4.14	21.17	9.04	6.31	19.39	13.17	10.68	6 211	3 237	2 465
Grass silage		6.18	6.20		8.31	11.92		9.91	13.15		8.61	11.18	0	3 211	4 093
Soya meal	0.77	0.41	0.43	0.72	0.34	0.17	0.41	0.17	0.03	0.62	0.08		251	100	66
Mineral components used, g/day															
Limestone	13.28	8.29	8.50	6.05	9.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2 038	1 831	952
Bovisal	0.00	0.00	0.00	0.00	0.00	1.59	0.00	0.00	0.00	0.00	0.00	0.00	0	0	145
Salt	15.3	20.9	20.9	20.1	26.7	29.5	24.5	30.5	33.4	23.5	31.5	33.6	8 132	10 700	11 423
Price, cent/day	99.6	103.5	104.2	120.0	124.8	128.6	129.0	134.2	137.9	145.1	150.9	154.3			
Price, EUR/period	111.5	116.0	116.7	109.2	113.5	117.0	117.4	122.1	125.5	132.0	137.3	140.4	470.12	488.92	499.60
Requirements deviations, %															
ME	0.0	0.0	0.0	6.4	1.0	1.0	14.3	0.2	0.0	0.0	1.0	0.0			
MP	0.0	– 0.6	0.0	0.0	– 1.0	0.0	0.0	– 1.0	0.0	0.0	– 1.0	0.0			
DM	– 7.1	– 1.3	– 1.4	– 9.3	– 8.5	– 6.2	– 12.2	– 18.3	– 16.9	– 9.3	– 3.4	– 2.9			
Ca	0.0	– 2.0	– 2.0	0.0	0.0	– 6.4	20.1	5.1	5.6	6.7	11.3	10.4			
P	34.2	15.0	15.0	39.0	12.6	5.0	52.3	13.0	6.2	44.0	28.5	22.0			
Total deviation	41.2	19.0	18.4	54.6	23.1	18.6	98.8	37.6	28.7	60.0	45.2	35.4			
Price deviation, %	0.0	4.0	4.6	0.0	4.0	7.2	0.0	4.0	6.9	0.0	4.0	6.4			
Ratio between minerals															
Ca:P	1.3	1.5	1.5	1.2	1.5	1.5	1.2	1.4	1.5	1.2	1.4	1.4			
Physical ration attribute															
CF, kg/day	1.03	1.29	1.28	1.42	1.67	1.81	1.82	1.94	2.06	1.87	2.30	2.38			
CF, %	20	23	23	20	23	25	20	24	25	20	23	24			
DM, kg/day	5.2	5.6	5.6	7.2	7.2	7.4	8.9	8.3	8.4	9.3	9.9	10.0			

LP = solution obtained by the first module; WGP I = solution obtained by the second module, first scenario; WGP II = solution obtained by the second module, second scenario

CONCLUSIONS

From the results obtained it is apparent that combination of deterministic linear programming technique and weighted goal programming supported by penalty function is useful approach, especially if this is the ‘engine’ from user-friendly optimization tool. Namely, it enables one to formulate least-cost ration not taking to much risk of worsening the ration’s nutritive value that is the main drawback of LP.

Refined control is possible through penalty function system that differs between different deviation sizes for each goal separately. This is becoming more and more important in nutrition management.

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