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A LINEAR PROGRAMMING MODEL FOR BETTER DECISION MAKING IN THE GOAT SECTOR

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ABSTRACT

In this study a linear programming model was applied and the main structural and economic characteristics of the optimal organization of Greek goat farms were analyzed. The analysis was based on farm accounting data collected from 96 goat farms in northern Greece, through face-to-face interviews with farmers. The farm size in terms of does was used as a classification criterion and three farm size groups were formulated (small/medium/large size farms). Based on technical and economic data calculated for the surveyed farms and on specific indicators defined by livestock experts, a linear programming model was implemented for each of the three size groups of farms and the optimal plans under which farms maximize their gross margin were estimated. The optimal plans reveal the main structural characteristics of the farms and indicate the adjustments required to fully exploit the available technology. The results show that under the optimal plan all farms should increase the number of animals they rear. Small farms make full use of the available grazing land, while there is a small reduction in the use of grazing land in medium and large size farms. The farms under the optimal plans recommend to reduce production of feed on-farm and procure feed from the market, and produce cheese on-farm. The optimal structure indicates that goat farming should return to its traditional features and become a purely livestock farming activity operating under extensive production systems, making use of pastures of mountainous/disadvantaged areas, and avoiding excessive use of fodder. Under the production pattern, the farms will reduce production costs and improve their resilience and sustainability.

Keywords: *Dairy goat farming, linear programming, profit maximization, decision making.*

INTRODUCTION

The manager of a goat farm, among other issues, has to consider how to allocate the production factors available in order to achieve the production objectives he has set. Given that the factors of production are limited in quantity and that there are

usually various organizational and operational patterns of goat farms (e.g., the head of the goat farm is also active in crop production, or cultivates a land area for the production of feedingstuffs, or uses some acres of land as pasture, or operates a secondary farm, etc.), the need for a rational use of the available factors of production arises immediately. This implies that a methodology must be used to indicate the most appropriate combination of the available factors of production.

Achieving the maximum gross margin of the goat farm requires finding the optimum ratio of the combination of the factors of production and using them in the most efficient way. Among the methods have been adopted for determining the optimal combination of production factors is the mathematical programming, which considers the problems of optimization of an objective function, with many variables and constraints (Zioganas, 1980; Pavlou, 1996; Kalentzi, 2003; Kitsopanidis, 2006). Depending on the form of the objective function, several variants of mathematical programming arise, one of which is the linear programming (Loukakis, 1994).

Linear programming is a particularly popular tool in the decision-making process, providing solution to a variety of practical business problems with many variables and constraints (Spreen and Takayama, 1980; Burton et al., 1987; Sher and Amir, 1994; Theodorides, 2008; Batzios, 2021). Particularly, it solves problems of optimal allocation, placement or utilization of the quantity-constrained production factors of a production unit or organization, aiming in maximizing the profit or minimizing the cost (Loukakis, 1994; Gonzalez-Alcorta et al., 1994; Kalentzi et al., 2003). It should be noted that the application of linear programming depends on certain basic conditions that must be met, such as the existence of an objective purpose for maximum profit or minimum cost, the existence of quantity-limited production factors, and the allocation of the production factors to more than one alternative uses (Papanagiotou, 2008). A linear programming model can indicate "where to use and in what quantities" the production inputs for achieving the most efficient use of them and maximize the economic results of the farm.

The aim of this study is to develop a linear programming farm-scale model for the dairy goat farms and to apply it on different farm size groups in order to obtain the optimal structure of the farms, considering that these findings could contribute to the improvement of the sustainability and competitiveness of the goat sector.

MATERIALS AND METHODS

The limited production resources available make it extremely important for a goat farm to know how to use them in the most efficient way, in order to obtain the maximum profit or incur the minimum cost. The optimal combination of productive factors is indicated, as already stated, by linear programming model (Papanagiotou, 2008). The linear programming is a method by which maximum or minimum quantities of physical or monetary units are achieved, after certain conditions and constraints are imposed (Paparizos, 1999; Kitsopanidis, 2006). In other words, it is a method of optimizing a linear function under certain constraints (Sultan, 1993; Rardin, 1998; Theodoridis, 2008; Papanagiotou, 2008; Batzios,

2021) and requires the existence of: a) an objective (max or min), b) various production divisions of the farm and their requirements in terms of production factors, and c) constraints.
For the goat industry, the Linear Programming model can algebraically be expressed as follows:

$$\sum_{j=1}^{n} c_j x_j = z = \max \text{ (or min)} \ \} \text{ Objective function (1)}$$

$$\sum_{j=1}^{n} a_{ij} x_j \leq bi \ \} \text{ Constraints (2)}$$

$$\text{and } x_j > 0 \ \} \text{ Non - negativity constraints (3)}$$

Where:
j = production divisions (j = 1, 2, 3, …, n)
x_j = number of physical units (acres or animal heads) in the production division j
c_j = gross profit of the production division j
Z = the maximum gross profit (or the minimum cost) of the goat farm
i = available factor of production (i = 1, 2, 3, …, m)
a_{ij} = quantity of available production factor i, required by the unit of the production division j
b_i = available quantity of production factor i, representing the specific constrains.

In the framework of this study, a linear programming model was elaborated for each of the three size groups of farms used (small, medium and large size farms). By solving these three models, the main structural elements of the optimal organization of the goat industry were revealed and the adjustments required to fully exploit the available technology were suggested in comparison with the existing structure of the industry. Furthermore, the comparison between the existing structure and the optimal plan demonstrates the deficit in terms of efficiency and cost-effectiveness. The implementation of the three linear programming models was based on technical and economic data of a farm management survey sample, as well as on indicators defined by livestock experts. In particular, for each farm size group, a normative (what ought to be) model for maximizing the gross margin (objective function) was developed with constraints that simulate the basic requirements of the composition of the goats' ration, thus predicting the satisfaction of the nutritional needs in protein and energy from feed sources (home-produced and purchased feed). The average goat farm of each size group is represented by a set of variables (activities) accounting for the variable costs of the main feed crops (wheat, barley, maize and alfalfa), the prices of purchased feedstuffs (wheat, barley, maize spelt, cotton oilcake, bran, silage, alfalfa and straw) and the revenues derived from the sales of milk, cheese and meat from young and adult goats withdrawn from the farm. The model includes a list of land constraints that express irrigated and non-irrigated land availability, land for

growing home-grown fodder (wheat, barley, corn, alfalfa) and grazing land, labor constraints related to human labour (family and hired), constraints related to the produced products (goat milk yield and milk deliveries to processing industry, cheese production, milk ratio for cheese production, goat carcass weight for meat sale), and constraints that link the protein and energy requirements to the respective provided by the administered feeds (minimum energy and protein requirements, maximum and minimum ratios of roughage and concentrated feeds, minimum requirements for bran, cotton oilcake and corn, nutrients derived from administered feeds per acre for home-grown and per kg of the purchased feeds). Moreover, constraints related to veterinary and other animal care costs, and constraints that calculate the total variable costs (excluding the cost of hired labour) and the gross margin resulting from the revenues of the four basic products described above are also included.

The solution of the linear model demonstrates the main figures and economic outcomes of the optimal structure of goat farming. In all solved models, and with the relevant constraints, the animal yield and the total area available for feed production and grazing are kept constant, but a change in the number of rearing animals is allowed. In addition, it should be noted that income subsidies and revenue from crop production have not been incorporated into the model, thus a net economic outcome of the activity exclusively related to the goat sector has been calculated.

Study Area and empirical data

For the empirical application of the linear programming model in the goat industry, primary accounting data were collected through a farm management survey of 96 farms, carried out in 2018. The surveyed farms were located in the area of Macedonia and Thrace in northern Greece, and operate under various farming systems (intensive, semi-intensive, extensive and semi-extensive), thus embodying the prevailing characteristics of goat farming in Greece. The study area constitutes an important goat farming center in Greece, accounting for 25.85% of the total goat population reared in the country (ELSTAT, 2022) and producing 31.20% of the total quantity of goat milk (ELSTAT, 2020). The primary accounting data were obtained by conducting an on-site interview with the goat farmers, and completing a specially designed questionnaire, which is reflected in all the agricultural accounts of the goat farm. Moreover, the “farm size” (number of does: adult female animals in the farm) was used as a classification criterion of the surveyed farms and three farm size groups were formulated, “Small size farms: ≤199 does”, “Medium size farms: 200 to 399 does”, and “Large size farms: ≥400 does”. Using the farm size as classification criterion, the surveyed farms in the sample were divided into 3 groups, with the first group comprising 23 farms (small-sized farms), the second 42 farms (medium-sized farms) and the third 31 farms (large-sized farms).

RESULTS AND DISCUSSION

Table 1 presents the structure of the goat industry resulting from the solution of the linear programming models for the three size groups of farms, which fully utilizes the existing technology. The comparative consideration of the optimal plans with the existing ones indicates the adjustments that are required for maximizing the economic performance. In particular:

Table 1. Results of the linear programming model simulation in terms of farm size

	Small size farms		*Medium size farms*		*Large size farms*	
	Existing plan	*Optimal Plan*	*Existing plan*	*Optimal Plan*	*Existing plan*	*Optimal Plan*
Number of animals (does/farm	134	233	274	358	562	595
Available land area						
Irrigable land (acres/farm)	61.00	12.80	58.60	17.80	66.94	29.00
Dry land (acres/farm)	26.00	0.00	29.60	0.00	37.30	0.00
Pasture (acres/farm)	158.00	158.00	256.00	236.00	546.00	385.00
Labour						
Family labour (hours/farm)	2877	2877	4536	4536	5229	5229
Hired labour (hours/farm)	827	827	961	961	3791	3791
Purchased feed						
Wheat (kg/farm)	1760	8761	2095	18668	5306	19877
Straw (kg/farm)	1304	8801	4607	0	10726	0
Bran (kg/farm)	424	4693	942	0	5626	10649
Cotton oilcake (kg/farm)	957	3754	1119	5210	7968	8519
Products						
Quantity of milk (kg/farm)	30150	34681	39549	36899	84300	64781
Cheese (kg/farm)	529	3557	53	3514	280	4889
Meat of young goats (kg/farm)	851	1399	1512	1973	3174	3361
Meat of adult goats (kg/farm)	270	466	314	409	1229	1297
Value of products						
Milk (€)/farm	15422	17444	20539	19114	44931	34528
Cheese (€)/farm	3117	13872	219	14759	1495	25911
Meat of young goats (€)/farm	3600	6995	6471	8444	12971	13712
Meat of adult goats (€)/farm	456	788	412	536	1506	1595
Total income (€)/farm	22595	39099	27641	42853	60723	75746
Total Variable Cost (€)/farm	21685	15093	24068	14547	45207	22193
Gross Margin (€)/farm	910	24006	3573	28306	15516	53553

"Small-sized group (≤199 does/farm)

Studying the results regarding the "Small size average farm" (up to 199 goats), it can be seen that in the optimal structure, the average farm is expected to rear larger number of animals compared to the existing production plan (increased by 74%). There is thus a significant increase in the size of the farm that achieves the highest milk yield compared to the larger size farms. In terms of land use, all the available pasture land (158 acres/farm) is fully utilized in the optimal structure, but the number of irrigated acres is reduced from 61 to 12,8 acres/farm for maize cultivation. Furthermore, in the optimal structure, the dry land is not cultivated at all and the farm prefers turning to the market for the supply of concentrated feedingstuffs. No difference in the human labour used (family and hired labour) is expected as a result of adapting the farm to the optimal structure. Indeed, the labour available is fully utilized, indicating that the marginal cost of hired labour is less than the marginal income resulting from the use of that input. Concerning the purchased feed, there is a large increase in concentrates, as the roughages are covered by grazing. Thus, it becomes cost-effective to purchase concentrated feedingstuffs, rather to produce them on farm. There is a large increase in the purchase of wheat, bran and straw. Thus, the small size average farm should focus its activity on rearing the animals by grazing to meet their nutrient needs and in parallel feeding them mainly concentrated feedingstuffs to be purchased on the market during the period when grazing is not available. It is clear that in small size farms, there is an irrational use of feed with a high rate of employment of the available labour in cultivating feedingstuffs, thus implying high production costs.

The increased number of animals reared results in a larger quantity of milk and meat produced with a substantial diversification of cheese production on the farm, with respect to the existing structure. In the optimal plan there is an increase in cheese production from 529 to 3557 kg/farm, thus taking advantage of the added value of the milk produced. This increase is also largely linked to the relatively low price the producer receives for goat's milk compared to sheep's milk.

The total income in the optimal structure of the small size farm is increased by 73%, while the total variable cost is expected to decrease by 69.6%. Moreover, the gross margin is expected to be highly increased from 6.8€/doe to 103€/doe, indicating the effect of adaptation of the industry on its profitability.

"Medium-sized group" (200 to 399 does/farm)

The obtained results for the "Medium size average farm" indicate that in the optimal structure the average farm is expected to rear larger number of animals (increased by 31%), compared to the current plan. In addition, there is a slight reduction in the available pasture area, a reduction in the irrigated land from 58,6 to 17,8 acres/farm, while 29,6 acres/farm of dry land are not cultivated at all, with the farm choosing to purchase the concentrated feedingstuffs. Moreover, there is no difference in human labour used (family/hired labour), which is fully utilized, but there is a fairly large increase in the purchased wheat and cotton oilcake, indicating that it is cost-effective to purchase concentrated feedingstuffs than to produce them on farm. For feed roughages, the needs are covered by grazing. The increased

number of animals reared does not imply an increase in the quantity of milk produced and delivered to processing establishments, but an increase in the on-farm cheese production. Simultaneously, there is an increase in the meat quantity from both young and adult animals.

In the optimal plan, the total income/farm is increased by 55%, while subsidies and income from crop production have not been included. The total variable cost, which includes the costs of producing feed, the costs of purchased feedingstuffs and other animal care costs is expected to decrease from 88€/doe to 41€/doe. Furthermore, the gross margin is expected to increase significantly, demonstrating the effect of the sector's adaptation on its profitability.

"Large-sized group" (≥400 does/farm)

Concerning the results for the "Large size average farm" in the optimal structure, the average farm is expected to rear a slightly higher number of animals compared to the existing plan. In addition, the optimal plan indicates a significant reduction in the area of pasture available, a reduction in irrigated areas from 66.94 to 29.00 acres/farm, while 37.30 acres/farm of dry land are not cultivated at all, with the farm preferring to purchase concentrated feedingstuffs. Moreover, the needs for roughages are covered by grazing, while there is a fairly large increase in the purchases of wheat, bran and cotton oilcake. At the same time, there is an increase in concentrated feedingstuffs, indicating that it is cost-effective to purchase mainly concentrated feedingstuffs rather than to produce them on farm. There is no difference in the human labour used (family and hired labour) in the optimal structure of the farm, compared to the current situation.

In the optimal structure, there is a fairly large increase in cheese production from 280 to 4,889 kg/farm, thus exploiting the value added for the milk produced. However, small increases are recorded in the quantities of meat from young and adult goats.

Moreover, the total income is estimated to increase by 25%, while the total variable cost is expected to decrease from 80€/doe to 37€/doe. Finally, the gross margin is expected to be significantly increased from 28€/doe to 90€/doe, demonstrating the effect of the adaptation of the sector on its profitability.

CONCLUSION

The implementation of the linear programming model in the goat industry, with regard to the classification variable of 'farm size', provides empirical findings that could be used for the rationalization of the production process with a more efficient use of production factors.

Based on the optimal plan, small and medium size farms significantly increase the number of reared does, while the large size farm rears a slightly larger number of does. The small size farms make full use of the available grazing land, while medium and large size farms show small reductions in the acres to be grazed. Furthermore, goat farms are reported to cultivate substantial areas of irrigated maize and alfalfa acres for feed production, but the optimal plan recommends

reducing the irrigated acres and not cultivating dry land, with the farms turning rather to purchased feed, finding it cost-effective to purchase mainly concentrated feed rather than producing it on the farm. Therefore, they should focus on grazing the animals to fulfil their nutrient needs from the roughage, as well as on the parallel feeding of concentrated feeds to be purchased on the market, during the period when grazing is not available. For all size groups of goat farms, it is suggested to increase the amount of meat produced from young and adult animals, as well as to increase the amount of cheese production, thus taking advantage of the value added for the milk produced. Within the optimal plan, the total income will be increased for all farm size groups, with the percentage increase becoming smaller and smaller as the farm size increases. Furthermore, the total variable cost that summarizes feed production costs, purchased feed costs and other animal care costs is expected to decrease, while gross margin will be increased substantially, indicating the effect of the industry's adaptation on its profitability.

The application of the linear programming model provides useful findings for improving the sustainability of the goat farming, at the level both of policy making and of producers. The optimal plan indicates that goat farming should return to its traditional features and become a purely livestock farming activity operating under extensive production systems, making use of the pastures of mountainous and disadvantaged areas, and avoiding the excessive use of fodder. The sector will thus achieve a reduction in high production costs, which currently cannot be compensated for by the low price the producer receives for goats' milk, and improve its resilience and sustainability.

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