SUBCLINICAL MASTITIS PREDICTION IN DAIRY CATTLE BY APPLICATION OF FUZZY LOGIC

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The main purpose of this study was to detect subclinical mastitis in a large sized dairy herd milked using automated milking systems. Recording of data was performed on the private dairy farm Karapinar of the province of Konya, Turkey. A data set of 346 milkings from 170 cows was used. Mastitis alerts were generated via a Fuzzy Logic (FL) model with the input data of lactation rank (current lactation number), milk yield, electrical conductivity, average milking duration and season. The output variable was somatic cell counts obtained from milk samples collected monthly throughout the 15 months of the sampling period. Cattle were judged healthy or infected based on somatic cell counts. The evaluation of the model was carried out according to sensitivity, specificity and error rate. The FL model yielded 82% sensitivity, 74% specificity, and 60% error. Fuzzy logic seems one of the useful tools to develop a detection model for mastitis. With more informative parameters, the error rate can be decreased.
Keywords: Dairy cattle, fuzzy logic, subclinical mastitis, bacterial disease, somatic cell count.

INTRODUCTION

Mastitis is a disease typically characterized by inflammation of the mammary gland caused by microorganisms (usually bacteria) that invade the udder, multiply and produce toxins that are harmful to the mammary gland and cause substantial economic loss in the form of decreased milk yields (Osteras *et al*., 1999; Schroeder, 2012; Wilson *et al*., 2004). The udder reacts against mastitis to destroy the bacteria causing the infection, neutralize toxins and repair milk secretion tissues. Mastitis is classified according to the strength of the udder's reaction. Subclinical mastitis is a form in which there is no swelling of the gland or observable abnormality of the milk, although there are changes in the milk that can be detected by special tests like the California Mastitis Test (CMT) and somatic cell count (Batra *et al*., 1983; Sargeant *et al*., 1998).

Today, with enterprises using computerized herd management systems that automatically record such traits as milk yield, milk flow rate and electrical conductivity, such programs may alert users to the presence of mastitis in cows based on extreme deviations in electrical conductivity. However, these alarms are so frequently wrong that the practice of using electrical conductivity alone to predict mastitis seems nonviable (Atasever and Erdem, 2008).

Somatic cell count (SCC) of milk samples has gained a wide recognition as an aid in the detection of subclinical mastitis (Batra *et al*., 1986; Sargeant *et al*., 1998). SCC depends on such factors as cow age, breed, lactation rank, milk yield, udder anatomical and physiological features, stress, season, nutrition, shelter conditions, milking technique and the presence of mastitis (Raubertas and Shook, 1982; Jones *et al*., 1984; Goncu, 2002; Şeker *et al*., 2000; Cedden *et al*., 2002; Risvanli and Kalkan, 2002; Uzmay *et al*., 2003; Bademkıran *et al*., 2005; Kul *et al*., 2006; Porcionato, 2010). Some studies have reported that increased SCC is negatively related to milk yield (Raubertas and Shook, 1982; Jones *et al*., 1984).

Of the economic losses caused by mastitis, 20–30% is the result of clinical mastitis, while 70–80% are the result of subclinical mastitis, making the latter a serious problem in dairy cow production. In 90% of events in which udder and milk appearance are normal but SCC is elevated, milk quality and premiums decrease, and income and milk yields decline (Tekeli, 2005).

In Turkey, annual economic losses caused by mastitis are estimated at around $41.5 million, despite the fact that each $1 spent on effective mastitis control programs returns $5 to the producer (Tekeli, 2005). Knowledge of mastitis-causing factors and a willingness to take necessary measures are considered the most important steps in overcoming the barriers to ensuring high-quality milk production and protecting animal welfare (Atasever and Erdem, 2008).

This study investigated performance of FL for early detection of subclinical mastitis in situations where detection would be difficult using conventional methods.

MATERIALS AND METHODS

In this study, data from February 2010–April 2011 of Karyem Private Dairy Farm were used to develop and validate FL model for classifying dairy cows into healthy

and mastitis-infected groups. Animal subjects used in the study consisted of 170 Holstein-Friesian cows raised in the Karyem Agricultural Enterprise, situated in the Karapinar district (37°47′ north, 33°35′ East and 994 m altitude) of the Konya province. In the sampling periods the cows extracted for calving were replaced with newly added cows.

The Karyem Agricultural Enterprise used a professional herd management system that immediately records all events and used this information to predict future problems to allow for the highest levels of profitability. The program allows animal specific information to be entered by the user or to be automatically registered by the system. As animals are milked using the automatic milking system, the system automatically collects such data as milk yield, average milking duration (min/cow), and milk electrical conductivity. Cows were housed in a free stall barn and milked twice daily (03:00 to 06:00 and 15:00 to 18:00) in a 2 x 12 side-closed milking parlour (Afikim, AFIFARM). For this study, milk samples were collected from the automatic milking system in 50 mL tubes once a month (from February 2010 until April 2011) from 03:00 to 06:00 am with the help of a sampling apparatus (a bottle installed to the cow's milking system, where milk drops during milking). Milk samples were collected with all due care, given that the primary goal was to calculate milk SCC. Experiment was carried out according to Selcuk University Faculty of Agriculture Guidelines.

Slides of collected milk samples were prepared to count the SCC microscopically using the lane counting method. (Torlak, 2005). Counts were done twice in order to increase reliability of the SCC figures, and an average of the two counts was taken. The udder health of the cow was determined via the SCC. Here, two cases were investigated: 1) Somatic cell count less than 225 000 cells/ml is 'healthy' case; 2) Somatic cell count more than 225 000 cells/ml is 'subclinical mastitis' case.

Fuzzy set theory was developed by Azerbaijani American scientist, Lotfi Asker Zadeh in 1965. Zadeh (1965) argued that the vast majority of human thought is blurred rather than precise. The concept of fuzzy sets is the basis of FL theory. The FL control method is especially convenient in cases in which characteristics of information are uncertain or indefinite and the system is so complex that it cannot be analyzed using conventional methods (Elmas, 2003). Fuzzy sets re-define uncertainty by eliminating certain transitions and mathematically assigning a value of degree of membership to all individuals in the universe. This degree is compatible with the concept of fuzzy sets and acknowledges the degree of similarity among individuals. Thus, individuals may be assigned larger and smaller values as indicated by degrees of membership in fuzzy sets. These degrees of membership are expressed by real values from 0–1 (Nabiyev, 2005).

Another feature of FL is that it is contented with unclear, incomplete, inaccurate and even contradictory cases of processed data and information. FL does not completely solve very complex problems, but it does assist in the development of more effective methods. FL can greatly facilitate the use, design and testing of products and can provide better control than standard systems. Application of FL is also easy, fast and economical.

Input and output values and their intervals in established model for the prediction of subclinical mastitis by means of FL are shown in Table 1. As the table shows, LR, MY, EC, AMD and S were used as input data, and the output data of mastitis detection were obtained.

Table 1. Input – output values and their intervals.

Input/Output	Trait	Intervals
Input data	LR	1 – 7 (integer)
	MY	10 – 50 (daily) (litre)
	EC	3 – 6 (mS/cm)
	AMD	3.7 – 19 (minute)
	CS	1 – 4 (integer)
Output data	MD	0 – 1 (real number)

Verbal expressions and fuzzy sets for LR, MY, EC, AMD and MD are given in Table 2. As Table 2 shows, the verbal expressions established for LR were *first*, *middle* and *last*; for MY *low*, *normal*, *high* and *very high*; for EC *low*, *normal*, and S *high*; for AMD *short*, *normal* and *long*; for S *winter*, *spring*, *summer*, and *autumn*; and for MD *healthy* and *subclinical mastitis*.

Table 2. Verbal expressions for LR, MY, EC, AMD, CS and MD.

Trait	Verbal Expression	Value Intervals
LR	First	$1 \leq x < 2$
	Middle	$1 < x < 5$
	Last	$4 < x \leq 7$
MY	Low	$10 \leq x < 20$
	Normal	
	High	$28 < x < 42$
	Very high	
EC	Low	$3 \leq x < 4$
	Normal	
	High	
AMD	Short	
	Normal	
	Long	
CS	Winter	
	Spring	
	Summer	
	Autumn	
MD	Healthy	
	Subclinical mastitis infected	

Calculation of membership degrees was achieved by means of the Mamdani Fuzzy Model, Weight Average and Min-Max inference methods, and the "centroid" method of defuzzification was used. Various functions were used to graph input and output membership. Here, triangular (1) and trapezoidal (2) membership functions were used to calculate membership degrees of the input and output values generated (Baykal, 2004).

$$\mu_A(x; a_1, a_2, a_3) = \begin{cases} a_1 \leq x \leq a_2, & then \quad (x - a_1)/(a_2 - a_1) \\ a_2 \leq x \leq a_3, & then \quad (a_3 - x)/(a_3 - a_2) \\ x > a_3 \text{ or } x < a_1, & then \quad 0 \end{cases}$$

$$\mu_A(x; a_1, a_2, a_3, a_4) = \begin{cases} a_1 \leq x \leq a_2, & then \quad (x - a_1)/(a_2 - a_1) \\ a_2 \leq x \leq a_3, & then \quad 1 \\ a_3 \leq x \leq a_4, & then \quad (a_4 - x)/(a_4 - a_3) \\ x > a_4 \text{ or } x < a_1, & then \quad 0 \end{cases}$$

Evaluation: In this study, correctly assigned subclinical mastitis cases in the subclinical mastitis prediction model are classified as "True Positive" (TP). Mastitis alerts outside the current subclinical mastitis period are "False Positive" (FP) observations. Undetected subclinical mastitis is "False Negative" (FN), and if there are no alerts, observations outside the subclinical mastitis period is classified as "True Negative" (TN).

The sensitivity represents the number of correctly detected samples with subclinical mastitis out of all samples with subclinical mastitis:

$$Sensitivity\,(\%) = \frac{TP}{TP + FN} \times 100$$

The specificity indicates the percentage of correctly identified healthy samples of all samples of health:

$$Specificity\,(\%) = \frac{TN}{TN + FP} \times 100$$

The error rate represents the percentage of samples with wrong detected subclinical mastitis of all samples on which an alarm was produced:

$$Error\,(\%) = \frac{FP}{FP + TP} \times 100$$

RESULTS AND DISCUSSION

Analysis of the results revealed that the daily milk yield (MY) of Holstein-Friesian cows in 6 lactation ranks (LR) and 4 seasons (S) (spring, summer, autumn and winter) varied from 14.29 ± 1.680 to 34.20 ± 2.430 kg/min; electrical conductivity (EC) from 3.99 ± 0.097 to 4.50 ± 0.322 mS/cm; average duration of milking (AMD) from 4.38 ± 0.317 to 9.04 ± 1430 min/cow; and SCC from 29488 to 228026 cells/ml respectively.

For the FL realized via the Matlab program, 5 inputs (LR, MR, EC, AMD, S) and 1 output (MD) were available. The LR graph formed in Matlab is illustrated in Figure 1. For the first and last lactation ranks, the fuzzy set trapezoidal membership function was selected, while for the middle fuzzy set the triangular function was used. The MY graph formed in Matlab and containing 4 verbal expressions is illustrated in Figure 2. For the *low* and *very high* fuzzy sets the trapezoidal membership function was selected; for the *normal* and *high* fuzzy sets the triangular function was used. In the EC graph, illustrated in Figure 3, for the *low* and *high* fuzzy sets the trapezoidal membership functions was selected, and for the *normal* fuzzy set the triangular function was used. The AMD graph, illustrated in Figure 4, divides the input data into three ranges as *short, normal* and *long,* and shows the verbal expression memberships. The S graph drawn by the program, as shown in Figure 5, uses the four seasons as 4 the conditional fuzzy sets. In FES, however, this input is entered as discrete. Figure 6 shows the output graphic MD. The system output gives us one of two answers: the cow is *healthy* or *subclinical mastitis infected*, with a value assigned between 0 and 1. As this value approaches 0 the animal is healthy, and as it approaches 1 the animal can be assumed to be infected with subclinical mastitis.
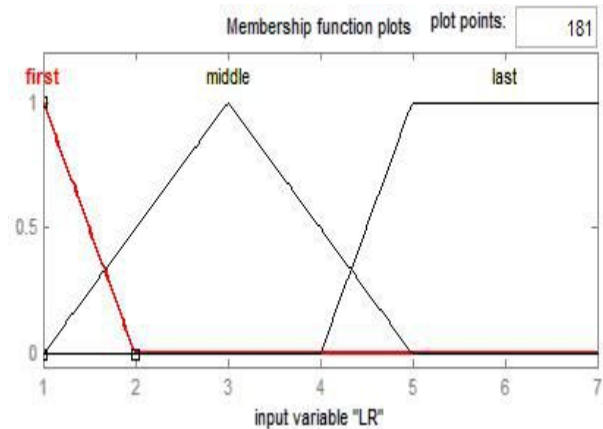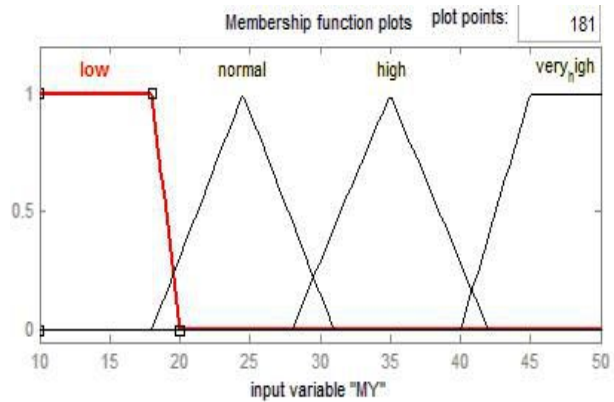

Figure 1. LR membership function graph.
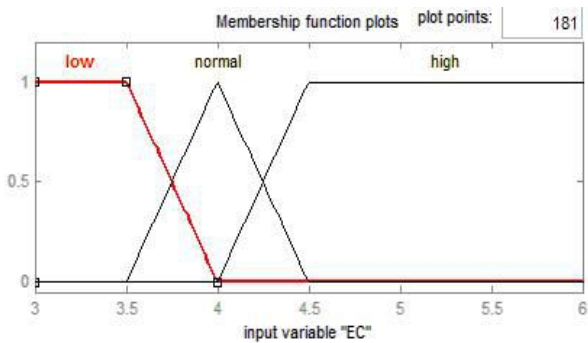
Figure 2. MY membership function graph.

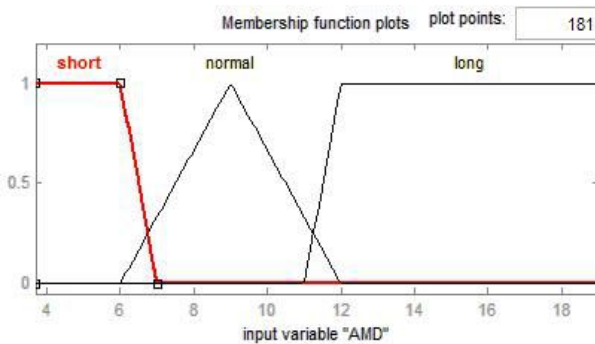**Figure 3. EC membership function graph.**

Figure 4. AMD membership function graph.
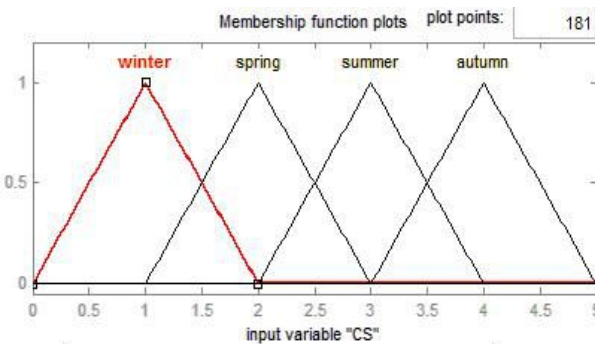

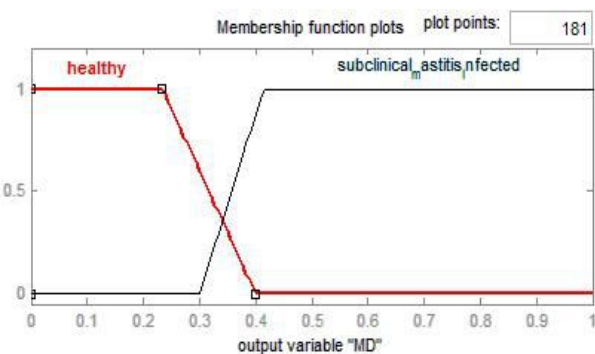**Figure 5. S membership function graph.**

Figure 6. MD membership function graph.

Rules were formed from the data obtained from sampling day milkings (MY, AMD, EC, S, LR) during the 15 months of observation and taking into account the SCC as observed in the laboratory. Below are some common MD situations for healthy cows as given in our MD model:

Rule 1: *If* LR is Last; MY is Normal; EC is Normal; AMD is Short; S is Autumn *Then* MD is Healthy.

Rule 24: *If* MY is Very High *Then* MD is Healthy.

Rule 25: *If* EC is Low *Then* MD is Healthy.

Rule 26: *If* AMD is Short *Then* MD is Healthy.

Rule 69: *If* LR is First; MY is Low; EC is Low; AMD is Short; S is Spring *Then* MD is Healthy.

Rule 74: *If* LR is Middle; MY is Low; EC is Normal; AMD is Short; S is Spring *Then* MD is Healthy.

Some subclinical mastitis infected cases in our MD model are given below:

Rule 13: *If* LR Last; MY is High; EC is High; AMD Normal; S is Autumn *Then* MD is Subclinical Mastitis infected.

Rule 35: *If* LR is Middle; MY is Normal; EC is Normal; AMD is Normal; S is Winter *Then* MD is Subclinical Mastitis infected.

Rule 41: *If* LR is Middle; MY is High; EC is High; AMD is Long; S is Winter *Then* MD is Subclinical Mastitis infected.

Rule 42: *If* MY is Low; EC is High; AMD is Long *Then* MD is Subclinical Mastitis infected.

Rule 47: *If* LR is Last; MY is High; EC is High; AMD is Normal; S is Winter *Then* MD is Subclinical Mastitis infected.

Rule 48: *If* LR is First; MY is Normal; EC is Normal; AMD is Short; S is Spring *Then* MD is Subclinical Mastitis infected.

Rule 68: *If* LR is Last; MY is High; EC is Normal; AMD is Normal; S is Spring *Then* MD is Subclinical Mastitis infected.

The relationships between mastitis detection and LR, MY, EC, AMD and S are shown in Figures 7, 8, 9, 10 and 11, respectively.
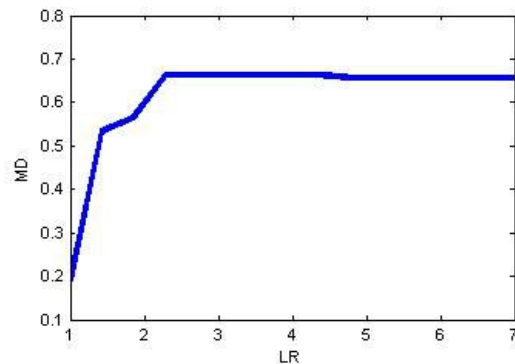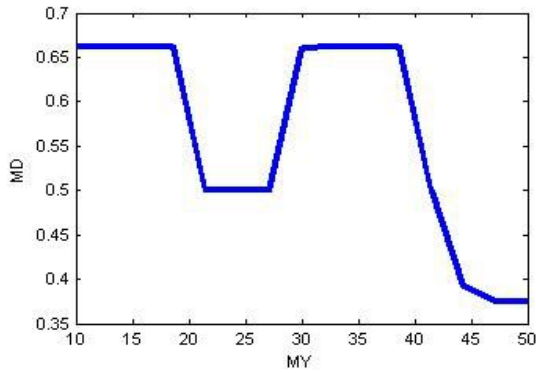
Figure 7. Relation between LR and MD.

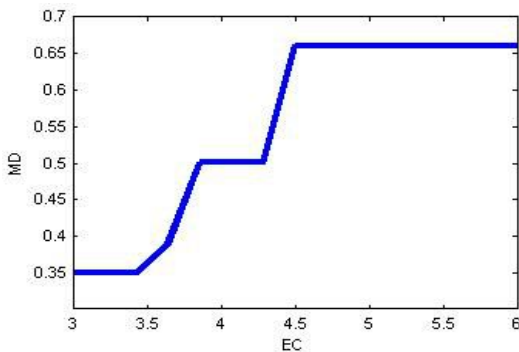
Figure 8. Relation between MY and MD.

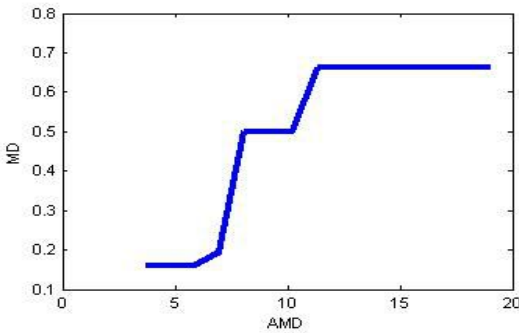**Figure 9. Relation between EC and MD.**

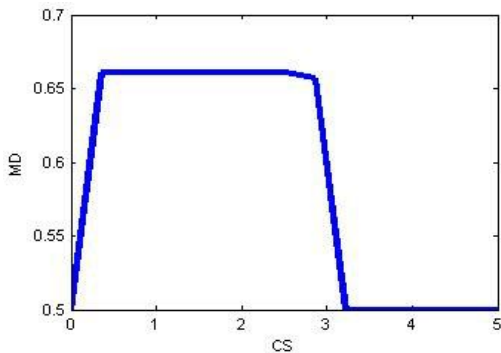
Figure 10. Relation between AMD and MD.

Figure 11. Relation between S and MD.

As Figure 7 shows, subclinical mastitis appeared more frequently from the 2nd to the 6th lactation. Figure 8 shows the relationship between milk yield and subclinical mastitis. In cases of low and high milk yield, mastitis is more likely, but in cases of normal and very high yield it is less frequent. As Figures 9 and 10 show, increased electrical conductivity and average milking time are related to the appearance of subclinical mastitis. During winter and spring, cases of subclinical mastitis increase, but from summer to late fall they decrease, as illustrated in Figure 11. Figures 12–21 show the 3-dimensional relationships between the inputs (LR, MR, EC, AMD, and S) and the output.
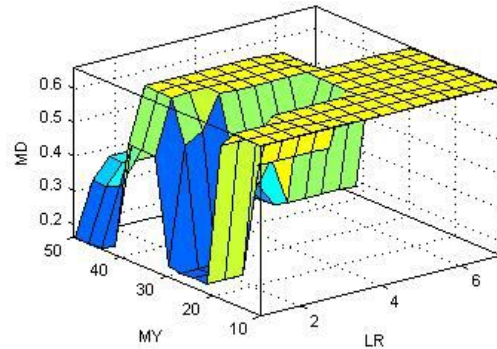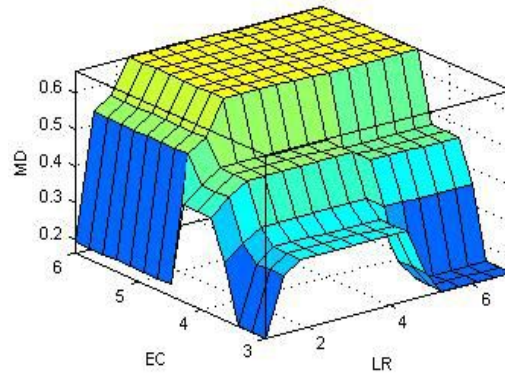

Figure 12. Relation between LR, MY and MD.

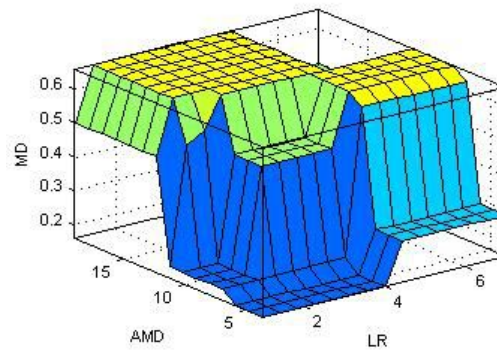**Figure 13. Relation between LR, EC and MD.**

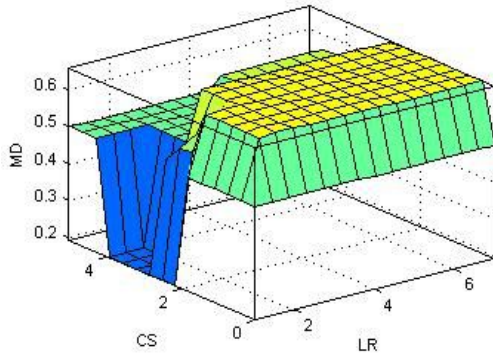**Figure 14. Relation between LR, AMD and MD.**

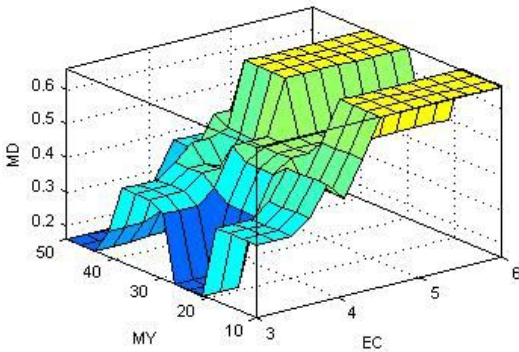**Figure 15. Relation between LR, S and MD.**

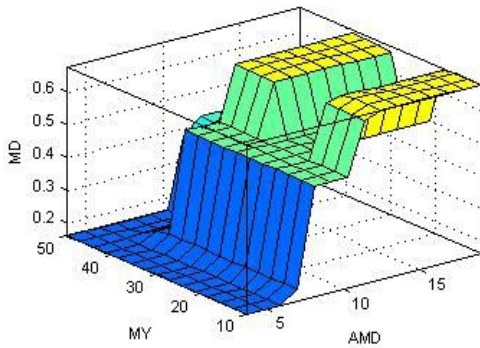**Figure 16. Relation between EC, MY and MD.**

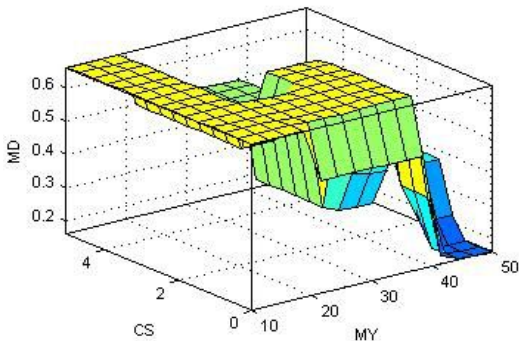**Figure 17. Relation between AMD, MY and MD.**

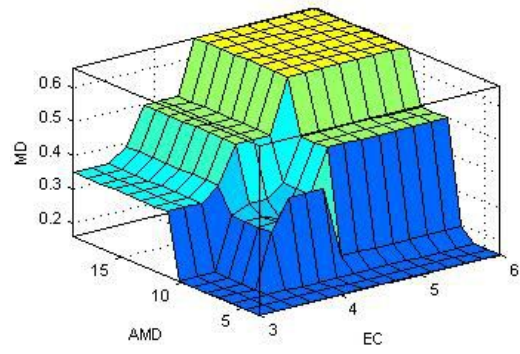**Figure 18. Relation between S, MY and MD.**

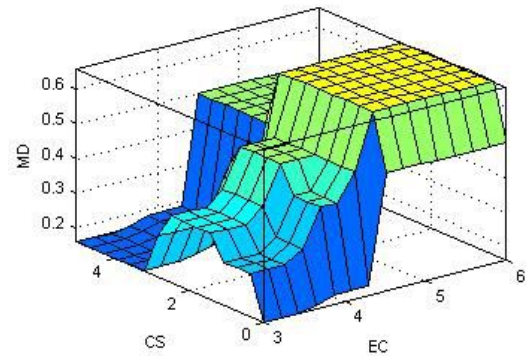**Figure 19. Relation between AMD, EC and MD.**

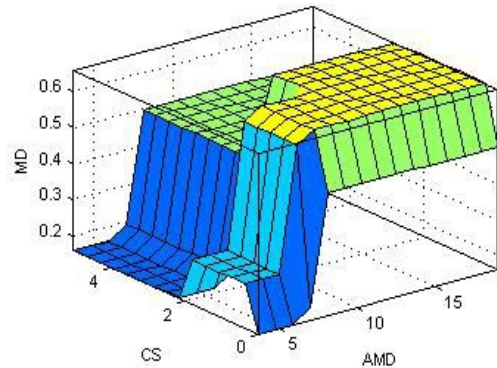**Figure 20. Relation between S, EC and MD.**

Figure 21. Relation between S, AMD and MD.

For example, given 1 for LR, 15 for MR, 5.5 for EC, 12 for AMD and 2 for S, the observed output value appears next to the statement MD (0.677). Other results can be found by supplying different input data (for example, given LR=2, MY=40 l; EC=4 mS/cm, AMD=6 min., and S=4, the appropriate response for these inputs is MD=0.174). Thereafter, all data were run through the Fuzzy Expert System, with the results indicating healthy and subclinical mastitis infected cows.

The sensitivity rate was found to be 82%, the specificity rate was found to be 74% and the error rate was found to be 60%.

Conclusion: It is highly important for enterprises with large numbers of animals to be able to quickly derive foreknowledge via existing computer data as to which animals are at risk of developing subclinical mastitis. This paper assayed early mastitis detection by means of the FL. Using the input data of LR, MY, EC, AMD and S model based on the three distinct methods were able to identify mastitis at a level of success that would have been impossible using conventional methods.

In the end, the study's FL model yielded a sensitivity rate of 82%, a specificity rate of 74%, and an error rate of 60%.

Given these results, it is recommended that a mastitis warning system be devised by adding more improved FL model with high sensitivity, to the herd management program, especially in large herd enterprises. Such a system will eliminate the need for intensive laboratory work in lieu of data obtained from milking (electrical conductivity, the average milking duration, and milk yield) and data obtained from the system (lactation rank and season).

REFERENCES

Atasever, S. and H. Erdem. 2008. Relationships between mastitis and electrical conductivity of raw milk in dairy cows. J. Fac. Agri. 23:131-136.

Bademkiran, S., S. Yesilmen and K. Gurbulak. 2005. The effect of daily milking frequency on clinical mastitis and milk yield of dairy cows. Y.Y. Univ. J. Fac. Vet. Med. 16: 17-21.

Batra, T.R. 1986. Relationship of somatıc cell concentration with milk yield in dairy cows. Can. J. Anim. Sci. 66: 607-614.

Batra, T.R. and J.A. Mcallister.1983. Incidence of subclinical and clinical mastitis in pureline and crossline dairy cattle. Can. J. Anim. Sci. 63:173-780.

Baykal, N. and T.Beyan. 2004. Bulanik mantik: ilke ve temelleri. Bicaklay kitabevi, Ankara.

Cedden, F., A. Kor and S. Keskin. 2002. Somatic cell counts in goat milk during late lactation period and its relationship with milk yield, age and some udder measurements. J. Agric. Sci. 12: 63-67.

Elmas, C. 2003.Fuzzy Logic Controllers, Seckin Pub. Co., Ankara.

Goncu, S. and K. Ozkutuk. 2002. Factors effective at somatic cell count (scc) in the milk of black and white cows kept in intensive dairy farms at Adana province and their relationships with mastitis. Hayvansal Uretim (Anim. Prod.) 43: 44-53.

Jones, G.M., E.R. Pearson, A.G. Clabaugh and M.C. Heald. 1984. Relationship between somatic cell counts and milk production. J. Dairy Sci. 67: 1823-1831.

Kul, E., H. Erdem and S. Atasever. 2006. Effect of different udder traits on mastitis and somatic cell count in dairy cows. J. Fac. Agric. 21: 350-356.

Nabiyev, V.V. 2005. Artificial intelligence, problems-methods- algorithms.Seckin Pub. Co., Ankara.

Osteras, O.S., L.V. Edge and W.S. Martin. 1999. Determinants of success or failure in the elimination of major mastitis pathogens in selective dry cow therapy. Department of Population Medicine, University of Guelph, Guelph, ON, Canada N1G 2W1.

Porcionato, M.A.D., B.V.W. Soares, M.B.C. dos Reis, S.C. Cortinhas, L. Mestieri and V.M. dos Santos. 2010. Milk flow, teat morphology and subclinical mastitis prevalence in Gyr cows. PesquisaAgropec. Bras. 45: 1507–1512.

Raubertas, R.F. and E.G. Shook. 1982. Relationship between lactation measures of somatic cell concentration and milk yield. J. Dairy Sci. 65: 419-425.

Risvanli, A. and C. Kalkan. 2002. The effect of age and breed on somatic cell count and microbiological isolation rates in milk of dairy cows with subclinical mastitis. Y.Y. Univ. J. Fac. Vet. Med. 13: 84-87.

Sargeant, J.M., M.H.Scott, E.K.Leslie, J.M.Ireland and A. Bashiri.1998. Clinical mastitis in dairy cattle in Ontario: Frequency of occurrence and bacteriological isolates. Can. Vet. J. 39: 33-38.

Schroeder, J. W. 2012. Mastitis control programs: Bovine mastitis and milking management. North Dakota State University, Fargo, North Dakota 1.5M-4-97, 200-7-12.

Seker, I., A. Risvanli, S. Kul, M. Bayraktar and E. Kaygusuzoglu. 2000. Relationships between CMT scores and udder traits and milk yield in Brown-Swiss cows. Lalahan Hay. Aras. Ens. Derg. 40: 29-38.

Tekeli, T. 2005. Mastitis: Quality milk production and somatic cell count in the process of the European Union. Guzelis Pub. Co., Konya.

Torlak, E. 2005.Çig sütlerde mikroskobik somatic hucre sayım yöntemleri. Quality milk production and somatic cell count in the process of the European Union. Guzelis Pub. Co., Konya.

Uzmay, C., I. Kaya, Y. Akbas and A. Kaya. 2003. Effects of udder and teat morphology, parity and lactation stage on subclinical mastitis in Holstein cows. Tr. J. Vet. Anim. Sci. 27: 695-701.

Wilson, D.J., N.R. Gonzalez, J. Hertl, F.H. Schulte, J.G. Bennett, H.Y. Schukken and T.Y. Grohn. 2004. Effect of clinical mastitis on the lactation curve: a mixed model estimation using daily milk weights. J. Dairy Sci. 87: 2073-2084.

Zadeh, L.A. 1965. Fuzzy sets. Information and Control 8: 338-353.