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An Analysis of Eco-Efficiency Scenarios in Dairy Farming: Simulations of Milk Production

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Abstract. Farming eco-efficiency requires the approach of economic efficiency, as well as the impact upon the environment. The analysis of eco-economic efficiency of a dairy farm was done by simulating different levels of milk production. The study starts from the real situation of a farm in which the crops and forage basis, productions, rations, the cost and income were quantified and the nutrient balances P, N and K, as well as the profit value were calculated. By simulating with ±25% the peak milk production, 4 scenarios were enacted with the use of the N-CyCLE software: the minimization of P, N and K balances, respectively the profit maximization. The increase of milk production correlates positively with the profit ($r=+0.935$ on $p<0.001$) and also with the nitrogen balance ($r=+0.471$ on $p<0.05$). The four scenarios significantly influence the value of profit – the scenario towards maximizing the gross margin generates the highest profit (896.5 euro/cow), and the scenario towards nitrogen minimum balance generates the lowest profit (503.08 euro/cow). The eco-economic character of the farm was obtained using barycentric coordinates of ½ weights from the values of N's scenario at the gross margin rates with the computer algebra software Maple13. The optimization of milk production through gross margin maximization and the nitrogen minimization allows expressing the eco-economic character; in this case, at a peak production of 40 kg/day, the farm acquires an eco-economic character when the nitrogen balance is 91.5 kg N/ha/year and the profit is 769 euro/cow.

Keywords: dairy farm, eco-efficiency, N balance, gross margin, milk yield.

INTRODUCTION

Animal production must be seen from several perspectives: economic efficiency, environment sustainability and social acceptance. From an economic perspective, the increase of production is desired with a view to raising the difference between income and costs, respectively the profit growth. In light of environment sustainability, increased production in dairy farms must be approached in terms of the impact upon the environment of the entire resulting production, involving particularly nitrogen (N), potassium (K) and phosphorus (P). When both perspectives are taken into account, the eco-economy of production may be mentioned. As a rule, any eco-economic production involves a maximum profit, without altering the environmental conditions.

In animal husbandry and crop farming 13 nutritive elements are necessary *(Whitehead 2000)*, but in the case of dairy farms, the emphasis is on nitrogen and phosphorus due to their major role in both forage/feed production, and in their impact upon the environment *(Tamminga 2003);* from the N and P inputs considered, 85% of nitrogen and 67% of

phosphorus are lost in the environment (Mouritz *et al.* 2003). Increasing milk production requires the increase of the protein amount in the feed ratio, which is an expensive resource (Hopkins and Whitlow 2001), with a variable utilization yield. Administrated in excess, proteins are released in the environment in the form of nitrogen, in a quantity proportional to the intake (Stallings *et. al.* 2009).

The aim of this study is to estimate the eco-economic efficiency (the balance of P, N and K nutrients and respectively the profit) of a dairy farm through quantitative simulation of milk production.

MATERIALS AND METHODS

The dairy farm, viewed from the perspective of a whole system and not only focused on the dairy unit, has an effective of 38 dairy cows, Holstein breed, maintained in an open system, in a closed shelter with removable walls, mono-diet feeding from stock, with a single feed mixture.

The quantification of inputs corresponding to the feed basis inventoried was performed quantitatively by estimating the productions expressed in tones/year and qualitatively through the chemical composition value and variability of the main types of forage used in dairy cows' feed in the farm. The N-CyCLE Application facilitated the introduction of data targeting livestock, milk production, milk compounds, growing areas, ratio composition and economical parameters, manure management, fertilization and crop rotation.

In order to calculate the profit, both proportional costs and indirect ones were considered. The income is mainly provided by milk; 320.170 kg milk are sold per year, with 0.29 euro/kg, with 3,8% fat and 3.2% protein. Additionally, the milk with more than 3.2% protein and 3.8% fat, additionally gets 4.65 euro/kg protein and 3.49 euro/kg fat. The productive outputs consisted of milk, meat and manure production.

The procedure and equipment of two autolaboratories were used in order to quantify inputs and outputs; analyses of the forage basis were performed, as well as quantitative and qualitative determinations upon the production and metabolic status of animals – the chemical composition of the forage, the ratio formulation and the metabolic surveillance through milk, blood, urine, rumen liquid and fatty deposits.

The testing of hypotheses was carried out using N-CyCLE (Nutrient-Cycling Crops Livestock Environment) in order to record the dynamics of the income, the balance of nitrogen, phosphorus and potassium, when milk production exhibits increases, respectively decreases. The N-CyCLE software is used in order to optimize the feeding strategies, forage crops and manure utilization in dairy farms (Pellerin *et. al.* 2010). The simulation of eco-efficiency was realized with the computer algebra software Maple13.

Starting from the existing productive value of the farm, variations were simulated with ±25% of peak milk production and 4 scenarios: minimizing the balance of P, N and K, respectively maximizing profit.

RESULTS AND DISCUSSIONS

When simulating the quantitative milk production, two linear correlations were identified, both positive with Pearson coefficients with large values, as follows:

i) the peak milk production is positively and significantly correlated with the gross margin r=+0.935 on p<0.001;

ii) the peak milk production is positively and significantly correlated with the nitrogen balance (N) r=+0.471 on p<0.05;

The simulation of peak production variations induced modifications of the gross margin in the four tested scenarios (Table 1).

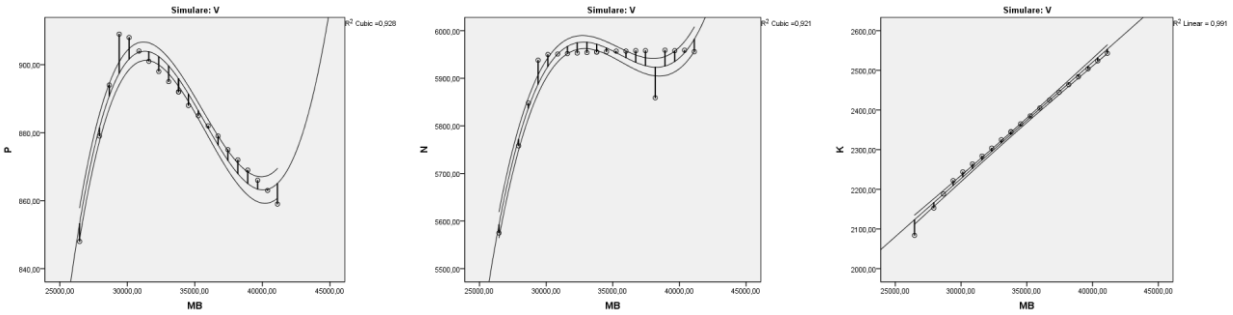
The averages of the profit generated through the four scenarios are significantly different (*F=71.778 on p<0.001*); differences between the profit averages generated by the scenarios of the maximum gross margin with the minimum potassium balance (*14290.43 euro on p<0.001 Tukey Test*), a minimum nitrogen balance (*14988.05 euro on p<0.001 Tukey Test*) and a phosphorus minimum balance (*14006.33 euro on p<0.001 Tukey Test*) are statistically significant, suggesting a dichotomy between economic efficiency and the ecological compound of the farm, viewed as a unique system. In terms of profit, the election of scenarios of maximizing the gross margin and minimizing the nitrogen proves to be conclusive, because the differences in the obtained profit can be sustained by means of scenarios of minimizing N, respectively minimizing P or K.

Tab. 1

The average gross margin in the four possible scenarios

Scenario	Profit / farm (euro)		Profit/cow (euro)
	X	Sx	
Gross margin maximum (GM)	34104.90	935.75	897.50
P-minimum (P)	20098.57	984.97	528.91
N-minimum (N)	19116.86	687.45	503.08
K-minimum (K)	19814.48	768.98	521.43

From the **perspective of economic efficiency,** the obtained profit is the highest **when the maximizing of production is desired** (34104.90±93575 or 897.5 euro/cow) (Fig. 1).



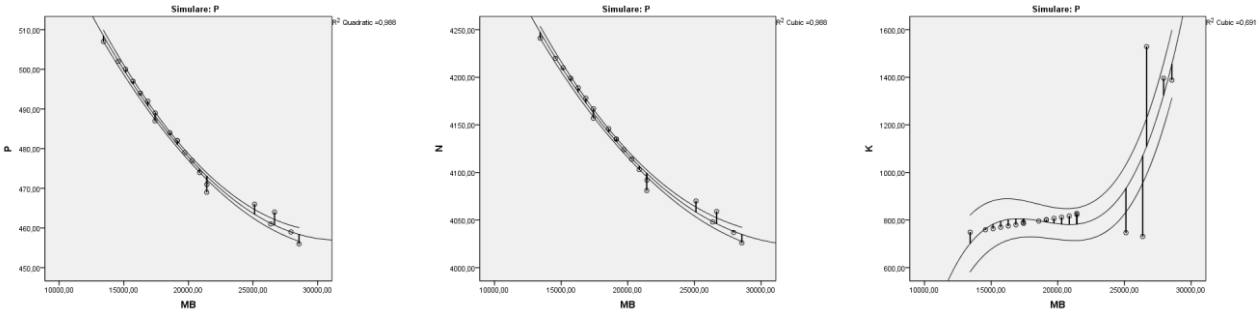
Distribution GM-P, R^2=0.928 | Distribution GM-N, R^2=0.921 | Distribution GM-K, R^2=0.991

Fig.1. Scenario of the gross margin increase

The scenario of enhancing the economic efficiency by increasing the milk production has the effect of reducing the phosphorus, and significant growth of the nitrogen balance (the ratio export/import=50.4-50.2%) and of potassium; basically, a markedly economic increase conducted only in the direction of increasing milk production support, can only have an economic effect and not an ecological one, not being able to sustain the environmental character from the eco-economic expression of the farm.

From an ecological perspective, when the minimizing of the **phosphorus balance** is intended, the obtained profit has the value (20,098.57 ±984.97), a negative correlation being present r=-0.974 on $p<0.05$ between phosphorus and the gross margin (Fig 2).

The simulation of increasing the milk production through the scenario of a phosphorus balance reduction results in the diminution of the income, as well as that of the P and N balances and slight increases of the K balances. Thus, minimizing the phosphorus balances generates economic losses, while having the effect of reducing the phosphorus and potassium from the system; the ecological character is partially sustained, but the economic one is diminished. In other studies, the association between the phosphorus input and the milk production could not be supported (Gourley *et. al.* 2011).

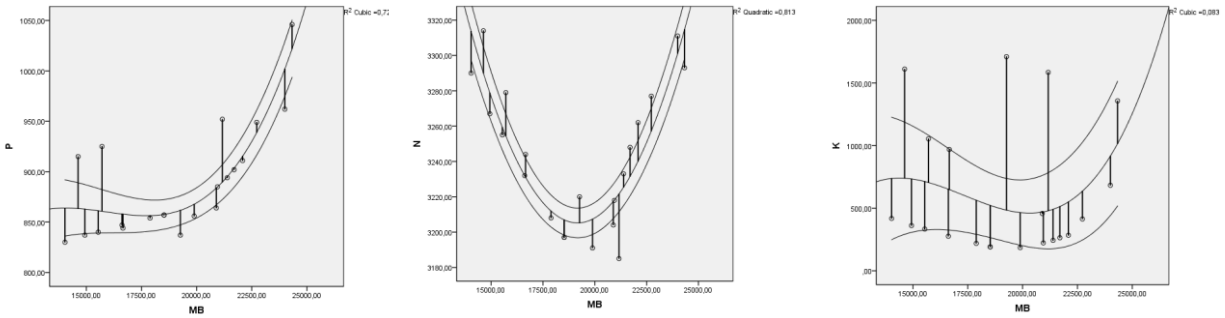


Distribution GM-P, R^2=0.988 | Distribution GM-N, R^2=0.988 | Distribution GM-K, R^2=0.691

Fig.2. Scenario of phosphorus minimizing

However, in farms with high production, the phosphorus input was higher, which can be explained by an increased demand of forage and chemical fertilizers purchased (Gourley *et. al.* 2011).

The nitrogen balance. When simulating the minimum N balance, the gross margin starts to decrease up to the value of 19116.48 euro, with 58% of the simulation that would allow the maximum of economic efficiency.



Distribution GM - P, R^2=0.723 | Distribution GM - N, R^2=0.813 | Distribution GM - K, R^2=0.083

Fig.3. Scenario of nitrogen minimization

In the case of reduced productions, the ratio export/import of nitrogen is 5.254/8.568 kg/ha or 2.234/3.643 kg N/hl milk, respectively 61.3%. In the case of high productions, the nitrogen utilization yield is of 60%.

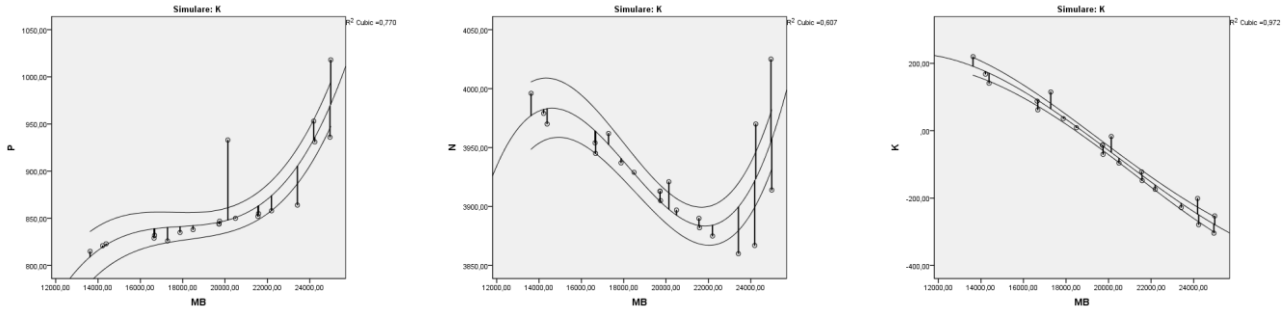
From this scenario, it can be noticed that the income is reduced, as well as the nitrogen balance (ratio export/import N=61.3-61.0%, 66kg of nitrogen/ha and year remaining unused),

the phosphorus balance records slightly increase, without a significant modification of the potassium balance (Fig.3). In other studies, it is stated that the increase of milk production is proportional with the N balance (Raison *et. al.* 2006, Gourley *et. al.*2011), as it is well-known that the efficiency of N utilization is limited by the cows' biological potential to transform the nitrogen from the feed and by the potential of the crops to use the nitrogen from fertilizers and manure (Powell *et. al.* 2010).

From an ecological point of view, feed rations supplemented with nitrogen for obtaining an optimal production instead of a maximal one is the way to reduce nitrogen losses in the environment, with minimum negative effects upon productivity and profitability (Ipharraguerre and Clark 2005). The greatest loss of nitrogen compounds in the form of air emissions and infiltrations into water is due to feed production for animals, especially of concentrates and corn silage, and among specific mill production activities, manure management had the strongest impact upon the environment (Castanheira *et. al.* 2010).

The potassium balance. In the scenario of K minimization, the gross margin drops up to the value of 19814.48 euro, exhibiting a difference up to 32% of the maximum possible gross margin value.

Minimizing the potassium balance does not result in lower profit (negative correlation, *r=-0.985 on p <0.001*) – the scenario being favorable to the eco-economy of the farm. At the same time, a decrease of nitrogen and an increase of phosphorus take place (Fig. 4).



Distribution MB – P, R^2=0.770 | Distribution MB – N, R^2=0.607 | Distribution MB – K, R^2=0.972

Fig 4. Scenario of potassium minimization

Most farmers try to minimize the negative economic effects of these losses through adapting management strategies regarding animal density, the feed ratio and the fertilization of the agricultural areas (Berentsen & Giesen, 1994, Aarts and col. 1999).

From a holistic perspective, in the studied system, the eco-ecologic character can be supported when the results are intermediate nitrogen balances and intermediate profits, but without exceeding 170 kg N/year and ha.

Using the peak production and the values from the scenarios of the maximum income and minimum nitrogen balance, new values were taken into consideration for the specified variables; these were calculated as barycentric coordinates of ½ for the minimum nitrogen scenario and maximum coordination corresponding to the scenario of the maximum gross margin. The eco-economic scenario of the farm is described by the above equation, whose graphic representation is given by the surface in figure 5:

$$z = -49519.87 + 690.99\sqrt{x} + 1370.5\sqrt{y}\ lny, with\ R^2 = 0.99$$

$$where:\ z = Income\left(\frac{kg}{year}\right), x = Production\left(\frac{kg}{day}\right), y = N(kg/year)$$

Tab. 2

Values of farm's eco-efficiency simulated at different productive levels

Production kg/day	Profit (euro)		N's balance (kg)	
	/farm	/cow	/ year and farm	/ ha and year
30	22.078	581	4.445	88.89
31	22.952	604	4.485	89.69
32	23.818	627	4.524	90.48
33	24.679	649	4.564	91.27
34	25.532	672	4.603	92.05
35	26.184	689	4.603	92.05
36	26.804	705	4.598	91.95
37	27.414	721	4.592	91.84
38	28.017	737	4.587	91.73
39	28.613	753	4.581	91.62
40*	29.205	769	4.576	91.52
41	29.786	784	4.571	91.41
42	30.413	800	4.574	91.48
43	31.051	817	4.581	91.61
44	31.689	834	4.588	91.76
45	32.323	851	4.596	91.91
46	32.951	867	4.603	92.06
47	33.574	884	4.611	92.21
48	34.188	900	4.618	92.35
49	34.807	916	4.626	92,52
50	35.414	932	4.634	92.67

*the real situation of the simulated farm: 38 cows, 50 ha land, with 40 kg peak production is: 33.791 euro, 5.955 kg N/year at 50 ha or 119.1 kg N/ha and year.

Based on these new values, a surface was generated which expresses the eco-economic character of the farm (see figure no. 5 and table no. 2).

According to the real data of the farm subjected to simulation having 50 ha, 38 cows and a peak production of 40 kg, an income of 33.791 euro is achieved (889 euro/cow). The annual N balance is 119.1 kg N/ha, with 50.9 kg less than the value considered acceptable (170 kg N/ha and year). The acquirement of an eco-economic character, in the sense given by the present study (after the scenarios of N reduction and MB maximization) would lead to a profit diminution of 13.5% to 29,205 euro/farm (769 euro/cow) and a N reduction in the system of 23.2% - the annual N balance being 4,567 kg/farm, respectively 91.52 kg N/ha.

According to the study, eco-economy may become a viable political strategy only if the ecological character can be subsidized with 120 euro/cow with a maximum production of 40 kg milk/day.

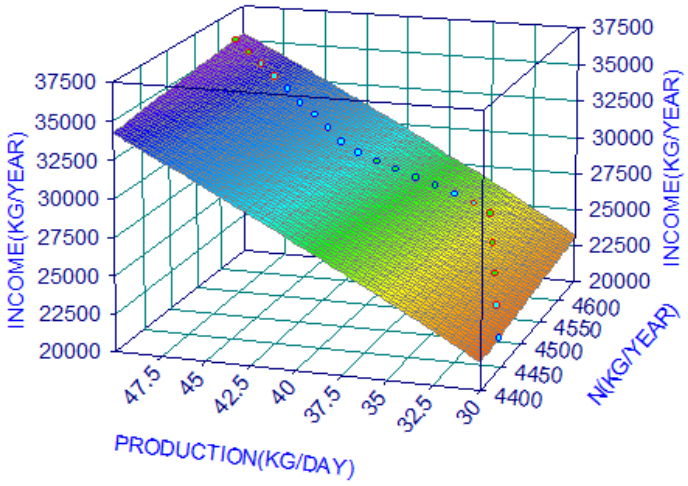


Fig. 5. Graphic representation of the eco-efficiency function of the farm subjected to simulation – output generated through Maple®13

CONCLUSIONS

- The scenario of maximizing the gross margin expresses the maximum economic efficiency of the farm subjected to simulation.
- The scenario of minimizing the nitrogen balance expresses the ecologic character of the simulated farm.
- In the case of simulating different productive levels, the eco-efficiency character of the farm can be sustained by the interpolation of the two scenarios.

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