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Development of a Fuzzy Model to Determine the Optimum Shear Strength of Wheat Stem

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***Abstract*– In this study, an optimization model based on fuzzy logic was developed to determine the optimum value for cutting force of wheat stem. The input parameters of the fuzzy model were stem moisture, stem cutting height and bevel angle of cutting blade. In order to write the fuzzy rules for the stem cutting height, two low (0-15 cm), two middle (10-25 cm) and two high (20-35 cm) membership functions were considered. In the case of moisture content four membership functions, namely, suitable (0-20%), semi suitable (10-30%), high (20-40%), and very high (35-50%) and for the blade bevel angle three membership functions, including very low (0-10º), low (10-20º) and common (15-30º) were assigned. Three membership functions were also assigned to the shearing strength, including good (0-3000), middle (2920-3574 kPa), and bad (3500-4300 kPa). The results showed that the fuzzy model used in this study had an acceptable prediction for determining the level of shear force to cut the stem. The developed fuzzy model had an accuracy of 91%, 97% and 100%, respectively in bad, middle and good levels to predict the stem shearing strength.**

***Index Terms*– Fuzzy Logic, Fuzzy Model, Wheat Stem and Shear Strength**

I. INTRODUCTION

FUZZY logic is a powerful concept for handling nonlinear, time varying, and adaptive systems. It permits the use of linguistic values of variables and imprecise relationships for modeling system behavior. Intelligent systems based on the fuzzy logic are often used in sorting processes for detecting defects in biological and medical sciences.

Fuzzy logic can improve grading processes by using fuzzy sets to define the degrees of overlap. Moreover, application the "if-then" logics can improve the interpretation and explanation the results and provide a widespread view on the construction of decision process (Johannes et al., 2003). Zadeh (1965) introduced the concept of fuzzy sets as a means for describing complex systems without the requirements for precision.

Zadeh (1973) proclaimed a principle called the "principle of incompatibility", which states that complexity and precision are incompatible due to the inability of the human mind to comprehend complex systems in a detailed manner. By reducing the need for precision it is possible to more easily express known qualitative relationships about complex systems. Zadeh (1973) noted that this method for dealing with uncertainty would have particular applicability in soft systems such as psychology, sociology, and economics.

Fuzzy logic may also be useful for descriptive systems, those that fall somewhere between hard systems and soft systems, such as biology and agriculture. Fuzzy logic approaches provide a suitable framework for modeling these systems due to their ability to handle "fragmentary, uncertain, qualitative and blended knowledge typically available for biological systems" (Konstantinov and Yoshida 1992). Verma (1995) developed a fuzzy decision support system (DSS) to aid decisions related to quality sorting of tomatoes.

Six fuzzy models were developed and linked to develop the DSS. The outputs of fuzzy DSS predicting quality and the day of the highest quality was very accurate when compared with the data provided by an expert.

Some other examples of reported fuzzy logic applications includes a model to predict the effects of multiple stresses on tree growth (Schmoldt 1991), organizing bioengineering knowledge in fuzzy models that can be used for prediction (Dohnal 1985; Linko 1988), predicting right soil moisture for land preparation (Thangaradivehu and Colvin 1993), feeding strategies on large dairy farms (Edan et al. 1992), and grading beef quality (Nakamishi et al. 1993). Based on the growing evidence from the literature showing successful use of fuzzy logic for modeling, DSS and controls, it appears that applications to biological and agricultural systems are inevitable.

The objective of this study was to modelling the shear strength of wheat stem according to initial condition of the product harvest using fuzzy logic. In the current study, the input parameters of the fuzzy system were namely, stem moisture, stem cutting height and bevel angle of the cutting blade.

These parameters were initially in the form of real numbers. First, the fuzzy system converts these crisps to fuzzy values. The fuzzy logics are applied by use of the Mamdani product (minimum) interface engine (Mamdani and Assilian, 1975). Then the fuzzy logics are processed. Finally, the fuzzy system defuzzifies the result using center of maximum defuzzifier and provides a real value indicating the level of stem shear strength.

II. FUZZY SETS

Fuzzy logic starts with the concept of fuzzy set. A fuzzy set is defined as a system without certain member that has a clear boundary. The fuzzy set can include all of the elements of the universe of discourse only by one relative degree of membership (Zadeh, 1965). In other words, a fuzzy set is defined as a set of ordered pairs in the following form:

$$D = \{(x, \mu_D(x))\ \ x \epsilon X, \mu_D(x) \epsilon [0,1]\} \quad (1)$$

Where x is a member of the X, that is to say the universe of discourse, and D is a fuzzy set in the X. In eq. (1), $\mu_D(x)$ is the membership function of D which indicates the degree and/or order in which each x element of X belongs to D. This definition assigns a natural number ($\mu_D(x)$) to each x element of D in [0 1] interval. The higher values of $\mu_D(x)$ indicates the higher degrees of membership. The number of fuzzy rules which are necessary to develop a fuzzy control system is directly proportional to the number of each experimental factor, e.g. cutting height (Kavdir, Guyer. 2003).

The membership function is defined as a graphical representation of the magnitude of participation of each input. It associates a weighting with each of the inputs that are processed, define functional overlap between inputs, and ultimately determines an output response. The rules use the input membership values as weighting factors to determine their influence on the fuzzy output sets of the final output conclusion.

Once the functions are inferred, scaled, and combined, they are defuzzified into a crisp output which drives the system. There are different memberships functions associated with each input and output response. Triangular membership function is common, but bell, trapezoidal, haversine and, exponential types have also been used. More complex functions are possible but require greater computing overhead to implement. In this study, the triangular and trapezoidal membership functions were selected. A triangular membership function is defined as a function having three points in the variation range of a parameter (Fig. 2). In the case of a trapezoidal membership function four points are needed. The triangular membership function is mathematically defined as the following equation:

$$f(x; a, b, c) = \begin{cases} 0, & x < a \\ \dfrac{x-a}{b-a}, & a \le x < b \\ \dfrac{c-x}{c-b}, & b \le x < c \\ 0, & c \le x \end{cases} \quad (2)$$

Equation (2) can be written in the compact form:

$$f(x; a, b, c) = max\left(min\left(\frac{x-a}{b-a}, \frac{c-x}{c-b}\right), 0\right) \quad (3)$$

Where, x is input vector, and a, b, c are numbers which are obtained by measurements.

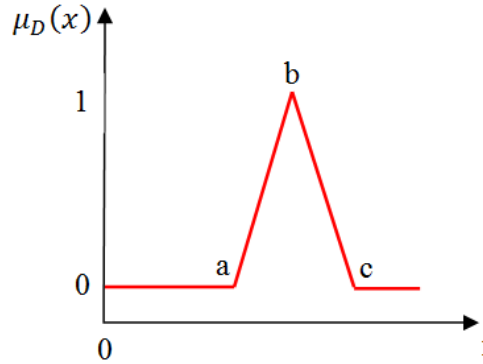

Fig. 1. The overall form of a triangle membership function

Fuzzy sets and fuzzy operators are acts and actuators in fuzzy logic. If fact, the "if-then" rules formulize the necessary conditions for fuzzy logic to decide and grading. A single fuzzy logic is written as below:

$$\text{IF x is A, THEN y is B} \quad (4)$$

Where A and B are defined linguistic variables for x and y variables by fuzzy sets in the range of X and Y, the universes of discourse.

Fuzzy logics could also be written in combined form by use of AND operator:

$$R_i: \text{IF } x_i \text{ is } A_i \text{ AND } y_i \text{ is } B_i \text{ THEN } Z_i \text{ is } C_i, \ i = 1,2, \dots, n \quad (5)$$

Where A_i and B_i are fuzzy sets for x_i and y_i inputs which assign linguistic variables such as low, middle and high and n is the number of rules (Mamdani and Assilian, 1975). In the current study, C_i includes the linguistic variables to determine the level of force and energy required for cutting the wheat stem.

In order to write the fuzzy rules, for the cutting height linguistic variable two low membership functions (0-15), two middle membership functions (10-25) and two high membership functions, all in cm were considered. In the case of moisture content four membership functions, namely, suitable (0-20), semi suitable (10-30), high (20-40), and very high (35-50) and for the cutting blade bevel angle three membership functions, including very low (0-100), low (10-20) and common (15-30) were assigned. Totally, 36 rules were obtained using AND operator. Three membership functions were also assigned to the output, including good (0-3000), middle (2920-3574), and bad (3500-4300).

By use a deffuzifier, the output variable converts to a real value. Defuzzification is the process of producing a quantifiable result in fuzzy logic, given fuzzy sets and corresponding membership degrees. It is typically needed in fuzzy control systems. These will have a number of rules that transform a number of variables into a fuzzy result, that is, the result is described in terms of membership in fuzzy sets. Defuzzification is interpreting the membership degrees of the fuzzy sets into a specific decision or real value. There are many different methods of defuzzification such as center of gravity (COG), mean of maximum (MOM), center of maximum (COM), and first of maximum (FOM) (Zimmermann, 1996). In this study, the COG method was selected for conducting the processes. The COG method is a common and useful defuzzification technique. The process of the fuzzy logic model accomplishment in MATLAB software is shown in Fig. 2 to Fig. 9. In Fig. 2, the overall form of the fuzzy model in MATLAB software is illustrated.

The following rules were used to establish a relationship between the input and output variables. These rules were obtained through the primary experiments and the reliable references by expert person:

- 1. If (height is low) and (moisture is very high) and (angle is very low) then (shear strength is very bad)
- 2. If (height is low) and (moisture is very high) and (angle is low) then (shear strength is very bad)
- 3. If (height is low) and (moisture is very high) and (angle is common) then (shear strength is very bad)
- 4. If (height is low) and (moisture is high) and (angle is very low) then (shear strength is very bad)
- 5. If (height is low) and (moisture is high) and (angle is low) then (shear strength is very bad)
- 6. If (height is low) and (moisture is high) and (angle is common) then (shear strength is very bad)
- 7. If (height is low) and (moisture is semi suitable) and (angle is very low) then (shear strength is very bad)
- 8. If (height is low) and (moisture is semi suitable) and (angle is low) then (shear strength is very bad)
- 9. If (height is low) and (moisture is semi suitable) and (angle is common) then (shear strength is bad)
- 10. If (height is low) and (moisture is suitable) and (angle is very low) then (shear strength is very bad)
- 11. If (height is low) and (moisture is suitable) and (angle is low) then (shear strength is bad)
- 12. If (height is low) and (moisture is suitable) and (angle is common) then (shear strength is bad)
- 13. If (height is middle) and (moisture is very high) and (angle is very low) then (shear strength is very bad)
- 14. If (height is middle) and (moisture is very high) and (angle is low) then (shear strength is very bad)
- 15. If (height is middle) and (moisture is very high) and (angle is common) then (shear strength is very bad)
- 16. If (height is middle) and (moisture is high) and (angle is very low) then (shear strength is very bad)
- 17. If (height is middle) and (moisture is high) and (angle is low) then (shear strength is very bad)
- 18. If (height is middle) and (moisture is high) and (angle is common) then (shear strength is bad)
- 19. If (height is middle) and (moisture is semi suitable) and (angle is very low) then (shear strength is very bad)
- 20. If (height is middle) and (moisture is semi suitable) and (angle is low) then (shear strength is very bad)
- 21. If (height is middle) and (moisture is semi suitable) and (angle is common) then (shear strength is bad)
- 22. If (height is middle) and (moisture is suitable) and (angle is very low) then (shear strength is bad)
- 23. If (height is middle) and (moisture is suitable) and (angle is low) then (shear strength is bad)
- 24. If (height is middle) and (moisture is suitable) and (angle is common) then (shear strength is good)
- 25. If (height is high) and (moisture is very high) and (angle is very low) then (shear strength is very bad)
- 26. If (height is high) and (moisture is very high) and (angle is low) then (shear strength is very bad)
- 27. If (height is high) and (moisture is very high) and (angle is common) then (shear strength is bad)
- 28. If (height is high) and (moisture is high) and (angle is very low) then (shear strength is very bad)
- 29. If (height is high) and (moisture is high) and (angle is low) then (shear strength is bad)
- 30. If (height is high) and (moisture is high) and (angle is common) then (shear strength is bad)
- 31. If (height is high) and (moisture is semi suitable) and (angle is very low) then (shear strength is bad)
- 32. If (height is high) and (moisture is semi suitable) and (angle is low) then (shear strength is bad)
- 33. If (height is high) and (moisture is semi suitable) and (angle is common) then (shear strength is bad)
- 34. If (height is high) and (moisture is suitable) and (angle is very low) then (shear strength is bad)
- 35. If (height is high) and (moisture is suitable) and (angle is low) then (shear strength is good)
- 36. If (height is high) and (moisture is suitable) and (angle is common) then (shear strength is good)

In order to validation the fuzzy model, the shear strength of 72 wheat stems were assessed by the expert person.

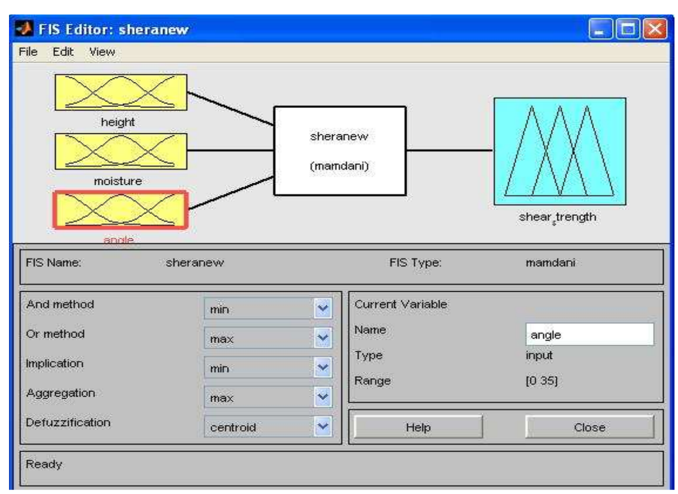

Fig. 2. Overall form of fuzzy modeling for shearing energy of wheat stem

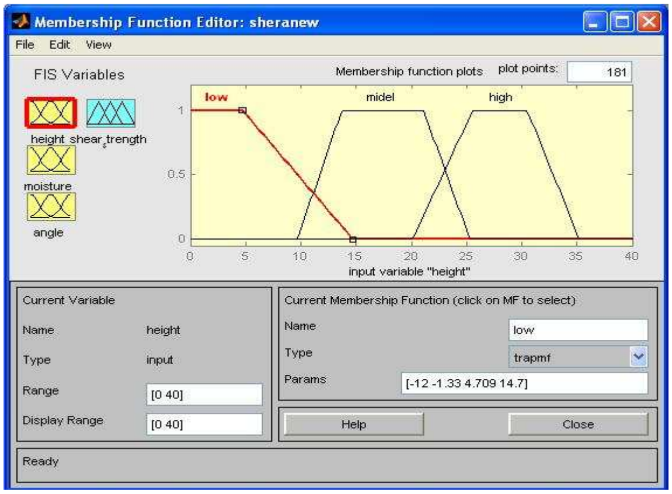

Fig. 3. The membership functions used to give a description of the stem cutting height

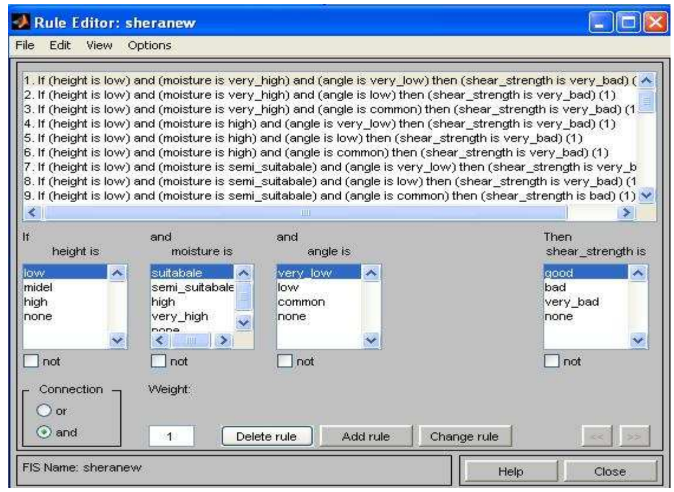

Fig. 6. Definition the fuzzy rules in MATLAB software for cutting the stem

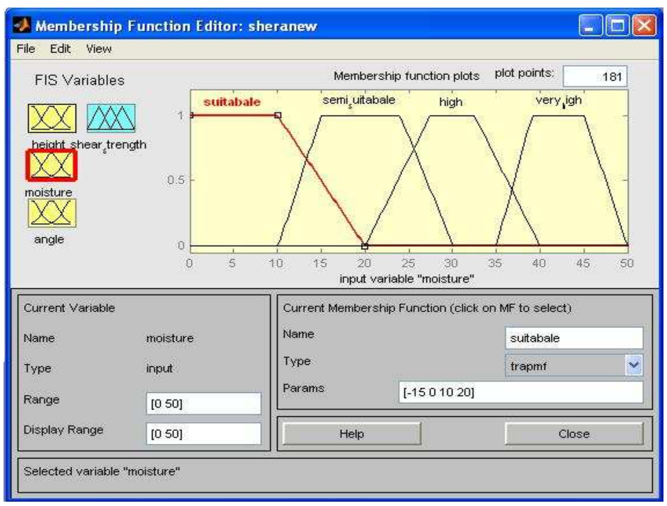

Fig. 4. The membership functions used to give a description of the stem moisture content

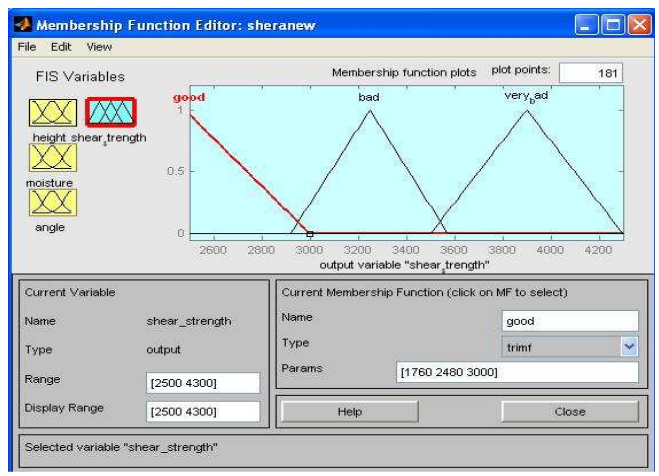

Fig. 7. Membership functions used for describing the shear force of the stem

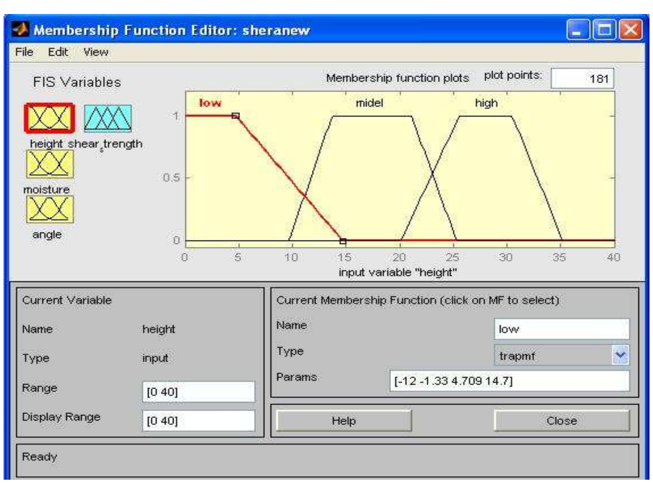

Fig. 5. The membership functions used to give a description of the cutting blade bevel angle

III. RESULTS AND DISCUSSION

Table 1 shows that the fuzzy model used in this study had an acceptable prediction for determining the level of shear force to cut the wheat stem. The fuzzy model used in the current research had an accuracy of 91%, 97% and 100%, respectively in bad, middle and good levels to predict the stem shearing strength. Fig. 9 indicated the proper accomplishment of the applied fuzzy rules in the model. For example, with decreasing the linguistic variable of moisture and/or by increasing the cutting height variable, the shearing strength would decrease.

Table 1: Prediction of the wheat stem shear strength using fuzzy logic

Output MF	Expert	Fuzzy	Accuracy (%)
Bad	22	20	91
Middle	35	34	97
Good	5	5	100

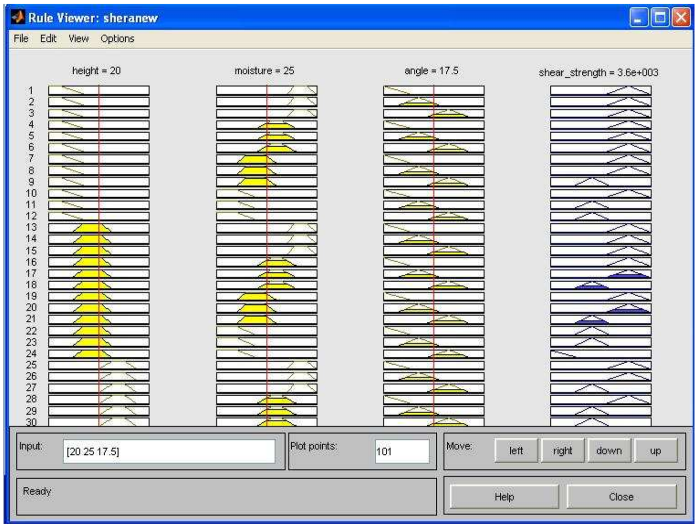

Fig. 8. The process of application of fuzzy rules in MATLAB software

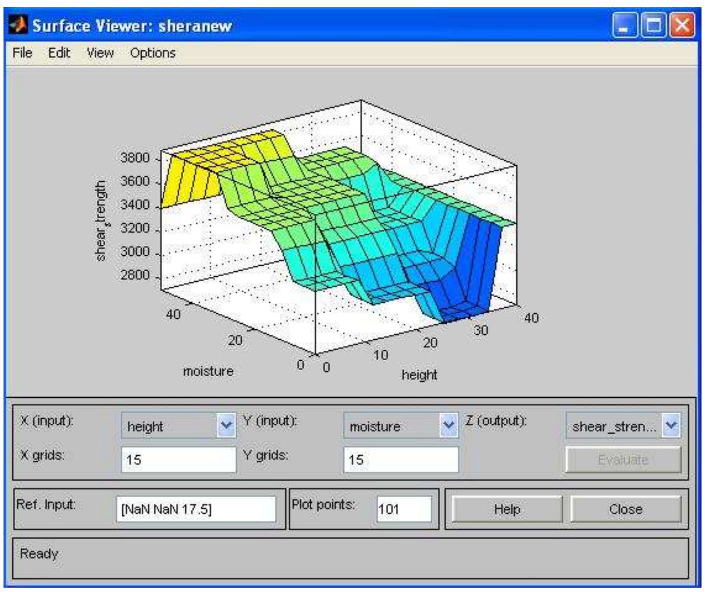

Fig. 9. Control level of the set of rules

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