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in

Dubeuf J.-P. (ed.).
L'évolution des systèmes de production ovine et caprine : avenir des systèmes extensifs face aux changements de la société

Zaragoza : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 61

2004
pages 73-80

Application of integrated resource management tools: Decision support for small ruminant dairy Mediterranean farming systems

R. Ruiz*, E. González-Estrada*, L. Oregui and M. Herrero*,*****
*Institute of Ecology and Resource Management (IERM), University of Edinburgh,
West Mains Road, Edinburgh EH9 3JG, Scotland, UK
**Basque Institute for Agricultural Research and Development (NEIKER AB),
Apdo. 46, 01080 Vitoria-Gasteiz, Spain
***International Livestock Research Institute (ILRI), PO Box 30709, Nairobi, Kenya

SUMMARY – Small ruminant systems in the Mediterranean basin are conditioned by many constraints. Dairy farmers have to develop specific managerial strategies and practices aimed at increasing the profitability and sustainability of the system, and adjust to new political guidelines. The main objective of this work is to present the application of a decision-support system (DSS) for the integrated analysis of farming systems in the Mediterranean basin. The core of the methodology consists of the integration of: (i) simulation models of biological processes; (ii) a geographical information system (GIS); and (iii) a multiple-criteria optimisation model. This DSS aims to provide researchers, technical advisors and policy makers with an analysis tool that takes into account the dynamic biological, economic and social subsystems that operate at farm and regional level. The application of such DSS might guide the design of strategies that enhance the profitability and sustainability of small ruminant systems.

Key words: Decision-support, simulation, optimisation, GIS.

RESUME – *"Application d'outils pour la gestion intégrée des ressources : Aide à la décision pour les systèmes d'élevage méditerranéens de petits ruminants laitiers". La production de petits ruminants dans le bassin méditerranéen est déterminée par de nombreux facteurs. Les éleveurs ont donc du développer des stratégies de conduite et des pratiques rentables durables et simultanément les ajuster à de nouvelles orientations politiques. Le principal objectif de ce travail est la présentation d'un logiciel pour le développement d'un système d'aide à la décision (DSS) pour l'analyse intégrale des systèmes pastoraux en région méditerranéenne. Cette méthodologie intègre : (i) des modèles informatiques pour simuler des processus biologiques ; (ii) un système d'information géographique (SIG) ; et (iii) un modèle pour optimiser plusieurs paramètres. Il intègre les relations qui existent entre les sous-systèmes biologiques, économiques et sociaux. Ce DSS est destiné à la recherche, au développement et aux décideurs politiques et peut jouer un rôle très important dans la définition de stratégies destinées à améliorer la profitabilité et la durabilité des systèmes de production des petits ruminants.*

Mots-clés : *Appui, décision, simulation, optimisation, SIG.*

Introduction

The search for management strategies that ensure the sustainable use of natural resources can be regarded as one of the main objectives facing agro-ecological research. Nowadays it is commonly accepted that this objective should be attained not only within a biological or ecological point of view, but also within a socio-economic perspective. In consequence, the number of factors involved in the search of sustainability and the level of complexity of the relationships between them is important, both of them increasing with the level of extensification of the system.

The sheep and goat livestock systems of the Mediterranean basin, mainly dairy ones, are a good example of that complexity. In general terms, they are based upon the exploitation of local breeds, very well adapted to the local conditions under which they have been reared for centuries. A huge variety of management strategies were developed throughout the years to make use of vast areas with low value for cropping, later known as less favoured areas, to consume by-products coming from agricultural activities, etc.

Particularly during the last third of the XX century, these systems had to face different challenges. One of the most important was the organisation of the sector in many areas, which brought about the creation of administrative structures, farmers associations, extension services, and the implementation of breeding programmes to improve the genetic characteristics of local breeds for milk production (Barillet, 1990; Sanna *et al.,* 1994). These systems were also driven to adapt to policies established at different levels, and to trends observed in the markets.

Organizations and institutions in charge of the regional research and development programmes in the small ruminant sector have tried to develop new technologies and supervised their transfer, adoption and evaluation, with different degrees of success. The effectiveness of these enterprises can be improved by the use of adequate analysis tools to assess the feasibility and long-term effects of such technologies within a holistic framework. Thus, these analysis tools can enhance the processes of technology transfer and technical assistance, and support local farmers in their decision-making processes.

In this context, the main objective of this paper is to present a methodological framework for the application of a decision-support system (DSS) for the integrated analysis of sheep and goat farming systems in the Mediterranean basin. This DSS should be capable of dealing with the complexity typical of these systems and accessible to extension services for advisory purposes.

The DSS and the biological environment

The physical complexity of the Mediterranean basin is characterised by the patchy structure of land use systems and vegetation (Gomez Sal, 2000), which have played a significant role in the evolution of the livestock systems. Variability of land resources can be easily recognised in relation to small ruminants feeding systems: crops and agricultural by-products, natural or improved pastures in valleys, grasslands in mountainous areas that can be communally managed, etc. Thus, the DSS should reflect the marked seasonality in climatic conditions typical at these latitudes, which has an effect on ecological attributes in terms of biodiversity, ecological structure and vegetation throughout the year. Such space-time shifting pattern affects both the amount and the nutritive value of the feeding resources available (Frutos *et al.*, 1998).

Regarding the animal element, the other main biological factor directly involved in the productive activity, the DSS should be able to evaluate feeding strategies and management practices. The extensive feature of these systems means that food intake is mainly achieved by grazing. Therefore, the direct interactions established between the grazing resources and animals will determine their nutrient utilisation, the yields achieved, and the evolution of the herbaceous and shrubby covers, especially under severe environmental conditions (Morand-Fehr and Doreau, 2000). These features condition the productive and reproductive behaviour of the individuals within the flock. Although these systems primarily make use of grazing as a feeding source, indoor or supplementary feeding during some periods of the productive cycle is common (Zervas *et al.*, 1994; Sanna *et al.*, 1995; Oregui *et al.*, 1997). These practices impose an additional cost to the livestock rearing activity. Thus, the feeding system is one of the most important issues that farmers include in their decision-making process (Duru *et al.*, 1988), as they try to achieve efficient production strategies that cover animal requirements and fulfil production objectives.

The DSS and the socio-economic environment

Small ruminant livestock systems in these latitudes usually follow a small-scale farm organization pattern. Therefore, the concept, features and implications of a family-farm system are observed (Osty, 1978). In this context, the production system not only includes the physical structures needed to develop the productive activities (lands, flock, buildings, etc.), but it also involves the social group responsible for them and the relationships established between its integers. Consequently, a DSS must recognise the human component in the decision-making process through the understanding of the farmers' personal goals and management styles according to the farmers' social and economic contexts (Solano *et al.*, 2001). In addition, the farm cannot be considered in isolation from the rest of the community in which it develops its activity. So the dynamic role played by other actors needs to be taken into account in the decision making process, such as neighbour farmers, advisory services and policies designed at local, regional, national or European level.

Both the marketing process and the final consumer of the products should also be taken into consideration. Regarding the former, the price of traditional products obtained from small ruminants (milk, meat and wool) usually shows an annual seasonal pattern as a consequence of the fluctuations in supply and demand, which conditions the income level. Dairy farming differs from meat production in that substantial value can be added to the final product obtained at the farm level. Such possibility depends on market accessibility and it is influenced by labour availability and/or the farm's level of mechanisation. Although a certain level of investment may be required, cheese making facilitates and improves both the net revenue of the farm and the profitability of family labour (Nafarrate *et al.*, 2001).

Efforts to promote and protect the quality of typical sheep and goat products and relate them to the area of origin and the characteristics of the livestock system cannot be forgotten (Morand-Fehr *et al.*, 1998). The establishment of labels of origin and quality trademarks have represented a challenge and a way to improve the incomes achieved by farmers. In addition, the social prestige obtained by certain farmers within the rural community as a consequence of the outstanding quality of their products can be even considered as an objective for the household.

These labels have helped to improve the consumers' perception not only of the products, but also of the important social role that extensive systems can play. In this context, extensive systems are linked to landscape maintenance and habitat conservation, which are important public services to the urban population. Apart from the obvious direct benefits, environmental conservation may also produce new sources of income for the farmer, either through subsidies or alternative activities for the household system.

The DSS and the objectives expected from the Mediterranean extensive systems

As stated above, a thorough analysis of small ruminant systems must recognise the human component as the source of the production systems' objectives and goals. In a broad sense, both economic and non-economic goals are not mutually exclusive and coexist in the farmers' minds (Solano *et al.*, 2001). A DSS should therefore comprise the analysis of the trade-offs between economic profitability, environmental conservation and any other objectives that farmers' may include as production objectives. Although economic profitability has traditionally been the primary production objective, the current social conditions in Mediterranean countries have meant that production objectives are being transformed by farmers' social welfare issues. This situation has resulted in farming activities being dismissed by younger generations as a way of living, even in the case of profitable and viable farms. This scenario highlights the need to recognise as objectives of production, farmers' concerns about improving their standards of living and their access to leisure time and better labour conditions.

A DSS should also include objectives related to environmental concerns and/or the production of high-quality product that are of interest to policy-makers in response to social interests. Consequently, a DSS should not only focus on analysis at the farm level, but also at larger levels (regional, national, etc.). Therefore, tools capable of dealing with such a wide-scope level of approach should be included.

Summing up, it is important to consider that, under such complexity and with increasing levels of uncertainty at different levels (markets, policies, etc.), the improvement of extensive farming systems sustainability will require a higher demand for advice and assistance (Doppler, 1994). According to McCown *et al.* (1994) the adaptation to new scenarios will be more complex, expensive and risky. Therefore, a DSS can play a leading role in the ex-ante analysis of the risk and opportunities a new scenario offers, and exploring into the possibilities for the evolution of livestock farming systems.

Proposal of a methodological framework for applying decision support systems

The proposed methodological framework has already been applied within the context of smallholder dairy cattle in Latin America with interesting results (Herrero *et al.*, 1997, 1999), and is currently being adapted to sheep production (González-Estrada *et al.*, 2000).

As stated by Dent *et al.* (1994) the basic configuration of a DSS should be able to link biological data with databases providing information about the physical environment, economic and socio-cultural features (Fig. 1). These databases are linked and updated through the interaction of both simulation models and geographic information systems (GIS), which provide inputs for optimisation models.

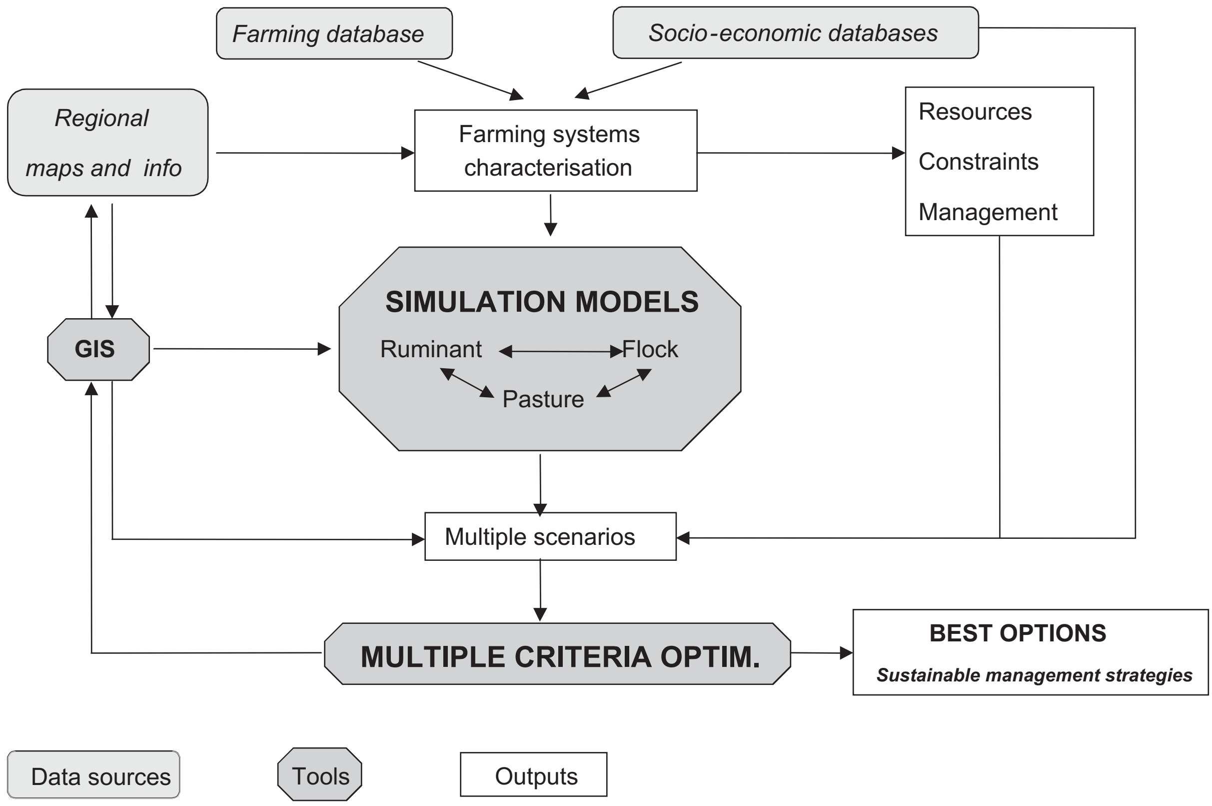

Fig. 1. Methodological framework for a decision support system (adapted from Herrero *et al.*, 1997).

Models to simulate biological processes

Biological simulation models are computer tools designed to represent the behaviour of the biological components of the livestock activity. When properly built, they are a cost-effective way to generate a wide range of possible scenarios and to test different management options. The modelled outputs correspond to a set of "technical coefficients" that indicate the level of utilisation for the resources and activities of a given managerial regime. Once tested and validated, they can play an important role in analysing agricultural systems.

According to Thornton and Herrero (2001), an efficient modelling system should achieve a balance between the level of detail, the precision required, the model's flexibility, and the data requirements. The modelling framework should be based on a system that permits the integration of a range of models suited to the particular conditions of the system under study and varying in level of aggregation and data requirements.

Three different but interdependent levels of biological models are considered to be basic in the case of extensive small ruminant systems. These models could be linked through "standard data communication protocols" (Thornton and Herrero, 2001). Such models can be grouped in:

(i) Grazing resources models. They should be designed to simulate the seasonal pattern of vegetation resources in terms of forage yield, sward structure and nutritive value. They could also be related to a soil model and weather simulators.

(ii) Sheep performance models. This category refers to a set of tools designed to estimate individual ewe and lamb performances, intake prediction, body weight changes and forage/supplement interactions.

(iii) Flock models. They are required to determine flock dynamics, stocking rates, lambing intervals, mortality and culling rates and lamb yields and sales.

These models should be integrated by generic and modular components requiring minimum datasets. As a result, models could be modified and adapted to the variety of crops, breeds, environmental conditions and management regimes that prevail in the extensive systems for sheep and goats.

The calculation of inputs and technical coefficients will preferably be based on knowledge of physical, chemical, biological and environmental processes; however, when this kind of knowledge is incomplete or even absent, calculations can be based on expert knowledge, records or literature data and field observations.

Geographic information systems (GIS)

The analysis of small ruminant extensive systems requires the handling of a wide range of spatially-distributed variables. Through GIS-based tools it is possible to include the spatial arrangement of resources in regional-scale analyses to project, explore and predict agricultural land use (Stoorvogel and Antle, 2001). Thus, the complexity of the Mediterranean small ruminant systems can be better represented through the spatial reference of their biophysical, economic and social variables within a GIS context.

Linking simulation modelling to spatial information with GIS is becoming increasingly important in attaining a complete analysis at landscape or regional level. Such integration of tools allows a two-way exchange of information between simulation models and GIS. Handling of geo-referenced variables can produce some of the input that feeds the simulation models. These variables or technical coefficients are the product of the landscape characterization. Characterization at the landscape level can produce information of variables such as: (i) biophysical resources – vegetation cover, climate distribution, land use, soil and terrain characteristics, watering points; (ii) economic resources – access to marketing centres, milk distribution routes; and (iii) social resources – land tenure forms, population settlements, cadastral information, protected natural areas.

At present, data sources for the production of GIS tools are increasing in number, quality and accessibility. Several government and private institutions in Mediterranean countries have the ability to supply aerial photographs, digital maps and remotely-sensed data. In addition, reliable data at field level can be obtained by the use of global position systems (GPS) receivers and, no less important, sketched maps and aerial photography interpretation through participatory techniques (Booltink *et al.*, 2001).

With the use of GIS, models can be extended from point-based application to spatial applications, combining the analytical characteristics of simulation modelling with the querying and display capabilities of GIS (Hill *et al.*, 1999). GIS tools can facilitate the generation of scenarios for the application of optimisation techniques. In these techniques, the inclusion of spatial variables is of special interest when the scenario analysis incorporates communal land issues, environmental conservation issues and/or extensive grazing resources management (González-Estrada *et al.*, 2000). Thus, integrating GIS-based simulation models with optimisation techniques is a very efficient way of assessing the spatial variability that influences the management, productivity and profitability of farms.

Optimisation

One of the main characteristics of the family-farm system is that it does not follow easily achievable optimisation criteria. Using a DSS it is possible to select the set of activities within a farming system that makes the best use resources to achieve the objectives set by the decision-maker. In the proposed methodological approach, a multiple-criteria decision-making model (MCDM) plays this role. Based on mathematical optimisation, the MCDM is an invaluable tool for scenario analyses and the impact assessment of ex-post and ex-ante changes in the farming system (Herrero *et al.*, 1996). Thus, agricultural, ecological, economic and social data generated from simulation modelling and GIS can be integrated in a holistic framework through the application of the MCDM.

The objective to be optimised will depend on the level at which the assessment is carried out. Hence, a MCDM can be designed to undertake analyses at household, landscape or regional levels. The consideration of different scenarios allows a quantification of trade-offs among different productivity and sustainability indicators. For example, an analysis of trade-offs may show the opportunity cost of environmental quality in order to increase agricultural production or income (Stoorvogel and Antle, 2001). Spatial analysis from GIS is a means of assuring that individual objectives at a farm level are constrained by regional policies such as regulations over communal land, land use and environment protection.

The use of MCDM's in small ruminant systems in the Mediterranean region can enhance the assessment of immediate and long-term effects of new technologies and policies adopted. At a farm level, they could be able to assess: (i) effects of changes in feeding practices on the productive and reproductive behaviour of small ruminants; (ii) quantitative and qualitative changes of feed sources; (iii) labour availability and opportunity costs of off-farm labour; (iv) trade-offs between management practices and extensification level, farm's economy and sustainability of resources; and (v) market behaviour and its impact on commercialisation of goods and products' added value.

At a regional level, such assessment can include: (i) price control of agricultural production and inputs; (ii) governmental programmes for technical assistance and subsidy analysis; (iii) management of communal land and stocking rates; and (iv) climatic variability and effects on agricultural production and grazing resources.

Perspectives

The future of sheep and goat extensive systems is really uncertain in many areas of Mediterranean countries, and even the conservation of certain local breeds is nowadays endangered (Ugarte *et al.*, 2001). The development of a DSS seems to be essential in the search of their sustainability.

The main objective of a useful DSS for extensive systems is to establish the ideal set of activities that maximise farmer profit according to the particular features of a particular farm, but at the same time optimise the use of grazing resources. The application of this methodology allows the assessment of trade-offs between socio-economic and biological factors involved in the prevailing agricultural systems within the region considered. Then, different objectives can be met providing the flexibility of tailored decision-making system for a region based on the performance of individual farms.

This methodology should result in three fundamental stages of information process:

(i) Inventory of current resources integrating socio-economic and agro-ecological information, including constraints at farm and regional level.

(ii) Description and exploration of alternative managerial strategies through the analysis of new scenarios evaluating trade-offs emerging from the interaction of the various biophysical resources and the socio-economic factors for farm and regional development.

(iii) Identification of the set of activities that produces the best use of resources and submission of results to the judgement of the decision-makers involved.

Thus, this methodological framework could be used in the ex-post and ex-ante assessment of the wide number of variables that define the small ruminant extensive systems. In addition an explorative analysis of different scenarios could also be carried out. During the last years several research groups, some of them involved in small ruminant systems, have made substantial advances specially in relation to modelling and economic analysis. Participatory research among several groups involved in different systems would enrich the design of a DSS by providing different points of view and would definitively result in a more effective tool, making the research and advisory to farmers more efficient.

Acknowledgments

The first author wishes to thank the European Commission for a postdoctoral fellowship at the IERM, University of Edinburgh (Contract number QLCK5-CT-2000-51381) and the Department of Education, University and Research of the Basque Government for the financial support.

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