# Sweet Sorghum for Bioethanol Production: A Mamdani-type Fuzzy Inference System

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**Abstract** In this paper the annual bioethanol production at a bioethanol plant in relation to the cultivating area with sweet sorghum and to the land's yield was estimated by the building a Mamdani-type fuzzy inference system using the Fuzzy Logic Toolbox Graphical User Interface (GUI) Tools of Matlab (Intelligent system). Data for this study were collected by research papers. This industrial unit will contribute to the local development as it can provide jobs for a great part of the rural population for the cultivation of sweet sorghum. The cultivation of sweet sorghum is one of the new promising energy crops for bioethanol production and it constitutes a way out from the problems that the agricultural sector faces nowadays. In this paper an ideal solution was estimated which is formulated as follows "the bioethanol plant absorbing the sweet sorghum's production of a cultivating area of 39,700 acres and having a mean land's yield in the order of 3,150 liters bioethanol/acre/year would produce 124,000 tons of bioethanol annually". Such a vast area of land would offer a complementary occupation to a significant number of young farmers for the cultivation of sweet sorghum which will probably be well subsidized, will provide economic motives to the planters, support the agricultural economy and sustain the population in the countryside.

**Keywords** sweet sorghum, bioethanol plant, fuzzy logic, Mamdani-type FIS

## Introduction

### In General

The authors believe that the establishment of a bioethanol production industrial unit which will use sweet sorghum as a plant raw material will comprise respiration on local level because apart from the biofuel production, the cultivation of sweet sorghum which will probably be well subsidized, will provide economic motives to the planters, support the agricultural economy and sustain the population in the countryside. In this paper the annual bioethanol production at a bioethanol plant in relation to the cultivating area with sweet sorghum and to the land's yield was estimated by the building a Mamdani-type fuzzy inference system using the Fuzzy Logic Toolbox Graphical User Interface (GUI) Tools of Matlab (Intelligent system).

### Sweet Sorghum (*Sorghum bicolor var. sweet*)

It is a single-stemmed annual C4 grass, which reaches a height of 1-5 m. It has a strong root system and a layer of heavy disilicate covers the epidermis of the root preventing collapse of the roots in drought conditions. It has fibrous, spreading roots and the system may extend to at least 1.5 m away from the plant, and is most abundant in the top 0.9 m, although it may extend to twice that depth. It is probably indigenous to N-E Africa and it is now grown between 40°N and S. It has been proposed as a"Four F's Crop" (Food, Fuel, Fodder and Fibre) with Asia maximising all four outputs, whereas Europe and Brazil are increasing sugar production for fuel ethanol [1].

Biomass production ranges from 15.7 to 22 t dm/ha in the USA [2], with 22 t dm/ha recorded from Spain [3]. Little seed is produced in temperate regions but this is a benefit as most of the energy is used for vegetative growth [4].  An annual gross energy yield of 18.3 Mj/kg of dry matter has been calculated [5]. The sweet sorghum's yield for the infertile rainfed lands ranges from 2,700-2,880 liters bioethanol/acre, while for the fertile irrigated lands from 3,280-3,600 liters bioethanol/acre [2-4]. This grass has an extensive root system, which aids drought tolerance, only requires moderate fertility, can grow on neutral to acid soil, and it is resource efficient especially for nitrogen and water [2].

**Working with the Fuzzy Logic Toolbox**
The Fuzzy Logic Toolbox provides apps to let you perform classical fuzzy system development and pattern recognition. In general, using the Fuzzy Logic Toolbox, you can [6-7]:
- Develop and analyze fuzzy inference systems
- Develop adaptive neurofuzzy inference systems
- Perform fuzzy clustering.

**What Are Fuzzy Inference Systems?**
Fuzzy inference is the process of formulating the 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: Membership Functions, Logical Operations and If-Then Rules. Two types of fuzzy inference systems can be implemented in the Fuzzy Logic Toolbox: Mamdani-type and Sugeno-type. These two types of inference systems vary somewhat in the way outputs are determined [8-10].
Mamdani-type inference is a type of fuzzy inference in which the fuzzy sets from the consequent of each rule are combined through the aggregation operator and the resulting fuzzy set is defuzzified to yield the output of the system. Sugeno-type inference is a type of fuzzy inference in which the consequent of each rule is a linear combination of the inputs. The output is a weighted linear combination of the consequents.
Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology. Mamdani's method was among the first control systems built using fuzzy set theory. It was proposed in 1975 by Ebrahim Mamdani [8] as an attempt to control a steam engine and boiler combination by synthesizing a set of linguistic control rules obtained from experienced human operators. Mamdani's effort was based on Lotfi Zadeh's 1973 paper on fuzzy algorithms for complex systems and decision processes [11].
Mamdani-type inference expects the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. It is possible, and in many cases much more efficient, to use a single spike as the output membership function rather than a distributed fuzzy set. This type of output is sometimes known as a singleton output membership function, and it can be thought of as a pre-defuzzified fuzzy set. It enhances the efficiency of the defuzzification process because it greatly simplifies the computation required by the more general Mamdani method, which finds the centroid of a two-dimensional function. Rather than integrating across the two-dimensional function to find the centroid, the weighted average of a few data points is used. In general, Sugeno-type systems can be used to model any inference system in which the output membership functions are either linear or constant [12-13].
Fuzzy inference systems have been successfully applied in fields such as automatic control, data classification, decision analysis, expert systems and computer vision. Because of their multidisciplinary nature, fuzzy inference systems are associated with a number of names, such as fuzzy-rule-based systems, fuzzy expert systems, fuzzy modeling, fuzzy associative memory, fuzzy logic controllers, and simply (and ambiguously) fuzzy systems [14-15].

**Methodology**

**Fuzzy Logic Toolbox Graphical User Interface (GUI) Tools to build a Mamdani-type fuzzy inference system**
The Fuzzy Logic Toolbox Graphical User Interface (GUI) Tools were used in this paper to build a Mamdani-type fuzzy inference system (FIS). The following GUI tools were used to build, edit and view the fuzzy inference system:

Fuzzy Inference System (FIS) Editor to handle the high-level issues for the system—How many input and output variables? What are their names? Fuzzy Logic Toolbox software does not limit the number of inputs. However, the number of inputs may be limited by the available memory of the machine. If the number of inputs is too large or the number of membership functions is too big, then it may also be difficult to analyze the FIS using the other tools.

Membership Function Editor to define the shapes of all the membership functions associated with the input and output variables of the FIS.

Rule Editor to edit the list of rules that defines the behavior of the system using full English-like syntax.

Rule Viewer to view the fuzzy inference diagram. Rule Viewer is used as a diagnostic to see, for example, which rules are active or how individual membership function shapes influence the results. Rule Viewer lets you view the detailed behavior of a FIS to help diagnose the behavior of specific rules or study the effect of changing input variables.

Surface Viewer to view the dependency of one of the outputs on any one or two of the inputs. It generates and plots an output surface map for the system. Surface Viewer generates a 3-D surface from two input variables and the output variable of a FIS.
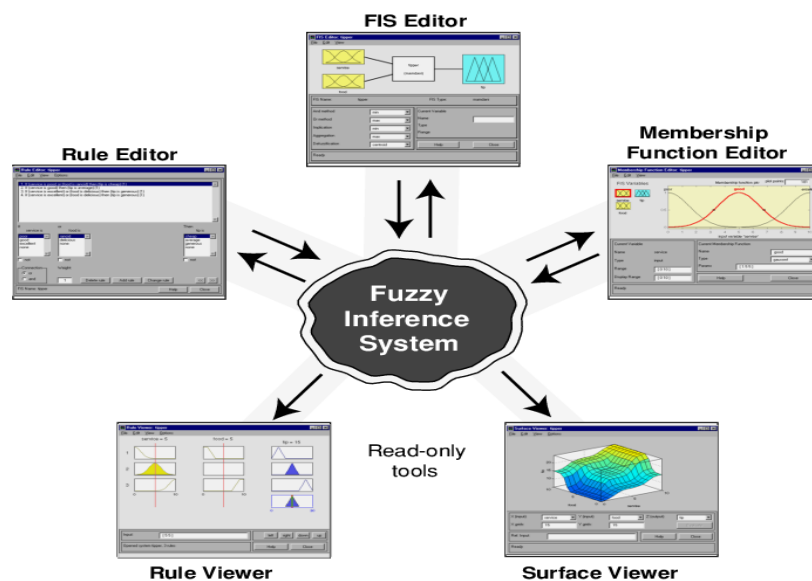


*Figure 1: A Mamdani-type fuzzy inference system using the Fuzzy Logic Toolbox Graphical User Interface (GUI) Tools. The Membership Function Editor (top right), FIS Editor (center), Rule Editor (top left), Rule Viewer (bottom left) and Surface Viewer (bottom right)*

**The Problem**

Given two sets of numbers, the first one between 0 and 53,000 acres and the second one between 0 and 3,600 liters bioethanol/acre/year that respectively represent the cultivating area with sweet sorghum and the land's yield. What should the annual production of bioethanol be? In this paper the annual bioethanol production at a bioethanol plant in relation to the cultivating area with sweet sorghum and to the land's yield was estimated by the building a Mamdani-type fuzzy inference system using the Fuzzy Logic Toolbox Graphical User Interface (GUI) Tools of Matlab (Intelligent system). Data for this study were collected by research papers concerning the range of sweet sorghum yield for various land categories (infertile rainfed land, fertile irrigated land).

**Results-Discussion**

**Building of a Mamdani-type Fuzzy Inference System**

Fuzzy Approach

The following 3 rules were set:

- If cultivating area with sweet sorghum is small and land is infertile rainfed, then the annual production of bioethanol is low;

- If cultivating area with sweet sorghum is satisfactory, then the annual production of bioethanol is satisfactory;
- If cultivating area with sweet sorghum is large or land is fertile irrigated, then the annual production of bioethanol is high.

The four basic steps for building and simulating of a fuzzy logic system are the following [7,13,16]:

- Defining inputs and outputs;
- Creating membership functions;
- Creating rules;
- Simulating the results of a fuzzy logic system.

1st Step-defining Inputs and Outputs

The Mamdani-type fuzzy inference system was selected in the FIS Editor. This problem has 2 input variables and 1 output variable. The input 1 variable is the "cultivating area with sweet sorghum". The input 2 variable is the "land's yield". The output variable is the "annual production of bioethanol" (Fig. 2).
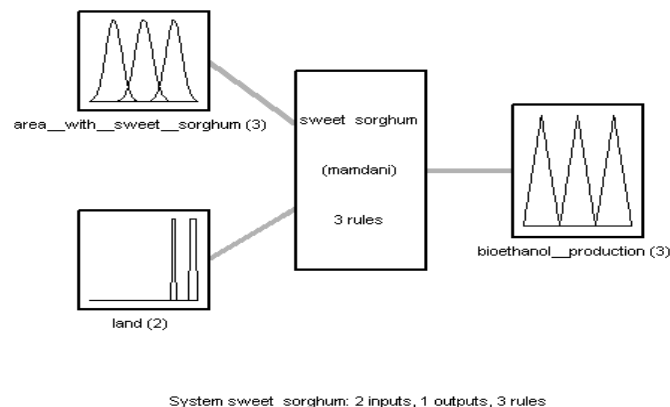


*Figure 2: Defining inputs and outputs*

2nd Step-creating Membership Functions

The membership functions for the 3 variables were defined, namely for the variables: "cultivating area with sweet sorghum", "land's yield", "annual production of bioethanol". The gaussmf was selected as a type of membership function for the input 1 variable "cultivating area with sweet sorghum". The number of membership functions is 3 (small, satisfactory, large). The range of "cultivating area with sweet sorghum" is between 0 and 53,000 acres (Fig. 3).
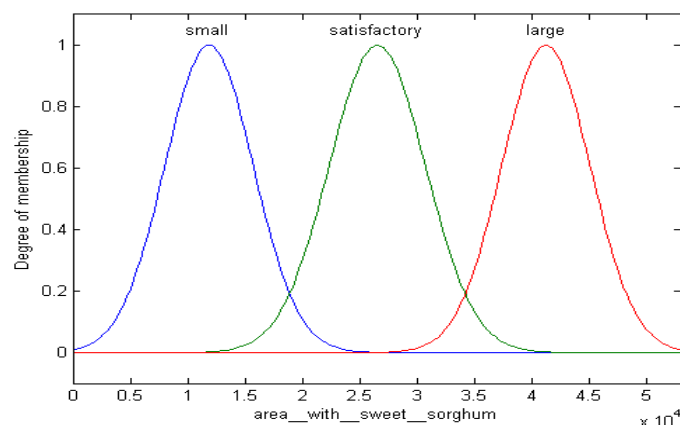


*Figure 3: The three membership functions (small, satisfactory, large) for the input 1 variable "cultivating area with sweet sorghum"*

The trapmf (trapezoid membership function) was selected as a type of membership function for the input 2 variable "land's yield". The number of membership functions is 2 (infertile rainfed, fertile irrigated). The range of "land's yield" is between 0 and 3,600 liters bioethanol/acre/year (Fig. 4).
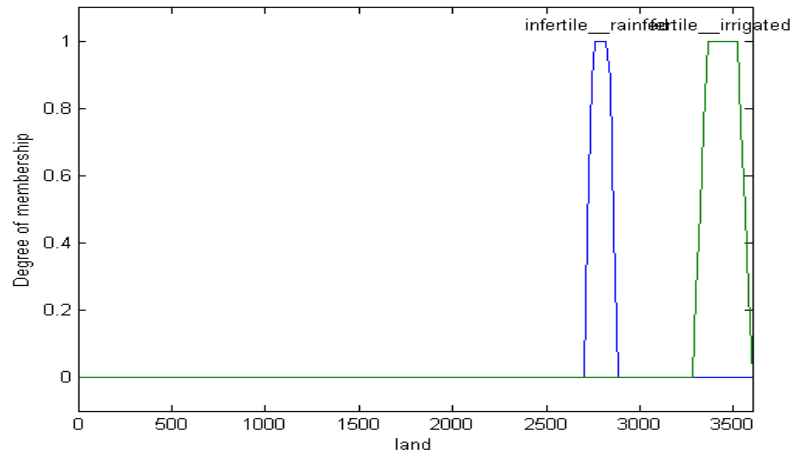
*Figure 4: The two membership functions (infertile rainfed, fertile irrigated) for the input 2 variable "land's yield"*

The trimf (triangular membership function) was selected as a type of membership function for the output variable "annual production of bioethanol". The number of membership functions is 3 (low, satisfactory, high). The range of "annual production of bioethanol" is between 0 and 150,000 tons of bioethanol/year (Fig. 5).
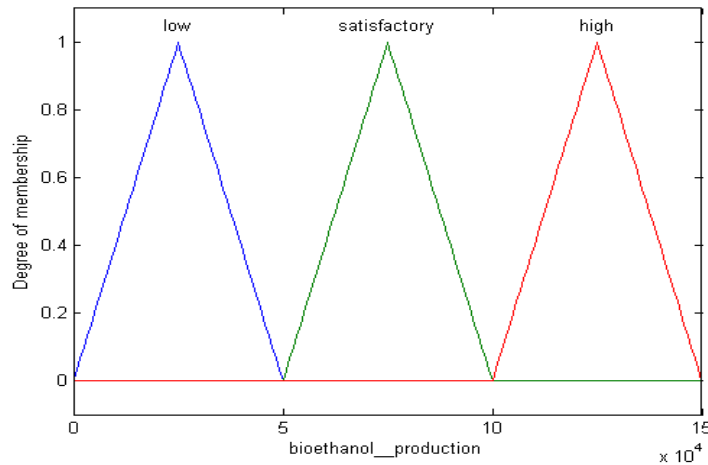


*Figure 5: The three membership functions (low, satisfactory, high) for the output variable "annual production of bioethanol"*

3rd Step-creating Rules

Rule statements are constructed automatically in the Rule Editor. The 3 rules of fuzzy approach were added in the Rule Editor (Fig. 6).
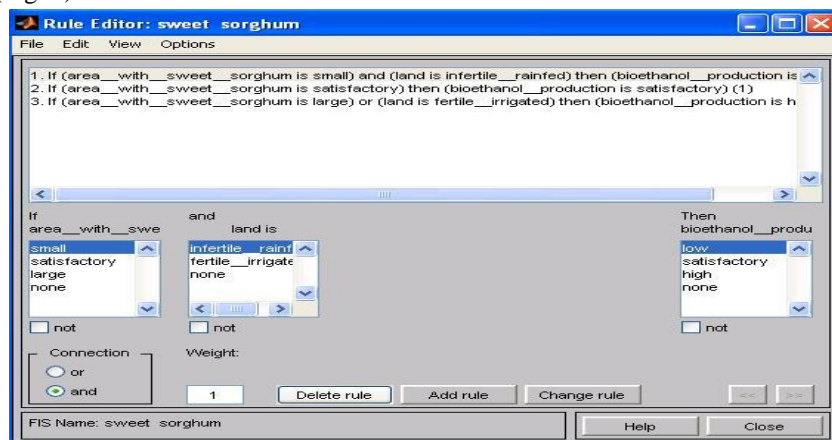


*Figure 6: The rule editor: the three rules are appeared in the up part of this window*

4th Step-simulating the Results of a Fuzzy Logic System

The results of Rule Viewer (Fig. 7) and Surface Viewer (Fig. 8) of a Mamdani-type fuzzy inference system are simulated and analyzed.
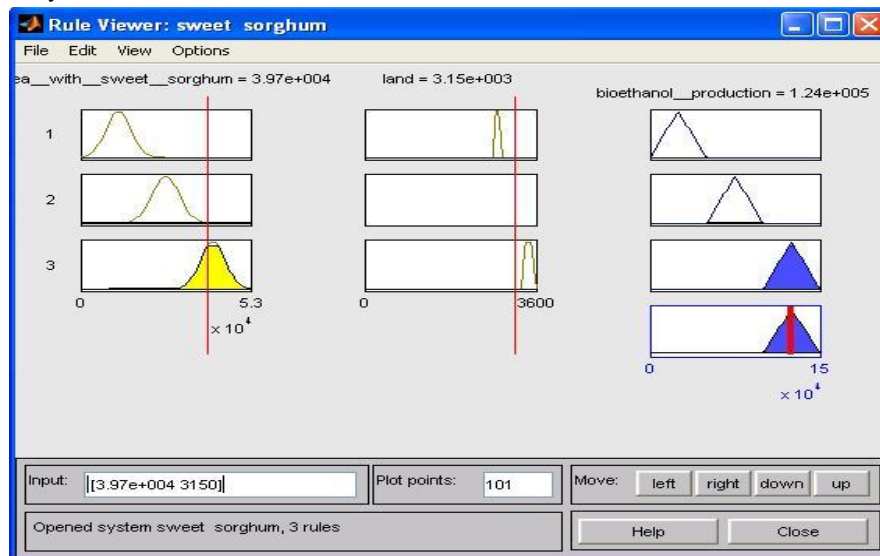


*Figure 7: The rule viewer*

In the Rule Viewer (Fig. 7), each column shows a set of membership functions for a particular variable. 3 membership functions for "cultivating area with sweet sorghum" input 1 variable, 2 membership functions for "land's yield" input 2 variable and 3 membership functions for "annual production of bioethanol" output variable are presented in Fig. 7.

Each membership function in this set is associated with a particular rule and maps input variable values "cultivating area with sweet sorghum" and "land's yield" to rule input values. In other words, the number of rows here is the number of rules that the authors have. The first row corresponds to the first rule, the second row corresponds to the second rule and the third row corresponds to the third rule. The plots in the output column show how the rules are applied to the output variable. The bottom right plot shows how the output of each rule is combined to make an aggregated output and a defuzzified value. The red line provides the defuzzified value for the annual production of bioethanol. The input value for "cultivating area with sweet sorghum" is 39,700 acres and the input value for "land's yield" is 3,150 liters bioethanol/acre/year and they correspond to an output value for "annual production of bioethanol" equal to 124,000 tons of bioethanol.
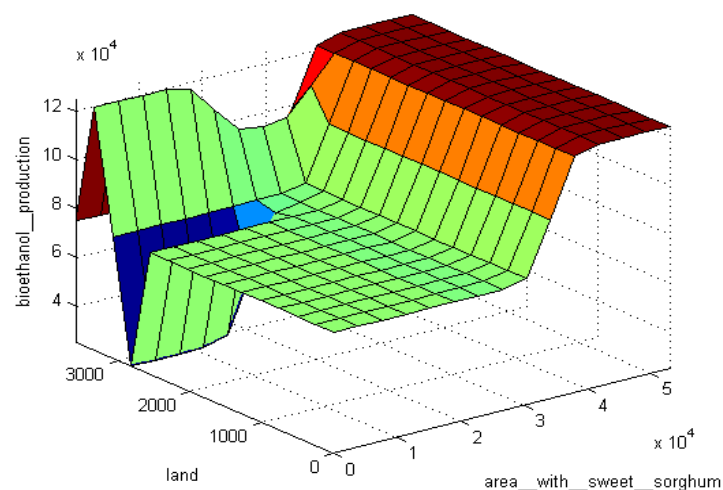


*Figure 8: The surface viewer: annual production of bioethanol as it is affected by the cultivating area with sweet sorghum and land's yield*

The Surface Viewer (Fig. 8) displays a surface that represents a mapping from the "cultivating area with sweet sorghum" and the "land's yield" to the "annual production of bioethanol". This shows a high value of annual production of bioethanol for large cultivating area with sweet sorghum and fertile irrigated lands, a low value of annual production of bioethanol for a small cultivating area with sweet sorghum and infertile rainfed lands as well as a large flat area in the middle corresponding to a satisfactory (medium) annual production of bioethanol for satisfactory (medium) cultivating area with sweet sorghum.

**Conclusion**

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. Using the editors and viewers in the Fuzzy Logic Toolbox, the rules set were built, the membership functions were defined and the behavior of the fuzzy inference system (FIS) was analyzed.

In this paper the annual bioethanol production at a bioethanol plant in relation to the cultivating area with sweet sorghum and to the land's yield was estimated by the building a Mamdani-type fuzzy inference system using the Fuzzy Logic Toolbox Graphical User Interface (GUI) Tools of Matlab (Intelligent system). Data for this study were collected by research papers concerning the range of sweet sorghum yield for various land categories (infertile rainfed land, fertile irrigated land). This industrial unit will contribute to the local development as it can provide jobs for a great part of the rural population for the cultivation of sweet sorghum. The cultivation of sweet sorghum is one of the new promising energy crops for bioethanol production and it constitutes a way out from the problems that the agricultural sector faces nowadays. The authors built a Mamdani-type fuzzy inference system, namely defined inputs and outputs, created membership functions, created rules and the authors simulated the results of Rule Viewer and Surface Viewer of the fuzzy inference system. The Surface Viewer shows a high value of annual production of bioethanol for large cultivating area with sweet sorghum and fertile irrigated lands and a satisfactory (medium) annual production of bioethanol for satisfactory (medium) cultivating area with sweet sorghum. By the Rule Viewer is shown that the input value for "cultivating area with sweet sorghum" is 39,700 acres and the input value for "land's yield" is 3,150 liters bioethanol/acre/year and they correspond to an output value for "annual production of bioethanol" equal to 124,000 tons of bioethanol/year. This constitutes the ideal solution in the problem, which was found by using of the Fuzzy Logic Toolbox Graphical User Interface (GUI) Tools of Matlab. In other words, the bioethanol plant absorbing the sweet sorghum production of a cultivating area of 39,700 acres and having a mean land's yield in the order of 3,150 liters bioethanol/acre/year would produce 124,000 tons of bioethanol annually. Such a vast area of land would offer a collateral occupation to a significant number of young farmers for the cultivation of sweet sorghum which will probably be well subsidized, will provide economic motives to the planters, support the agricultural economy and sustain the population in the countryside.

**References**

[1]. FAO Ecocrop (2009). The environmental requirements and uses of the world's crops http://ecocrop.fao.org/ ecocrop/srv/en/cropFindForm

[2]. Richard, E., Tew, T., Cobill, R. and Hale, A. (2008). Sugar/energy canes as feedstocks for the biofuels industry. In: Proceedings of the Short Rotation Crops International Conference. *Biofuels, Bioenergy and Bioproducts from Sustainable Agricultural and Forest Crops*. August 19-21, 2008. Bloomington, Minnesota, USA.

[3]. Fernández, J. (2006). Bioenergy crops in the Mediterranean, practical experiences. In Proceedings of Sustainable Bioenergy Cropping Systems for the Mediterranean. Madrid, Spain, 9-10 February 2006.

[4]. Moore, K. J. (2008). Herbaceous biomass: state of the art. In: Proceedings of the Short Rotation Crops International Conference *Biofuels, Bioenergy and Bioproducts from Sustainable Agricultural and Forest Crops*. August 19-21, 2008. Bloomington, Minnesota, USA.

[5]. ECN-Biomass (2009). Energy research Centre of the Netherlands Version: 4.13. P.O. Box 1, 1755 ZG Petten. http://www.ecn.nl/phyllis/single.html

[6].    Jang, J. 1993. ANFIS: Adaptive-Network-based Fuzzy Inference Systems. *IEEE Transactions on Systems, Man and Cybernetics*, Vol. 23, No. 3, pp. 665-685.

[7].    Negnevitsky, M. 2005. Artificial Intelligence. A Guide to Intelligent Systems. Second Edition. Addison-wesley, Pearson Education Limited, Essex, England.

[8].    Mamdani, E. and S. Assilian. 1975. An experiment in linguistic synthesis with a fuzzy logic controller. *International Journal of Man-Machine Studies*, Vol. 7, No. 1, pp. 1-13.

[9].    Sugeno, M. 1985. Industrial applications of fuzzy control. Elsevier Science Pub. Co.

[10].   Jang, J.  and T. Sun. 1997. Neuro-Fuzzy and Soft Computing: A Computational Approach to Learning and Machine Intelligence, Prentice Hall.

[11].   Zadeh, L. 1973. Outline of a new approach to the analysis of complex systems and decision processes. *IEEE Transactions on Systems, Man and Cybernetics*, Vol. 3, No. 1, pp. 28-44.

[12].   Nguyen, H. and Walker, E. 2006. A First Course in Fuzzy Logic. CRC Press Taylor and Francis Group, Boca Raton.

[13].   Sivanandam, S., Sumathi, T. and Deepa, L. 2007. Introduction to Fuzzy Logic Using Matlab. Springer, Berlin Heidelberg.

[14].   Dubois, D. and H. Prade. 1980. Fuzzy Sets and Systems: Theory and Applications, Academic Press, New York.

[15].   Ross, T. 2010. Fuzzy Logic with Engineering Applications. Third Edition, Wiley, Chichester, UK.

[16].   Berkan, R. and Trubatch, S. 1997. Fuzzy system design principles. Wiley-IEEE Press, New York.