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OPTIMIZATION OF BULLS FATTENING RATION APPLYING MATHEMATICAL DETERMINISTIC PROGRAMMING APPROACH

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Abstract

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The more specialized beef farms demand the more precise management to achieve economically justified outcome. Undergoing CAP reform and market liberalisation are just some of numerous factors that are going to have significant impact especially on expenditures rise in the beef sector. Forage variable cost already range between 40 % and 70 % of total variable cost of bulls fattening in Slovenia. Ration formulation is therefore becoming fundamental lever of beef farms management. To support beef farmers we present a user friendly tool developed in Excel framework that utilizes mathematical deterministic programming techniques. Paper illustrates the supplementation of linear program by weighted goal program resulting in more efficient beef ration formulation. User can decide either to minimize forage costs, to achieve more balanced ration or to implement own weights about importance of both, always based on feed at his/her disposal. In this way the tool developed is applicable for practical decision making on beef farms, enabling cost-effective and nutrient-balanced beef production.

Key words: linear programming, weighted goal programming, ration optimization, beef farming, beef economics

Abbreviations: a_{ij} - The quantity of the i-th nutrient in one unit of j-th feed; b_i - The amount of the i-th resource available – right hand side (RHS); C - Objective function (LP); CF - Crude fibre; c_j - j-th feed cost; d_i+ - Positive deviation variables including over achievement of the i-th goal; d_i- - Negative deviation variables including under achievement of the i-th goal; DM - Dry matter; g_i - Expected daily requirement of the i-th nutrient (goal); LP - Linear program; MCDM - Multi criteria decision making; ME - Metabolic energy (expressed in MJ - mega Joule); MP - Metabolisable proteins; MVM - Mineral-vitamin mixture; WGP I- Weighted goal programming, the first scenario; WGP II - Weighted goal programming, the second scenario; WGP - Weighted goal program; w_i - Weight expressing the relative importance of achieving of the i-th goal; X_j - The level of j-th feed; Z - Objective function (WGP)

Introduction

Process of further commercialisation of already specialized agricultural holdings is demanded through numerous factors. Progressive abolition of initial CAP scheme and increasing environmental and other public demands are leading to rapid market fluctuations. These facts already have and are going to have also in

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the future significant impact on beef farming. Besides direct consequences on beef market there are indirect influences that are going to provoke an increasing economic challenge for beef farmers. One of them is undoubtedly (further) reform of the CAP in relation to growing importance of renewable energy that is going to happen. As a result energy crop production has come to offer an alternative for agricultural enterprises as it opens new income sources for arable farmers besides food production. Simultaneously additional demand is going to lead to higher prices and better economic position of arable farmers is expected (Zeller and Hдring, 2007). This non-food production and positive effect on prices is definitely going to cause significant issue for livestock sector, where cereals and some other crops are indispensable inputs.

Slovene gross margin calculations (Jeric, 2001) show that feed expenses in beef production range between 40 and 70 % of total variable costs. Formulation of balanced and as cheap as possible daily ration for animals is therefore becoming the fundamental lever for improving economic situation. It includes both choosing the most suitable and cheapest feed that is at disposal (on the farm and/or market) in that moment as in the meaning of its efficient use. The latter means that ration should be balanced not only on the level of energy, proteins and fibre but also on the level of macro and micro minerals and vitamins. Finally this results in animals' health, consequentially also in production and profitability.

Nutritionist doctrine assures that animals use feed most efficient when the nutrients in the daily rations match their daily requirements. Such ration is termed as 'balanced ration'. As already stated there are numerous factors that should be taken into consideration to prepare balanced rations. In order to help breeders to deal with these challenges many tools have been developed. In the literature we can find numerous examples utilising mathematical techniques for solving nutrition management problems. The most frequent technique used is deterministic linear programming. 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 linear programming technique is least-cost ration formulation. For the first time it has been used by Waugh (1951). He optimized livestock ration in economic terms with classical linear program. In the literature one can find this technique also to assess the value of forages in providing the energy requirements of growing animals (Magowan and O'Callaghan, 1986), to maximize intake of energy, nitrogen, phosphorus or sodium, or to minimize feeding time of free-living beavers (Nolet et al., 1995).

Common to all minimisation or maximisation problems is single objective function as the basic concept of linear programming. 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 linear programming could be deficient method for ration formulation (Rehman and Romero, 1984; 1987). In many real life situations like livestock ration formulation, decision maker does not search for optimal solution on the basis of a single objective (usually cost minimization of the diet), but rather on the basis of several different objectives (Lara and Romero, 1994). Rehman and Romero (1984) mentioned as the main weakness of utilizing the linear program for least-cost ration formulation in exclusive reliance on cost function as the only and the most important decision criteria. After all, this is very rigid assumption. Ration formulation is namely much more complex process and economic issue is only one of many objectives on one hand and constraints on the other.

Rehman and Romero (1984) are also mentioning mathematical rigidity of constraints, which usually results in fact that set of equations does not have a feasible solution. This means that no constraints' (e.g. given nutrition requirements) violence is allowed at all, irrespective of deviation level. On the other hand there are no upper limits (minimization case) or lower limits (maximization case). The latter could reflect in rise of prime-cost or, what is lately becoming even more important, increase pollution with surplus elements due to unbalanced ration.

Limitation problem could easily be solved by adding additional constraints, but this could rapidly lead to over-constrained and complex model that has no feasible solution (Lara, 1993). Of course this rigidity could not yield an applicable solution. In other words relatively small deviations in right hand side (RHS) would not seriously affect animal welfare, but would result in a feasible solution (Lara and Romero, 1994).

The most appropriate method that partly overcomes listed problems of linear program is weighed goal programming (WGP). It is a pragmatic and flexible methodology for resolving multiple criteria decision making (MCDM) problems what ration formulation definitely is. Tamiz et al. (1998) are pointing out that goal programming has been and still is the most widely used MCDM technique. It is an appropriate tool to deal with nutrition management problems and has been introduced by Rehman and Romero (1984). Based on linear programming it is special form of it (Zadnik Stirn, 2001) and could be therefore also solved by simplex algorithm (Rehman and Romero, 1993).

Important part in formulating WGP is to set targets and their values. This is actually domain of nutritionists and experts from this field of science. Basic concept of WGP formulation is to set weights to belonging goals. One of many possibilities could be sensitivity analysis, where only binding goals should be considered. Rehman and Romero (1993) strongly recommend its application, especially when one is not confident about priorities of the goals. Quality of obtained results is strongly dependent on selection of preferential weights. To reduce bias of obtained result sometimes also additional technique to define weights should be used (Gass, 1987).

In most cases obtained solution is compromise between contradictory goals. Compromise is enabled with deviation variables. WGP in comparison with LP therefore allows deviations, but they are not desired. 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. 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’. The relative importance of each deviation variable is determined by belonging weights. The objective function is defined as 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).

Observed goals are measured in different units of measurement and this is why deviation variables could not simply be summed up and taken as absolute values. Therefore all objective function coefficients have to be transformed with mathematical process of normalization (equation 1) into the same units of measurement.

$$w_i\left(\frac{d_i^+}{g_i}\right) + w_i\left(\frac{d_i^-}{g_i}\right) \qquad (1)$$

Material and Methods

Optimization tool for beef ration formulation has been developed in Microsoft Excel framework. In its basic version it includes a macro called solver that in the case of linearity utilizes simplex algorithm. Our aim is to describe how combination of LP and WGP could be used to prepare user friendly tool for ‘optimal’ ration formulation, illustrated by beef production example. It is developed in the shape of an open spreadsheet model. For any analysed case it could be rapidly updated with appropriate input data. Also the set of goals and their priorities could be changed. Initial

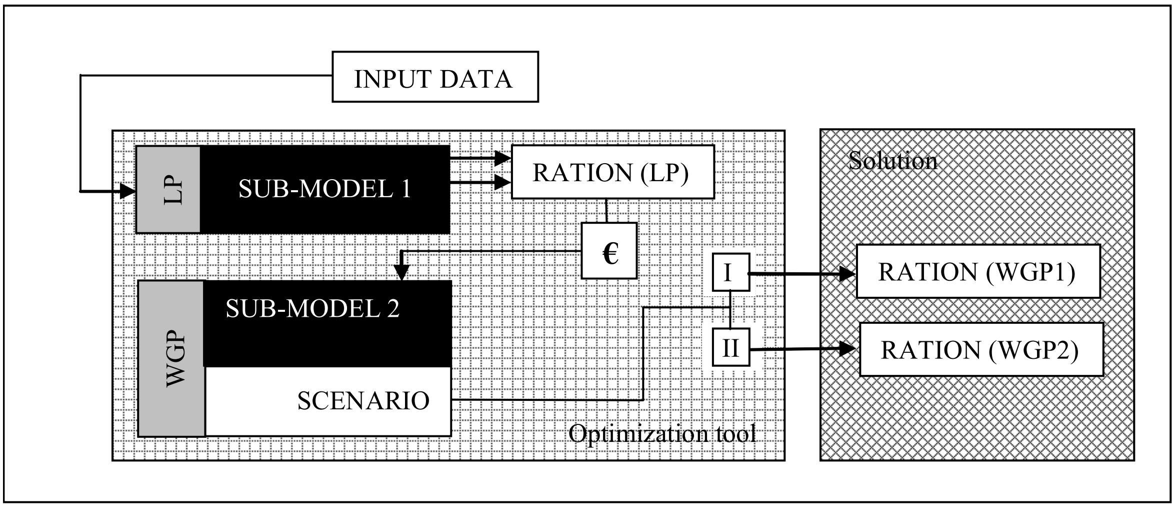

Fig. 1. Scheme of developed tool for beef ration formulation

model version is linked with another already developed tool for estimation of ruminants' nutritional requirements (Zgajnar et al., 2007) that is the main source of 'technological' input data.

In the article presented tool for beef ration formulation is based on two sub models (Figure 1). The first sub-model is actually 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. As already pointed out, LP has some drawbacks that could reflect in complex practical situation as useless solution. Therefore the second sub-model, supported by WGP, should formulate especially from nutrition viewpoint more reliable ration. One of the goals in the second sub-model is also to draw close to obtained ration cost from the first sub-model. Combination of both should yield more nutritionally balanced ration that is in terms of costs comparable with the obtained solution form LP.

The first sub-model could be mathematically formulated as shown in equations (2) to (4). 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). From practical viewpoint of presented approach, LP might neglects ratios between the four observed mineral elements if they in real case situation lead into an over-constrained model that has no feasible solution.

First (LP) sub-model:

Obtained LP solution should meet all nutrition requirements imposed at lowest possible cost (c_j). For all purchased feed we consider market prices and for home produced feed marginal costs. These two fac-

$$\min C = \sum_{j=1}^{n} c_j * X_j \quad \text{such that} \tag{2}$$

$$\sum_{j=1}^{n} a_{ij} X_j \le b_i \quad \text{for all } i = 1 \text{ to m, and} \tag{3}$$

$$X_j \ge 0 \tag{4}$$

tors are mostly dependent on markets situation including CAP measures in place and of course also on the technology applied. Technological coefficients (a_{ij}) present the quantities of the ith nutrient in one unit of the jth feed.

Second (WGP) sub-model:

$$\min Z = \sum_{i=1}^{k} w_i \frac{d_i^- + d_i^+}{g_i} \quad \text{such that} \tag{5}$$

$$\sum_{j=1}^{n} a_{ij} X_j = g_i \quad \text{for all } i = 1 \text{ to r and } g_i = 0 \qquad (6)$$

$$\sum_{j=1}^{n} a_{ij} X_j + d_i^- + d_i^- = g_i \quad \text{for all } i = 1 \text{ to r and } g_i \neq 0 \qquad (7a)$$

$$\sum_{j=1}^{n} c_j X_j + d_i^- + d_i^- = C \quad \text{for all } i = 1 \text{ to r} \qquad (7b)$$

$$\sum_{j=1}^{n} a_{ij} X_j \leq b_i \quad \text{for all } i = 1 \text{ to m} \qquad (8)$$

$$d_i^+, d_i^-, X_j \geq 0 \qquad (9)$$

The meanings of the first and the second sub-model notations:

Z and C - objective function;

a_{ij} - the quantity of the *i*th nutrient in one unit of *j*th feed;

X_j - the level of *j*th feed;

c_j *j*th feed cost;

b_i - the amount of the *i*th resource available - right hand side (RHS);

g_i - expected daily requirement of the *i*th nutrient (goal);

w_i - weight expressing the relative importance of achieving the *i*th goal;

d_i^+, d_i^- - positive and negative deviation variables including over- and under achievement of the *i*th goal

WGP sub-model could be formulated in mathematical terms as shown in equations (5) to (9). The objective function is defined as weighted sum of undesired deviation variables from observed goals (5) and is subject of minimization. The relative importance of each goal is represented by weights (*w*) associated with the corresponding positive or negative deviations. Because of the normalization process, only goals that have nonzero target values (7a, 7b) could be relaxed with positive and negative deviations. In other case (6) we would face forbidden division by zero.

The second sub-model is directly connected with the first one through cost function (7b). Obtained target value (*C*) from the first sub-model enters in the second sub-model as goal that should be met as close as possible. All the rest constraints that do not have defined target value or do not have priority attribute are considered in equation (8). One of the main assumptions of the linear programming is also non-negativity that is considered in equation (4) for the first sub-model and in equation (9) for the second one.

Input data

The primal aim of developed tool is to assist breeders in formulating a ration that is both from nutritional and from economic viewpoint more efficient. It could be used also to assess the variable cost of feed used.

In this paper we are going to present a hypothetical case. We presumed that beef fattening starts at 200 kg of live weight and stops at 650 kg. This fattening horizon has been divided into three periods with different average daily weight gains (Table 1). Nutritional requirements are presented in absolute values (Table 2) and have been assessed with the spreadsheet model for ruminants' nutritional requirements estimation (Zgajnar et al., 2007). It calculates requirements for metabolic energy (ME), metabolisable proteins (MP), dry matter consumption (DM), mineral elements (Ca, P, K, Na and Mg) and the minimal and maximal crude fibre (CF) for any breeding period investigated.

Table 1
Assumptions concerning growth pattern for beef cattle fattening

Indices	Fattening period		
	First	Second	Third
Average daily weight gain, g/day	900	1100	1000
Starting live weight, kg	200	350	500
Finishing live weight, kg	350	500	650
Fattening duration, day	167	136	150

Table 2
Nutrition requirements divided into three breeding periods, presented as constraints (LP) and goals (WGP) with belonging weights

Indices	Fattening period						Weights within scenario	
	First		Second		Third			
	LP	WGP	LP	WGP	LP	WGP	S I	S II
ME (MJ)	>9.881	9 881	>11.003	11 003	>14.085	14 085	70	70
MP (g)	>71.114	71 114	>71.335	71 335	>82.950	82 950	100	100
DM (kg)	<1.036	1 036	<1.310	1 310	<1.467	1 468	33	33
CF min (kg)	>186	>186	>236	>236	>264	>264		
CF max (kg)	<269	<269	<341	<341	<381	<381		
Price (eurocent)		*C1*		*C2*		*C3*	1	100
Ca (g)	>6.460	6 460	>6.582	6 582	>7.800	7 800	5	5
P (g)	>3.735	3 735	>4.297	4 297	>4.950	4 950	5	5
Na (g)	>836	836	>961	961	>1.275	1 275	5	5
Mg (g)	>1.171	>1.171	>1.441	>1.441	>1.800	>1.800		
K (g)	>9.320	>9.320	>11.791	>11.791	>13.208	>13.208		
Ca:P (%)	(1.5-2):1		(1.5-2):1		(1.5-2):1			
K:Na (%)	(5.5-10):1		(5.5-10):1		(5.5-10):1			
Max hay (kg/day)	2		2		2			
Min grass silage (kg/day)	5		5		5			

The most important constraints for all three fattening periods are presented in Table 2. Basic set of constraints in both sub-models (LP and WGP) is more or less the same. Constraints presented in Table 2 differ only in mathematical sign when they are transformed into goals. The first sub-model (LP) claims only satisfaction of minimum or maximum constraints. As stated earlier this might lead into unrealistic solution. Linear sub-model is therefore included into the tool foremost to give rough estimate of the lowest possible cost for the animal diet that could be formulated with disposable feeds.

In the process of ration formulation one should also consider other 'non-nutrition' constraints. For example this could be quantity of feed that must or might be included into the diet. 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 grass mowing is gathered in hay and all the rest are gathered in grass silage. This is why both models must take into consideration maximal constraint of 2 kg hay per day and at least 5 kg of grass silage per day (Table 2).

Initial version of presented WGP model includes seven goals. Importance of each goal is defined with weights ranging between 0 and 100. As the most important goal in our case is satisfaction of protein requirements. We vary importance of 'cost goal' that manifests in two scenarios (Table 2). In the first scenario economics has rather low importance, while in the second scenario it has the highest possible weight. Satisfaction of energy requirement has in both scenarios the same weight. Much lower weight is foreseen for the dry matter intake that presents consumption capacity. At first glance it seems that all three mineral goals (Ca, P and Na) are, due to low weights, almost neglected. However this is not true. Developed model includes several safety nets that prevent mineral deficits as also their toxic concentrations in the ration. Nutritionists' doctrine says that it is more important to satisfy ratios between Ca and P and also between K and Na than to meet the estimated mineral requirements.

In analyzed hypothetical case we assumed that both sub-models might choose between six different feed and four different mineral-vitamin components (Table 3). Described feed characteristics are mostly dependent on soil structure, fertilization management and intensity of production.

We assumed that hay, grass silage and maize silage are grown on the farm. Since these forages are usually not tradable, we estimate variable cost of their production. Fixed costs were not considered at all. All the rest forage on disposal could be purchased at market prices (Table 3).

Results

Presented tool for nutrition management is built as an open system, which means that any beef case could be analysed. A hypothetical case has been chosen to test developed approach. Fattening time has been divided into three periods with different daily weight gains (0.9 kg, 1.1 kg and 1.0 kg). The first period starts at 200 kg body weight and than in each period bull gains 150 kg on weight. Fattening stops at 650 kg body weight.

Formulated rations for all three breeding periods are presented in Table 4. In the first period there is significant difference between formulated rations. Quantity of hay is the same in all three rations and achieves the highest allowed quantity (2 kg/day). Grain maize and rape seed cakes are included only in the second ration (WGP I) where the price is not of so high importance. From nutrition viewpoint this ration is the most suitable what manifests also in the lowest total deviation from nutrition requirements. The latest has been observed as one of those parameters that measures the 'quality' of obtained results. Total deviation has been in WGP I solution almost two times lower than in LP solution and 1.3 times lower than in WGP II solution where priority of cost goal is the same as satisfaction of protein target value. The third solution is from nutrition viewpoint still satisfactory. It misses protein requirements for one percent and deviation from mineral requirements are slightly higher than in WGP I. It is only 2.7 % more expensive than the least-cost ration compared with 31.1 % cost increase of WGP II solution. In all three formulated diets mineral requirements are covered only with limestone and salt. This is due to rich mineral content assumed in used feedstuff.

The second fattening period has the highest average daily weight gain (1.1 kg/day) that result in the shortest fattening period. Linear program suggest very simple ration that is again the cheapest, but with 21.2 % energy surplus. Therefore protein-energy ratio is totally unbalanced. The second (WGP I) and the third daily ration (WGP II) differs from the parallel rations in the first period mostly in increased inclusion of grass and maize silage and decrease of soya meals and rapeseed cakes. From nutrition viewpoint most balanced ration (WGP I) in the second fattening period is 21.1 % more expensive than LP one, but total deviation is for 148 % reduced in comparison with LP and 51 % in comparison with WGP II. The latest ration is from nutrition viewpoint much better than LP solution, and for practice due to its simplification compared to WGP I and costs lowered by 18.6 % the recommended one.

For the third fattening period our tool yields solutions with comparable facts already pointed out. Cost of the feed included into ration plays significant role in LP's and WGP II solutions. WGP II yields better ration for the same daily price as LP. In this period the highest difference between ration costs is noticed. Expenditure of WGP I ration is for 65.6 EUR higher than in the case of still balanced WGP II ration during the third period only, and for the whole fattening period examined even 120 EUR per animal higher. This dif-

Table 3
Nutritive value of assumed feed

Indices	DM, g/kg	ME, MJ/kg DM	MP	CF	Ca	P	Mg	Na	K	Price/VC, cent
			g/kg DM							
Feed on disposal										
Hay	860	7.52	64.33	200	4.31	2.65	1.51	0.26	13.81	8.02
Grass silage	350	2.93	19.1	800	1.85	1.08	0.68	0.11	6.56	4.04
Maize silage	320	3.03	12.67	600	1.99	1.69	0.54	0.03	3.03	2.55
Grain maize	880	10.39	64.28	0	0.18	3.17	0.97	0.18	2.9	30
Soya meal	880	10.21	166.5	0	2.64	6.07	2.02	0.88	15.49	46
Rapeseed cake	900	9.75	99	0	2.29	5.54	2.2	1.76	7.92	37
Mineral and vitamin components										
MVM 1*	930	0	0	0	171.86	57.2	0	110.53	0	58.08
MVM 2*	930	0	0	0	130.94	81.84	29.46	98.21	0	67.56
Salt	950	0	0	0	0	0	0	334.4	0	50
Limestone	950	0	0	0	818.4	0	0	0	0	16.4

*Commercial names of mineral – vitamin mixtures are Bovisal 1 and Bovisal 2

ference is difficult to be outweighed by likely small increase of daily weight gains when WGP I solutions would be followed in practical feeding.

Discussion

The results showed that mathematical deterministic programming techniques can be successfully applied in the ration formulation process. In the presented analysis an example has been solved for illustration that utilised approach partly mitigates the mentioned drawbacks of LP (single objective function), which can still be useful to estimate the lowest possible fodder cost.

It is logical that daily ration costs are higher in both WGP solutions. Price increase is mostly dependent on weights set to cost function (I=1, II=100). In this paper we are presenting two extreme economic situations, while the solution to be followed in practice should be somewhere between both. Anyhow, economic weight is likely to be high, therefore close to 100.

The structure of the rations would be much different if all feed would be produced on the farm. Significant discrepancy is expected especially in LP and WGP II solutions, where feed cost has high importance.

Obtained rations are satisfactory, especially if we consider only foreseen nutrition requirements in initial version of the tool. But if we focus on micro elements and vitamins rations presented very likely do not meet animal requirements. This issue could be simple solved by setting new constraints for minimal incorporation of any (one) mineral-vitamin components (e.g. Bovisal 1 or Bovisal 2) into the ration. Their quantities are usually prescribed by producer.

Conclusions

Presented approach of combining linear programming with weighted goal programming enables to consider more than just one objective. This is becoming more important also in nutrition management and seems to be emphasised in line with general globaliza-

Table 4
Obtained results and daily rations formulated with LP and WGP scenarios

Duration, days	Fattening period, daily ration									Whole period (453 days)		
	First			Second			Third					
	LP	WGP I	WGP II	LP	WGP I	WGP II	LP	WGP I	WGP II	LP	WGP I	WGP II
	167			136			150			453		
Feed used, kg/day												
Hay	2	2	2	2	2	2	2		2	907.9	607.9	907.9
Grain maize		0.82			0.82			1.9		0	532.1	0
Maize silage	0.65	1.91	5.25	18.56	5.22	7.43	16.77	6.45	12.18	5.147.1	1 997.50	3 714.50
Grass silage	12.03	5.83	5.91	5.02	10.21	10.9	7.62	14.81	10.48	3.834.4	4 583.70	4 043.00
Soya meal	0.05		0.38			0.15				8.8	0	83.3
Rapeseed cake		0.59			0.18					0	122.8	0
Mineral components used, g/day												
Limestone	2.22	11.47	4.04		5.69	2.25		10.82	4,39	370.4	4 312.60	1.638.2
Salt	27.03	16.36	21.37	29.88	27.41	30.85	32.67	30.13	33.67	13 478.40	10 978.70	12.816.1
Price, cent/day	70	91.8	71.9	85.1	103.1	87.3	91.1	134.8	91.1			
Price, EUR	116.7	153.1	119.9	116.1	140.6	119	136.7	202.3	136.7	369.5	495.9	375.6
Price deviation from LP, %	0	31.1	2.7	0	21.1	2.5	0	48	0	0	34.2	1.7
Requirements deviations, %												
ME	1.1	0	0	21.2	0	0	6.7	0	0,0			
MP	0	0	-1	0	0	-1	0	0	-0.7			
Total deviation*	359.2	198	261	319.5	171.7	222.4	273.7	179.4	253			
Ratio between minerals												
Ca:P	1.7	1.6	1.5	1.5	1.5	1.5	1.6	1.5	1.5			
K:Na	10	10	10	10	10	10	10	10	10			
Physical ration attribute												
CF, %	25.8	19.8	23	22.3	21.9	23.9	22.8	19.7	23.6			
DM, kg/day	6.2	5.7	5.8	9.5	7.9	8.1	9.8	9	9.3			

* includes percentage deviation from requirements for ME, MP, DM, Ca, P, Mg, Na and K

tion impacts. Even though the tool presented is from nutrition viewpoint not very precise, the approach enables to formulate least-cost ration not taking too much risk of worsening its nutritive value. This type of risk could be mitigated by careful weights appointment. With more detailed set of nutrition constraints and goals the difference between the 'practical uses of the nominee ration' would be even higher in favour of weighted goal programming technique.

Results obtained by tool presented in the paper are directly applicable assuming there is 'perfect' data availability about costs, quantity and quality of feed on disposal. But we know this is never the case. Therefore one can address questions like: "How does variability in feedstuffs affect the decision we make in formulating rations?" This is definitely an interesting issue that should be answered. In the modelling sense it means to deviate from deterministic to stochastic concept.

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