International Journal of Horticultural Science and Technology (2023) Vol. 10, No. 4, pp. 387-396

International Journal of Horticultural Science and Technology
Journal homepage: http://ijhst.ut.ac.ir

A Modeling Approach to Automate the Functioning of Tomato Greenhouses

Mohamed Habib Sellami[1,2]*, Farhat Sahbani[3]

1 Laboratory of soft material and Electromagnetic modeling, Faculty of Science Tunis, University Tunis El Manar, Tunis, Tunisia
2 Department of Hydraulic, High School of Engineering, Medjez El Bab, IRESA, University of Jendouba, Jendouba, Tunisia
3 Faculty of Science Bizerte, University of Carthage, Bizerte, Tunisia

ARTICLE INFO

Article history:

Received: 31 August 2022,
Received in revised form: 22 October 2022,
Accepted: 28 October 2022

Article type:

Research paper

Keywords:

PID controller,
fuzzy logic controller,
modeling,
Matlab/Simulink environment,
irrigation.

ABSTRACT

Farmers and experts are continuously searching for optimal conditions to improve the productivity of tomatoes in greenhouses. To provide an answer to their concerns, we have developed a modeling approach to automate the functioning of a greenhouse cultivated with tomato plants. For the aeration, heating, and irrigation systems, we compared the Proportional Integral Derivative (PID) controller response to the Fuzzy logic (FL) controller response. For the aeration system, the response of both controllers was stable, with a pick of about 1.09 for the PID controller and zero for the fuzzy controller. Likewise, there was no overtaking for the fuzzy controller but about 8.28% for the PID controller. The rise time for the fuzzy controller was less than that of the PID controller (627 s). We signaled a stable response for the PID controller and the fuzzy logic controller for the irrigation system. The pick and the overtake were equal to zero for the fuzzy logic controller but were 1.28 and 28.2 s for the PID controller, respectively. In the case of both controllers, the rise time was the same, equaling 18.3 s. The regulation time was less than 35 s for the fuzzy logic controller and 31.1 s for the PID controller.

Abbreviations: Proportional Integral Derivative (PID), Fuzzy Logic (FL)

Introduction

In numerous studies (Dehnavard et al., 2017; Oboulbiga et al., 2017; Araujo et al., 2018; Ben Aîch et al., 2019; Ben Aîch, 2020), experts have highlighted the significant nutritional value of tomatoes. The number of consumers of this fruit-vegetable is rising all over the world (Gharbi et al., 2017; Souri and Dehnavard, 2018; Souri and Bakhtiarizade, 2019; Branthôme, 2020). To respond to this tendency, farmers are turning more and more towards cultivating tomato plants in greenhouses. Greenhouses are considered micro agricultural fields in which all input parameters can be easily controlled and monitored (Ben Ali et al., 2018; Jomaa et al., 2019; Zlem and Ebubekir, 2019). Proposing models to automate greenhouse operations enables an increase in plant productivity while reducing the risk of disease dispersal (Mansour et al., 2018; Sahbani and Ferjani, 2018; Sahbani and Sellami, 2020).

In this study, we have developed a modeling approach to automate the operation of every part of a tomato greenhouse (aeration system, heating system, freezing system, and irrigation system). Both the Proportional Integral Derivative (PID) controller and the Fuzzy Logic (FL) controller have been used (Smriti and Ravi, 2014; Goodchild et al., 2015; Didi et al., 2017; Fuseini et al., 2018; Gadelhag et al., 2018; Martinez et al., 2018; Anamekere et al., 2019; Mattara et al., 2020). Our approach involved input parameters and those

* Corresponding author's email: Sellami.fac@gmail.com

needed for validation from an experimental protocol set up in Sejnan, Tunisia (Sahbani and Ferjani, 2018; Sahbani and Sellami, 2020).

Material and Methods

Experimental protocol

The Tunisian Institute for Agricultural Research was the owner of the experimental facility in Sejnan. It is a rural area in the north of Tunisia, around 25 kilometers from the Mediterranean Sea and 82 kilometers from Bizerte. Mediterranean weather usually prevails. It has very hot, dry summers (with temperatures between 19 and 30 °C and relative humidity levels as high as 35%) and very mild, humid winters (with temperatures between 7 and 15 °C, and relative humidity that reaches 85%) (Sahbani and Sellami, 2020).

We designed a drip irrigation system to supply 30 plots with tomato plants inside a glass greenhouse (36 m^2 in surface area, 2.5 m in height). We used the deficit irrigation approach to irrigate the plants. Throughout each stage of development, we monitored the water supply, morphological parameters, agronomic parameters, soil factors, and climatic parameters. Near the tested drippers, sensors were placed to detect pressure, water flow, and soil moisture. Other sensors were positioned within the greenhouse to measure the relative air temperature. A meteorological station nearby provided information on air temperature, relative humidity, wind speed, solar radiation, and evaporation (Sahbani and Ferjani, 2018; Sahbani and Sellami, 2020).

Simulation tools and basic concepts of the controllers

We utilized the Simulink environment for both the PID controller and the fuzzy logic controller. This tool was used for signal processing and numerical analysis. It enables matrix calculations to be made as well as graphic displays of the outcomes. It can be used for both system conception/simulation and real-time automatic control when coupled with Matlab. By automating the heating, cooling, and aeration systems, we minimized human intervention to control the interior temperature and humidity. To maximize the tomato yield, we considered the requested thresholds for the given characteristics (Sahbani and Ferjani, 2018; Sahbani and Sellami, 2020). We were aware that the relationship between temperature and relative humidity was inverse. Therefore, establishing the proper temperature immediately resulted in an ideal relative humidity. The cause of the water condensation at the greenhouse wall was the evaporation of moisture after irrigation. However, numerous diseases of the tomato may spread as a result of water condensation. Applying our modeling approach to control irrigation supplies, aeration, and heating inside the greenhouse was aimed at reducing this occurrence directly and minimizing the hazards of water deficiency.

Results

Implementation of numerical PID controllers for aeration, watering, and heating in the greenhouse

Using a control loop feedback mechanism, a PID controller (Proportional-Integral-Derivative) is a scientific tool. It enables the monitoring and employment of all automating-required programs. The industrial sector, precision agriculture sector, and domestic sector primarily benefit from these applications (Ho et al., 1995; In Chen and Mills, 1997; Kao et al., 2006; Hung et al., 2008; Dos Santos, 2009). It can be used to control process factors like temperature, flow, pressure, and speed. By computing the difference between a set point and a measured process variable, this is accomplished. So we make sure that every procedure is under constant, regulated supervision. To function, the PID controller integrates derivative control (D), integral control (I), and proportional control (P) (in series or parallel).

Proportional control is a type of linear feedback control system in which the controlled variable is corrected. That correction is proportional to the difference between the desired and measured values (set point SP and process value PV). The outputs of the integral control are proportional to the integral of the time error. The derivative control slows the rate at which the controller outputs change. It is used for reducing the magnitude of the integral component and its overshoot while improving process stability.

The aeration system was numerically represented by the transfer function shown below:

$$H(z) = \frac{-(0.07867Z+0.0616)}{Z^2-1.478Z+0.4786} \quad (1)$$

The corresponding numerical PID parameters are:

0.32165 For the proportional P
0.029455 For the integral I
0.67399 For the derivate D
0.88783 For the filtering N

The irrigation system of the tomatoes in the greenhouse was numerically represented by the equation below:

$$H(z) = \frac{(0.09136Z+0.6345)}{Z^2-1.608Z+0.6345} \qquad (2)$$

Its numerical PID parameters are:
0.32165 For the proportional P
0.029455 For the integral I
0.67399 For the derivate D
0.88783 For the filtering N
The heating control system for the greenhouse under consideration was represented by the numerical transfer function shown below:

$$H(z) = \frac{-(0.0001033Z+1.422^{-7})}{Z^2-Z} \qquad (3)$$

The correspondent numerical PID parameters are:
-273.793 for the proportional P
-1.4466 for the integral I
1514.6952 for the derivate D
0.057765 for the filtering N

Fuzzy logic controller implementation for greenhouse aeration, irrigation, and heating

The fuzzy logic (FL) controller controls system inputs and outputs using linguistic variables. Many researchers (Yager and Filev, 1994; Altas and Sharaf, 2007) believe that we can apply this controller to any system without having to understand its operating principles or dynamics. This method considers many alternatives to decisions such as “yes” or “no”, “true” or “false”. It assigns a level of truth to each possibility (Sivanandam et al., 2007; Kiranpreet et al., 2010; Suryakant et al., 2012; Eddahhar et al., 2013). In its scale of measurement, there are indications of certainly true, relatively true, possibly true, potentially false, relatively false, and certainly false.

To put the fuzzy logic controller into action, the following steps must be accomplished (Izzuddin et al., 2018; Sahbani and Ferjani, 2018; Varun, 2018):

Fuzzification is the process of transforming i crisp input into linguistic variables or fuzzy values.

Fuzzy knowledge base stores information about all fuzzy input-output relationships. It also has a membership feature. It specifies the input variables to the fuzzy rule base as well as the output variables to the controlled plant.

Fuzzy Inference Engine is a collection of fuzzy “if-then” statements is used by the fuzzy inference system (FIS). The system’s response to various conditions is then determined. A fuzzy rule base provides the FIS with these “if-then” statements. The fuzzy rule base is tasked with storing knowledge about how the process works according to each domain. FIS is classified into two types, Mamdani FIS and Sugeno FIS (Kiranpreet et al., 2010; Jomaa et al., 2019).

Defuzzification is the conversion of fuzzy data into crisp values. They can then be used as input to another system. This conversion is accomplished by using the fuzzy inference engine.

Fuzzy controller implementation for the greenhouse irrigation system

To implement this controller, we established fuzzy rules between the internal temperature of the greenhouse, soil humidity, and watering amount. Irrigation was done when the temperature was high and the soil humidity was low (Rafiuddin et al., 2015; Satyajit et al., 2017; Carlos et al., 2017; Rajaprakash et al., 2017; Fuseini et al., 2018).

According to the results of the experimental study (Sahbani and Sellami, 2020), the optimal internal air temperature and soil humidity for normal tomato plant development is 20 °C and 50%, respectively. They were thought to be fixed consignments for the watering command. We established the fuzzy controller’s various rules based on these instructions (Table 1).

Table 1. Fuzzy controller rules for the internal temperature and soil humidity to automate the irrigation system.

Hs/Ti	F	T	CH
feeble	AC	AC	AL
Middle	PA	AC	AL
High	PA	PA	AL

Ti: internal temperature, Hs: soil humidity, F: cold, T: warm, CH: hot, PA: no action, AC: short action, AL: long action.

We considered Ti for temperature, Hs for soil humidity, and Ur for irrigation as inputs and outputs, respectively. The choice is whether to irrigate with short or long action. Both triangular and trapezoidal presentations were used here.

Fig. 1 (A), Fig. 1 (B), and Fig. 1 (C) depict the membership function for Hs (soil humidity), Ts (soil temperature) and Uir (irrigation system), respectively.

When the numerical value is between 50 and 53 units, the soil humidity is low. When its numerical value falls between 62 and 68 units, it is considered average. When the numerical value is between 77 and 80 units, it is considered high. When the temperature in the greenhouse is between 20 and 20.5 degrees Celsius, the air is considered cold. When the numerical value ranges between 21.5 and 22.5, it is lukewarm, and it is hot when it exceeds 23.5 units.

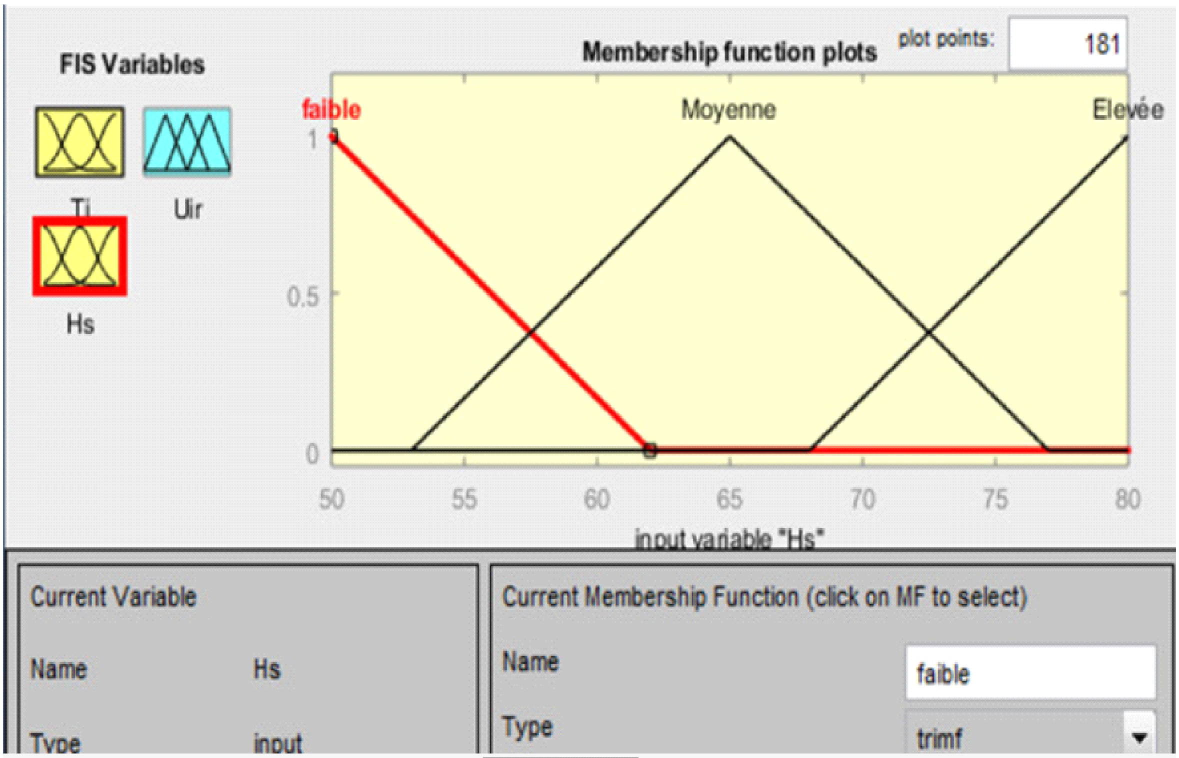


Fig. 1. (A) Current membership function for the soil humidity inside the greenhouse.

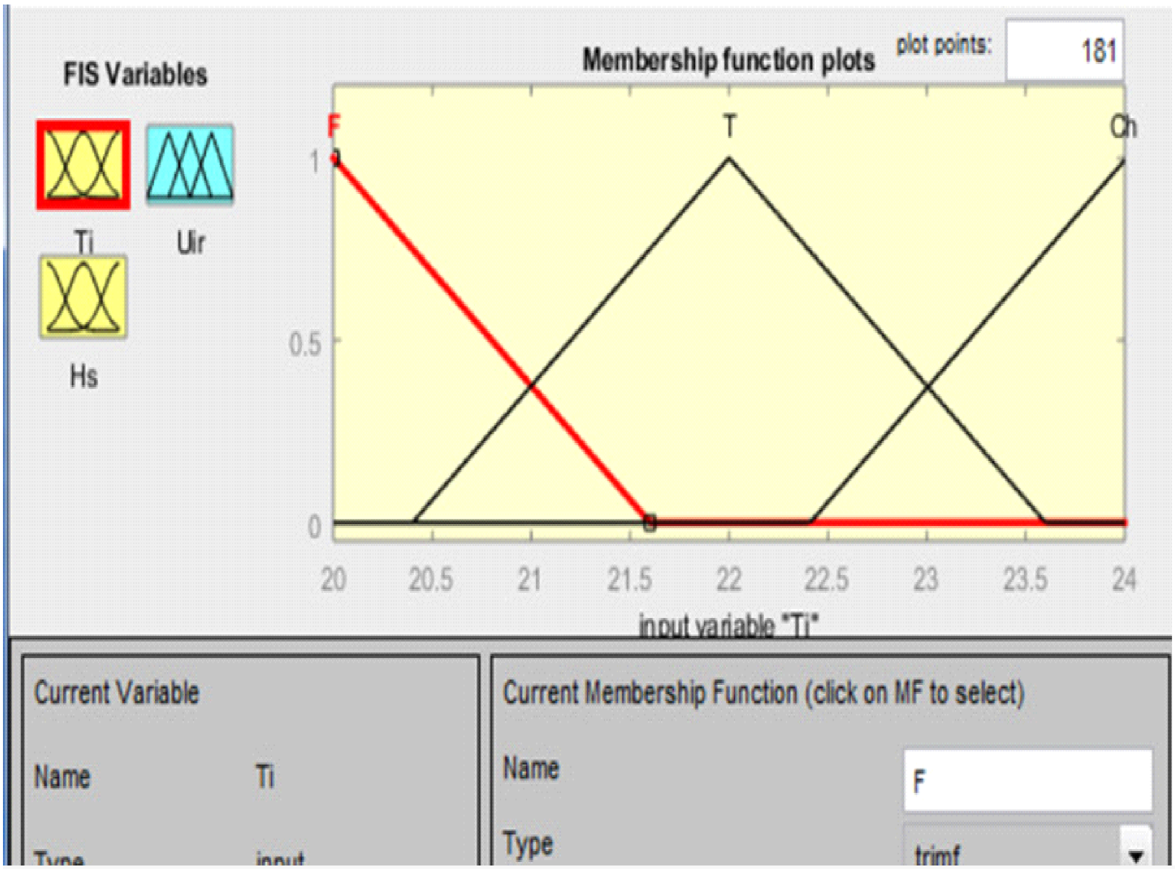


Fig. 1. (B) Current membership function for soil temperature inside the greenhouse.

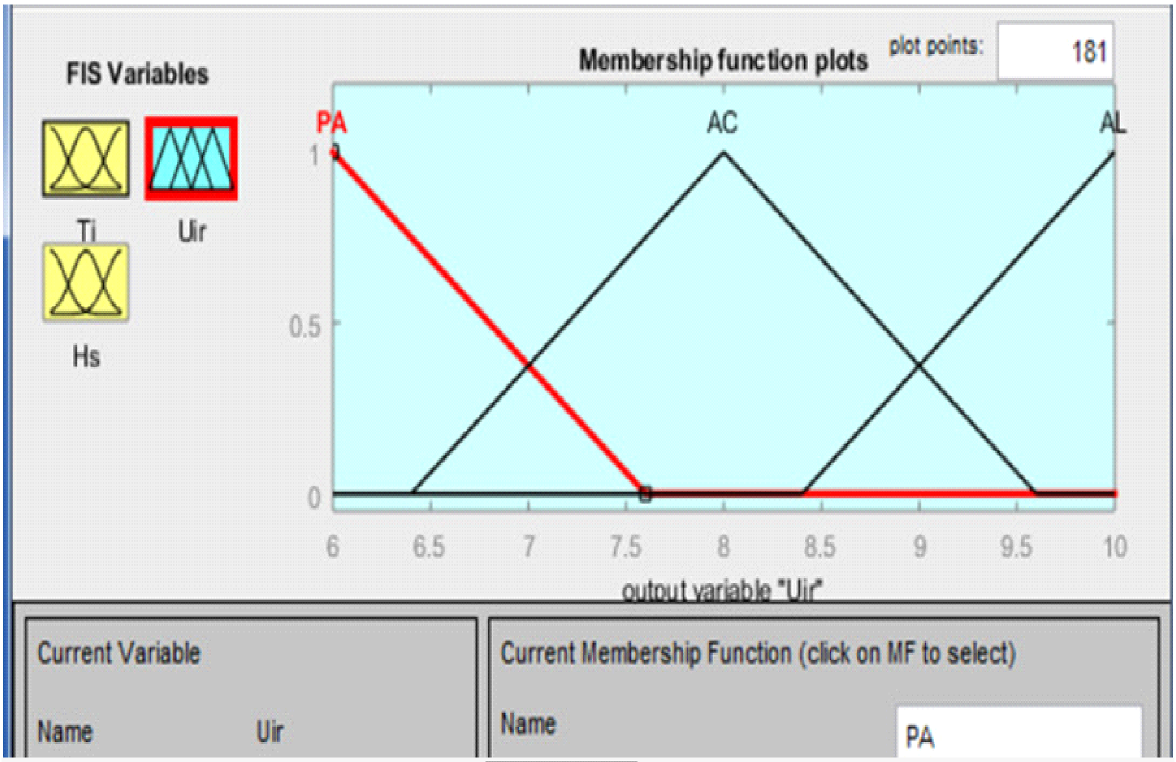


Fig. 1. (C) Current membership function for the irrigation system inside the greenhouse.

Fig. 1. Current membership functions for the inputs (soil humidity Hs (Fig.1 (A)), soil temperature Ti (Fig.1 (B)) and for the outputs (irrigation system Uir (Fig.1 (C))) to automate the greenhouse watering operation.

Between 7.5 and 8.5 units, the action is short, and it is long somewhere between 9.5 and 10 units. The inference rules for the irrigation system inside the greenhouse are

If (Ti is F) and (Hs is feeble) then (Uir is AC)
If (Ti is T) and (Hs is feeble) then (Uir is AC)
If (Ti is CH) and (Hs is feeble) then (Uir is AL)
If (Ti is F) and (Hs is average) then (Uir is PA)
If (Ti is T) and (Hs is average) then (Uir is AC)
If (Ti is CH) and (Hs is average) then (Uir is AL)
If (Ti is F) and (Hs is high) then (Uir is PA)
If (Ti is T) and (Hs is high) then (Uir is PA)
If (Ti is CH) and (Hs is high) then (Uir is AL)

To implement this controller, we proposed fuzzy relationships between the internal temperature of the greenhouse, door opening and closing, and aeration. If the temperature is high and the door is only partially open (feeble), we must aerate the greenhouse to keep it cool. The thresholds for action for internal temperature and door opening are 20°C and 50%, respectively. We built the fuzzy controller for the tomato greenhouse using these two consignments. The fuzzy inference matrix is shown in the table below (Table 2).

Table 2. Fuzzy rules to automate the aeration system inside the greenhouse.

Ouv/Ti	F	T	CH
Feeble	PA	PA	PA
Average or middle	AC	AC	AC
Hugh	AL	AL	AL

F: Cold, T: Lukewarm, CH: Hot, PA: No action, AC: Short action, AL: Long action.

We took the temperature (Ti) and the degree of openness of the greenhouse door (OUV) as inputs and the aeration as output (Uaeration). The decision is whether to command aeration with long or short actions. The aeration inference rules were implemented using the Matlab/Simulink environment. As a result, the aeration membership functions are depicted in Fig. 2, including Fig. 2 (A), Fig. 2 (B), and Fig. 2 (C) which show the membership function for air temperature (Ti), door openness (OUV) and aeration, respectively.

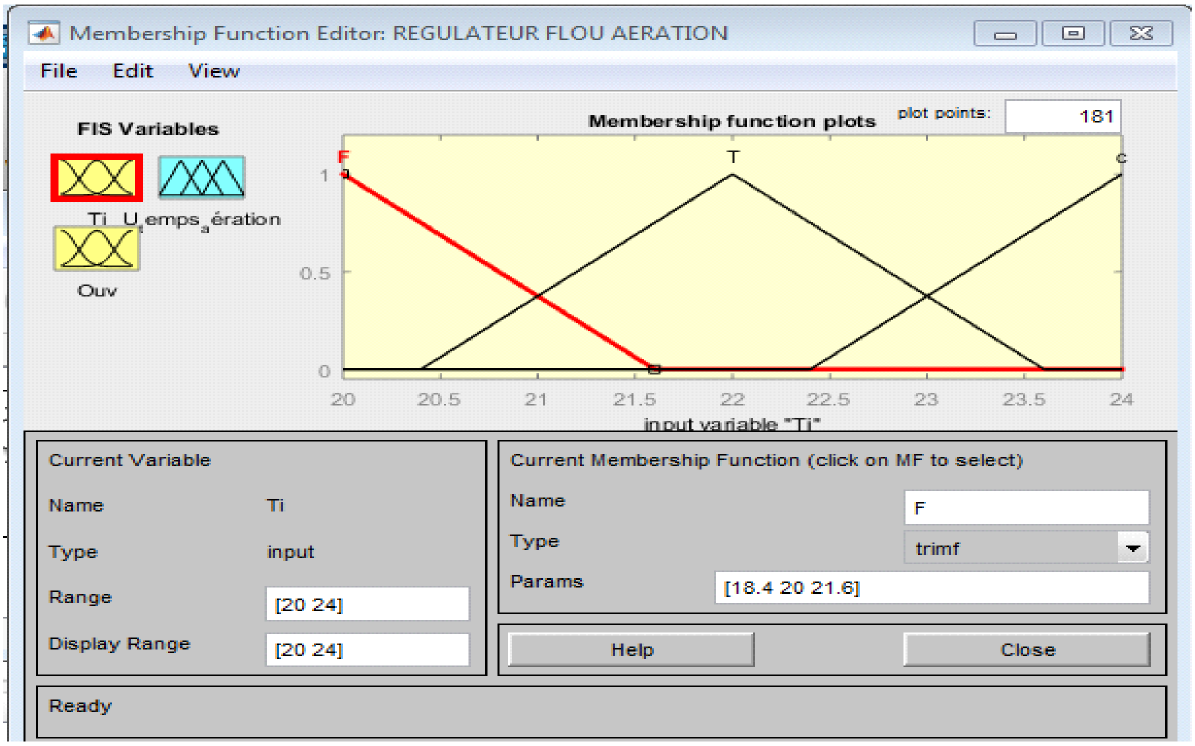


Fig. 2. (A) Membership function for the temperature Ti inside the greenhouse.

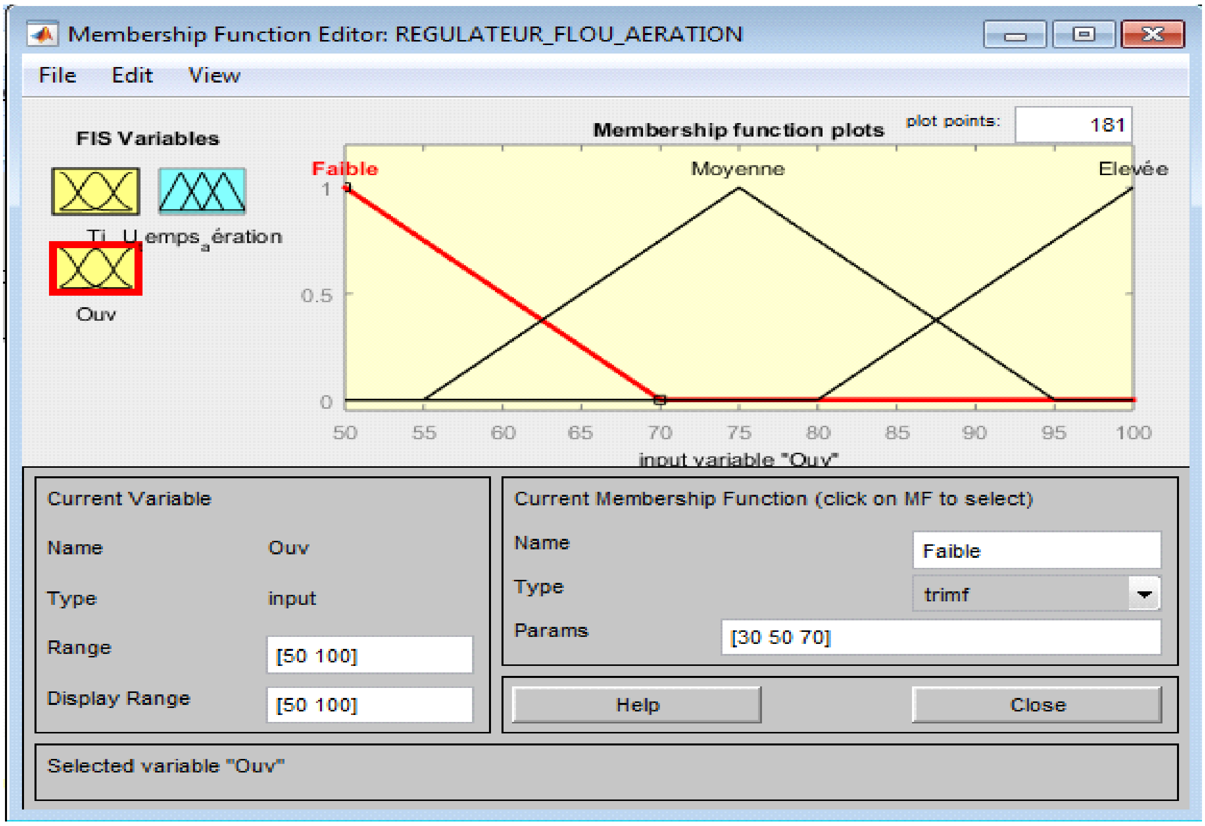


Fig. 2. (B) Membership function for the door openness (OUV) for the greenhouse.

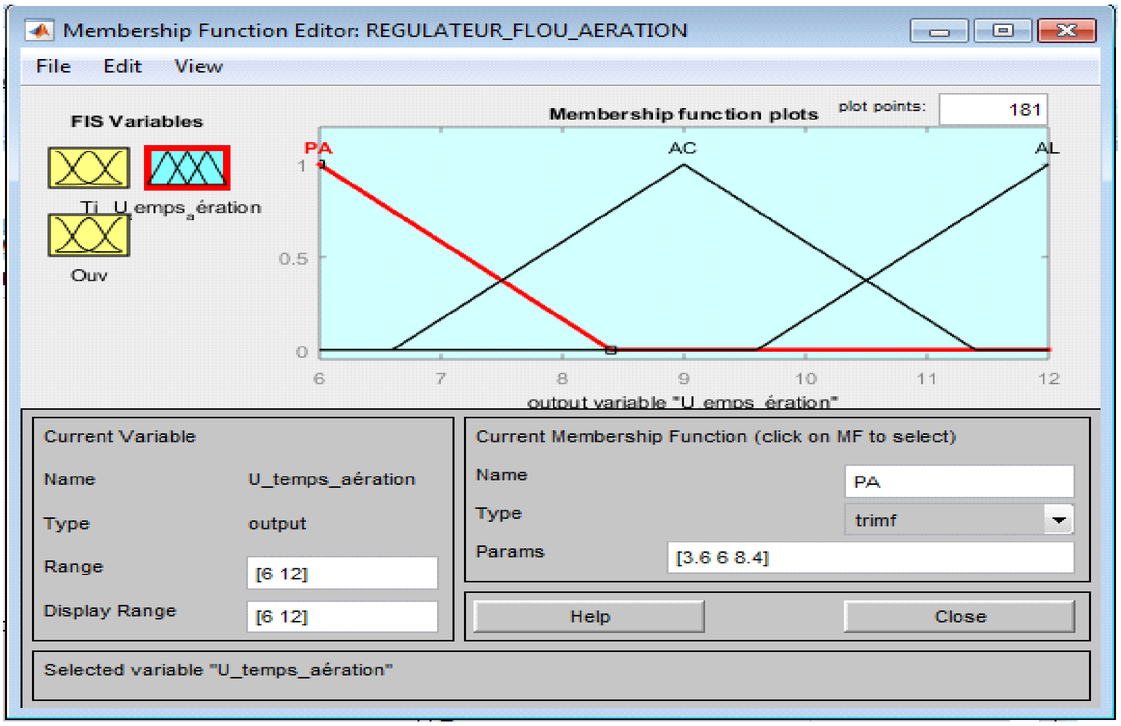


Fig. 2. (C) Membership function for the aeration as output.

Fig. 2. Membership functions for greenhouse aeration to meet the cold requirements of plants: (Fig. 2 (A)) for the temperature, (Fig. 2 (B)) for the door openness, (Fig. 2 (C)) for the aeration of the greenhouse.

When the numerical value of the door openness is between 50 and 55 units, we can say that it is weak. When the corresponding numerical value is between 70 and 80 units, it is considered average. When it is between 95 and 100 units, it is considered high. When the numerical value of the greenhouse air is between 20 and 20.5, it is considered cold. When the numerical value ranges between 21.5 and 22.5, it is considered lukewarm, and it is considered hot when it exceeds 23.5 units. We can confirm that there is no aeration action when the aeration numerical value is between 6 and 6.8 units. Between 8.4 and 9.6 units, the action is short. It is long when occurring between 11.4 and 12 units.

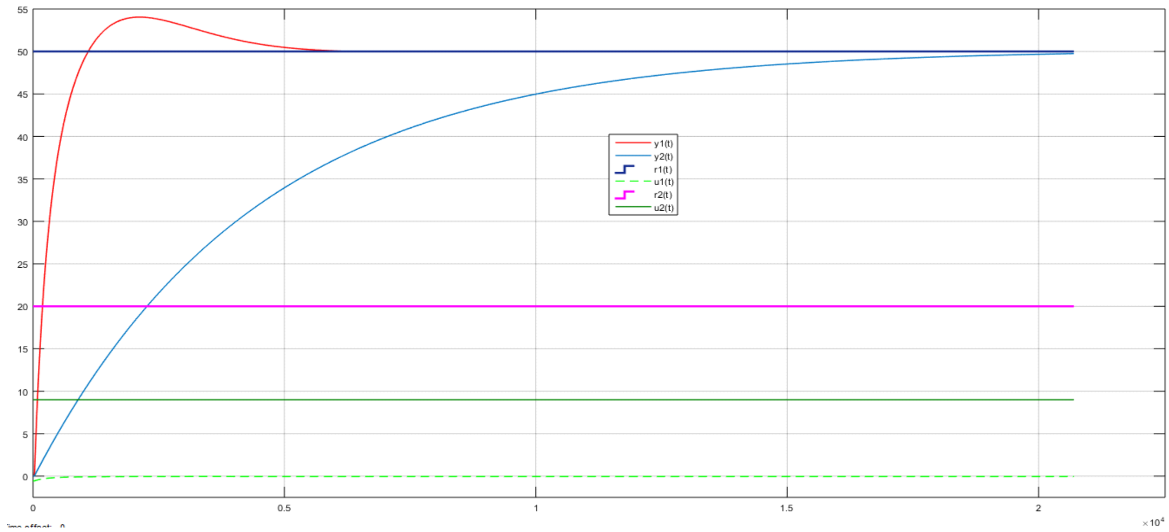
Discussion

Aeration of the greenhouse is an important process for ensuring optimal tomato plant growth. It allows for the cooling of the greenhouse and its internal space, the reduction of condensation, and the exchange of fresh air with the external environment. The automatic activation of aeration is primarily determined by the temperature threshold. The responses of the PID controller and the fuzzy logic controller of the aeration system inside the greenhouse are shown below (Fig. 3).

We can say that the response is stable for both controllers, with a pick of about 1.09 for the PID controller and zero for the fuzzy controller. We discovered that the fuzzy controller has no overtaking, whereas the PID controller has about 8.28%. The fuzzy controller has a shorter rise time than the PID controller (627 s).

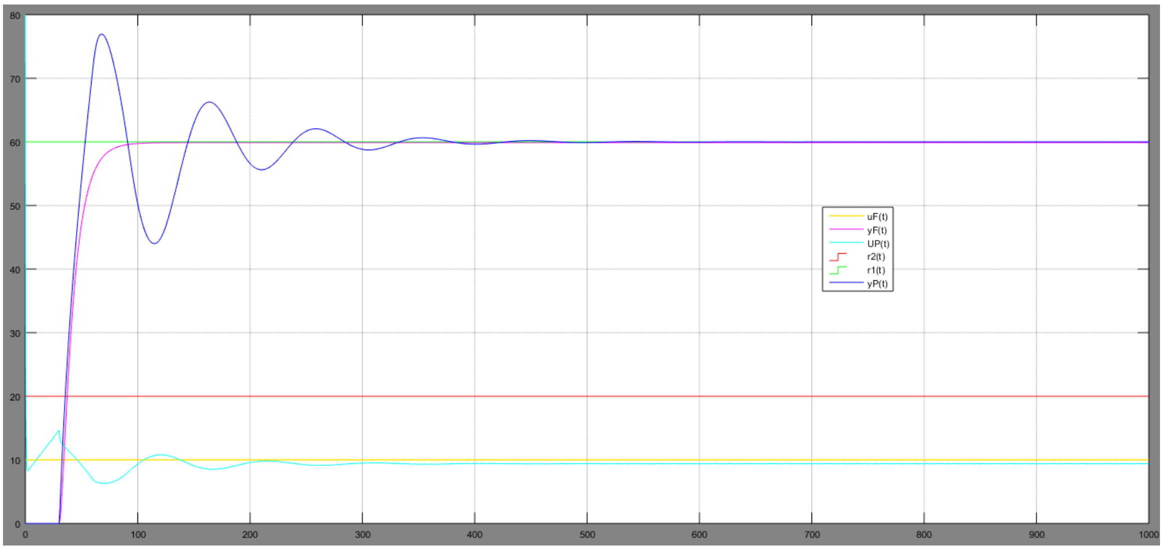
When the temperature and humidity levels inside the greenhouse exceed certain thresholds, the leaf transpires more and soil water content decreases. As a result, we must intervene by watering the plant exactly, with the amount of water that it requires. The controller enables the system to be turned on and irrigation instructions to be issued. The graph below (Fig. 4) compares the evolution of the response function for irrigation actions ordered by the PID controller and the fuzzy logic controller.

We signal a stable response for both controllers in the watering system (PID controller and the fuzzy logic controller). For the fuzzy logic controller, the pick and overtaking were both equal to zero. They were approximately 1.28 and 28.2 seconds for the PID controller, respectively. The rise time was approximately 18.3 seconds. The fuzzy logic controller had a regulation time of about 35 seconds and the PID controller had a regulation time of about 31 seconds.



y1(t) system response with PID controller, y2(t) system response with fuzzy controller, r1(t) opening instruction, r2(t) temperature instruction, u1(t) PID command, u2(t) fuzzy command.

Fig. 3. The response of the aeration numerical system to the fuzzy logic controller and PID controller inside the greenhouse.



uf(t) Fuzzy command, yf(t) Fuzzy response, up(t) PID command, r2(t) Instruction of the temperature, r1(t) Humidty instruction, p(t) PID response.

Fig. 4. Compared evolution of the numerical response functions for irrigation actions ordered by the PID controller and the fuzzy logic controller.

The curve had a general trend that showed the PID response exhibits an amortized oscillation in the domain of 5 to 38 units and stabilizes at 40 units. The FL response reaches its stabilization state at approximately 10 units.
Thus, we can completely automate the operation of all systems inside a tomato greenhouse using either the PID controller or the fuzzy flow controller (heating, aeration, freezing, irrigation). Fuzzy logic, however, is more commonly used to deal with uncertain and fluctuating data. For the greenhouse sector, which employs precision agriculture principles, we must establish domains of values for each parameter and make an appropriate decision at the right time. Such a decision entails watering or fertilizing plants

based on their actual needs. We characterize plants, soil, and climate using linguistic variables (i.e. crop type, leaf moisture, soil texture, soil moisture level, temperature, and relative humidity).

As a result, the fuzzy command is recommended when creating models to automate irrigation systems and the operation of all processes within greenhouses (e.g. heating, freezing, and aeration). The fuzzy logic command is used for making decisions if we cannot estimate the input/output parameters with high precision. It allows the operator or farmer to incorporate customized decisions into the inference rules and membership functions.

Conclusion

Automating the operation of greenhouses necessitates the development of models. These models must take into account plant characteristics, soil parameters, and local climate data. In this research, we successfully developed a model for controlling the exact amount of water, temperature, and humidity required by tomato plants in a greenhouse.

Acknowledgments

The authors would like to express their gratitude to the Tunisian National Institute of Research for the greenhouse prototype and the Tunisian Transport Minister for providing access to the meteorological station.

Conflict of interest

The authors indicate no conflict of interest for this work.

References

Altas IH, Sharaf AM. 2007. A generalized direct approach for designing fuzzy logic controllers in Matlab/Simulink GUI environment. International Journal of Information Technology and Intelligent Computing 4(1), 27.

Anamekere IJ, Harrison OE, Enyenihi HJ. 2019. Modeling of automatic sprinkler irrigation process using finite state machine (FSM) and proportional integral derivative (PID) controller. Universal Journal of Engineering Science 7(4), 75-81.

Araujo EF, Mauri AL, Araujo RF, Ribeiro Amaro HT, Henriques da Silva DJ. 2018. Physiological and sanitary quality of organic tomato seeds treated with clove basil extracts. Communicate Scientiae 9(1), 6-33.

Ben Aich F, Ben Farhat M, Ouni A, Ben Ahmed H, Chalh A. 2019. Differentiation of salt stress tolerance of six varieties of tomato (*Solanum Lycopersicum* L.) based on physiological factors. Vie et Milieu- Life and Environnent 69(4), 215-223.

Ben Aîch F. 2020. Effects of salinity on the physiological and metabolic behavior of three Solanaceae (tomato, pepper, and eggplant) and improvement of their tolerance by physiological means. Ph.D. Thesis, Faculty of Sciences, University Tunis El Manar, Tunisia.

Ben Ali R, Bouadila S, Mami AK. 2018. Development of a fuzzy logic controller applied to an agricultural greenhouse experimentally validated. Applied Thermal Engineering 141, 798-810.

Branthôme F-Xa. 2020. Global Consumption of Tomato Products. Editor: Tomato News (Western Pacific Trust Company funding). p.14.

Carlos RA, Jesús CC, Aura PL. 2017. Low-cost fuzzy logic control for greenhouse environments with web monitoring. Electronics 6(71), 12.

Chen PC, Mills JK. 1997. Synthesis of neural networks and PID control for performance improvement of industrial robots. Journal of Intelligent and Robotic Systems 20(2–4), 157–80.

Dehnavard S, Souri MK, Mardanlu S. 2017. Tomato growth responses to foliar application of ammonium sulfate in hydroponic culture. Journal of Plant Nutrition 40(3), 315-323.

Didi F, Bibi-Triki N, Draoui B, Abène A. 2017. Modeling a fuzzy logic controller to simulate and optimize the greenhouse microclimate management using MATLAB SIMULINK. International Journal Mathematical Sciences and Computing 3, 12-27.

Dos Santos C. 2009. Tuning of PID controller for an automatic regulator voltage system using a chaotic optimization approach. Chaos, Solitons and Fractals 39, 1504-1515.

Eddahhar A, Guerbaoui M, Elafou Y, Outanoute M, Lachhab A, Belkoura L, Bouchikhi B. 2013. Implementation of the fuzzy controller to reduce water irrigation in a greenhouse using LabVIEW. International Journal of Engineering and Advanced Technology Studies 1(2), 12-22.

Fuseini SI, Dominic K, Stephen M. 2018. Smart irrigation system using a fuzzy logic method. International Journal of Engineering Research and Technology 11(9), 1417-1436.

Gadelhag M, Ahmad L, Pourabdollah A. 2018. Human activities recognition based on neuro-fuzzy finite state machine. Technologies 6(4), 110.

Gharbi E, Martínez JP, Benahmed H, Lepoint G, Vanpee B, Quinet M, Lutts S. 2017. Inhibition of ethylene synthesis reduces salt tolerance in tomato wild relative species *Solanum chilense*. Journal of Plant Physiology 210, 24–37.

Goodchild MS, Kühn KD, Jenkins MD, Burek KJ, Dutton AJ. 2015. A method for precision closed-loop irrigation using a modified PID control algorithm. Sensors and Transducers 188(5), 61-68.

Ho WK, Hang CC, Cao LS. 1995. Tuning of PID controllers based on gain and phase margin specifications. Automatica 31(3), 497–502.

Hung ML, Lin JS, Yan JJ, Liao TL. 2008. Optimal PID control design for synchronization of delayed discrete chaotic systems. Chaos, Solitons and Fractals 35(4), 781–785.

Izzuddin TA, Johari MA, Rashid MZA, Jali MH. 2018. Smart irrigation using the fuzzy logic method. Journal of Engineering and Applied Sciences 13(2), 515-522.

Jomaa M, Abbes M, Tadeo F, Mami A. 2019. Greenhouse modeling, validation, and climate control based on fuzzy logic. Engineering, Technology and Applied Science Research 9(4), 4405-4410.

Kao CC, Chuang CW, Fung RF. 2006. The self-tuning PID control in a slider-crank mechanism system by applying particle swarm optimization approach. Mechatronics 16(8), 513–22.

Kiranpreet K, Vikram M, Inderjeet SiG. 2010. Fuzzy logic-based image edge detection algorithm in MATLAB. International Journal of Computer Applications 1(22), 55-58.

Mansour HA, Eldardiry EI, Abd El-Hady M. 2018. Validation by aqua crop model for faba bean yield, water productivity under the smart controller of drip irrigation system, and compost fertilizer in sandy soil. European Journal of Academic Essays 5(5), 138-144.

Mansour HA, Pibars SK, Gaballah MS. 2018. Effect of the smart drip irrigation system and water deficit on contour maps of soil moisture distribution. Worldwide Journal of Multidisciplinary Research and Development 4(2), 313-320.

Martinez Baquero JE, Corredor Chavarr FA, Jimenez Moreno R. 2018. Design of controller PID and stability analysis for drying of corn grains. International Journal of Applied Engineering Research 13(21), 15410–15416.

Mattara CS, Abhilasha S, Venkatesan K, Ramanujam K, Chinnapalaniandi P. 2020 Design and robustness analysis of intelligent controllers for commercial greenhouses. Mechanical Sciences 11, 299–316.

Oboulbiga EB, Parkouda C, Sawadogo-Lingani H, Compaoré Ella WR, Sakira AK, Traoré AS. 2017. Nutritional composition, physical characteristics, and sanitary quality of the tomato variety mongol F1 from Burkina Faso. Food and Nutrition Sciences 8, 444-455.

Özlem A, Ebubekir E. 2019. The control of greenhouses based on fuzzy logic using wireless sensor networks. International Journal of Computational Intelligence Systems 12(1), 190–203.

Rafiuddin S, Wahyu H, Piarah BJ. 2015. Controlling smart greenhouse using the fuzzy logic method. International Journal on Smart Material and Mechatronics 2(2), 116-120.

Rajaprakash S, Jaichandran R, Ramalingam P, Nagappan A. 2017. Fuzzy logic controller for effective irrigation based on field soil moisture and availability of water. Journal of Advance Research in Dynamical and Control Systems 9(1), 90-97.

Riahi J, Vergura S, Mezghani D, Mami AK. 2020. Intelligent control of the microclimate of an agricultural greenhouse powered by a supporting PV system. Applied Sciences 10(4), 1350.

Rouphael Y, Colla G, Giordano M, El-Nakhel C, Kyriacou MC, De Pascale S. 2017. Foliar applications of a legume-derived protein hydrolysate elicit dose-dependent increases in growth, leaf mineral composition, yield, and fruit quality in two greenhouse tomato cultivars. Sciences Horticulturae 226, 353–360.

Sahbani F, Ferjani E. 2018. Identification and modeling of drop-by-drop irrigation system for tomato plants under greenhouse conditions. Irrigation and Drainage 67(4), 550-558.

Sahbani F, Sellami MH. 2020. Experimental analysis of the effect of deficit irrigation on the productivity of a greenhouse tomato crop in Sejnane, Tunisia. International Journal of Agriculture, Environment and Bioresearch 5(05), 30-45.

Satyajit Ramesh P, Chandrakant Balkrishna P, Ravindra Ramchandra M. 2017. Greenhouse air-temperature modeling and fuzzy logic control. International Journal of Electronics Engineering Research 9(5), 727-734.

Sivanandam SN, Sumathi S, Deepa SN. 2007. Introduction to fuzzy logic using MATLAB. Springer-Verlag Berlin Heidelberg. p. 419.

Smriti KR, Ravi M. 2014. Comparative study of P, PI, and PID controller for speed control of VSI-fed induction motor. International Journal of Engineering Development and Research 2(2), 2740-2744.

Souri MK, Dehnavard S. 2018. Tomato plant growth, leaf nutrient concentrations, and fruit quality under nitrogen foliar applications. Advances in Horticultural Science 32(1), 41-47.

Souri MK, Bakhtiarizade M. 2019. Biostimulation effects of rosemary essential oil on growth and nutrient uptake of tomato seedlings. Scientia Horticulture 243, 472-476.

Varun K. 2018. Application of fuzzy logic in the water irrigation system. International Research Journal of Engineering and Technology 5(4), 3372-3375.

Willians R, Fábio Meneghetti UA, Ritaban D, Derek MH. 2019. Fuzzy control system for variable rate irrigation using remote sensing. Expert Systems with Applications 124, 13-24.

Yager RR, Filev DP. 1994. Essentials of fuzzy modeling and control. Special Interest Group on Artificial Intelligence Bulletin 6(4), 22-23.