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FUZZY MODELING OF SALINITY EFFECTS ON RADISH YIELD UNDER REUSE WATER IRRIGATION

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KEYWORDS

artificial intelligence, saline water, optimization.

ABSTRACT

The increase of water usage for food production in recent years has triggered researches on ways to optimize the use of water and to reuse saline water. The present study analyzes the effects of reused saline water in the irrigation of radish culture and the construction of a fuzzy logical mathematic model so that producers may evaluate their production. The experiment, measuring the development of radish bulb at five saline water levels, was developed in a greenhouse in the Botucatu, Campus of the São Paulo State University (UNESP), Botucatu/SP, Brazil. Results showed that salinity caused reduction in fresh and dry matter of the bulb and affected ratings throughout the culture cycle. From the developed fuzzy model, it was possible to verify that the fuzzy modeling helps in the analysis of the experimental data and makes it possible to perform simulations capable of inferring points that were not experimentally determined.

INTRODUCTION

Radish is a small-size plant belonging to the Brassicaceae family, with edible round, oval, or cylindrical bulbs (Nishio, 2017). It has a short lifecycle with an attractive crop rotation although its consumption and aggregated value are low. According to Viciedo et al. (2017) and Mohamed et al. (2016), radish has high amounts of vitamin C and B6, folic acid, potassium, fibres, and low-calorie rates. As radish is grown in small areas close to cities and towns and depends on frequent irrigation, low-quality water is normally used, often with high rates of dissolved salts (Oliveira et al., 2015).

Recently, the theory of fuzzy logic has been employed to help farmers to evaluate finishing cattle (Gabriel Filho et al., 2016) and broiler well-being. Other important applications in Agricultural Sciences are to predict global warming effects on orchid cultivation (Putti et al., 2017a), determine sewage sludge effects on wheat crops (Putti et al., 2017b), and use fuzzy modelling to decide whether to automate irrigation (Li et al., 2019; Elleuch et al., 2019 and Krishnan et al., 2020).

In this context, artificial intelligence has been employed to analyse the behaviour of plants under certain conditions to choose the best cropping conditions. Accordingly, several studies have focused on the use of fuzzy logic for decision-making.

According to Carneiro et al. (2018), fuzzy logic-based modelling helps in several areas by developing a fuzzy controller to assist farmers in deciding whether to recommend a bean cultivar for a given location. One of the most expensive inputs in agriculture is fertilizer. In this sense, Prabakaran et al. (2018) developed a fuzzy system to optimise fertilizer application, increasing production by 30 to 50% with proper management. Along the same lines but with grapes, Badr et al. (2018) developed a fuzzy model associated with geostatistics to determine irrigation depths and/or fertilization rates in different regions to meet specific plant demands. Likewise, Viais Neto et al. (2019a, 2019b) also developed a fuzzy model to determine ideal irrigation depths and salinity levels for tomato crops.

The current study aims to analyse statistically the growth of radish bulbs irrigated with different saline water

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depths and establish a Fuzzy Logic-based system to help farmers to assess yield.

MATERIAL AND METHODS

Experimental Area

The experiment was performed at the *Fazenda Experimental Lageado* (Lageado Experimental Farm) in the Department of Rural Engineering, College of Agriculture of UNESP, in Botucatu (SP), Brazil. The area lies at the geographical coordinates of 22º 51’ S and 48º 26’ W, and a mean altitude of 786 m. According to Köppen’s classification, the local climate is classified as a *Cfa* type, which stands for a hot and humid temperate climate, with a mean temperature of 22 ºC in the hottest month, and a mean annual rainfall of 945.15 mm (Rossi et al., 2018).

The experiment was conducted in a tunnel-like greenhouse placed in a north-south direction (27 m long, 7 m wide, side height 1.7 m, and centre height 3 m). It was covered with a 150-µm-thick transparent polyethene at the top, and sides with shade screens (30% shading) to ward off insects and animals.

Crop management and practices

Seedlings were grown in polystyrene trays with 128 cells, filled with a commercial substrate (BIOPLANT®). One seed was sown per cell on December 14th, 2012 and then transplanted on December 27th, 2012.

The soil had the following chemical characteristics: pH ($CaCl_2$) = 5.1, O.M.= 11 g dm^{-3}, P (resin)= 6 mg dm^{-3}, K= 0.60 $mmol_c$ dm^{-3}, Ca= 22 mmolc dm^{-3}, Mg= 7 $mmol_c$ dm^{-3}, H+Al= 26 mmolc dm^{-3}, SB= 29 $mmol_c$ dm^{-3}, B=0.22 $mmol_c$ $dm^{-3,}$ Cu= 6 mmolc dm^{-3}, Fe = 20 mmolc dm^{-3}, Mn = 10.10 mmolc $dm^{-3,}$ Zn = 0.80 $mmol_c$ dm^{-3}, CEC= 55 mmolc dm^{-3} and V= 53%.

At 14, 21, and 28 days after transplanting (DAT), bulb dry and fresh matters were weighed on a 0.0001g precision scale, and bulb diameter and height were measured by a calliper.

The experimental design was a fully randomized block with 5 salinity levels (0.00, 1.25, 2.50, 3.75, and 5.00 dS m^{-1}) and 5 replications, with each parcel consisting of a 12-L pot grown with one radish plant. The irrigation depths used here were retrieved from the literature (Ayers; Westcot, 1991) and performed daily, with the soil tension at -10 kPa.

Fuzzy model

A Fuzzy Logic-based system was developed with an input processor (fuzzificator), a set of linguistic rules, a Fuzzy-inference method, and an output processor (defuzzificator), which generates a real output number (Figure 1).

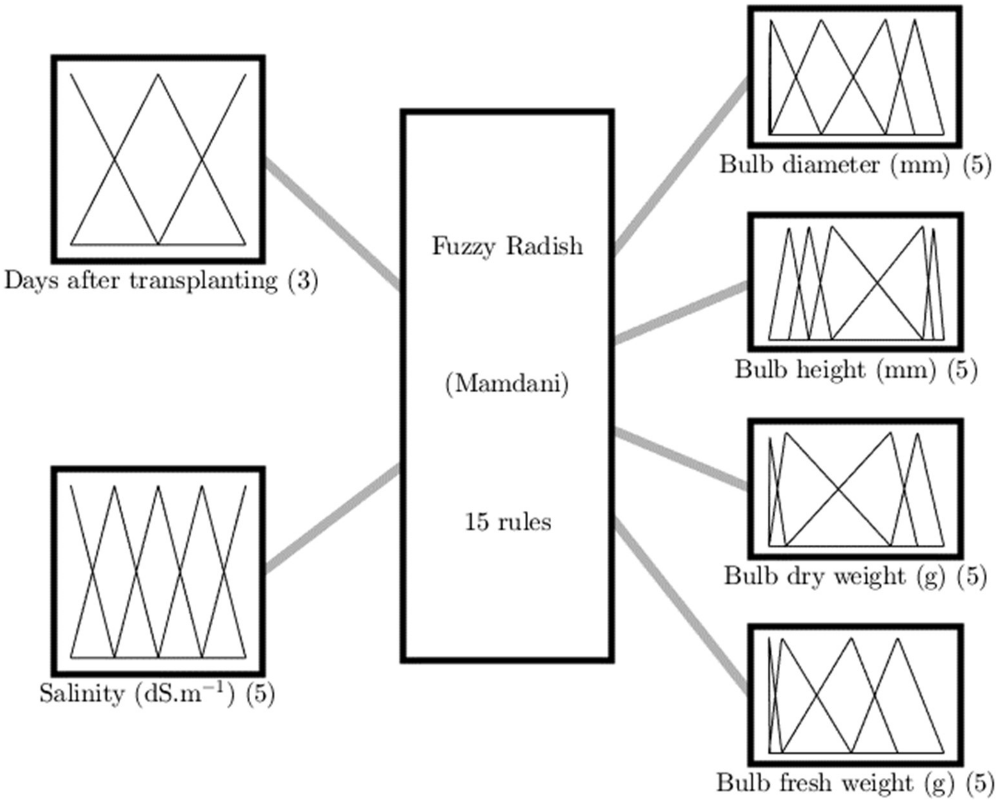

FIGURE 1. Fuzzy Logic-based system to evaluate radish bulb, with 2 inputs and 4 outputs.

Input variables comprised days after translation (DAT) and salinity levels (S). Table 1 and Figure 2 show the three pertinence functions named 14 DAT, 21 DAT, and 28 DAT for the DAT variable (Figure 2a). For the Salinity variable, the Figure 2b show five pertinence functions named Very Low (VL), Low (L), Average (A), High (H), and Very High (VH).

TABLE 1. Parameters of triangular membership functions for the input variables Days after transplanting and Salinity.

Input Variable	Fuzzy set	Delimitators
Days after transplanting	DAT14	[7 14 21]
	DAT21	[14 21 28]
	DAT28	[21 28 35]
Salinity	Very Low (VL)	[-1.25 0 1.25]
	Low (L)	[0 1.25 2.5]
	Medium (M)	[1.25 2.5 3.75]
	High (H)	[2.5 3.75 5]
	Very High (VH)	[3.75 5 6.25]

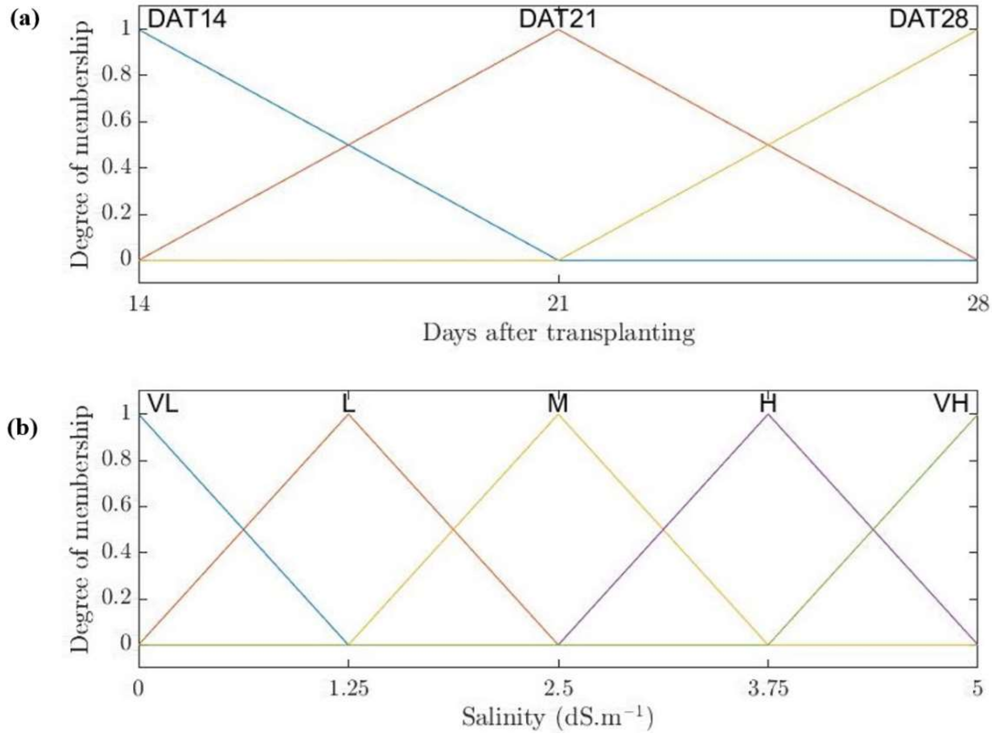

FIGURE 2. Membership functions of Fuzzy sets of the input variables Days after transplanting and Salinity, (a) Days after transplanting e (b) levels of Salinity.

Output variables consisted of Bulb diameter (BD), Bulb height (BH), Bulb dry weight (BDW), and Bulb fresh weight (BFW), which generated a fuzzy response to the variables analysed (DAT and S). The degree of Membership was established in five degrees, namely Very Low (VL), Low (L), Medium (M), High (H) and Very High (VH) (Table 2 and Figure 3), and the quartile of the data is represented by Q1, Q2, and Q3, with maximum and minimum rates.

TABLE 2. Definition of parameters of triangular membership functions for the all output variables.

Fuzzy set	Type	Delimitators
Very Low (VL)	Triangular	[Minimum – Q1, Minimum, Q1]
Low (L)	Triangular	[Minimum, Q1, Q2]
Medium (M)	Triangular	[Q1, Q2, Q3]
High (H)	Triangular	[Q2, Q3, Maximum]
Very High (VH)	Triangular	[Q3, Maximum, 2.Maximum -Q3)]

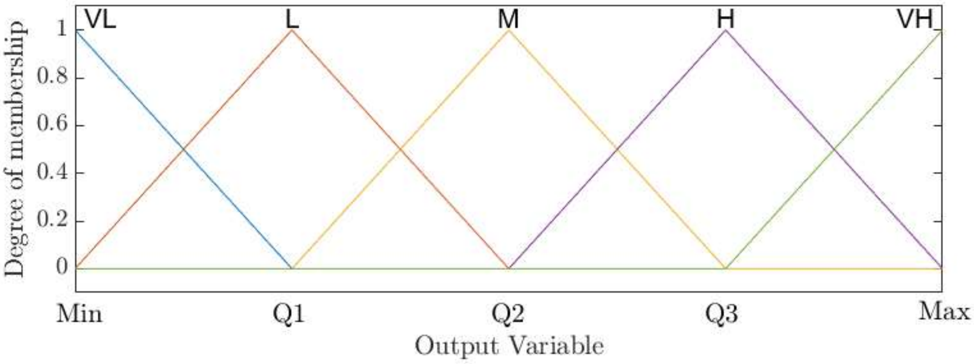

FIGURE 3. Membership functions of fuzzy sets of the output variables.

Fifteen (5×3) combinations between fuzzy sets of the four input variables were taken into account for the fuzzy system rule base. Fifteen pairs, Salinity x DAT, were established. Following the rules, Mamdani inference method was employed to calculate the rate of the output variables. This methodology was used similarly by Cremasco et al. (2010), Gabriel Filho et al. (2011, 2015, 2016, 2022), Pereira et al. (2008), Putti et al. (2014, 2017a, 2017b, 2021, 2022), Viais Neto et al. (2019a, 2019b), Martínez et al. (2020), Matulovic et al. (2021), Góes et al. (2021), Boso et al. (2021a, 2021b), and Maziero et al. (2022).

Analysis of variance and mean comparisons were carried out by Tukey's test at 5% probability using the Minitab 16 statistical software.

RESULTS AND DISCUSSION

Agronomic results

Table 3 and Figure 4 show the results regarding the effects of salinity levels on radish bulb diameter, height, and dry and fresh weights. The highest rates were detected at 28 DAT, or rather, at the harvest period, as reported by Bregonci et al. (2008).

TABLE 3. Analysis of variance for bulb growth (diameter, height, dry weight and fresh weight) of radish crop related to salinity levels (0, 1.25, 2.5, 3.75 and 5 dS m^{-1}).

Salinity (d Sm^{-1})	**DAT**											
	Bulb diameter (mm)			**Bulb length (mm)**			**Bulb dry matter (g)**			**Bulb fresh mass (g)**		
	14	**21**	**28**	**14**	**21**	**28**	**14**	**21**	**28**	**14**	**21**	**28**
0	2.4a	14.2a	35.7a	20.7a	29.5a	44.6a	0.10a	3.4a	32.0a	0.01a	0.19a	1.71a
1.25	2.5a	12.5a	26.7a	17.3ab	21.0a	46.6a	0.12a	4.0a	26.3ab	0.01a	0.14a	0.83b
2.5	2.9a	14.0a	29.0a	18.8ab	23.6a	47.9a	0.10a	3.7a	17.5b	0.01a	0.18a	1.10ab
3.75	2.6a	16.9a	32.5a	19.3ab	24.5a	47.9a	0.12a	4.6a	26.4ab	0.01a	0.15a	1.51a
5	2.6a	16.0a	34.9a	14.7b	29.4a	45.5a	0.12a	3.2a	30.1ab	0.01a	0.23a	1.67a

Legend: Means followed by the same letter do not differ statistically; capital letter in the column and small letter on the line by Tukey's test at 5% probability.

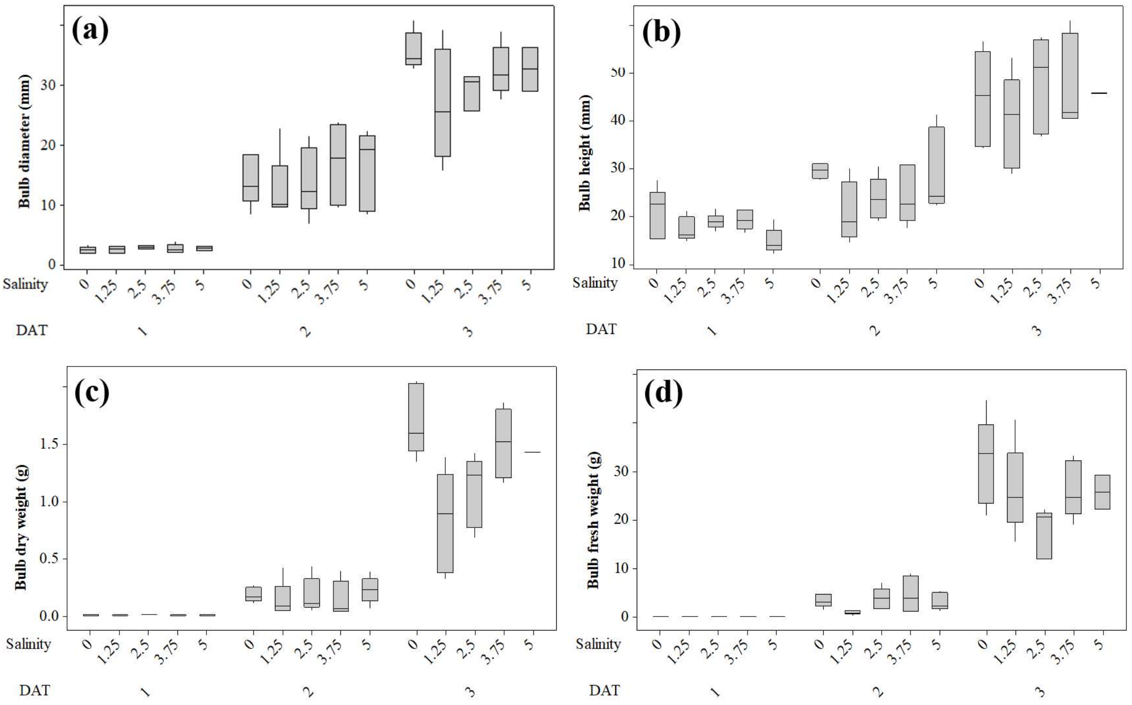

FIGURE 4. Boxplots of the output variables: (a) Bulb diameter, (b) Bulb height, (c) Bulb dry weight, and (d) Bulb fresh weight, according to salinity throughout the culture cycle.

Increased salinity did not affect bulb diameter throughout the radish cycle. This finding corroborates Oliveira et al. (2012) who stated that there are no differences up to 6 dS m^{-1}. Regarding length, shorter bulbs were observed at 14 DAT at 5 dS m^{-1}, showing a 50% decrease. Conversely, our findings disagree with those of Bregonci et al. (2008), who reported differences in all evaluations.

In terms of fresh weight, differences were only seen during harvest. This result can be attributed to salt accumulation in pots as fresh mass decreased. A smaller mass, on average 17.48 g per bulb, was obtained at a salinity of 2.5 dS m^{-1}, whereas there was a 55.37% reduction in the treatment with no salinity. Radish had the lowest bulb dry weight at a salinity of 1.25 dS m^{-1}. As bulbs weighed 0.83 g per root, there was a 47.97% reduction compared to the treatment without saline water irrigation.

Fuzzy model results

After statistical analysis, Fuzzy Logic modelling was performed, in which the model represented radish bulb development as a function of salinity level throughout the crop cycle.

The membership functions of the fuzzy sets of output variables (Figure 5) were generated with the parameters of Table 2 (minimum, maximum, and quartile rates).

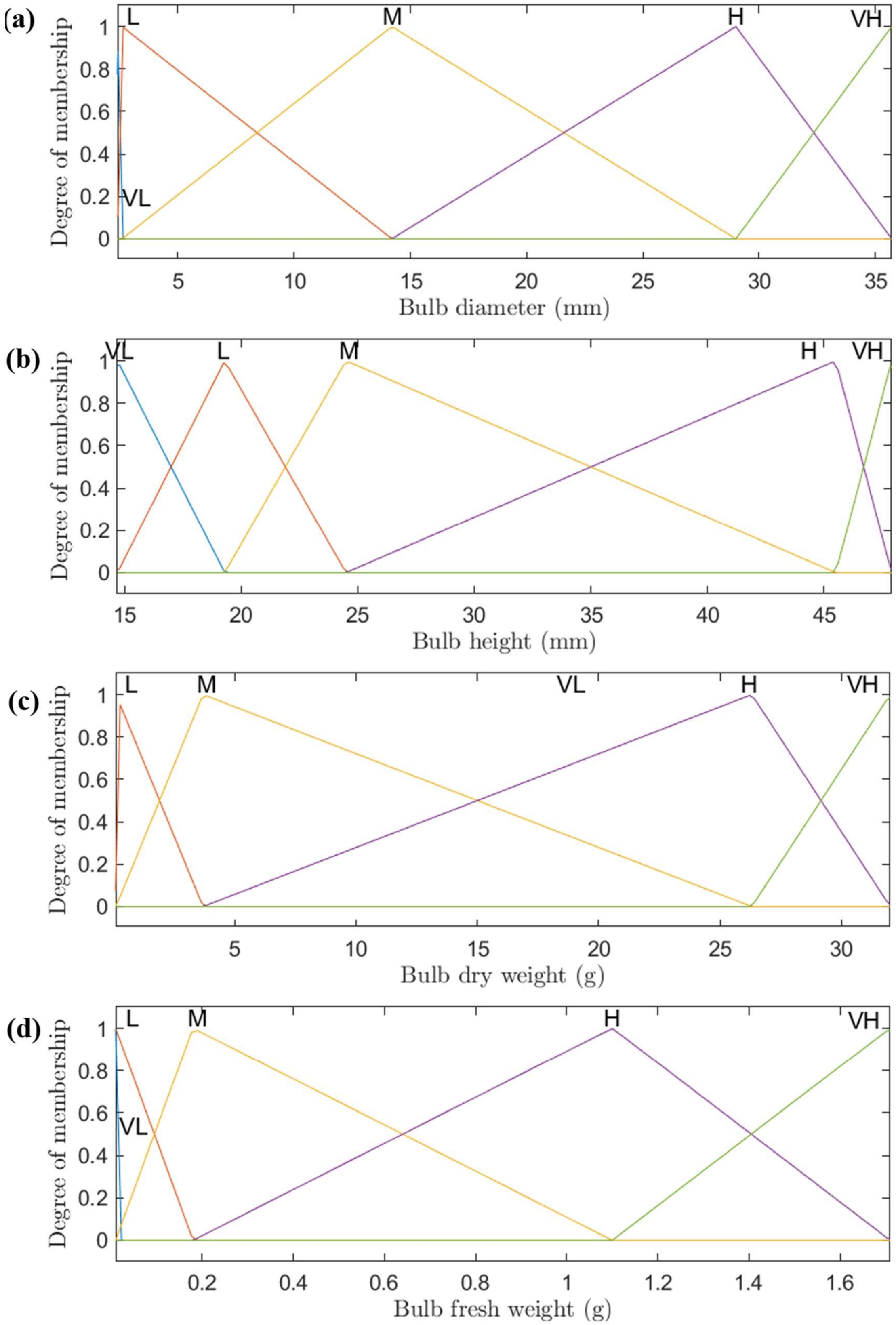

FIGURE 5. Membership functions of fuzzy sets of the output variables Bulb diameter, Bulb height, Bulb dry weight and Bulb fresh weight.

Base rules were built based on the identification of the highest degree of membership for each point in the domain of the function. Thus, 15 pairs of the form (DAT × Irrigation Level) were created.

The detailed base of rules for the Fuzzy system is shown in Table 4. The surface (a) and contour map (b) of the results are shown in Figures 6 and 7 respectively, according to days after transplanting and salinity levels.

TABLE 4. Rule base of fuzzy model.

Input variables				Output variables							
Salinity (dS m^{-1})		Days after transplanting		Bulb diameter (mm)		Bulb height (mm)		Bulb fresh weight (g)		Bulb dry weight (g)	
0	VL	14	DAT14	2.4	VL	20.7	L	0.1	VL	0.01	L
1.25	L	14	DAT14	2.5	L	17.3	L	0.12	L	0.01	L
2.5	M	14	DAT14	2.9	L	18.8	L	0.1	VL	0.01	L
3.75	H	14	DAT14	2.6	L	19.3	L	0.12	L	0.01	L
5	VH	14	DAT14	2.6	L	14.7	VL	0.12	L	0.01	L
0	VL	21	DAT21	14.2	M	29.5	M	3.4	M	0.19	M
1.25	L	21	DAT21	12.5	M	21	L	4	M	0.14	M
2.5	M	21	DAT21	14	M	23.6	M	3.7	M	0.18	M
3.75	H	21	DAT21	16.9	M	24.5	M	4.6	M	0.15	M
5	VH	21	DAT21	16	M	29.4	M	3.2	M	0.23	M
0	VL	28	DAT28	35.7	VH	44.6	H	32	VH	1.71	VH
1.25	L	28	DAT28	26.7	H	46.6	H	26.3	H	0.83	H
2.5	M	28	DAT28	29	H	47.9	VH	17.5	H	1.1	H
3.75	H	28	DAT28	32.5	VH	47.9	VH	26.4	H	1.51	VH
5	VH	28	DAT28	34.9	VH	45.5	H	30.1	VH	1.67	VH

Table 4 shows the rule base of the Fuzzy system, where the first three lines show the rules:

- *If* (Salinity is VL) and (DAT is 14), *then* (Bulb diameter is VL; Bulb height is L; Bulb fresh weight is VL and Bulb dry weight is L);
- *If* (Salinity is L) and (DAT is 14), *then* (Bulb diameter is L; Bulb height is L; Bulb fresh weight is L and Bulb dry weight is L);
- *If* (Salinity is M) and (DAT is 14), *then* (Bulb diameter is L; Bulb height is L; Bulb fresh weight is VL and Bulb dry weight is L).

The surfaces and contour maps of Fuzzy model are shows in Figure 6 and 7.

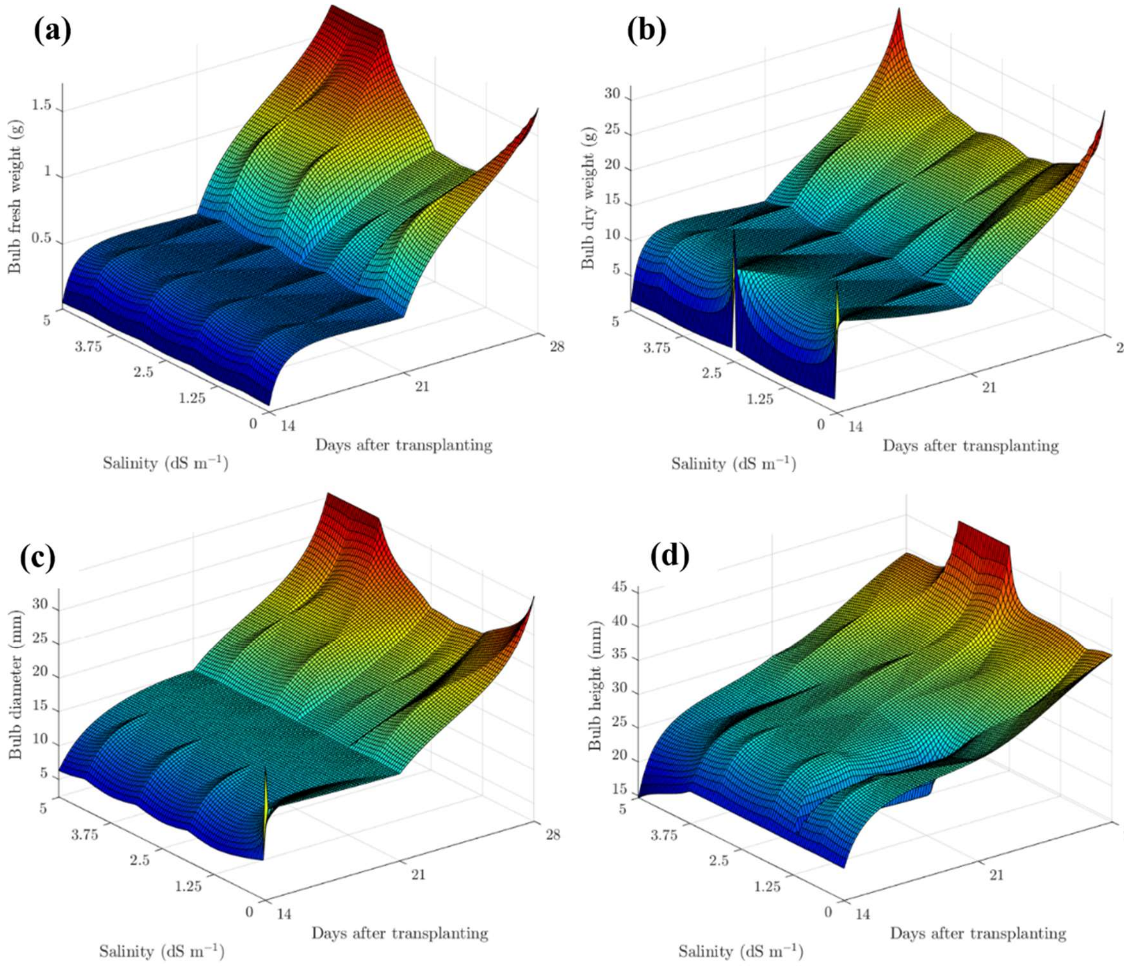

FIGURE 6. Surfaces of output variables Bulb diameter (a), Bulb height (b), Bulb dry weight (c) and Bulb fresh weight (d) in function of input variables Days after transplanting and Salinity.

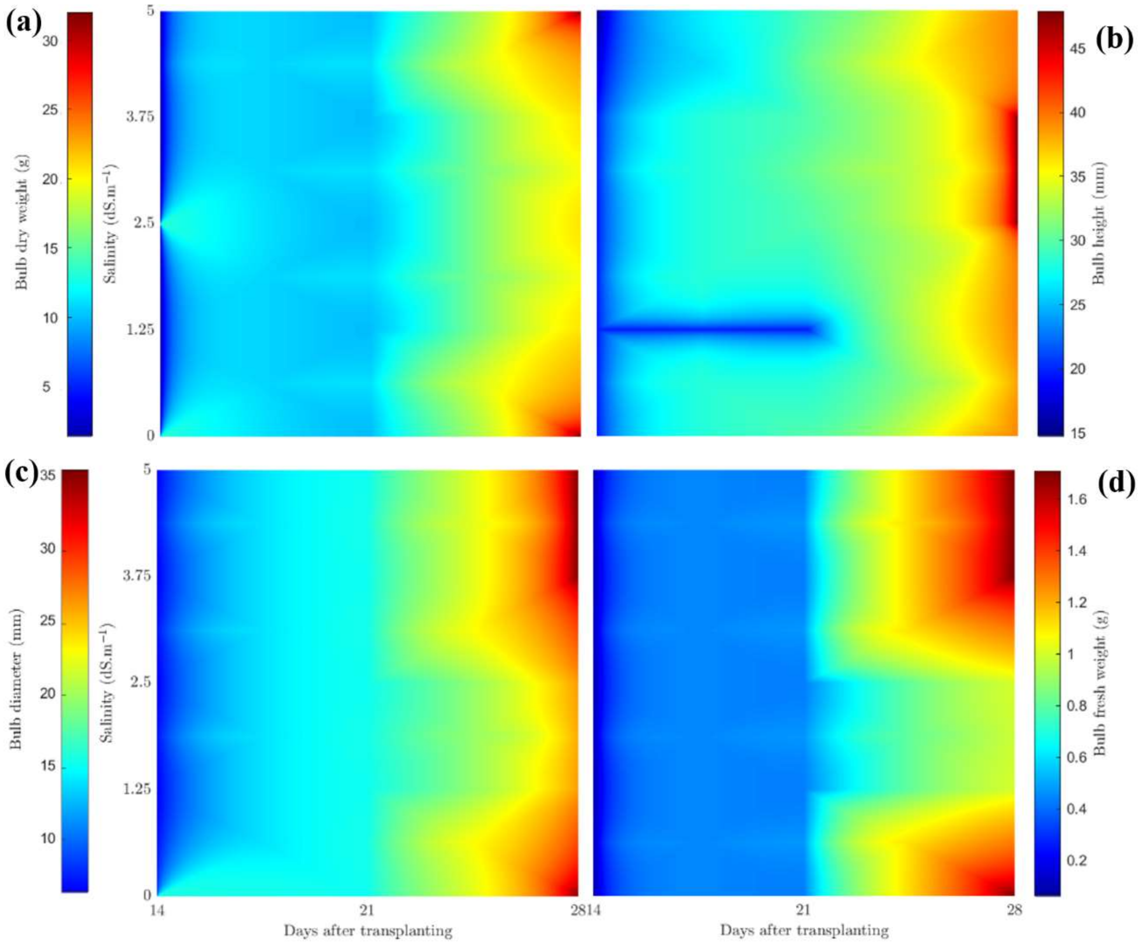

FIGURE 7. Contour maps of surfaces of output variables Bulb diameter (a), Bulb height (b), Bulb dry weight (c) and Bulb fresh weight (d) in function of input variables Days after transplanting and Salinity.

Figures 6a and 7a show the 3 ranges obtained throughout DATs (Table 3). Bulb fresh weight varied significantly throughout time and among treatments. Therefore, the behaviour of this variable as a function of saline irrigation throughout the radish cycle was efficiently represented by the model. Salinity level treatments did not show differences from 14 to 21 DATs. After 14 DAT, differences were close to 0 at 5 dS m^{-1}, decreasing green bulb phytomass. Such results may be associated with salt accumulation near the root system since higher salt levels had no severe effects on radish plants. Sanoubar et al. (2020) and Sun et al. (2017) observed that radish growth was affected by saline levels above 2 dS m^{-1}.

Salinity did not affect bulb dry mass until 21 DAT. A greater accumulation was observed at a dose of 5 dS m^{-1}. This is because plants developed more to compensate for the effects of salinity. Such results corroborate those of Sanoubar et al. (2020) and Sun et al. (2017), who also found less relative water content.

Bulb diameter varied significantly during the radish cycle but not among treatments. Therefore, the Fuzzy Logic-based model could represent bulb diameter as a function of saline irrigation and throughout the radish cycle. From 14 to 21 DATs, salinity did not affect bulb diameter, but it had a reducing effect at a salinity close to 2 dS m^{-1}. This result may be due to the salt accumulation closer to bulbs at this dose than at higher doses. The dose of 4.5 dS m^{-1} promoted larger bulb diameters. Likewise, Sanoubar et al. (2020) found no effect of salinity on different radish genotypes. According to this author, their short cycle can suppress potential serious effects. Basílio et al. (2018) also found a behaviour similar to that observed in our study.

Figures 6 and 7 show that the three bands were distinct throughout DATs (Table 3). These results demonstrate that the variable bulb height was statistically different along the cycle. Therefore, the Fuzzy Logic-based model could represent bulb height as a function of saline irrigation and throughout the radish cycle. Up to 21 DATs, there was no difference among salinity level treatments. At saline levels below 3.75 dS m^{-1}, shorter bulb lengths were observed in the region without salinization. Thus, due to radish short cycle (28 DAS) and treatment differences, no severe effects were noted. These results corroborate those obtained by Sakamoto & Suzuki (2019), who stated that low salinity levels do not cause changes in the radish root system.

CONCLUSIONS

Statistical conclusions show that radish is tolerant to saline irrigation. The current experiment established a mathematical and computational method to monitor radish throughout its cycle in terms of salinity rates. The method covers different salinity levels and harvest dates. The fuzzy Logic system is an easy tool to help farmers in crop evaluation.

This study uses a mathematical method capable of interpreting the evaluation of radish culture throughout its life cycle in relation to the adopted salinity levels. The use of saline water for the cultivation of radish is shown to be viable since the effects of the culture cycle are shortened. In this way, it can be observed that the proper management can provide agronomic performance in the cultivation.

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