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Wastewater reuse in citrus: a fuzzy logic model for optimum evapotranspiration

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ABSTRACT

We established a Mamdani fuzzy logic model to determine the effect of wastewater evapotranspiration on citrus cultivation. The model uses most influential variables of soil and leaves samples. Since the number of the input variables to the model is large, these variables were classified into five categories as follows: (i) soil macro-element concentration, (ii) soil essential elements concentration, (iii) soil electrochemical properties, (iv) leaves macro-elements concentration, and (v) leaves essential elements concentration. For simplification, the model was divided into seven submodels and one main model. The output of the main model considered the outputs of all submodels to the final decision. The model applied to a citrus orchard suggested the optimal wastewater irrigation rate at 125% of crop evapotranspiration.

Keywords: Citrus; Evapotranspiration; Macro element; Essential element; Fuzzy logic

1. Introduction

Agriculture is estimated to withdraw two-thirds of the worlds' fresh water, thus, accounting for 90% of the total water consumption [1] Within this context, increasing attention has been directed to the reuse of reclaimed urban wastewater (RWW) [2,3] for agricultural proposes. However, many studies confirmed the suitability and the benefits of irrigation with RWW evaluating the effects of RWW isolated on soil, plant, and yield [4–6]. The management of wastewater irrigation rates is usually based on soil moisture, crop transpiration, and rainfall. However, we did not find studies considering soil and plants nutrients concentration to define wastewater irrigation rates [7,8].

Few studies focused on models to evaluate suitability RWW irrigation based on irrigation rates, soil fertility, and plant nutrition properties together [9,10]. The fuzzy logic allows modeling of a system considering the basis of linguistic descriptions provided by the experts. The advantage of the fuzzy logic is to transform the linguistic information to a background analytical level using mathematical computations. The linguistic variables (e.g. low concentration of Ca) are

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transformed into categories (e.g. high, low, and optimum) with a degree, justifying the principle of fuzzy logic that "everything is a matter of degree". The expert's linguistic descriptions can develop a fuzzy inference using the models: i.e. provides evaluative inferences inputting information using the appropriate computations. Numerous applications of fuzzy logic have been developed in many research fields [10–13].

Zadeh [14] introduced the fuzzy concept as a quantitative approach to integrate factors such as human reasoning and knowledge. In recent years, fuzzy logic is used widely in wastewater treatment plants [15,16], recognizing its advantage that it considers quantitative and qualitative factors to the final decision [17].

Our aim is to establish a fuzzy logic model to evaluate the suitability of a citrus orchard irrigated with RWW. We hypothesizes that the effect of RWW irrigation on the citrus orchard is a matter of degree instead of being characterized simply as good or bad. The fuzzy logic method provides a figure of merit for the suitability RWW irrigation, indicating the necessary improvements, which can be realized in many ways—for example, the optimum percentage of crop evapotranspiration (ETc).

The suitability of a citrus orchard is complex since several, usually weakly correlated, parameters are considered. If, for example, the Fe soil concentration is optimum plant growth, the concentration of essential elements is good and the soil pH is acceptable, the suitability is "good". What suitability should be attributed to a soil which is deficient in Fe, adequate concentration of essential elements, and low pH: "good" or "bad"? And if is it so, in what extent? In addition, considering the optimum Fe concentration of 5–10 mg kg^{-1}, it does not mean that if the available soil Fe level of 10 mg kg^{-1} the soil suitability is appropriate, or in contrary a level of 11 mg kg^{-1} of Fe could signify unsuitability of the soil for citrus growth. Fuzzy logic introduces smoothness in transitions of the parameter values simplifying the treatment of multi-parameter models, and optimizating the baseline criteria according to the purpose of growth.

The fuzzy logic approach can deal with the varying and case-dependent membership rates of the parameters, via the use of fuzzy sets, and can include human experience and experimental inferences in terms of linguistic rules. It also shows how these parameters can be combined and with which weighting factors, in order to coherently describe the suitability of a given ETc.

The support of the proposed fuzzy sets is determined on the basis of the research experience as it is recorded in the literature. The membership functions can be, however, modified ad hoc in order to be adapted to the purposes of other kinds of horticulture or arboriculture.

The paper is organized as follows: firstly, the method of analysis of the essential and macro elements of leaves and soil is described. Then based on the optimum values of all parameters, the membership functions of four submodels were constructed. Finally based on the output of all submodels, the main model was constructed. In the last part of the paper, the model applied to Piracicaba citrus orchard from São Paulo State, irrigated with RWW.

2. Materials and methods

2.1. Crop and irrigation application and experimental design

In February 2007, 500 g $CaCO_3$ m^{-1} and ~26 g P m^{-1} were applied to the furrow before transplanting 300 citrus "Valência" [*Citrus sinensis* (L.) Osbeck] nursery trees on citrumelo "Swingle" (*Citrus paradisi* Macf. × *Poncirus trifoliata* Raf.) with a 6 × 4 m spacing. Soil fertilization was described by Pereira et al. [18].

The experimental design comprised three randomized blocks with five treatments. Each of the 15 plots contained 20 plants, 6 of them located centrally and 14 at the border. The treated RWW [18] was collected from the SEMAE-Wastewater Treatment Plant. Four RWW irrigation rates were applied based on the ETc 100% ETc, 125% ETc, 150% ETc, and 200% ETc, plus the control treatment (without irrigation). These irrigation rates with RWW, based on the ETc, were equivalent to 350, 437, 525, 700, and 0 mm RWW yr^{-1}, respectively. The need for irrigation was determined every three days. Citrus plants were irrigated with RWW from September 2007 to July 2009. Soil and lead sampling, and analysis were carried out according to Pereira et al. [18].

2.2. A model overview

Wastewater evapotranspiration has an important impact on soil properties [18], affecting leaves macroelements and essential elements concentration. The concentration of some elements in soil, in leaves and the electrochemical properties of soil, can predict the quality leaves and soil. Some electrochemical properties of soil, treated here as variables, can be considered. Since most of the variables are either uncorrelated or low correlated each other, a fuzzy model can describe the impact of increasing RWW irrigation rates, on Citrus cultivation, and indicate the optimal ET_C value.

The number of variables used as inputs to the model is large (23 here). To simplify the model, maintaining the accuracy, the model was divided into five classes forming five fuzzy logic submodels, three for soil and two for the leaves [19–22]. The output of each submodel ranged from 0 (bad) to 1 (excellent), characterizing the suitability of each class for citrus cultivation. Two cascade Mamdani fuzzy logic submodels were established in turn, one for soil and one for leaves, having as inputs the outputs of the corresponding submodels. The output of these models was also a single number ranging from 0 to 1, characterizing the suitability (quality) of soil or leaves. The outputs of soil and leaves model were used as inputs of a final fuzzy logic model that gave the final decision.

This division has also the advantage to describe the effect of ETc on each partial model (e.g. the effect of ETc on the leaves nutrients concentration). Fig. 1 shows a model overview.

The submodels of soil and leaves used were as follows:

- (S1) The soil macro-elements submodel inputs were the concentration of the elements K, Ca, Mg, and P.
- (S2) The soil essential elements submodel inputs were the concentration of the elements S, B, Cu, Fe, and Zn.
- (S3) The soil electrochemical properties submodel inputs were the values of pH, the soil exchange capacity (CEC), and the base saturation.
- (L1) The leaves macro elements submodel inputs were the concentration of the elements Na, P, K, Ca, and Mg.
- (L2) The leaves essential elements submodel inputs were the concentration of the elements S, B, Cu, Fe, and Zn.
- The output describes the acceptability of the given ET_C. The MATLAB [17,19] software was used for the implementation of the model.

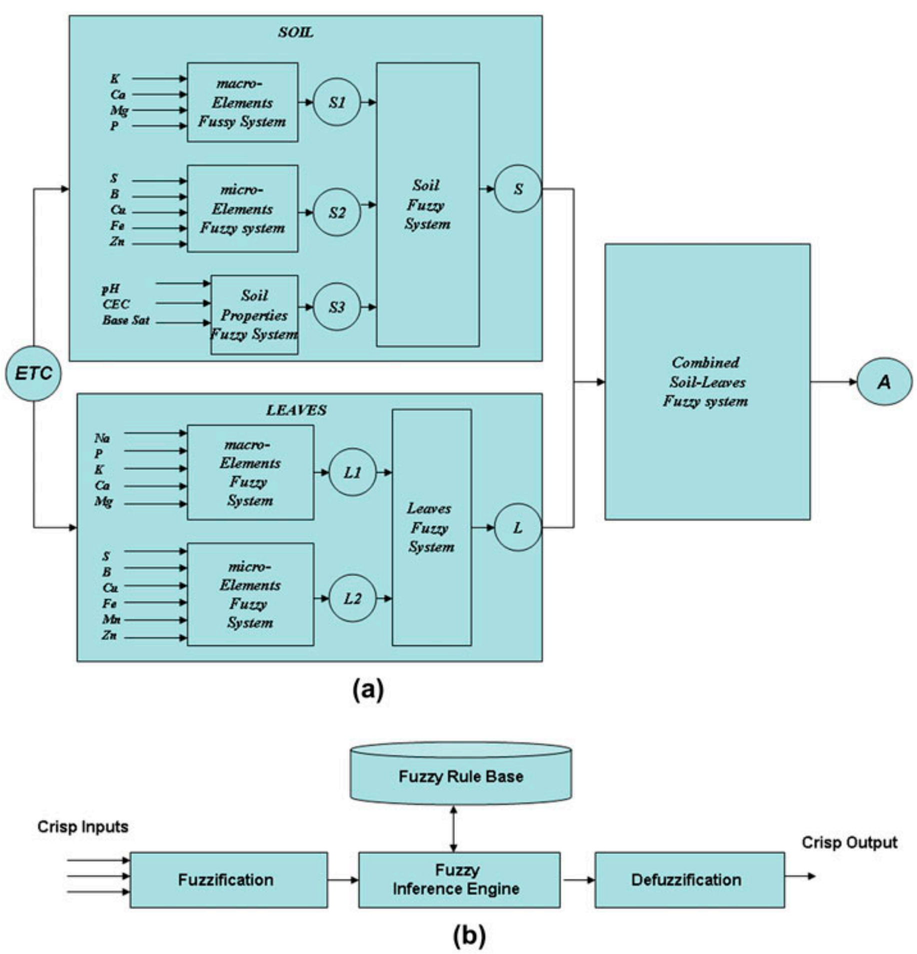

Fig. 1. A model overview (a) and the flow chart of a fuzzy inference system (b).

2.3. Membership functions

The membership functions (mf) of a fuzzy system measure the degree to which the fuzzy set elements meet the specific properties, or in other words they measure the "degree of belongingness" of an element to a specific fuzzy set. Membership value is between 0 and 1. The input space is referred to as universe of discourse or simply universe [21].

The feature of a membership function is defined by three properties: the support, the core, and the boundary. The support is the region of universe that is characterized by a nonzero membership. The core is the region of universe that is characterized by full membership (equal to 1), and the boundary is the region of universe that has a nonzero but not full membership. Some of the most commonly used membership functions are the Gaussian, trapezoid, triangular, etc. The mf used for the description of the models input variables are presented below.

2.4. The macro elements concentration in soil model

The concentration of each element of this category is characterized by three fuzzy sets with the linguistic variables: Low (L), Optimum (O), and High (H). For the description of Ca concentration, three mfs having trapezoidal or triangular shape, as shown in Fig. 2; and for each of K, Mg, and P, three trapezoidal mfs were used (Fig. 2). The core of the trapezoidal membership function "O" was determined by the optimum values as referred in bibliography [23]. Table 1 shows the critical values of soil macro elements concentrations in soil. Table 2 shows the parameters of all input mfs. Fig. 2 shows the mfs of inputs Ca and Mg [23]. The plateau of the "O" mf corresponds to the optimum critical range given in Table 1. The mf of the other inputs have similar structure.

The output of the macro element model was characterized by five overlapped triangular mf corresponding to four linguistic variables L, ML, M, H, VH starting from L (Low Acceptability) to VH (Very High Acceptability). Table 3 shows the parameters of output mf. Fig. 3 shows the output mf.

The fuzzy association between the inputs and output of the model is achieved via a number of IF-THEN rules. This rule-based system is known as fuzzy associative memory (FAM). The fuzzy logic theory involves several possibilities to define the OR, NOT, and AND logical operations as well as for the inference mechanism. Thus, there are more ways to implement a fuzzy decision system which apparently leads to alternative models. For this work, we considered the most common implication operators: min,

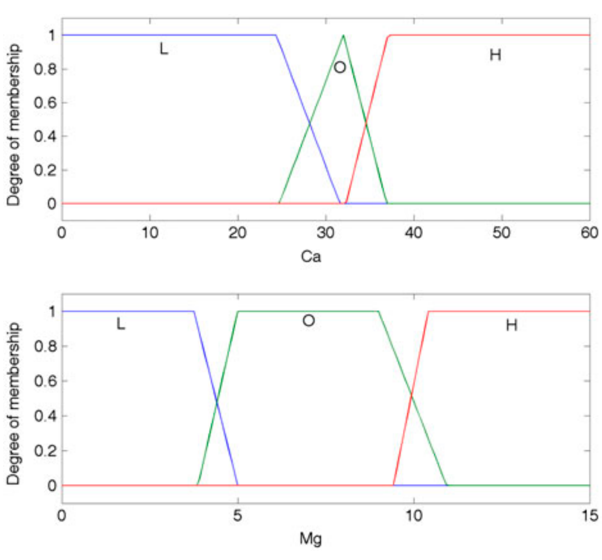

Fig. 2. Membership functions of soil Ca and Mg inputs.

Table 1
The optimum values of soil macro elements concentration for citrus according to Mattos et al. [23]

Elements	Critical range ($mg\,kg^{-1}$)		
	Low	Optimum	High
K	<0.8	1.6–3.0	>3.0
Ca		32.0	
Mg	<2.0	5.0–9.0	>9.0
P	<6.0	13.0–30.0	>30.0

Table 2
mf parameters for the macro elements inputs in soil

Element	L	O	H
K	Trapezoidal [–2 0 0.8 1.6]	Trapezoidal [1.1 1.6 3 3.5]	Trapezoidal [3 3.5 6 6.1]
Ca	Trapezoidal [–26 −0.34 24.4 31.6]	Triangular [24.7 32 37]	Trapezoidal [32.3 37 63.4 83]
Mg	Trapezoidal [–2 0 3.75 5]	Trapezoidal [3.87 5 9 11]	Trapezoidal [9.4 10.5 15 20]
P	Trapezoidal [–2 0 6 13]	Trapezoidal [6 13 30 35]	Trapezoidal [27 37 62 67]

Table 3
mf parameters for the soil macro elements output

mf	L	ML	M	H	VH
param.	[–0.25 0 0.25]	[0 0.25 0.5]	[0.25 0.5 0.75]	[0.5 0.75 1]	[0.75 1 1.25]

Note: mf = membership function; L = low; ML = medium low; H = high; and VH = very high.

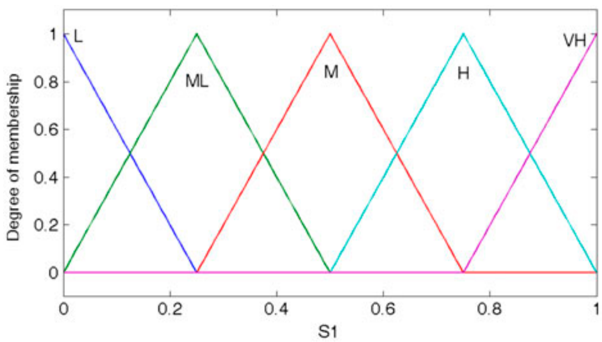

Fig. 3. Membership functions of soil macro elements output of submodel S1. L = low; ML = medium low; M = medium H = high, and VH = very high.

max, and the max–min (Mamdani implication) [17]. In a Mamdani fuzzy logic system model, the output is a fuzzy mf based on the rules created. Depending on the values used, the input mf are activated to a certain degree. The contributed output from each rule reflects this degree of activation. The final output is a fuzzy set created by the superposition of individual rule actions. An example of FAM rules used in this model is: "IF concentration of K is optimum (O) AND the concentration of Na is not optimum (notO) AND the concentration of Ca is optimum (O) AND the …, THEN the concentration of macro elements is High (H)". The operator notO means that the concentration belongs to either L or H mf.

For the macro elements submodel, 16 such rules were written with their respective FAM for macro elements submodel (Table 4). All inputs (columns) are connected via the AND logical operator. The first four rows correspond to IF/AND and the last row corresponds to the consequent THEN.

Since a crisp output value, the concentration in macro elements, is required, the output fuzzy set must be defuzzified. In the present paper, the centroid method was used for this action [19]. According to this method, for each input combination (O, notO) the degree of fulfillment and the consequent set of each rule are computed. Then, all consequent sets are aggregated and finally the centre of gravity of the resulted set was computed, giving the corresponding quality.

Fig. 4 shows the output of the model as function of two inputs namely Ca and K. The other inputs (Mg and P) are assumed to be constant at the values of 7.5 and 30 mg kg^{-1}. The output that characterizes the quality (Qs) of this submodel is a number between 0 and 1 and assesses the combination of soil macro elements concentration.

2.5. Description of the other submodels

A similar structure was assigned for the other submodels. Table 5 summarizes the optimum values used for the mfs construction. These values were based on existing bibliography [23].

Table 6 summarizes the shape and the properties of mfs used as inputs in each model. The construction of mfs (triangular or trapezoid) was based on the data presented in Table 5.

For each submodel with n inputs, the number of output was consisted by $n+1$ of triangular shape overlapped, equally spaced mfs, in the range of 0–1 (as the output of Fig. 2) corresponding to linguistic characterizations VH (1), H, M, … to L(0). The FAM

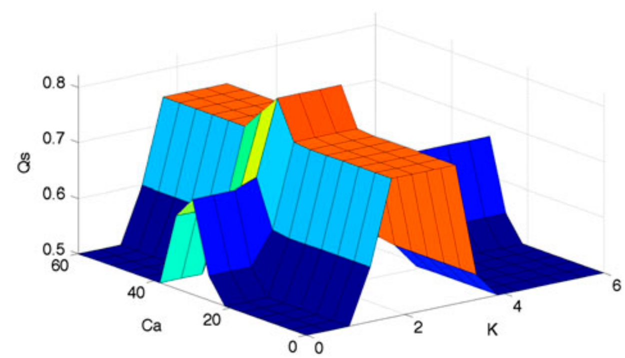

Fig. 4. Output of the soil macro elements submodel, as function of inputs Ca and K. The other inputs are assumed to be constant at the concentrations (Mg 7.5 and P:30 mg kg^{-1}).

Table 4
FAM for the decision soil macro elements submodel

K	O	notO	O	O	O	notO	notO	notO	O	O	O	notO	notO	notO	O	notO
Ca	O	O	notO	O	O	notO	O	O	notO	notO	O	notO	O	notO	notO	notO
Mg	O	O	O	notO	O	O	notO	O	notO	O	notO	notO	notO	O	notO	notO
P	O	O	O	O	notO	O	O	notO	O	notO	notO	O	notO	notO	notO	notO
output	VH	H	H	H	H	H	M	M	M	M	M	ML	ML	ML	ML	L

Note: O = optimum; notO = not optimum; VH = very high; H = High, M = medium, ML = medium low; L = low.

Table 5
Optimum values of other variables in mg kg^{-1}

	Low	Optimum	High
Soil essential elements			
S	<2	2–3	>5
B	>0.6	0.6–1.0	>1.0
Cu	<2.0	2.0–5.0	>5.0
Fe	3.6–14.4	14.4–30.0	30.0–60.0
Zn	<2.0	2.0–5.0	>5.0
Soil electrochemical properties			
pH		5.5–5.7	
CEC		35–47	
Base saturation	<25	51–70	>70
Leaves macro elements			
N	<23	23–27	>30
P	<1.2	1.2–1.6	>2
K	<10	10–15	>20
Ca	<35	35–45	>50
Mg	<2	3–4	>5
Leaves essential elements			
S	<2	2–3	>5
B	<80	80–160	>160
Gu	<10	10–20	>20
Fe	<49	50–120	>200
Mn	<34	35–50	>100
Zn	<34	35–50	>100

was constructed as follows: If all input variables belongs to the optimum mf the output is VH if all but one belongs to optimum mf is not optimum (either low or high) then the output is H if two are not optimum the output mf is M and so on. Finally, if all belongs to not optimum mf the output is L.

2.6. The soil and leaves sub models

Analogous structure was adopted for soil and leaves submodels. Each input had two sigmoid shaped mfs named low (L) and high (H). The structure of the output was as above. Fig. 5 shows the mfs of soil essential elements acceptability inputs and output as well. Table 7 summarizes the soil input mfs. The mfs of leaves had similar structure.

2.7. The main model

The soil and leaves acceptability model (three and two input correspondingly/one output model, as well the main model (two input/one output) was constructed in the same way. The final decision was a single number from 0 (bad) to 1 (excellent) (Fig. 6).

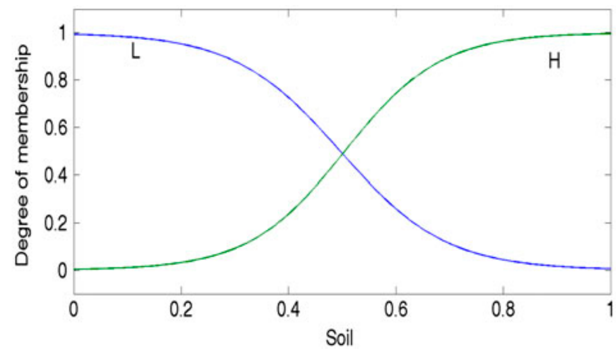

Fig. 5. Input mfs of soil and leaves sub model.

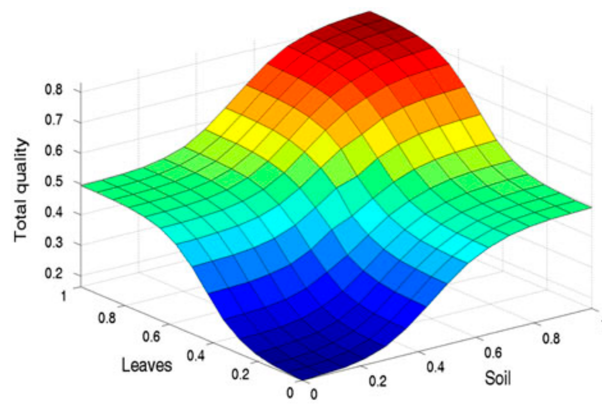

Fig. 6. The total model output.

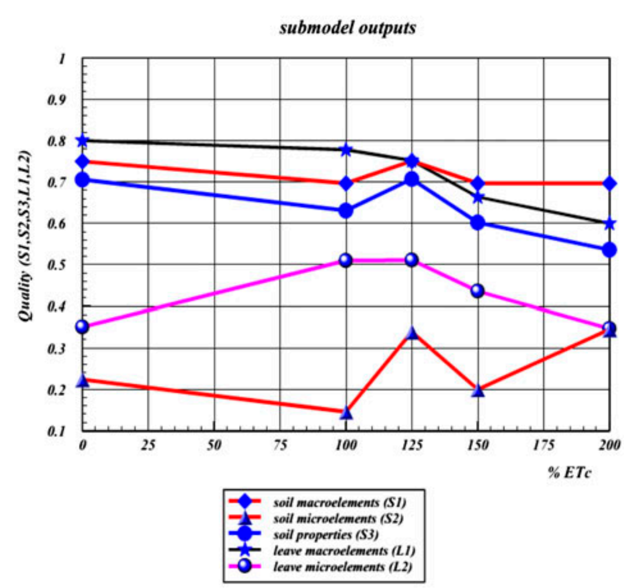

Fig. 7. Effect of % ETc on soil and leaves essential and macro elements on each submodels (S1, S2, S3, L1, and L2).

Table 6
Membership functions of other variables

	Low	Optimum	High
Soil essential elements			
S	Trapezoidal [–3 0 1.5 2]	Trapezoidal [1.5 2 3 5]	Trapezoidal [3 5 10 14]
B	Triangular [–0.8 0 0.8]	Trapezoidal [0.341 0.6 1 1.5]	Trapezoidal [0.8 1.5 2 2.5]
Cu	Trapezoidal [–3.6 0 1 2.5]	Trapezoidal [1.5 2 5 7]	Trapezoidal [4 6 10 14.6]
Fe	Trapezoidal [–21.6 3.6 12 18]	Trapezoidal [10 14.4 30 35]	Trapezoidal [25 35 70 80]
Zn	Triangular [–3 0 3]	Trapezoidal [1.4 2 5 6]	Trapezoidal [4 6 10 12.1]
Soil electrochemical properties			
pH	Trapezoidal [–2.5 4 5 5.4]	Trapezoidal [5 5.5 5.7 6]	Trapezoidal [5.6 6.2 8.1 8.7]
CEC	Trapezoidal [–18 −2 24 36]	Trapezoidal [25 35 47 57]	Trapezoidal [46 60.2 102 118]
Base saturation	Trapezoidal [–18 0 43 51]	Trapezoidal [39 51 70 75]	Trapezoidal [70 75 100 120]
Leaves macro elements			
N	Trapezoidal [–20 0 18 25]	Trapezoidal [20 23 27 30]	Trapezoidal [26 31 61 81]
P	Trapezoidal [–1.2 0 1 1.2]	Trapezoidal [0.9 1.2 1.6 2]	Trapezoidal [1.6 2 4 5]
K	Trapezoidal [–5 0 6.7 11.5]	Trapezoidal [8 10 15 20]	Trapezoidal [15 20 40 45]
Ca	Trapezoidal [–20 0 30 38]	Trapezoidal [32 35 45 55]	Trapezoidal [45 53 90 95]
Mg	Trapezoidal [–2 0 2 3.8]	Trapezoidal [2.5 3 4 5]	Trapezoidal [4 5 9 9.3]
Leaves essential elements			
S	Trapezoidal [–3.6 0 1.73 2]	Trapezoidal [1.7 2 3 4.8]	Trapezoidal [3.2 5 10 12.6]
B	Trapezoidal [–60.2 −15.5 54.6 80]	Trapezoidal [56.5 80 160 177]	Trapezoidal [153 184 275 300]
Cu	Trapezoidal [–10.3 −9.8 6 12]	Trapezoidal [8 10 20 22.8]	Trapezoidal [21 22.8 52.1 55]
Fe	Trapezoidal [–100 −1.68 36.1 56]	Trapezoidal [40.1 50 120 158]	Trapezoidal [59 213 324 453]
Mn	Trapezoidal [–104 −33.1 28.3 34.7]	Trapezoidal [29.3 34 50.5 66.4]	Trapezoidal [38.2 100 201 203]
Zn	Trapezoidal [–51.4 −2.58 29.2 35.9]	Trapezoidal [30.4 35 50 108]	Trapezoidal [58 100 153 155]

3. Case study

The experiment was carried out in Piracicaba, São Paulo State, Brazil (22˚43´ 04´´S; 47˚37´10´´W, 554 m), on a Rhodic Paleudult soil, irrigated with wastewater as described in the material and methods section. Tables A1–A5 in Appendix show the collected data.

The output of the five submodels shows that 125% ETc improves the soil (S1, S2, and S3) and leaves essential elements quality (L2) (Fig. 7).

The 125% ETc rate also improve the quality considering the combined effects on soil and leaves variables (Fig. 8).

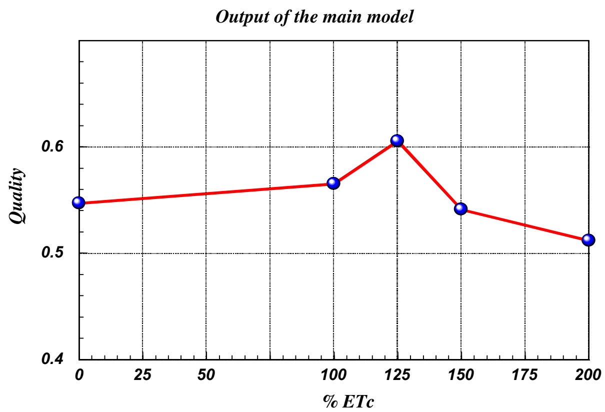

Fig. 8. Output of the final model considering the five submodels.

Table 7
Input membership functions of soil and leaves sub model

mf	Low (L)	High (H)
Macro elements	Sigmoid [–7 0.5]	Sigmoid [7 0.5]
Essential elements	Sigmoid [–7 0.5]	Sigmoid [7 0.5]
Properties	Sigmoid [–7 0.5]	Sigmoid [7 0.5]

Fig. 8 shows the output of the final decision model. It is obvious from this figure that 125% ETc clearly is the best choice for citrus growth.

4. Conclusion

A fuzzy logic model was applied to study the effect of % ETc on citrus growth. The large number of input variables was the main problem of the model. These variables were classified into five classes, namely the macro and essential element concentration of soil, the soil electrochemical properties, and the macro and essential element of leaves. The model was divided into five fuzzy submodels, one for each class. Two additional fuzzy models, one for soil and one for leaves, were designed. Finally, the final fuzzy model was designed to have two inputs (one for leaves and one for soil)/one output model. The division in submodels has the advantage that keeps the model as simple as possible (the total number of variables that manages is 23), and gives us the opportunity to study the effect of % ETc in each class of variables and on soil and leaves as well. The wastewater irrigation rate of 125% of ETc has the best effect on elements concentration of soil and citrus leaves, except for micro elements in leaves. We know that well-nourished plants have tended to grow higher; however, we did not use growth data at this MS. The model can be modified appropriately and can be applied to other cultivations as well.

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Appendix

Table A1
Soil macro elements data

ETC	K (mmolc dm^{-3})	Ca (mmolc dm^{-3})	Mg (mmolc dm^{-3})	P (mg/dm^3)
0.00	2.203684	18.26	9.96	16.80
0	2.18	18.26	8.71	20.52
0	2.51	15.77	8.71	18.74
100	2.33	29.05	14.94	32.38
100	1.82	23.24	12.45	27.97
100	1.85	16.6	9.33	27.55
125	1.9	11.62	5.6o	15.70
125	2.05	17.43	8.09	42.37
125	1.93	22.41	11.82	20.01
150	1.95	27.39	13.69	38.06
150	1.95	17.43	9.33	13.24
150	2.41	18.26	9.33	16.12
200	1.66	29.88	11.82	25.00
200	1.99	21.58	9.33	24.08
200	1.85	19.92	9.33	39.41

Table A2
Soil essential elements data

ETC	S ($g\,kg^{-1}$)	B ($mg\,dm^{-3}$)	Cu ($mg\,dm^{-3}$)	Fe ($mg\,dm^{-3}$)	Zn ($mg\,dm^{-3}$)
0.00	4.95	0.24	0.44	11.04	0.99
0	3.72	0.26	0.56	10.61	1.29
0	5.02	0.24	0.68	17.7	1.21
100	6.81	0.24	0.43	8.88	1.34
100	7.62	0.24	0.57	11.32	1.24
100	7.34	0.24	0.31	7.52	0.97
125	6.15	0.24	0.57	13.05	1.39
125	6.53	0.24	0.78	16.44	1.84
125	6.49	0.24	0.61	11.65	1.51
150	7.51	0.24	0.48	10.15	1.53
150	6.57	0.24	0.69	13.8	1.33
150	7.03	0.24	0.68	15.2	1.32
200	5.47	0.24	0.26	6.05	0.97
200	6.39	0.24	0.58	14.66	1.86
200	6.53	0.24	0.58	16.64	1.70

Table A3
Soil electrochemical properties data

ETC	pH	CEC	Base sat
0.00	5.30	41.91	56.97
0	5.30	39.77	73.29
0	5.89	39.00	69.20
100	5.41	54.89	84.38
100	5.34	47.8	78.47
100	5.2	39.30	70.68
125	5.21	30.70	62.28
125	5.31	39.45	69.88
125	5.91	45.13	80.12
150	5.30	51.16	84.10
150	5.37	39.71	72.29
150	5.86	39.52	26.82
200	5.63	50.89	85.20
200	5.32	41.75	78.80
200		41.80	74.40

Table A4
Leaves macro elements data

ETC	N ($g\,kg^{-1}$)	P ($g\,kg^{-1}$)	K ($g\,kg^{-1}$)	Ca ($g\,kg^{-1}$)	Mg ($g\,kg^{-1}$)
0.00	25.31193	1.325147	13.86561	19.18224	3.40026
0	25.657	1.377504	14.23363	15.53229	3.302695
0	28.78005	1.42667	15.54203	16.26794	3.204431
100	26.39043	1.176749	12.92635	20.45327	3.671465
100	30.06621	1.236514	12.84189	16.71435	3.239001
100	28.17908	1.009145	15.88376	19.92295	3.43444
125	27.58191	1.433256	13.65501	17.28941	3.341683
125	27.85729	0.906543	12.78481	20.97147	3.566881
125	28.53672	1.342987	12.65737	19.7919	3.37084
150	27.03904	0.992009	12.91507	18.87724	3.352319
150	27.9915	1.069878	12.65281	15.93398	3.099335
150	30.47061	1.279718	11.33435	14.34688	2.981396
200	23.63536	0.720572	11.10441	21.69433	3.594839
200	26.06319	0.579471	13.92722	19.84059	3.285365
200	27.65802	0.587178	13.04704	16.56592	2.967601

Table A5
Leaves essential elements data

ETC	S ($mg\,kg^{-1}$)	B ($mg\,kg^{-1}$)	Cu ($mg\,kg^{-1}$)	Fe ($mg\,kg^{-1}$)	Mn ($mg\,kg^{-1}$)	Zn ($mg\,kg^{-1}$)
0.00	4.692	137.9131	3.911294	72.68868	67.73338	16.8431
0	4.974849	120.7909	3.869437	81.13889	202.1561	15.90869
0	4.765299	144.8062	3.94825	83.49212	152.6082	16.58139
100	5.434845	146.8962	4.104937	85.43472	48.86471	13.61871
100	5.608194	115.5313	3.718173	74.95191	57.87329	16.11663
100	5.617775	129.7152	4.017093	119.666	154.3706	16.19582
125	6.287679	147	3.200563	88.73773	45.01904	13.52662
125	7.877827	155.2768	3.615903	100.7282	93.09684	15.42344
125	5.702948	130.1842	3.652285	93.68447	142.2972	16.59331
150	7.006856	131.3025	3.872666	70.83717	57.11119	1.464035
150	7.82361	193.7724	3.891591	69.23095	66.29304	20.33072
150	4.764855	168.6649	3.869945	72.53125	90.78778	11.9265
200	9.842618	168.3468	3.455094	78.39398	57.38526	11.39073
200	9.265547	166.8684	3.312951	77.00811	83.95066	11.54173
200	6.910383	185.0684	3.869331	74.00728	106.422	12.31078