Prediction of the Occurrence of Lameness in Dairy Cows using a Fuzzy-Logic Based Expert System. – Part I

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SUMMARY

A cause of claw lameness in dairy cows is biomechanical factors caused by imbalances of the pressure distribution under the hooves when cows are confined in modern dairy operations with hard concrete flooring. Clinically, the earliest diagnosis of claw lameness is only possible by visually observing faulty locomotion (i.e., lame gait). Unfortunately, the earliest pathological gait signs are typically characteristics of mild to severe degrees of lameness where veterinary intervention is already necessary, causing economic losses and concerns about animal welfare. Using a system that is based on thin pressure measurement film, the pressure distribution under the hooves of 32 dairy Holstein cows have been recorded under dynamic conditions (stance phase) to evaluate the effects of trimming in reestablishing the balance under the foot. The results obtained yielded a preliminary database on claw pressure distribution, which was correlated to claw length and nutritional factors to form a preliminary knowledge base, which after translation into linguistic terms were used for the Fuzzy Inference System which provides a method to help prevent claw lameness. The outcome of the defuzzification of the rules yielded information on the possiblities of increasing or decreasing chances of developing lameness problems based on nutritional and claw measurement information and input by the user into the software. Results can be seen through surface charts obtained from any combination of two input variables (nutritional: NDF (% DM) - neutral digestive fiber, NSC (% DM) -non structural carbohydrate, NFC (% DM) -non fiber carbohydrate and measurable: Toe length (mm)) yielding a unit-less qualitative lameness incidence possibility outcome. The system has performed satisfactorily in laboratory testing. LIP values ranged from 4.4 to 26.6%, 78 to 98.7% and 42 to 78% for the best, median and worse nutritional scenarios under a range of 60 to 115mm toe length.

Keywords: preventive diagnostic, dairy cows, fuzzy logic, lameness

1. INTRODUCTION

Lameness is among the most prevalent and costly clinical conditions in dairy cattle. Causes include rations and/or feeding conditions that encourage rumen acidosis; confinement of cows to harder, wetter, more abrasive floors; or un-grooved floors that are smooth and slippery. Flooring is of particular importance, because of pressure distribution and redistribution on claws. Uneven weight-bearing of hoof walls of cows managed on hard floors (i.e. concrete) leads to pressure redistribution on claws and thus causes greater pressure concentration and stress on claws (Raven, 1989).

Even though information concerning the incidence of foot diseases in intensively housed cattle in Brazil is limited, it is believed to be similar to that reported in the United Kingdom, where surveys involving 1821 herds reported that the average incidence of lameness requiring treatment by a veterinarian was 5.8% of cows. Of these, 88% relates to feet, where most of foot lesions involved the outer claw of the rear feet (Shearer and Van Amstel 2000). Studies at University of Florida Dairy Research Herd in 1995 reported 178 clinical lameness events in 346 cows, affecting 120 (35%) cows, in which, 27 out of 120 had more than one clinical event. The losses accounted for US$ 58, 266.00 (Shearer and Van Amstel 2000).

In Brazil, clinical and epidemiological aspects of the foot lesions responsible for lameness in four Holstein dairy herds in the Rio Grande do Sul state revealed over an 18-month period, 524 lame cattle out of 1043 were treated for lameness. The cumulative prevalence of lameness caused by foot lesions among all animals was 50.2%. A total of 524 animals presented 883 feet lesions. Most lesions (84%) occurred in the rear feet, and the major incidences were digital dermatitis (29.9%), sole ulcer (18.3%) and interdigital dermatitis (17.8%). Of the claw lesions, 91.5 % occurred in the hind lateral ones and of these, almost all occurred in abnormally shaped claws (Cruz et al, 2001).

Raven (1989) introduced the concept of hoof problems associated with the biomechanics of highly productive dairy cattle confined on hard flooring such as concrete, where hard flooring alters the mechanics of the locomotion of these cows and favors the occurrences of lameness problems. A new technology has been developed for measuring pressure distribution on human foot which has been adapted at the University of Florida (Carvalho, 2004) for measuring weight bearing dynamics under the feet of dairy cattle and the results yielded data that can help understand lameness problems of biomechanical origin (Figure 1).

Biomechanical related hoof pathologies require new approaches for optimizing their prevention because, clinically, the earliest possible diagnosis of claw lameness is made by visually observing faulty locomotion (i.e., lame gait). Unfortunately, the earliest pathological gait signs are typically characteristics of mild to severe degrees of lameness where veterinary intervention is already required, resulting in economic losses to the dairy industry and concerns about animal welfare.

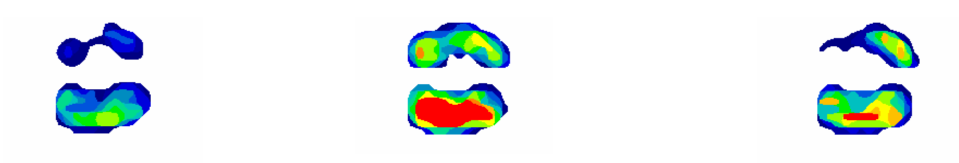

Figure 1. Pressure distribution using MatScan® software

Other relavant variables that can contribute to preventive diagnosis of the incidence of hoof pathologies include climatic variables thermal comfort indexes such as THI (Temperature Humidity Index), where THI can be related to increases in ruminal pH during heat stress and favors ruminal acidosis, through a mechanism that involves the loss of saliva through panting (physiological response for heat stress relief). Flooring mechanical properties (roughness) and their influences on claw rate of wearing and contact pressures are also important factors(De Belie et al., 2003). Locomotion scores (Manson and Leaver, 1989; Sprecher, 1997) through the identification of early stages of faulty locomotion related to lameness and also physical measurements, such as modified force plates used for observing limb asymmetry (Rajkondawar 2002B), have been used as preventive veterinary medicine in an attempt to predict lameness. Locomotion scores have been used more extensively due to its practicability on the visualization of lame cows although even the observation of its early scores already reflects some degree of lameness. In the case of the modified force plates, its practicability is an issue since it requires the construction of the system itself. A software using the knowledge provided by these systems and also that can be flexible to incorporate other type information pertinent to lameness prevention would be of great value as an additional tool.

After investigating available methods of prediction, it was concluded that Fuzzy Logic (Zadeh, 1965), was the appropriate tool for implementing an automated method of making preventive diagnostic decisions. Fuzzy Logic has the advantage of dealing with subjective concepts such as almost, approximately, etc. Subjective concepts which are not understood by the computer provide a higher degree of confidence compared to classical probability theory. Fuzzy Inference is a method that interprets the values in the input vector and, based on user-defined rules, assigns values to the output vector. The Fuzzy Logic Toolbox (Matlab®).provides a set of editors that can be used to build a Fuzzy Inference System (FIS).

The Fuzzy Set Theory (FST), Zadeh, 1965, provides a tool that can be efficient for monitoring and preventing a variety of pathologies in the medical and veterinary fields, since these areas are often surrounded by vagueness and subjectivity and are dependent on several sources of uncertainty due to the nature of the medical field. Warren et al. (2000), suggests some of the sources that represent fuzziness to be: lack of information, non-specificity, probabilistic nature of data and outcome, vagueness in formulation of recommendations, conflicts among various sets of alternatives, and fuzziness in determination of clinical signs. In his work, Warren discusses the application of FST theory in dealing with sources of fuzziness of textual clinical guidelines in formulating automated alerts and advice for a CPOL (Care plan on-line), an intranet-based chronic care planning system intended for general practitioners (GP). The client side of the CPOL is a relatively generic shell that receives guidelines and EMR (emergency room) specifics from a central server.

Other examples of the use of Fuzzy Logic are in detection of signs for optimization of the reproductive protocol of farms and for the effects of heat stress related production losses, which are areas that have been proven to benefit economically from correct monitoring of behavior patterns. Some of the work done for monitoring animal heat stress related to production losses was described by Amendola et al., (2004) and De Mol (2000) for mastitis and oestrus detection in dairy cattle.

This research aimed to estimate the occurrence of lameness in dairy cows housed in freestalls based on data from toe length and nutritional factors, using Fuzzy Logic. This paper describes the Fuzzy logic algorithm development to be used for implementing the proposed Expert's System for the preventive diagnostic, and decision making process on dairy cattle lameness based on this Fuzzy Logic algorithm.

2. METHODS

A natural question is the effectiveness of the use of Fuzzy Logic for prediction of health-status in Preventive Diagnostics, and to develop an Expert System aiming at the reduction of losses in order to maintain the economic feasiblity of the processes involved. The answer has two aspects: first the aspect that Fuzzy Logic is well suited for controlling/predicting a process or system that is nonlinear or too poorly understood to use conventional control designs, and second that it enables control engineers to systematically implement control and monitoring strategies used by human operators with experience and expertise.

In contrast to crisp set, a Fuzzy Set is a set without a crisp boundary. This means the transition from "belong to" set and "not belong to" set is gradual. This smooth transition is characterized by membership functions that give flexibility in modeling linguistic expressions. Fuzzy Inference is the process of mapping from a given input to an output using Fuzzy Logic. The mapping then provides a basis from which decisions can be made or patterns discerned. The process of Fuzzy Inference involves all of the concept's membership functions, if then rules and Fuzzy operators. The essential components of a Fuzzy System are the Fuzzy Inference engine, Fuzzy rule base and defuzzifier. The following definitions explain the blocks used in the Fuzzy System shown in Figure 2.

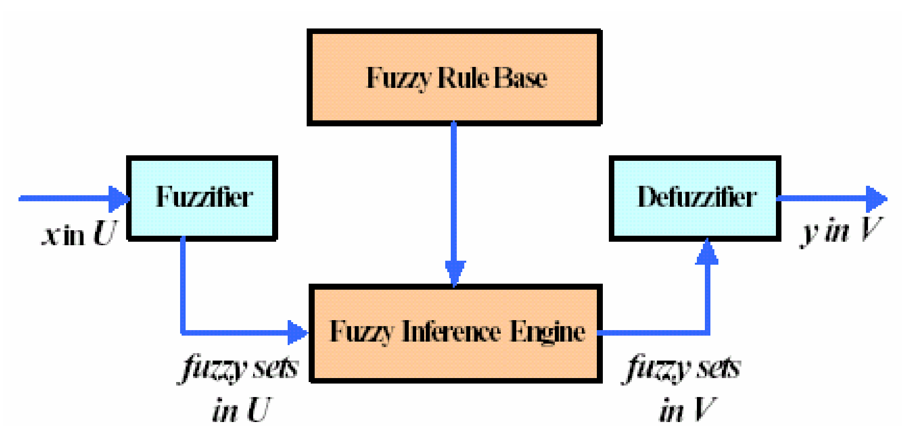

Figure 2: Fuzzy System process Fuzzifier.

Since the inputs in most applications are real numbers, the fuzzifier serves as the proper interface between the Fuzzy Inference engine and the physical world. The criteria in designing a fuzzifier are:

1. The Fuzzy set A should have a large membership value at x.
2. The fuzzifier should simplify the computations involved in the Fuzzy Inference engine.

In a Fuzzy Inference Engine, Fuzzy Logic principles are used to combine the Fuzzy IF-THEN rules in the Fuzzy rule base into a mapping from a Fuzzy set in an n-dimensional universe of discourse to a Fuzzy set in a one-dimensional universe of discourse. The Mamdani inference model was used in this research to design the Fuzzy Controller. The Mamdani Fuzzy Inference System employs the individual rule based inference scheme, and derives the output y when subjected to a crisp input x.

The preliminary knowledge base was created gathering information linking pressure distribution under the foot on trimmed *versus* untrimmed cows (Figure 1, Carvalho, 2004), associated with lameness occurrences under the same conditions (mean toe length of 90-95mm; Manske et al., 2002), which lead to assumptions of linearity between hoof growth and increase in pressure concentration. Nutritional component incompatibilities, such as: NFC (non-fiber carbohydrate), NSC (non-structural carbohydrate) and NDF (neutral digestive fiber) interactions are known to increase the risks associated with the incidence of SARA (sub-acute ruminal acidosis). The combination of these nutritional components interacting or not with the pressure factor (hoof overgrowth) was used to formulate the rules that govern the Fuzzy Set controller.

The input variables were composed of either Gaussian or Trapezoid membership functions and applied the Mandami inference method. An example of the toe length input variable membership function is presented in Figure 3. Graphical representation of Fuzzy System with three Fuzzy Sets is initially obtained by using Matlab® Fuzzy Logic Toolbox. Then the Matlab® simulations were obtained for one- input and two-input Fuzzy System and these results are compared with the graphs obtained from Fuzzy Logic Toolbox.

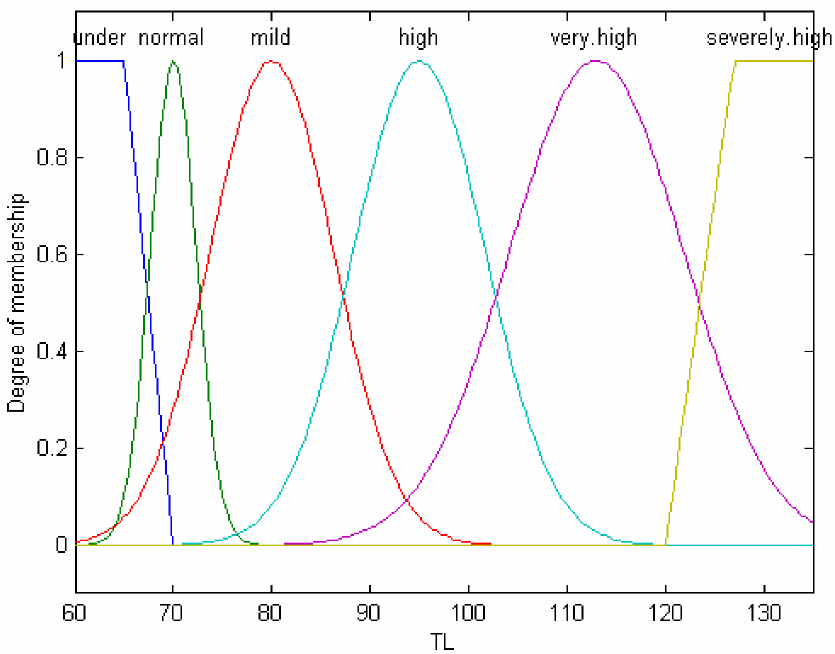

Figure 3. Toe length (mm) membership function

Matlab® Fuzzy Logic Toolbox was used to initially obtain the simulation for Fuzzy Logic Health-status certification, in preventive Diagnostics, and to develop a "specialist system", which has objectives turne to the desired application and consequent decision making process. The Fuzzy Logic Toolbox supported the design and analysis of Fuzzy Logic based systems by providing a method of interactively viewing and analyzing results.

3. RESULTS AND DISCUSSION

The Fuzzy Set controller was created using the software Matlab® v. 6.1 based on, 449 rules organized using macros from an Excel® workbook and implemented into the Matlab® interface to link four input variables: toe length (mm) (Carvalho, 2004 and Manske et al., 2002), neutral digestive fiber (NDF, %), non-structural carbohydrates (NSC, %) and non-fiber carbohydrate (NFC, %) (Stone et al., 2004) and giving the output Lesion Incidence Risk (very low, low, median, high, very high, extremely high). The first set of rules created (449) was reduced and substituted to create 162 rules after applying the Karnaugh mapping method which optimized the original set of rules without compromising the resulting output. The syntax of the rule number 1 from the rule editor window in Matlab® is given below as an example:

1 If (TL is under) and (NDF is low) and (NFC is low) and (NSC is low) then (LIP index is median)

For the linguistic variable toe length, the interval [60, 130], was considered which represented lengths (mm): [0 0 65 70] trapezoid function, 70±5 Gaussian function, 80±10 Gaussian function, 95±15 Gaussian function, 112.5±12.5 Gaussian function, and [115 122 150 155] trapezoid function, through linguistic terms of under, normal, mild, high, very high and severely high, respectively. This resulted in the following linguistic terms and value ranges: Under = [65 - 70mm], Normal = [67 - 73mm], Mild = [74 - 86mm], High = [88 - 102mm], Very high = [104 - 122mm], Severely high = [120 - 127mm]. These interval ranges were adopted based on expertise knowledge.

For the linguistic variable NDF, the domain interval was [21, 39], which represented percentages of <25, 28-32, >35 through linguistic terms of low, median and high, respectively. The trapezoid pertinent function was selected for this variable. For the linguistic variable NFC, the domain interval was [23, 52], which represented percentages of <30, 35-42, >45 through linguistic terms of low, median and high, respectively. The trapezoid pertinent function was selected for this variable. For the linguistic variable NSC, the domain interval was [21, 39], which represented percentages of <25, 28-32, >35 through linguistic terms of low, median and high, respectively. The trapezoid pertinent function was selected for this variable.

Regarding nutritional factors, unbalance of components such: NDF, NFC and NSC, is sufficient to provoke cases of metabolic related lameness. NFC and NSC represents carbohydrate levels in diet and when their level is high there is an increased risk of laminitis development through rumen acidosis. Conversely, when Neutral Detergent Fiber (NDF) is high the process of rumenal alkalinization is more efficient and risks of rumen acidosis is decreased. Therefore, these nutritional components should be balanced in order to minimize risks of laminitis. In addition, excessive toe length, is also known to be the sole cause of cases of the mechanical form of lameness. Carvalho 2004, observed that toe length mean of 90 mm (15 mm overgrowth over 75 mm considered to be normal claw) will carry a 6 % overall increase in pressure at the heel and lesion spot regions of the claw and increase the risks of sole ulcers (Raven, 1989; Peterse 1986; Shearer and Van Amstel, 2000). Based on these data, it was assumed that a linear increase will occur at longer claws proportionally. Using this assumption, a relationship of increased risks was formulated when associated to poor nutrition of the cows. Therefore, the severity of the scenarios created through the linkage of these four input variables, the results of the associations between nutritional and mechanical factors were assumed to increase lameness incidence possibilities by one, two and three risk levels because excessive toe length is associated to poor nutritional levels. This assumption was made based on observational experience because of the lack of experimental data assessing the incidence of lameness in cases involving these four variables together. Hence, lameness incidence possibilities results are maximized to a higher risk level according to the severity of the two factors as they merge together.

The results can be tested by changing the input variables values in the Matlab® rule viewer (Figure 4) and checked through the surface charts of any combination of two input variables (NDF, NSC, NFC and Toe length) with the output variable (Lesion incidence possibilities). Figure 5 is an example of the calculated surface for any given combination of two input/output variables. In this case, the possibilities of developing lameness (LIP) is shown as a non-linear function of a percentage of neutral detergent fiber and the conformation of the claw given by its toe length (TL). Surface charts, such as the one below, give an overall representation of the performance of the system and, in addition, can be very useful when checking for errors in the rule data bank, where data points could be displayed outside the expected pattern represented in the chart.

The decision support provided by the system lies in either controlling levels of the essential nutritional components of the ration formulation or by trimming the excessive horn tissue from claws through proven preventive trimming methods to produce acceptable lengths and degrees of balance. Insights are provided about flooring and bedding surface mechanical properties as well as recommending feasible improvements.

The system was tested using three different scenarios: best, median and worse, (adapted from Stone et al., 2004) of the nutritional aspects for the complete range of claw measurements (Tables 1 to 3 and Figure 6).

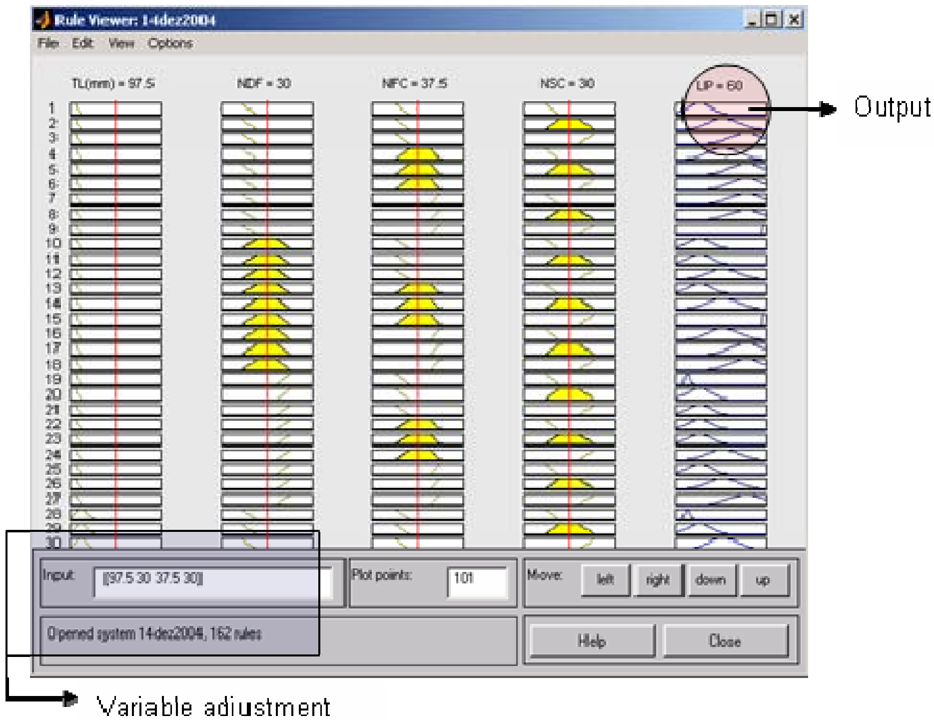

Figure 4. Matlab® rule viewer

This system responded satisfactorily to the proposed relationship between the input variables in the model according to expert knowledge (Carvalho, 2005; Agricultural Engineering College - State University of Campinas, Campinas-SP, Brazil). The nutritional components play a major role in the system, having best, median and worst scenarios running around 20, 65 and 97% of LIP and the toe lengths outside the range of normal claws increasing LIP by about 10 to 15% (Figure 6).

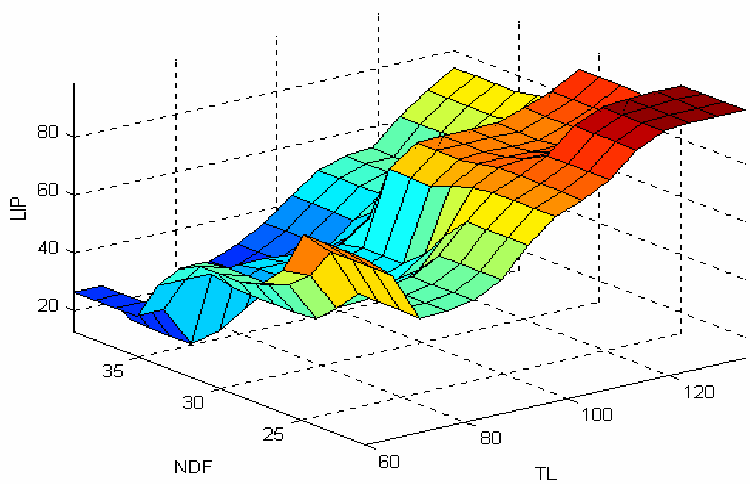

Figure 5. Surface chart of toe length and NDF versus LIP (Lameness Incidence Possibilities)

Table 1. Under best nutritional conditions.

TL (mm)	NDF (%)	NFC (%)	NSC (%)	LIP (%)
60	35	26	25	12.5
65	35	26	25	11.6
70	35	26	25	4.4
75	35	26	25	4.9
80	35	26	25	5.2
85	35	26	25	7.8
90	35	26	25	13.6
95	35	26	25	20.3
100	35	26	25	24.2
105	35	26	25	26.3
110	35	26	25	26.6
115	35	26	25	26.6

Table 2. Under worst nutritional conditions.

TL (mm)	NDF (%)	NFC (%)	NSC (%)	LIP (%)
60	25	45	35	96.6
65	25	45	35	86.9
70	25	45	35	78.0
75	25	45	35	78.0
80	25	45	35	78.3
85	25	45	35	79.6
90	25	45	35	82.7
95	25	45	35	89.4
100	25	45	35	96.3
105	25	45	35	98.3
110	25	45	35	98.6
115	25	45	35	98.7

The concept of providing support to medical opinion is one the various applications of Expert System and is indirectly one of the goals intended by this current project. The main goal is, however, related to the prevention of the pathology *per se*.

Similar systems have been reported for the prevention of some diseases such as the knowledge-based system for diagnosis of mastitis problems at the herd level which was proposed by Hogeveen et al. (1995). The knowledge base system is based on general mechanisms of mastitis infection using hierarchical conditional causal models. Pneumonia and jaundice Expert Systems were proposed by Roychowdhury et al. (2004) through the modeling of the knowledge and thinking process of a doctor. A Fuzzy Logic Controller is used to model the process and a genetic algorithm helps in the selection of a number of good rules from manually constructed large rule base, which is based on the opinion of ten doctors. According to the authors, once the rule base is optimized by the genetic algorithm (off-line), the system can diagnose the diseases on-line. The interface takes the symptoms as input variables and the output, grade of the disease, is determined.

Table 3. Under median nutritional conditions.

TL (mm)	NDF (%)	NFC (%)	NSC (%)	LIP (%)
60	30	38	30	52.4
65	30	38	30	50.4
70	30	38	30	36.7
75	30	38	30	42
80	30	38	30	42.2
85	30	38	30	42.3
90	30	38	30	43.8
95	30	38	30	57.5
100	30	38	30	76.2
105	30	38	30	77.9
110	30	38	30	78
115	30	38	30	78

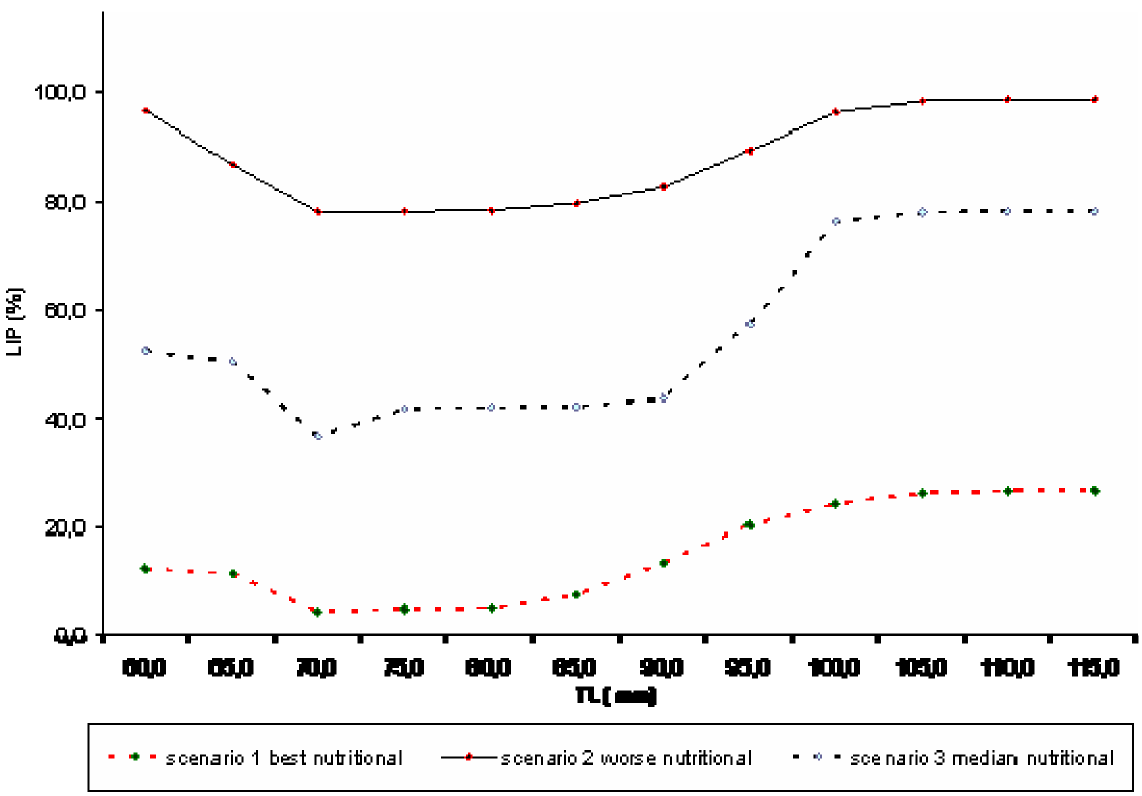

Figure 6. Nutritional aspects scenarios (%) under the complete range of claw measurements (mm).

Fuzzy Logic alone can be of great value for testing and validating other systems since it incorporates the attribute of vagueness as postulated previously; however, it may not be enough for support in preventive medicine, where the decision making process is a another important factor.

The user interface is still in the process of being implemented through the development of Expert System software (ES – PREVCASCO) designed to have user input data interact with databases filtering information and yielding diagnostic responses and suggestive decision making information. The ES will be implemented through the associations of more flexible coding languages such as: PHP programming, web development java script, open database connectivity (ODBC), etc. to suit the web flexibilities intended in its project.

4. CONCLUSIONS

LIP values ranged from 4.4 to 26.6%, 78 to 98.7% and 42 to 78% for the best, median and worse nutritional scenarios under a range of 60 to 115mm toe length. The system is a preliminary concept for controlling dairy cattle foot diseases and possesses a flexible structure open to improvements through addition of new variables as well as refinements and adjustments of the associations already been used. Parallel to the Fuzzy Set Controller, an user interface, is been created to interact with the controller and which will not only intermediate the user inputs through the rules, but also guide the user through a management type decision making process based on: ration calculation from grain mixtures, claw functional trimming, and structures modifications in an integrated Expert's System.

5. ACKNOWLEDGEMENTS

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