Implementation of Fuzzy Logic for Natural Ventilation in Greenhouse

N. Caglayan[1], C. Ertekin[2]

[1]Akdeniz University, Technical Vocational Training School, 07058 Antalya – Turkey
[2]Akdeniz University, Faculty of Agriculture, Dept. of Agricultural Machinery and Technologies Engineering 07058 Antalya – Turkey

e-mail of corresponding author: nuricaglayan@akdeniz.edu.tr

Summary

The ventilation performance is very important for the greenhouses with natural ventilation and it varies depending on the window openings. The window openings can be predicted and calculated using a computer simulation models and control systems. Many traditional systems are based on on-off and proportional control methods, which are not so effective drawbacks of these methods are loss of energy, labor, productivity in order to maintain a steady climate a more sophisticated system must be used. By using fuzzy logic programming greenhouse climate controller can be designed developed fuzzy logic controller is based on Matlab software.
The practical goal of this study, the behavior window openings in a open-roof greenhouse depending on inside temperature, relative humidity and outside temperature using fuzzy rules. Membership functions of fuzzy inference system are generated and simulation and analysis of the behavior of the designed control system is performed. Measurements of climate conditions vicinity of the greenhouse were obtained. Using the measured outdoor and greenhouse indoor conditions, the model parameters were calibrated statistically. The accuracy of the model are discussed by comparing the predicted and observed greenhouse temperatures.

Key words: fuzzy rules, window openings, climate control, open-roof greenhouse, ventilation.

Introduction

The climate conditions in a greenhouse can be provided by optimum openings levels of ventilations. If the fluctuations on greenhouse ventilations, such as the openings rates and their repetition counts, are set properly according to climate conditions and place, the indoor conditions can be arranged easily. Therefore, in the greenhouses with well-designed natural ventilation mechanism often provide very comfortable and pleasant environments for the plants (Caglayan and Ertekin, 2012). The internal state of the plant has been defined by two variables, namely the internal temperature and hygrometry ones. These two variables are correlated and strongly sensitive to the external meteorological conditions to the greenhouse (Bennis et al., 2008). When the temperature of the air increases, the relative humidity decreases; and when the temperature of the air decreases, the relative humidity increases. In addition, the difference between the temperature of the greenhouse and ambient conditions is also influential in the relative humidity amount of the greenhouse. In case the relative humidity of the greenhouse is high (>80%), the leaves of the plants increase, and the quality of the crop decreases, and the sensitivity of the plants to diseases and harmful insects and pests increases. For this reason, intense use of agricultural insecticides, pesticides and hormones becomes necessary (Zabeltitz, 1992).

In case the temperature in the greenhouse is more than the optimum temperature value, air ventilation must be employed. By using ventilation in the greenhouse, the plants may be protected from being harmed by the excessive temperature. It is not desired that the temperature in the greenhouse exceeds 30°C even on the hottest days. It is possible with a good ventilation that the temperature in the greenhouse is decreased 2-3°C below the outside temperature (Kurklu and Caglayan, 2005).

When the climatization control in greenhouses and the one in commercial and industrial buildings are compared, big differences are observed. For example, upon the quick changes in the sunlight, sudden changes occur in the heating and especially cooling loads in the greenhouses (Omid and Shafaei, 2005). The real problem which should be considered for the climatization control in greenhouses is the complex interaction between the parameters inside and outside the greenhouses. The control systems performed by using the traditional PID controllers are not suitable for these types of applications whose medium parameters have interaction among themselves (Fang et al., 2006). The temperature of the medium outside the greenhouse and the sunrays reaching inside the greenhouse affect the temperature of the medium inside the greenhouse directly. In addition, the temperature inside the greenhouse and the relative humidity are closely related with each other. While the absolute humidity amount is stable, if the temperature of the air decreases, the relative humidity value increases. The capacity of the cooling air to carry humidity decreases, and its relative humidity value increases. Contrary to this, if the temperature of the medium increases, the relative humidity value decreases. The warming air will expand since its density decreases, and the capacity of such air to carry humidity will increase. If vaporization does not occur proportionally with the temperature, the gap of humidity in the air increases and the relative humidity decreases.

By controlling the air temperature in the medium, the heat transition and energy balance in the body and leaves of the plant can be controlled. If the plants are put under a certain temperature value with stable amounts of sunlight and other factors, they do not grow (Kurklu and Caglayan, 2007).The relative humidity value affects the amount of the energy that is needed for the air circulation in the medium. Controlling the relative humidity value of the medium plays an important role for economic optimal climatization (Fang et al., 2006). Especially in conditions in which the growing plants are very close to each other, the high humidity in the greenhouse encourages the development of diseases. In greenhouse farming, the relative humidity during the day is usually between 25-70%, and this range does not pose a problem. On the other hand, the relative humidity during the night may exceed 90%. Especially on rainy winter days, the relative humidity value remains close to 100% during the day and night, and this leads to an important condensation in the greenhouse (Eshenaur and Anderson, 2004). An effective control system to be designed for climatization control must be successful in controlling the temperature of the medium and the relative humidity value. In automation systems, the structure and dynamic properties of the system to be controlled must be known well and be modelled mathematically. The temperature in the greenhouse, the outside temperature, the humidity and similar other environmental factors are related with each other. In a closed medium, a change in one of these values changes the other factors and makes it difficult to keep the temperature and the relative humidity at the desired levels (Yen et al., 1995). For this purpose, the studies on greenhouse automation has increased recently. In order to control the system variables, studies have focused mainly on the Fuzzy Logic Method and Specialist System Control Applications (Lafont and Balmat, 2002) controlled the air conditioning of the greenhouse according to the internal and external temperatures, total radiation, relative humidity and wind speed parameters. They stated that the climate of the greenhouse could be controlled successfully with this method.

In this study, the temperature and humidity of the greenhouse natural ventilation control modelling has been performed with the Fuzzy Logic Method, and the opening amounts of the windows have been determined according to the temperature and relative humidity amount in the greenhouse and according to the outside temperature values.

Material and methods

This study was conducted between the dates September 10 and 17 of September 2013, in a 5400 m^2 plastic greenhouse (Figure 1). The greenhouse has only roof windows and it does not have the side-wall windows. Tomatoes were grown in the greenhouse as the material. It was desired that the optimum growth temperature of the tomatoes in the

greenhouse would be 21-28°C (Buschermohle and Grandle, 2001) and relative humidity between the range of 50–70% is generally considered to be optimal for tomato pollination (Harel et al., 2014).

Temperature and a relative humidity sensor has been placed inside the greenhouse. In addition, a temperature sensor has been placed outside of the greenhouse. Thus, both inside and outside temperature and inside relative humidity values were measured in greenhouse. According to the outside temperature, inside temperature, and the relative humidity values in the greenhouse conditions, the opening and closures of the windows were performed by hand for the ventilation purposes. The windows of greenhouse can be opened between 0 and 150 cm. The measurements of the experiment were taken according to the openings at the roof windows given in Table 1.

Table 1. The openings of roof Windows

Time	The openings of roof Windows (cm)
08:30	25
09:30	50
10:30	75
11:30	100
12:30	125
13:30	150 (fully open)
14:30	125
15:30	100
16:30	75
17:30	50
18:30	25
19:30 – 08:29	0 (fully closed)



Figure 1. Experimental greenhouse

In measuring the internal and external temperature and the relative humidity measurements a data logger (Delta-T Devices inc.) was used. The measurements were made in every 30 seconds, and the average values were taken at every 1 minute and recorded in a computer. By using the temperature and the relative humidity data obtained, the Fuzzy Logic Modelling was made and the controllability of the window openings in the greenhouse was examined.

A Fuzzy Logic application in greenhouse

The Fuzzy Control System used in the study consists of blurring, clarification, and deduction units of the temperature in the greenhouse, the relative humidity, and the outside temperature values. For the optimum growth conditions for the tomatoes, the temperature in the greenhouse was determined as between 21 and 28°C; the relative humidity in the greenhouse was determined as 60% and 70%; and the outside temperature was determined as 22 and 26°C. Seven fuzzy sets were used to blur the internal and external temperatures, and five fuzzy sets were used to blur the relative humidity in the greenhouse. The graphical views of the membership functions of the temperature in the greenhouse, the relative humidity in the greenhouse and the outside temperature are given in Figures 2-4, respectively.

After the membership functions were formed in the application, it was necessary that the rule base should also be formed. The rule base consists of the rule lines. The total number of the rule lines is obtained by multiplying the temperature in the greenhouse, the relative

humidity, and the membership functions of the outside temperature. It is necessary that the fuzzy rules table is formed in order to evaluate the out section in the fuzzy logic process chart. Some assumptions may be necessary while forming the table. For example, the situation in which the temperature in the greenhouse is very low (T_i1), the relative humidity in the greenhouse is very low (H_i1), and the temperature outside is also very low (T_o1), is called as M1, the other fuzzy rules will be as given in Table 2.

Table 2. Fuzzy rules

	H_i1	H_i2	H_i3	H_i4	H_i5
T_i1+T_o1	R1	R2	R3	R4	R5
T_i1+T_o2	R6	R7	R8	R9	R10
T_i1+T_o3	R11	R12	R13	R14	R15
T_i1+T_o4	R16	R17	R18	R19	R20
T_i1+T_o5	R21	R22	R23	R24	R25
T_i1+T_o6	R26	R27	R28	R29	R30
T_i1+T_o7	R31	R32	R33	R34	R35
T_i2+T_o1	R36	R37	R38	R39	R40
T_i2+T_o2	R41	R42	R43	R44	R45
T_i2+T_o3	R46	R47	R48	R49	R50
T_i2+T_o4	R51	R52	R53	R54	R55
T_i2+T_o5	R56	R57	R58	R59	R60
T_i2+T_o6	R61	R62	R63	R64	R65
T_i2+T_o7	R66	R67	R68	R69	R70
T_i3+T_o1	R71	R72	R73	R74	R75
T_i3+T_o2	R76	R77	R78	R79	R80
T_i3+T_o3	R81	R82	R83	R84	R85
T_i3+T_o4	R86	R87	R88	R89	R90
T_i3+T_o5	R91	R92	R93	R94	R95
T_i3+T_o6	R96	R97	R98	R99	R100
T_i3+T_o7	R101	R102	R103	R104	R105
T_i4+T_o1	R106	R107	R108	R109	R110
T_i4+T_o2	R111	R112	R113	R114	R115
T_i4+T_o3	R116	R117	R118	R119	R120
T_i4+T_o4	R121	R122	R123	R124	R125
T_i4+T_o5	R126	R127	R128	R129	R130
T_i4+T_o6	R131	R132	R133	R134	R135
T_i4+T_o7	R136	R137	R138	R139	R140

	H_i1	H_i2	H_i3	H_i4	H_i5
T_i5+T_o1	R141	R142	R143	R144	R145
T_i5+T_o2	R146	R147	R148	R149	R150
T_i5+T_o3	R151	R152	R153	R154	R155
T_i5+T_o4	R156	R157	R158	R159	R160
T_i5+T_o5	R161	R162	R163	R164	R165
T_i5+T_o6	R166	R167	R168	R169	R170
T_i5+T_o7	R171	R172	R173	R174	R175
T_i6+T_o1	R176	R177	R178	R179	R180
T_i6+T_o2	R181	R182	R183	R184	R185
T_i6+T_o3	R186	R187	R188	R189	R190
T_i6+T_o4	R191	R192	R193	R194	R195
T_i6+T_o5	R196	R197	R198	R199	R200
T_i6+T_o6	R201	R202	R203	R204	R205
T_i6+T_o7	R206	R207	R208	R209	R210
T_i7+T_o1	R211	R212	R213	R214	R215
T_i7+T_o2	R216	R217	R218	R219	R220
T_i7+T_o3	R221	R222	R223	R224	R225
T_i7+T_o4	R226	R227	R228	R229	R230
T_i7+T_o5	R231	R232	R233	R234	R235
T_i7+T_o6	R236	R237	R238	R239	R240
T_i7+T_o7	R241	R242	R243	R244	R245

T_i1: Inside temperature: 1 (very low) - 7 (very high);
T_o1: Inside relative humidity: 1 (very low) - 5 (very high);
H_i1: Outside temperature: 1 (very low) – 7 (very high).

While forming the fuzzy rules table, the R values in this table were evaluated in the MATLAB package program. For example, if *R1* is asked to be defined from the fuzzy rules table, it may be defined with the AND operation which is used in the IF THEN rule equation (1):

$$R1=(T_i1 \curlywedge T_o1 \curlywedge H_i1)= \min (T_i1, T_o1, H_i1) \quad (1)$$

With this operation, the condition with the maximum value is selected. The maximum values founded for each opening as follows:

$$y=[\max(m_1)\ \max(m_2)\ \max(m_3)\ \max(m_4)\ \max(m_5)\ \max(m_6)\ \max(m_7)] \quad (2)$$

With this operation, the one having the minimum value is selected from the existing conditions. After this stage, the window openings must be named and classified. This naming is shown in Table 3. The "*R*" values in Table 2, and the classes named in Table 3 may be formed by depending on knowledge and experience. The selection of the window opening positions in Table 3 was performed with the fuzzy *OR* operation. For example for m_1;

$$\max(m_1) =(R1 \curlyvee R2 \curlyvee R3 \curlyvee R4 \curlyvee R5 \curlyvee R6 \curlyvee R7 \ldots) \quad (3)$$

$$m_1=(R1, R2, R3, R4, R5, R6, R7 \ldots)$$

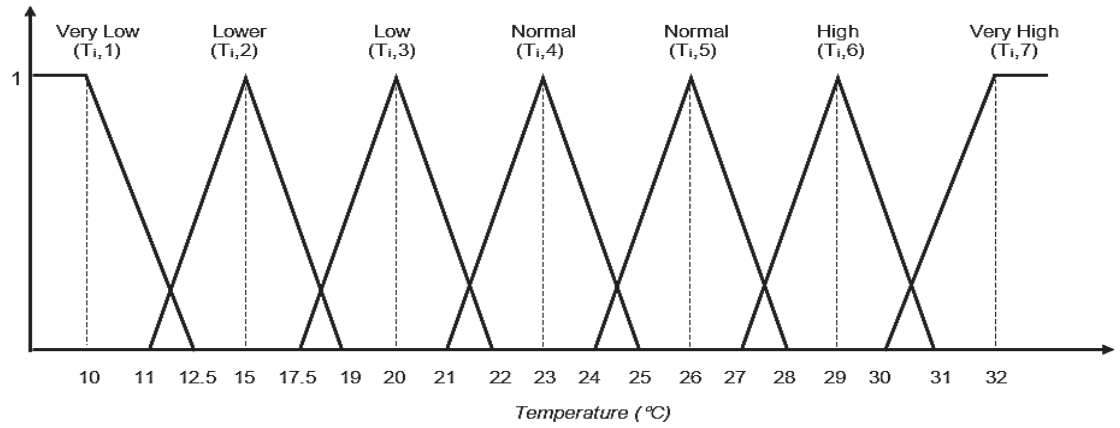


Figure 2. The membership functions for inside temperature (℃)

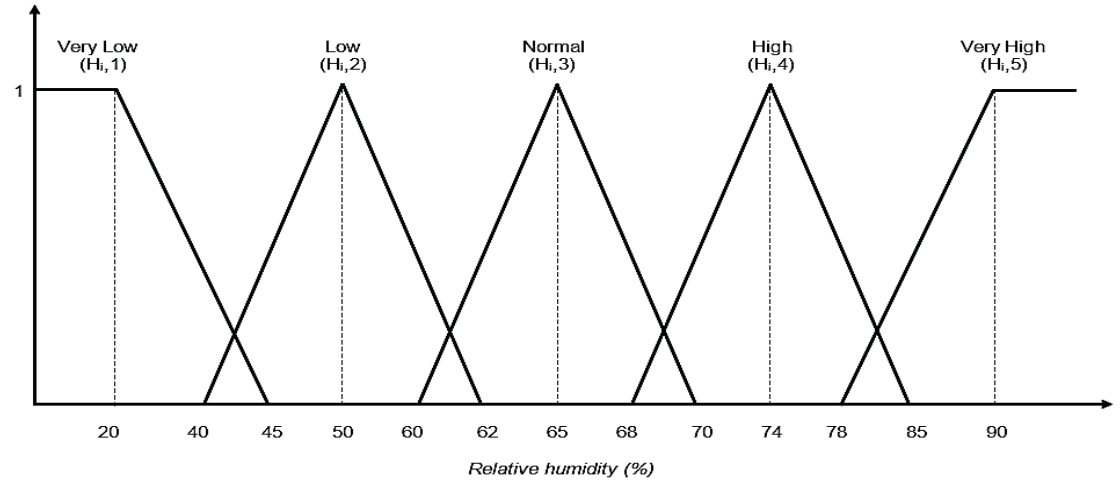


Figure 3. The membership functions for inside humidity (℃)

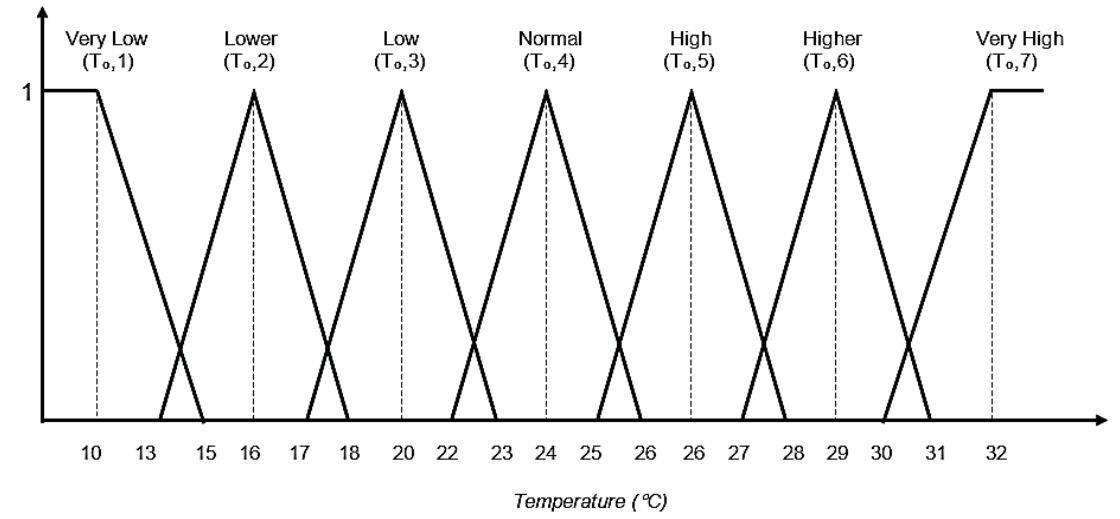


Figure 4. The membership functions for outside temperature (℃)

Table 3. The named of window openings

Window openings	Amount of window openings (cm)
m_1	0 (closed)
m_2	25
m_3	50
m_4	75
m_5	100
m_6	125
m_7	150 (fully open)

The "*y*" value here is necessary for the calculation of each area in the clarification process. In Figure 5, the seven areas in the membership function graphics formed for the clarification give us the numerical values of the window openings with the *Weighted Average Method*. The system success was found via the evaluation of these values. The trapezoid areas from the window opening status membership functions were calculated in Figure 5 and then the weighted average value of the seven areas were expressed with "Σ". The "Σ" value shows the end window opening amount.

The "Σ" value was found with the following equation (4):

$$\Sigma = \frac{[sp(1.25)+sq(2.25)+sr(3.25)+sw(4.25)+sx(5.25)+sy(6.25)+sz(7.25)]}{(sp+sq+sr+sw+sx+sy+sz)} \quad (4)$$

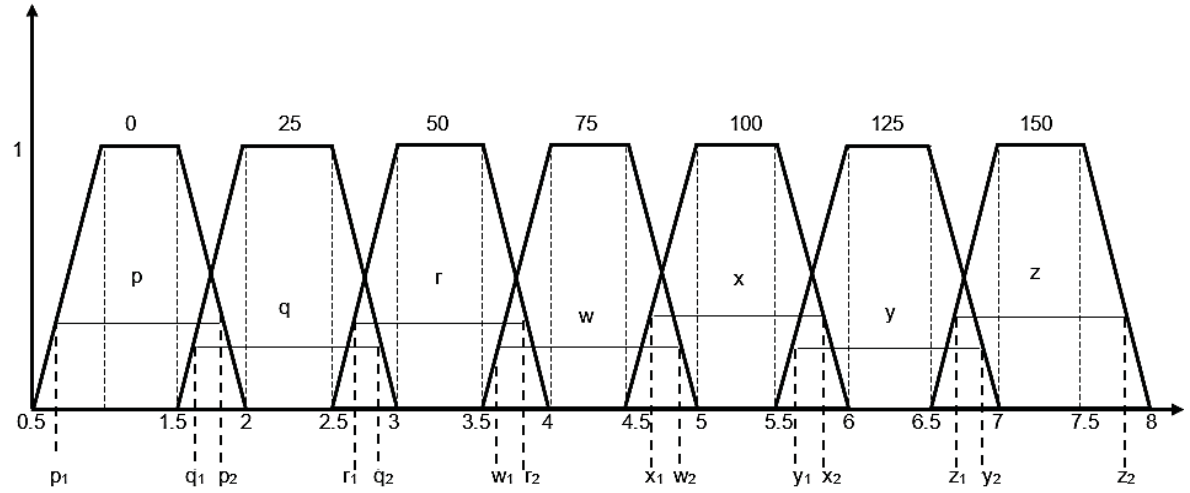


Figure 5. Outputs of membership functions

Results and Discussion

Depending on the measured climatic values in the greenhouse, and the climate demands of the tomato plant, the decision making process on the opening amount of the windows during the day has been modelled by using the fuzzy logic method. As it may be seen in Table 4, the amount of the relative humidity in the greenhouse is high at night and in the early morning hours due to the low temperatures outside. In this case, heating or ventilation is necessary.

Table 4. Behavior of output

Time	Outputs of membership functions	İnside temperature (°C)	The openings of roof Windows (cm)
00:00 -	1.2500	11.00-16.00	0
08:00	1.2500	17.55	25
09:00	2.8325	18.12	25
09:24	2.4371	19.58	25-50
09:51	2.7782	18.20	25
10:11	3.2400	19.15	25-50
10:25	3.2550	19.80	50
10:33	3.5148	20.51	50-75
10:45	4.2520	21.75	75-100
10:54	4.3564	22.64	100
11:14	4.5420	22.75	100
11:15	4.9850	22.55	100-125
11:18	5.3310	24.05	100-125
11:34	5.3500	23.80	100-125
11:35	5.1305	23.94	100-125
11:41	6.5700	23.80	125
11:44	7.0330	24.02	125-150
11:46	7.7000	24.10	125-150
11:49	7.3505	26.30	150
12:10	7.1500	25.85	150
12:12	7.0500	26.00	150
12:32	6.1000	25.78	125-150
12:47	5.6050	25.15	125
12:51	6.9326	25.60	125-150
13:34	7.1450	27.15	150
13:41	7.2913	28.05	150
13:51	7.3631	28.61	150
13:58	7.4852	30.30	150
14:24	7.5750	32.14	150
14:30	7.5705	32.14	150
14:37	6.2500	31.02	150
14:21	5.3000	27.40	125
15:29	4.7500	25.88	100-125
16:32	3.3200	22.12	100-125
17:24	2.4500	20.00	50-75
18:39	2.2500	18.55	25
19:37	1.600	17.40	25
20:45	1.2500	15.30	0
21:30	1.2500	14.10	0
22:44	1.2500	12.54	0
23:33	1.2500	11.12	0
23:42			

However, since the outside temperature is low, the temperature in the greenhouse is close to the threshold value of 10°C that enables the plants to continue physiological existence. Ventilation in such a case may cause the temperature in the greenhouse to decrease below 10°C, and the physiological existence of the plants may end. For this reason, no ventilation was made in the greenhouse. In such a condition, the greenhouse must be heated and the temperature in the greenhouse must be increased, and the relative humidity must be decreased.

The temperature in the greenhouse increases with the increase in the outside temperature. In conditions when the temperature in the greenhouse is below 21°C, it was planned that the windows of the greenhouse would be closed. In the application, sometimes when the temperature in the greenhouse was below 21°C (18-20°C), the windows were planned to be opened about 25, 25-50 and 50 cm. In conditions when the temperature in the

greenhouse was above 28°C, it was planned that the windows of the greenhouse would be fully open (150 cm). In the application, sometimes when the temperature in the greenhouse was above 28°C, the windows were not in the fully open position.

These missing points in the system may be due to the "*R*" values being classified or the membership functions being defined. Although the windows were in fully open position when the temperature in the greenhouse was above 28°C, the temperature in the greenhouse was more than that demanded by the plant. In such conditions, compulsory ventilation must be performed.

As a result, the fuzzy logic has given extremely good results in setting the climate in the greenhouse automatically. In this study, only three parameters (the temperature outside, the temperature inside, and the relative humidity) have been evaluated. As the number of the climate parameters increase, to use of traditional control methods in a greenhouse becomes more difficult. However, by using the fuzzy logic method, the efficient control of the greenhouse climate becomes possible without depending much on the number of the parameters. Due to its structural characteristics, the Fuzzy Logic Method provides infinite decision making flexibility between on-off.

References

Bennis, N., Duplaix J., Enéa, G., Haloua, M., Youlal H, 2008. Greenhouse climate modelling and robust control. J. Comput. Electron. Agric. 61, 96–107.

Buschermohle, M. J., Grandle, G. F., 2001. Controlling the environment in greenhouses used for tomato production. Extension Publication No. W 017.

Caglayan N., Ertekin C., 2012. A Study on Determination of Optimum Ventilation Openings in Greenhouses Using by the Decision Tree Method. International Conference of Agricultural Engineering CIGR-AgEng2012. July 8-12, 2012 Valencia, Spain.

Eshenaur, B., Anderson, R., 2004. Managing the greenhouse environment to control plant diseases. University of Kentucky College of Agriculture.

Fang, X., Junqiang, S., Jiaoliao, C., 2006. Rough sets based fuzzy logic control for greenhouse temperature. Mechatronic and embedded systems and applications. Proceedings of the 2nd IEEE/ASME International Conference pp. 1-5.

Harel, D., Fadida, H., Alik, S., Gantz, S., Shilo, K., 2014. The effect of mean daily temperature and relative humidity on pollen, fruit set and yield of tomato grown in commercial protected cultivation. Agronomy, 4, 167–177.

Kurklu A., Caglayan N., 2005. A study on the development of greenhouse automation systems. Akdeniz Uni. J. Faculty of Agric. 18(1):25-34.

Kurklu A., Caglayan N., 2007. A study on the development of an alternative climate control system utilizing a microcontroller and radio frequency waves, Akdeniz Uni. J. Faculty of Agric. 20(2), 229-239.

Lafont, F., Balmat, J. F., 2002. Optimized fuzzy control of a greenhouse. Fuzzy Sets Syst. 128, 47–59.

Omid, M., Shafaei, A., 2005. Temperature and relative humidity changes inside greenhouse. International Agrophysics, vol.19, pp. 153-158.

Zabeltitz, Chr. Von., 1992. Energy-efficient greenhouse designs for mediterranean countries. Plasticulture (96), pp:6-16.