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Research Article

Fuzzy Logic-Based Decision Support System for Dairy Cattle

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Abstract

Various methods have been developed to achieve the most suitable solution in the face of challenges of constantly changing living conditions. Fuzzy logic is one of these methods and frequently preferred by researchers in recent years. Fuzzy logic is based on artificial intelligence modeling the information that includes uncertainty in the most appropriate mindset of people, especially in the decision making process. It also offers flexible and realistic perspectives to people. In this study, a fuzzy logic-based decision support system designed using reproduction and milk yield records of Holstein Friesians. Inputs of designed system are 305-day milk yield (305 DMY), calving interval (CI), service period (SP), artificial insemination (AI), dry period (DP). Output of the system is determined as classification decision. Similarities between expert and system decisions were investigated. Kappa statistics were used for this purpose and fitting value was found as 92.6% (P<0.05).

Keywords: *Decision support systems, Fuzzy logic, Fuzzy sets*

Süt Sığırlarında Bulanık Mantık Tabanlı Karar Destek Sistemi

Özet

Sürekli değişen yaşam koşullarının sorunları karşısında en uygun çözüme ulaşmak için çeşitli yöntemler geliştirilmektedir. Bulanık mantık bu yöntemlerden biridir ve son yıllarda araştırmacılar tarafından sıklıkla tercih edilmektedir. Bulanık mantık yöntemi, belirsizlik içeren bilgileri insanların düşünce yapısına en uygun biçimde modellemektedir. Özellikle karar alma süreçlerinde insanlara gerçekçi ve esnek bir bakış açısı sağlayan yapay zeka temelli bir yöntemdir. Bu çalışmada Siyah Alaca ırkı süt sığırlarına ilişkin üreme ve süt verimi kayıtları kullanılarak, bulanık mantık tabanlı bir karar destek sistemi tasarlanmıştır. Oluşturulan sistemin girdileri 305 günlük süt verimi, buzağılama aralığı (BA), servis periyodu (SP), aşım sayısı (AS), kuru periyodu (KP) bilgilerinden oluşmaktadır. Sistemin çıktısı ise sınıf kararı olarak belirlenmiştir. Sistemin performansını değerlendirmek amacıyla uzman kararları ve sistem kararları arasındaki uyum araştırılmıştır. Bu amaçla kullanılan Kappa istatistiği ile uyumun % 92.6 değerinde olduğu tespit edilmiştir (P<0.05).

Anahtar sözcükler: *Karar destek sistemleri, Bulanık mantık, Bulanık kümeler*

INTRODUCTION

Success of herd management in animal breeding directly effects the continuation of profitable production process. One of the major components of herd management is the right and rational pick of animals. A successful picking policy is the vital element needed to reap economic benefits from animals [1]. Dairy cow breeders focus on two basic factors when picking animals; voluntary culling causes (low efficiency level etc.) and involuntary culling causes (breeding problems etc.) [2-4].

Individuals that work in the field of herd management often seek consultation from experts for their management process, which helps them in raising high amounts of profit. However, when considering the high rates charged by consultants and availability issues, such options are not a viable or long-term solution for breeders in terms of make decisions promptly. Therefore, information technology options offer a way out. Today, especially artificial intelligence based software technologies and designed systems can provide information to individuals in many fields, including the one we are concerned with here - animal field and herd management [5-9].

Fuzzy logic-based decision support systems, is one of the methods developed to achieve the optimum solution against the problems of constantly changing living conditions. The Fuzzy Logic method is common for such study fields as medicine, engineering and biology

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due to its usage in the processing of uncertainty of data set; recently, it is also preferred in agriculture, too. For instance, this method is used in animal breeding [6,7], estrus detection [10-12], detection of sicknesses such as mastitis and lameness [13-16], animal nutrition [8,17], prediction of various production traits (milk, egg, body weight etc.) and quality classification of animal products [18-23].

Strasser et al.[6] study is one of the first studies on fuzzy logic and culling the animals. In this study, a fuzzy logic based decision support system is developed in order to investigate the use of fuzzy logic for dairy cow culling. They have looked animals to be culled according to the decision support system on dairy cows' monthly milk yield, developed via use of the fuzzy logic method. Research has also been mentioned that support the idea that the fuzzy logic method can be used in future animal culling related studies. In the study of Wade et al.[7] such elements as milk yield index from the dairy cow, reproduction activity and lactation numbers have been considered as input variations for decision support system and for taking animals to dry - all done via the use of the fuzzy logic method has. Researchers mentioned in the results part of their study that the system, which has been designed by them, would be beneficial for the producers in culling, classification of animals and other issues. Memmedova et al.[9] in their study formed a desired unified culling model by using the fuzzy logic method and used age at first calving, calving interval and lactation milk yields as input variables. The output variable was also the classification of cows in terms of these traits. In addition, in their unified culling model, as in this study, they successfully determined animals to the subject of culling and they mentioned that the fuzzy logic could be successfully useable in the animal field as well.

In this study a Fuzzy Logic based Decision Support System has been designed in order to provide solutions for the classification problem. For this purpose, class of animals was determined that using these input variables; 305 daily milk yield (305 DMY), calving interval (CI), service period (SP), the number of artificial insemination (AI), dry period (DP). Also system's output was determined as classification decision. The purpose of system was to assist to breeders in the identification of animals which elite and removed from the herd.

MATERIAL and METHODS

Material

Reproduction and milk yield records of 121 Holstein Friesian cows were the material of this study. The designed decision support system's input variables are determined using factor analysis in order to determine which associated of the 11 different variables. Because of factor analysis, the Kaiser-Meyer-Olkin value found 0.54. Varimax factor rotation method was used in the analysis. Factors that have eigenvalue greater than one are considered significant. As a result of factor analysis; 305 daily milk yield (305 DMY), calving interval (CI), service period (SP), the number of artificial insemination (AI), dry period (DP) variables were identified as common factors. Three different classes are defined as "good (class 1) -normal (class 2) -poor (class 3)" for output variable. Ideal values for the input variables are defined as average of cows' own herd. Analysis of data was carried out with Matlab (R2010b) and SPSS 20.0 statistical package programme [24].

Method

Fuzzy Logic theory recognized for the first time in the research of Zadeh [25]. In his Fuzzy Logic theory the truthfulness of statements, between absolute truth or absolute wrong infinite number of truthfulness degree values in the cluster or contrary to numeric meaning of classical logic as sole "1" or sole "0", its defined as a function related to values between [0,1] [25-27]. Compared to human experts, the Fuzzy Logic method can provide more objective and flexible perception in situations that reflects uncertainty. Nonetheless, taking information from the data of the Decision Support System, this method also provides vital benefits to users, which are in the process of taking decision. Fuzzy system basically consists of four components. These components are fuzzifier, fuzzy rule base, fuzzy inference engine (decision unit) and defuzzifier.

In the fuzzification stage, fuzzy system operation preliminary is done in order to processing the data from outside using information in system's inference mechanism and fuzzy rule base [28,29]. Firstly, all membership functions including these function positions are determined.

In practice, the types used most in terms of membership functions are triangular, trapezoidal, bell shape, Gaussian, Sigmoidal, S and π [29]. In this research, expert opinion and a detailed literature review [12,14,18,19,23] of fuzzification stage triangular and trapezoidal membership functions are used. In this stage, variables' minimum and maximum values and the average values of the h erd is considered for fuzzy sets. Triangular membership function with such as a, b and c three parameters are expressed as,

$$\mu_A = (x;a,b,c) = \begin{cases} a \le x \le b, & (x-a)/(b \\ b \le x \le c, & (c-x)/(c \\ x > c \quad or \quad x < a, & 0 \end{cases} \qquad [1]$$

In Equation 1, b parameter is core of the membership function and values between a and c parameters refers to the support of the function.

Trapezoidal membership function with such as a, b, c and d parameters are expressed as [21,27].

$$\mu_A = (x; a, b, c, d) = \begin{cases} a \le x \le b, & (x-a)/(b \\ b \le x \le c, & 1 \\ c \le x \le d, & (d-x)/(d \\ x > d \quad and \quad x < a, & 0 \end{cases} \quad [2]$$

At trapezoidal membership function, part between a-b and c-d parameters forms the boundaries of the function; and values between b-c forms core of the function.

The data that come to system in fuzzy rule base after ready to be processed is processed by inference mechanism according to defined by the form "if- then" rules. A structural learning takes place according to defined parameters [27,28]. The information is modeled via a variety of methods in fuzzy inference mechanism. The methods, that is, the inference methods; these are the Mamdani method, the Larsen method, the Tsukamoto method or the Tagaki-Sugeno-Kang method. Mamdani method is widely used in decision support system studies. The Mamdani and Tagaki-Sugeno-Kang fuzzy inference methods can be used in Fuzzy Logic Toolbox of Matlab Programme. In this research, the Mamdani method was used because output variables are fuzzy set. Tagaki-Sugeno-Kang method is not preferred because the output variable is not a fuzzy set, it is a linear function or a constant value in Sugeno method [19,30].

Mamdani method's rule structure is as follows:

If $X_1=A_1$ and $X_2=B_1$ then $Z_1=C_1$

If $X_1=A_2$ or $X_2=B_2$ then $Z_2=C_2$

In these rule structures, X_1 and X_2 represent input variables; Z_1 and Z_2 represent the output variables. A_1, B_1, A_2 and B_2 represent membership functions; C_1 and C_2 show that fuzzy result set at the end of each rule [19,29,30]. The fuzzy result set consists of the area under the point where separate thresholds that defined for each rule. Threshold value is determined by "and-or" processor. When "and" processor is used the threshold degree of membership is equal to the smallest on the basis of fuzzy sets in intersection feature. "Or" processor is used is equal to the threshold value based on the union transaction largest membership degree in fuzzy sets.

The fuzzy set that is obtained from fuzzy inference engine transformation process is taking place to the absolute value in the defuzzication stage. In practices maximum membership principle, the mean of maximum membership, weighted average, centroid, smallest of maximum and largest of maximum methods are used as defuzzification methods [27,28]. In this research, the centroid method is used as the defuzzification method. Centroid method is most prevalent and commonly used in many applications in animal science. Also this method is determined by the structure of problem's suitability and detailed literature review [12,19,23]. Defuzzification value is calculated as following [29].

$$y^* = \frac{\sum_{i=1}^{n} y_i \cdot \mu_c(y_i)}{\sum_{i=1}^{n} \mu_c(y_i)} \quad [3]$$

In this equation y_i represents the defined output variable, μ_c (y_i) represents output variable's membership degree and y* represents the defuzzification value.

RESULTS

Decision support system has benefited from the work done previously on fuzzy logic [9,12,19,23], the knowledge and experience of experts, the textbooks on animal breeding [4,31] for decision support system of input variables, the formulation of rules and membership functions of creation. An overview of the system is located in *Fig. 1*.

In order to carry out the fuzzification process, not only was the membership function of each input determined but also their position on the x-axis has also been defined. According to the formed fuzzy logic based decision support system, for its input variables' number of artificial insemination "low, medium and high"; calving interval "short, normal and long"; service period "short, medium and high"; dry period "low, medium and high"; 305 day milk yield "low, medium, high and very high"; fuzzy sets have been determined. Designed fuzzy system that was created using Matlab fuzzy logic tool box for number of artificial insemination, calving interval, service period, dry period and 305 day milk yield membership function of each input variable and output variable for representing classification decision are presented in *Fig. 2*.

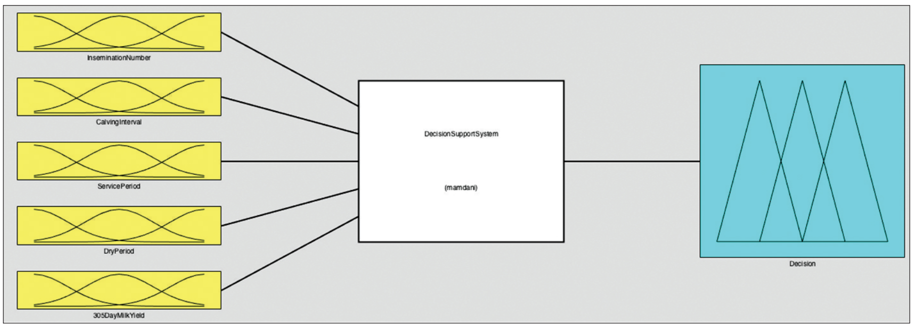

Fig 1. Designed fuzzy system structure

Şekil 1. Tasarlanan bulanık sistem yapısı

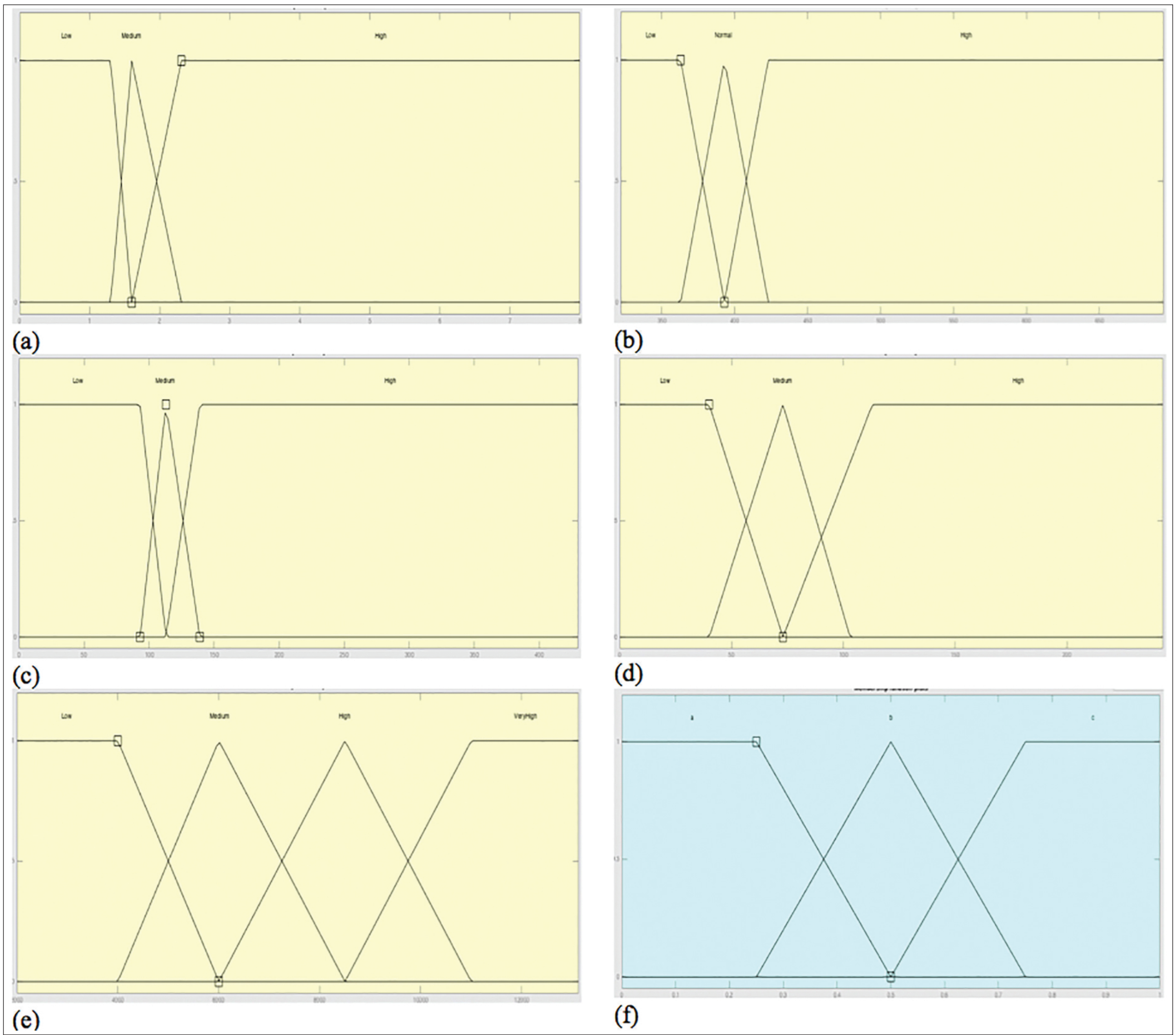

Fig 2. The input variables. The number of artificial insemination (a), calving interval (b), service period (c), dry period (d), 305 day milk yield (e); the output variable: classification decision (f)

Şekil 2. Girdi değişkenleri. Aşım sayısı (a), buzağılama aralığı (b), servis periyodu (c), kuru periyodu (d), 305 günlük süt verimi (e) girdi değişkenlerine ait üyelik fonksiyonları; sınıflandırma kararını temsil eden çıktı değişkeni (f)

In this research, the Mamdani method is used as an inference method and according to the information in fuzzification unit 328 fuzzy the "if-then" rules are written. Some of these rules are shown as follows:

Rule 163 If AI low and CI low and SP low and DP low and 305 DMY high Then Decision (1).

Rule 81 If AI high and CI high and SP high and DP high and 305 DMY low Then Decision (3).

Rule 272 If AI medium and CI low and SP low and DP medium and 305 DMY very high Then Decision (1).

In *Fig. 3* the "if-then" rules' prepared view with the fuzzy logic toolbox in the Matlab programme is located.

A three dimensional relation between 305 day milk yield and calving interval can be seen at *Fig. 4;* the relation between 305 day milk yield and classification decision can be seen at *Fig. 5*.

In *Fig. 4*, it can be noted that the increase in 305-day milk yield suggests that the decision to low class should not be taken. That means, the increase in milk yield indicates the animals, which will be identified as in the good class (Class 1). In *Fig. 6* the relation between calving interval and classification decision can be seen; in *Fig. 7* the relation between service period and classification decision can also be observed. An increase for both two variables can lead to a decision for the decision that animals can be taken in low class. In *Table 1*, input variables' value and some parts of system and expert decisions are located.

The similarities between expert decision and system decisions were researched using Kappa statistics to evaluate the performance of the system and 92.6% value has been found to fit ($P<0.05$). According to result of analysis in one hand, animals in Class 1 are the most productive cow in terms of milk yield and reproductive traits. On the other hands, animal in Class 3 are candidates

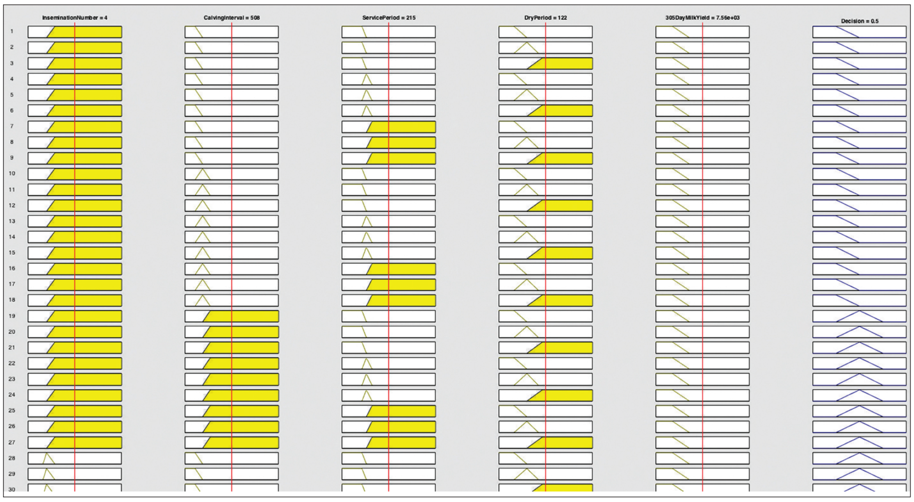

Fig 3. Rule viewer

Şekil 3. Matlab programında kural gösterim penceresi

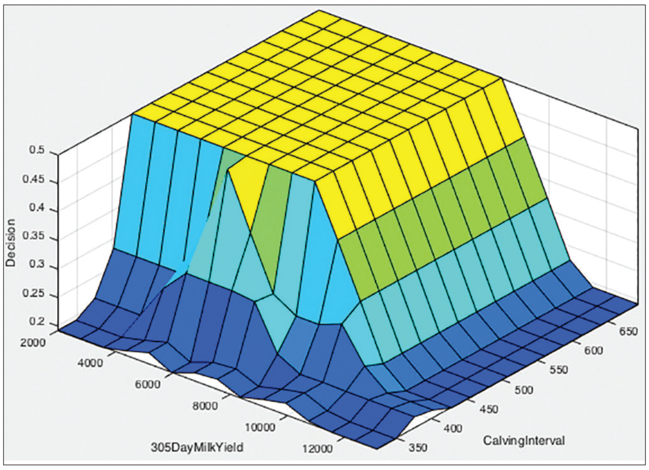

Fig 4. Surface viewer of study's input variables (305 Day milk yield, Calving interval) and output variable (Classification decision) in Matlab

Şekil 4. Matlab programında çalışmanın girdi değişkenleri (305 Günlük Verimi, buzağılama aralığı) ve çıktı değişkenine (sınıflandırma kararı) ilişkin yüzey gösterim penceresi

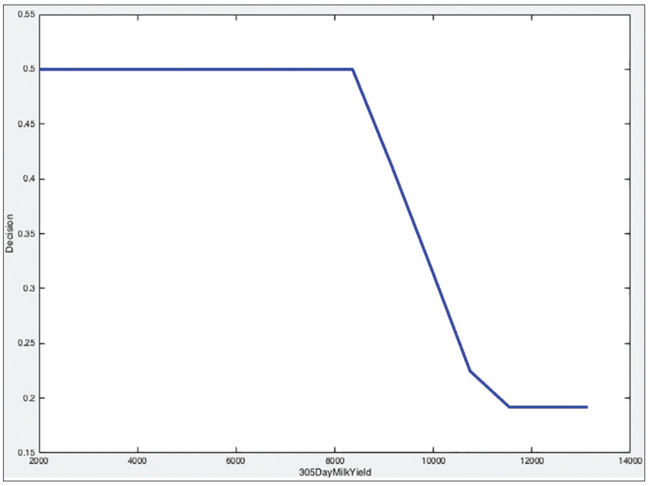

Fig 5. 305 Day milk yield input variable- Classification decision (System output)

Şekil 5. 305 günlük süt verimi girdi değişkeni ile sınıflandırma kararı (Sistem çıktısı) ilişkisi

to leave the herd and yield level can be interpreted as the lowest of animals.

DISCUSSION

In this study, it is aimed to classify animals using milk production and reproductive information for dairy cows. It refers to the output variable, which will take place in the class of animals that are detailed in viewing with five different input variables obtained factor analysis results. According to our results of analysis in examined data set, the distribution of the class of cows is as follows: 35 dairy cows in class 1, 171 dairy cow class 2 and 15 dairy cow in the class 3. As a result of the classification, it is observed that animals, which are located in class 1, can be chosen as breeding animals and the third class of animals can have the possibility of culling. In this study, 328 fuzzy rules written for designed fuzzy logic based decision support system. Thus, both milk yield and reproduction information could be evaluated simultaneously with different perspectives. The research results show that 305-day milk yield and calving interval are very important for the classification of animals. Besides from that, obtained results supported by literature information and expert opinion. The study analyzes indicates that even if the milk yield of examined dairy cows are high, calving interval and insemination numbers can be an obstacle against the selection as breeding animals due to high values.

There are limited number of studies in the literature that focuses on culling, classification etc. decision taken through usage of the fuzzy logic method. Strasser et al.[6] is one of these studies. Strasser et al.[6] used monthly production information in their study. The monthly production data as well as reproductive information is

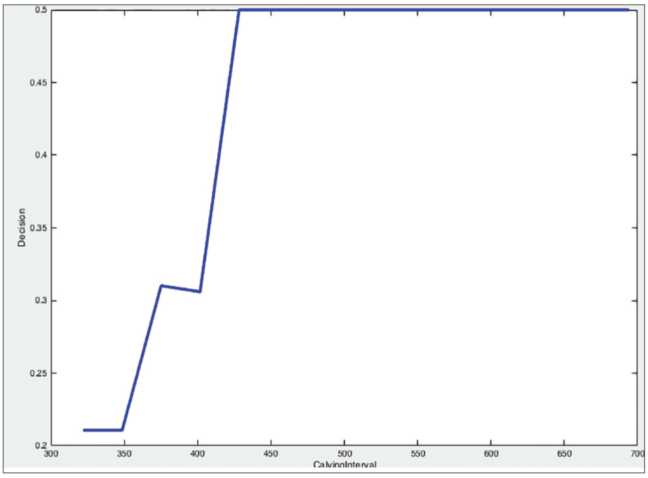

Fig 6. Calving interval input variable - Classification decision (System output)

Şekil 6. Buzağılama aralığı girdi değişkeni ile sınıflandırma kararı ilişkisi (Sistem çıktısı)

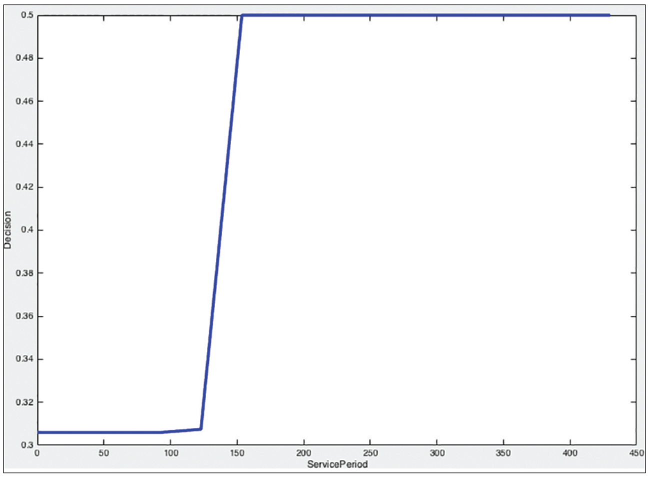

Fig 7. Service period input variable- Classification decision (System output)

Şekil 7. Servis periyodu ile sınıflandırma kararı ilişkisi (Sistem çıktısı)

***Table 1.** The analysis results by using Matlab*

***Tablo 1.** Matlab programı ile elde edilen analiz sonuçları*

305 DMY	Number of Insemination Number	Calving Interval	Service Period	Dry Period	System Decision	Expert Decision
9288	1	333	57	50	Class1	Class1
8591	2	363	83	76	Class1	Class1
8443	4	473	188	70	Class2	Class2
11121	4	430	157	58	Class2	Class2
9869	6	466	176	76	Class3	Class3

used also in our study. Similar to the results of our work, researchers reported that can be used successfully for the study of the fuzzy logic by culling animals. Wade et al.[7] is one of the other studies about culling and fuzzy logic. Different from Wade et al.[7], we looked at instead of milk yield index, the 305 day milk yield; and instead of reproduction activity, the calving interval, service period, dry period and number of artificial insemination information in our study. Memmedova et al.[9] formed a desired unified culling model by using the fuzzy logic method. Different from those studies, in this study (even though different input variables and number of data have been used) the results achieved were of a similar nature. The greater number of data and the number of variables are given place in our work with success rates similar values.

In this study, it is given to a greater number of input variables and If-Then rules. In this context, examining simultaneously in terms of both milk yield and the reproductive ability of the animals were provided according to examined works. It is aimed to gain much more detailed and flexible perspective to the solution of the classification problem in comparison with the other related studies. Our work has a similar success rate with studies in the literature. In our study, the elimination of errors in the solution of classification problems stemming from people and aimed to prevent cost increases.

Today, problems are becoming more complex and the systems, which emerged in the past in order to solve problems, could not respond to the problems of today by way of offering adequate solutions. The system variables mentioned may not bear enough absolute value for mathematical modeling; in these situations, expert consultation might be needed. Expert persons provide insights due to "very few, few, medium, many" like linguistic qualifier. Insights derived from experts can be transferred to a computer environment through fuzzy logic mathematical based systems and could provide solutions suitable for real life. Computer systems such as fuzzy logic that can mimic expert insights since they too hold 'expert information'; moreover, the increasing use of these systems may mean lowering expert expenses. It can be said that this approach is an alternative perspective for traditional methods in animal science.

In this study, a decision support system that has been constructed via using the fuzzy logic method was used to provide help for researchers that study on animal field in terms of taking the decision to classification due to milk yields and reproduction data. Compared to expert insights and the system's decisions, it is noted that there is a 92.6% success rate of the classification. The designed system's success in terms of animal classification showed that fuzzy logic based decision support systems will be also successful in the animal field, too. Furthermore, it can be that in the future combined systems that use fuzzy logic and other artificial intelligence methods both might provide perspectives that are even more useful for researchers against uncertainties in the animal field.

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