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Simucapra: Educational Software Application for Animal Nutrition based on MATLAB*

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This paper proposes the pedagogic use of MATLAB software in a field where its use is not common, Animal Science (AS). Although it is usual to develop and validate different mathematical models in AS, the use of this software package has not yet become a standard. This paper presents the use of this software for teaching Animal Nutrition, one of the main subjects in the Agricultural Engineering degree at the Technical University of Valencia, Spain. Two software applications implemented in MATLAB are presented. These applications cover different laboratory lessons of the subject. One of the main advantages of using this software is its GUIDE interface, which can create easy-to-use packages. Moreover, MATLAB offers an unbeatable computing power and a large number of free toolboxes. In addition, it has great capabilities of importing (or exporting) data generated by other widely used programs.

Keywords: MATLAB; animal nutrition; educational software

INTRODUCTION

THE NUMBER OF SOFTWARE PACKAGES for numerical and symbolical data analysis has grown exponentially over the last few decades. This growth has increased the use of these packages in university laboratories. Of the several software packages that are available, the authors suggest the use of MATLAB for several reasons. MATLAB is one of the most widely used software applications for numerical calculus [1–4]. One of its most attractive features stems from the fact that it is a modular program. Therefore, it is easy to increase the number of tasks that can be done by producing toolboxes created by the users themselves. In addition, many toolboxes can be found free on the Internet: two of the main sites where these toolboxes are available are the website of the company that develops MATLAB (www.mathworks.com), and also a website that is directly related to it (www.mathtools.net). Another interesting feature of this software is its simplicity; there are many basic and advanced operations that are already implemented. Therefore, if a user is interested in creating a function for a task that is frequently used, this function is likely to be already implemented, or at least, it will be easy to implement with a simple combination of other already existing functions. Another reason for the wide use of MATLAB is that the programming instructions (conditional sentences, control of data flow, etc.) are basically the same as the ones used in other programming languages (Basic, Pascal, Fortran, C, etc.). Furthermore, there are free software applications that are quite similar to MATLAB, e.g., Octave (www.octave.org) and Scilab (www.scilab.org).

Although MATLAB is a commercial software, the vast majority of academic institutions have licenses to use it, and there is also a student version that can be bought at a reduced price. Finally, the authors consider that the most important reason for its extended use lies in its robustness and versatility. All these reasons have led MATLAB to become an essential tool for physicists, mathematicians, and engineers around the globe. It has also been widely used to support laboratory lessons for many university degree programs. However, Animal Science has yet to adopt it [5–8].

An in-depth analysis of the Animal Production curricula yields several laboratory problems that could be solved with MATLAB. A list of different possible application topics and specific examples include the following:

- Time prediction modeling: Milk prediction during lactation of ruminant animals, animal voluntary intake through time, etc.
- Classification modeling: Characterization of the nutritive value of feed ingredients, characterization of animal production systems.

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Table 1. Animal Production syllabus in the Agricultural Engineering degree program

Common subjects of the agricultural engineering degree program		
Year	**Subjects**	**Type**
First	Engineering Mathematics Fundamentals I (annual) 105 h (52.5 h Theory + 52.5 h Laboratory)	Compulsory
	Engineering Physics Fundamentals I (annual) 105 h (52.5 h Theory + 52.5 h Laboratory)	
	Engineering Chemistry Fundamentals (annual) 105 h (52.5 h Theory + 52.5 h Laboratory)	
Second	Engineering Mathematics Fundamentals II (annual) 45 h (22.5 h Theory + 22.5 h Laboratory)	Compulsory
	Engineering Physics Fundamentals II (annual) 45 h (22.5 h Theory + 22.5 h Laboratory)	
Animal production syllabus relating to animal nutrition		
Third	Animal Production Bases (first semester) 90 h (50 h Theory + 40 h Laboratory)	Compulsory
	Animal Production Technology (second semester) 60 h (30 h Theory + 30 h Laboratory)	Compulsory
Fourth	Animal Nutrition (second semester) 120 h (60 h Theory + 60 h Laboratory)	Compulsory
Fifth	Animal Feeding (first semester) 60 h (30 h Theory + 30 h Laboratory)	Compulsory

- Optimal feeding calculation: Determination of low-cost compound feed for intensive domestic species.
- Regression modeling: Efficiency of energy retention vs. energy intake.

The goal of this paper is to highlight the role that MATLAB can play in teaching and research in Animal Science and Production. One of the principal areas in the training of an Agricultural Engineering is Animal Nutrition (AN). Therefore, AN has been chosen to illustrate the potential usefulness of MATLAB. Two Graphical User Interface (GUI) applications have been developed.

The outline of the paper is the following. The next section presents the Animal Nutrition syllabus, which is encompassed within the Agricultural Engineering curriculum. After that, two software applications are described in detail, ending the paper with the conclusions of the work.

ANIMAL NUTRITION IN THE AGRICULTURAL ENGINEERING DEGREE PROGRAM

Animal Nutrition is an important topic in the Agricultural Engineering degree program. Routine methods for predicting animal performance for use in livestock feeding management are constantly changing. Static systems of feed requirements are beginning to be replaced by dynamic simulation models that are able to characterize animal response to a wider range of input conditions than those of traditional systems. These input conditions are characterized by an expanding set of management options such as feed intake, energy digestibility and eating cost, locomotion energy expenditure and maintenance, etc. In the last few years, a significant effort has been made to develop educational materials that facilitate student learning in the field of Animal Nutrition. There are also some virtual instruments that are particularly appropriate for compound feed formulation based on linear programming; however this software is basically for commercial purposes.

This paper presents the use of MATLAB for developing several applications in order to have an alternative to these commercial packages. The idea is to use MATLAB applications as a learning aid for the compulsory Animal Nutrition course, which is given in the second semester of the fourth year of the Agricultural Engineering degree program at the Technical University of Valencia (Spain). This subject is taken by the student in their third year of specialization. It is run by the Animal Science Department and belonged to Animal Production syllabuses. As mentioned above, this course falls within the Animal Production syllabus, which consists of several subjects. Table 1 shows the first cycle (first two years) with general basic subject such as Mathematics, Chemistry and Physics, and the second cycle (from third to fifth year) with main subjects relating to Animal Nutrition.

Before starting the Animal Nutrition course, the experience of the students in basic subjects such as Mathematics, Chemistry and Physic is homogeneous. These students, who have already completed the first and second year, have a solid theoretical background in Mathematics that is applicable to the use of MATLAB.

The Animal Nutrition module has a duration of 120 hours, which are divided equally between lectures and laboratory sessions. Although the lecture sessions include all domestic animal species, the laboratory sessions are focused on dairy goat farms due to the proximity to the University of some farms, the University Experimental farm and the experience of the lecturers. The Animal Nutrition module is focused on the theoretical bases of feed evaluation and animal requirements. The module has been structured into three blocks. In the first block, the students are introduced to the features and methods of obtaining the main nutritive characteristics of feeds (Feed Nutritive Value). This block also provides the background for understanding feed evaluation associated with nutritive value. In the second block, feeding systems and feed evaluation methods are reviewed and some applications are developed in order to learn about different types of models; the results are analyzed, and the most suitable models in each case are discussed (Feed Nutritive Prediction methods). Finally, in the third block, the foundations of Animal Nutritive Requirements are presented. Mathematical models to predict animal response in livestock production systems are developed. The following mathematical models are studied:

- linear regression;
- non-linear regression;
- polynomial regression;
- exponential equation;
- second-order differential equation.

Therefore, the Agricultural Engineering degree program presents a syllabus in which the development and analysis of non-linear models is a key subject. This is the reason why the authors propose MATLAB as a powerful tool for being used in the laboratory. Since students may not have prior knowledge of this tool, the development of MATLAB software applications using the GUIDE (*Graphical User Interface Development Environment*) tool is proposed [9]. The main advantages of this tool are as follows:

- It can be used in theory lessons to illustrate concepts as well as to serve as an aid in the laboratory to carry out practical experiments.
- It is simple, easy to use, flexible and interactive.
- It is adaptable to Animal Science, since it has a malleable structure that enables the tool to be easily extended to other subjects and research applications.

SOFTWARE APPLICATION: THE GUIDE TOOL

GUIDE is a useful framework for the development of software applications. The graphical display contains devices, or components, that enable the user to perform interactive tasks. There are two different stages during development:

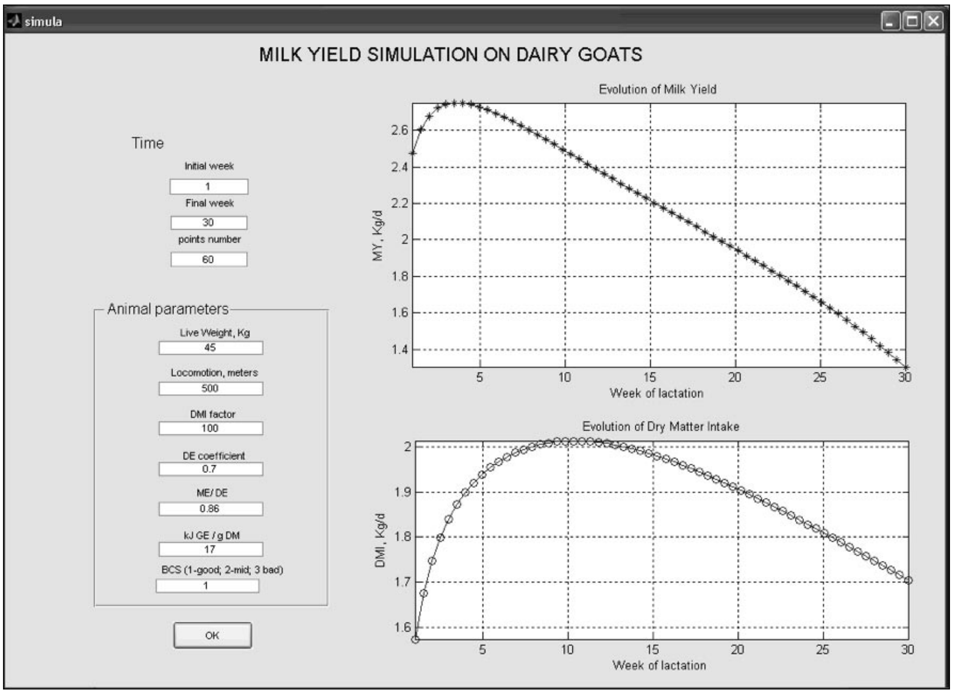
1. *The Graphical User Interface (GUI) Layout.* In this stage, all the elements needed to perform the interactive tasks are added to the GUI, using the GUIDE Layout Editor. These elements can be: panels, buttons, text fields, sliders, and menus. All the graphical characteristics exhibited by these elements (color, font-size, positioning, etc.) are easily updated with this editor. After finishing the lay-out of the interface and saving it, MATLAB creates two files. The first file contains the interface (extension *.fig) and the M-file contains the code of the GUI (extension *.m). The next step is to add code to the M-file to make it perform a specific task when it is selected or modified. This stage is the easiest part of the development process.
2. *Application programming.* The M-file initializes the GUI and contains a framework for the most commonly used callbacks for each component. The callbacks include the commands that are executed when a user clicks a GUI component. Therefore, the result is a basic program that manages the position and the main action performed by each component. The next step is to add code to the M-file in order to perform the desired computing action. This is the main task and is the most difficult part of the development of applications of this kind.

SOFTWARE APPLICATION: MILK YIELD AND DRY MATTER INTAKE PREDICTION

The level of animal productivity (in our case milk yield, MY) is influenced by many animal factors: first, internal factors within the animal, which include breed, age and diet (which is a function of both the composition of the diet and the physiological state of the animal); second, external factors such as environmental conditions.

In our application, we have selected a few factors that accurately simulate milk yield during lactation and that allow the students to manipulate the tool under different parameters. Therefore, Live weight (LW) during lactation was modeled to develop the application by means of a second-order differential equation. There are some parameters in this model that, depending on the goat being studied, are fitted with a least mean squares method. Once the parameters have been established, the physiological data of the goat are used to perform the LW modeling. Other animal factors, such as locomotion expenditure and maintenance, were adjusted using empirical equations. In other cases, such as digestibility coefficient and gross energy of diets, constant values were used.

Therefore, students simulate milk production and dry matter intake upon observed data from different farms. Hence, students could create different scenarios (e.g. different nutritive value of diets), and evaluate observed and predicted milk production and intake. Comparing observed and predicted values, students can analyze and



simula

MILK YIELD SIMULATION ON DAIRY GOATS

Time

Initial week: 1

Final week: 30

points number: 60

Animal parameters

Live Weight, Kg: 45

Locomotion, meters: 500

DMI factor: 100

DE coefficient: 0.7

ME/ DE: 0.86

kJ GE / g DM: 17

BCS (1-good; 2-mid; 3 bad): 1

OK

Fig. 1. GUI of the application for milk yield and dry matter intake prediction.

discuss which inputs have more relevance under field conditions.

Since this process can be tedious, the use of a user-friendly interface that performs this modeling in a quick and easy way is proposed. Students will be able to pay more attention to proposing different cases and discussing them in the classroom rather than spending their time programming the software. The main advantages of the user interface are as follows:

- Students can simulate different physiological animal situations such as body weight, energy of diet, digestibility, and heat fermentation using different parameters.
- Students can simulate different animal management conditions such as locomotion and body condition score (body reserves) using different equations with fixed equation parameters.

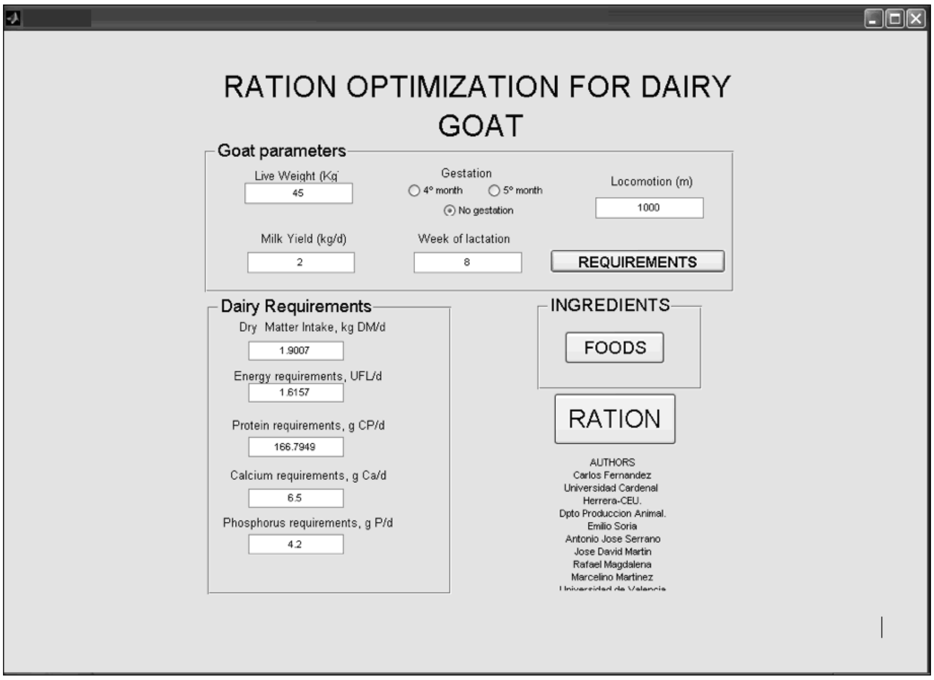
The application developed for this purpose is shown in Fig. 1. The MY and Dry Matter Intake (DMI) modeling are given for a particular set of parameters. Figure 1 shows two areas that are completely different: one area is the animal data interface and the other is the representation of the variables being studied. Data can be easily modified so that changes in the predicted variables are quickly reflected.

The left side of Fig. 1 shows the parameters of the goat used in this application. The student can change these parameters in order to obtain different animal conditions. The parameters are defined as follows.

- LW is the live body weight of the goat expressed in kg.
- Locomotion is the distance, in meters, needed to determine walking expenditure
- DMI factor is the metabolizable energy (ME) intake per kg of metabolic LW (expressed as kJ ME/kg LW$^{0.75}$).
- Energy digestibility coefficient (DE coefficient).
- Correction of heat fermentation is due to the ratio ME/DE.
- Gross energy of the diet evaluated (kJ GE/g DM of the diet).
- Body Condition Score (BCS) related to body reserves (1: good, 2: medium, 3: bad).

SOFTWARE APPLICATION: LEAST COST RATION FORMULATIONS

The optimal diet (ration) calculation is a problem that can benefit from the computational power of MATLAB. It uses MATLAB capabilities to solve constrained-function-optimization problems and to import and export data to other formats, for instance, MS Excel. The problem is quite straightforward to define: the optimal feed for each goat must be determined taking into account the restrictions related to animal requirements (dry matter, energy, protein, calcium and phosphorus). Restrictions can be of different types, mainly equalities and inequalities. In addition to these constraints regarding animal needs there are other constraints related to feeding that must also be taken into account. Since goats are ruminant animals, they need fiber in their diet, so a fixed percentage of forage is used to avoid an imbalance in ruminant fermentation. In summary,



RATION OPTIMIZATION FOR DAIRY GOAT

Goat parameters

Live Weight (Kg: 45

Gestation: ○ 4° month ○ 5° month ● No gestation

Locomotion (m): 1000

Milk Yield (kg/d): 2

Week of lactation: 8

Dairy Requirements

Dry Matter Intake, kg DM/d: 1.9007

Energy requirements, UFL/d: 1.6157

Protein requirements, g CP/d: 166.7949

Calcium requirements, g Ca/d: 6.5

Phosphorus requirements, g P/d: 4.2

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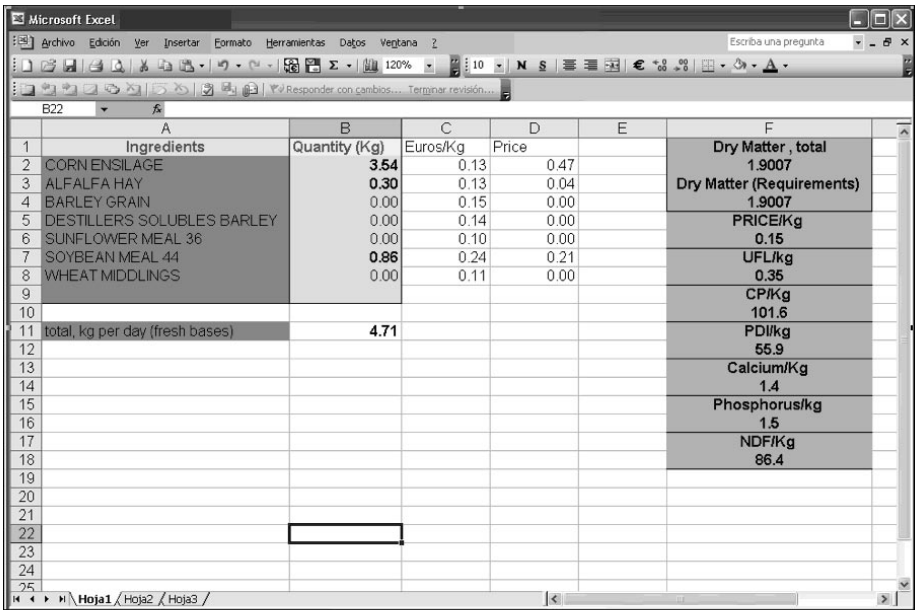
Fig. 2. GUI of the application for optimum diet prediction.



Microsoft Excel

B22

	A	B	C	D	E	F
1	Ingredients	Quantity (Kg)	Euros/Kg	Price		Dry Matter , total
2	CORN ENSILAGE	3.54	0.13	0.47		1.9007
3	ALFALFA HAY	0.30	0.13	0.04		Dry Matter (Requirements)
4	BARLEY GRAIN	0.00	0.15	0.00		1.9007
5	DESTILLERS SOLUBLES BARLEY	0.00	0.14	0.00		PRICE/Kg
6	SUNFLOWER MEAL 36	0.00	0.10	0.00		0.15
7	SOYBEAN MEAL 44	0.86	0.24	0.21		UFL/kg
8	WHEAT MIDDLINGS	0.00	0.11	0.00		0.35
9						CP/Kg
10						101.6
11	total, kg per day (fresh bases)	4.71				PDI/kg
12						55.9
13						Calcium/Kg
14						1.4
15						Phosphorus/kg
16						1.5
17						NDF/Kg
18						86.4

Fig. 3. Excel spreadsheet with the final report generated by the application.

it is a typical linear programming problem [10], which can be defined as follows:

$$
\begin{aligned}
&\min[a_1 \cdot x_1 + a_2 \cdot x_2 + a_3 \cdot x_3 + \ldots\ldots\ldots a_N \cdot x_N] \\
&b_1 \cdot x_1 + b_2 \cdot x_2 + b_3 \cdot x_3 + \ldots\ldots\ldots b_N \cdot x_N \geq \alpha_1 \\
&c_1 \cdot x_1 + c_2 \cdot x_2 + c_3 \cdot x_3 + \ldots\ldots\ldots c_N \cdot x_N \geq \alpha_2 \\
&\ldots\ldots\ldots\ldots \qquad (1) \\
&s_1 \cdot x_1 + s_2 \cdot x_2 + s_3 \cdot x_3 + \ldots\ldots\ldots s_N \cdot x_N \geq \alpha_k \\
&x_i \geq 0 \forall \mathrm{i}; x_n \geq treshold \cdot \sum_{k=1}^{N} x_k
\end{aligned}
$$

In Equation (1), x_i is the quantity of the i-th food (ingredient) that the student can select to prepare the diet of the goat; b_i, c_i . . . s_i are the nutritive values of the ingredients selected to elaborate the diet; α_i are the nutritive requirements of the goat; and α_i is the corresponding price. The inequalities represent the restrictions that must be fulfilled because they reflect the physiological needs of the goat. It must be pointed out that the first task is to calculate the goat's needs. These calculations are integrated with the solution of the linear programming problem in the application.

It must also be taken into account that the characteristics of the food, namely its nutritive value, are constantly changing thus a file is needed to save these characteristics. The problem is quite complex (the complexity depends on the number of different foods and the constraints that the farmer or the student chooses). In addition, depending on the solution, new feeds can be chosen, requiring further calculations. In order to overcome the difficulty of calculating nutritive requirements of animals and nutritive value of food, a visual tool in MATLAB has been designed. This tool is shown in Fig. 2.

As in the MY application, this application offers several sections with different functionalities. The first step is related to the physiological description of the goat (the upper-left part of Fig. 2). Once the initial animal parameters have been filled in, the *Requirements* button is pressed and the different requirements of the animal, expressed in the French unit system, are shown (the lower-left part of Fig. 2). The next step consists of pressing the *Food* button. This action opens an Excel spreadsheet with the list of feed ingredients in order to select the group of raw materials to feed the animals. Once the ingredients are selected, the datasheet is saved and, finally, the ration is calculated. Again, the advantages of using this software are evident. Loading and saving the datasheet from MATLAB is easy and intuitive. After loading the variables, the problem of optimization with constraints is carried out, giving the user a report on the right side of the screen where the quantity of each food and its cost per kg are presented (Fig. 3). This information is extremely valuable for the farmer.

CONCLUSIONS

This paper presents two MATLAB-based software applications that can be used for teaching and research purposes in an Animal Nutrition course. These tools interactively show the results obtained with simulation techniques during lectures and also provide support for practical tasks in laboratory sessions. The applications have been developed with a GUI to simplify their learning and use. Since these tools are useful for understanding feed nutritive value, animal requirements, and the formulation of diets, they can also be used to advise farmers.

This software is available upon request from the authors (Technical University of Valencia Editions).

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