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NEURO-FUZZY MODELING AS SUPPORT FOR DECISION-MAKING IN THE PRODUCTION OF IRRIGATED CORIANDER UNDER MULCH IN THE SEMI-ARID REGION

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KEYWORDS

Mathematical modeling, irrigation management, vegetation cover.

ABSTRACT

Reducing water consumption by crops in semi-arid regions is an important factor for the sustainability of agriculture in these locations. In this sense, this study aims to evaluate the neuro-fuzzy inference method as a support for decision-making in irrigated coriander cultivation. The experiment was performed in two cultivation cycles in Pentecoste-CE, Brazil. The experiment was conducted in randomized blocks arranged in a split-plot design with five primary treatments, consisting of irrigation depths (50, 75, 100, 125, and 150% of the localized evapotranspiration, ETc_{loc}), and five secondary treatments, consisting of different levels of bagana mulch (0, 25, 50, 75, and 100%, equivalent to 16 t ha^{-1}). Neuro-fuzzy models with two input variables and eight output biometric variables were developed to evaluate growth (plant height, number of roots, and root length) and yield variables (productivity and shoot and root fresh and dry mass). In the first cycle, the best results occurred close to 55% ETc_{loc} and between 40 and 50% of mulch; in the second cycle, water consumption returned results between 50 and 80% ETc_{loc}. The fuzzy and multiple regression models showed MAE, MSE, and RMSE errors of 9, 22, and 10% lower, respectively. The neuro-fuzzy model might be a viable option for decision-making in irrigated crops, being able to optimize the use of natural resources and available water in semi-arid regions. The use of 55% of irrigation depth and a range of 40 to 50% of mulch can be a strategy for a higher water use efficiency.

INTRODUCTION

The use of mulch on the soil is an agricultural practice that favors the reduction of crop evapotranspiration, soil temperature, and irrigation depths. Its use is an extensively recommended practice, particularly in semi-arid regions, contributing to improved crop performance and increased soil moisture retention (Almeida et al., 2020). It consists of synthetic (e.g., plastic films) (Fawibe et al., 2019) or organic materials (e.g., carnauba bagana), which provide benefits for agriculture, such as better protection against erosion, lower temperature range, increased microbial activity, and higher conservation of water and nutrients (Almeida et al., 2020; Souza et al., 2017).

Bagana is an agro-industrial residue generated after the extraction of wax from carnauba (*Copernicia prunifera*) leaves and has been used as substrate, organic fertilizer (Albano et al., 2017), and mulch to reduce the evaporation in irrigated crops (Almeida et al., 2020; Souza et al., 2017). Among these crops, coriander (*Coriandrum sativum* L.) stands out for its high consumption and socioeconomic importance (Prachayasittikul et al., 2018), ensuring a quick return on investment, providing an increase in income for families, and enabling family farming in semi-arid regions such as the Brazilian Northeast (Zamora et al., 2019).

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Mathematical models can optimize decision-making and reduce the use of natural resources, being increasingly useful for agricultural activities to work properly in the context of dynamic agriculture (Gabriel Filho et al., 2022), also leading to the possibility of savings in production costs.

Neuro-fuzzy modeling can be considered an important option in scenarios of increasingly scarce natural resources for decision-making tasks, as individual variables are not defined in exact terms, thus being an option for the planning of irrigation management and use of mulch, minimizing costs and, consequently, preserving natural resources (Putti et al., 2021).

Several fuzzy systems have been successfully applied in agricultural engineering, such as cattle production (Maziero et al., 2022), irrigation (Viais Neto et al., 2019; Putti et al., 2017, 2021; Matulovic et al., 2021; Gabriel Filho et al., 2022), optimization of agricultural implements (Góes et al., 2022), increase in plant vitality (Putti et al., 2017), and market of agricultural products (Martínez et al., 2020).

In this context, this study aims to evaluate the neuro-fuzzy inference method as a support for decision-making in irrigated coriander cultivation under the effect of carnauba bagana in a no-tillage system at different irrigation depths in a semi-arid region.

MATERIAL AND METHODS

Description and design of the experimental area

The data were collected from an experiment carried out in an area belonging to Prece (Program of Education in Cooperative Cells) located in the Cipó community, in the municipality of Pentecoste, State of Ceará, at the geographic coordinates 39°12′46″ W and 3°55′20″ S, and 56 m above sea level. According to the Köppen classification, the regional climate is BSw′h′, characterized as hot and semi-arid, with irregular rainfall distributed from February to May, average annual rainfall of 860 mm, evaporation of 1,475 mm, average annual temperature around 26.8 °C, and average relative humidity of 73.7%.

Figure 1 shows the daily precipitation and temperature data at the experimental time. The average temperature of the first cycle was 28.6 °C, while the second cycle had a value of 29.7 °C; the average relative humidity was 50.9% in the first cycle and 59.8% in the second cycle. Precipitation was only recorded in the first production cycle, totaling 22.7 mm. The average reference evapotranspiration (ETo) was 5.5 and 5.6 mm day^{-1} for the first and second cycles, respectively.

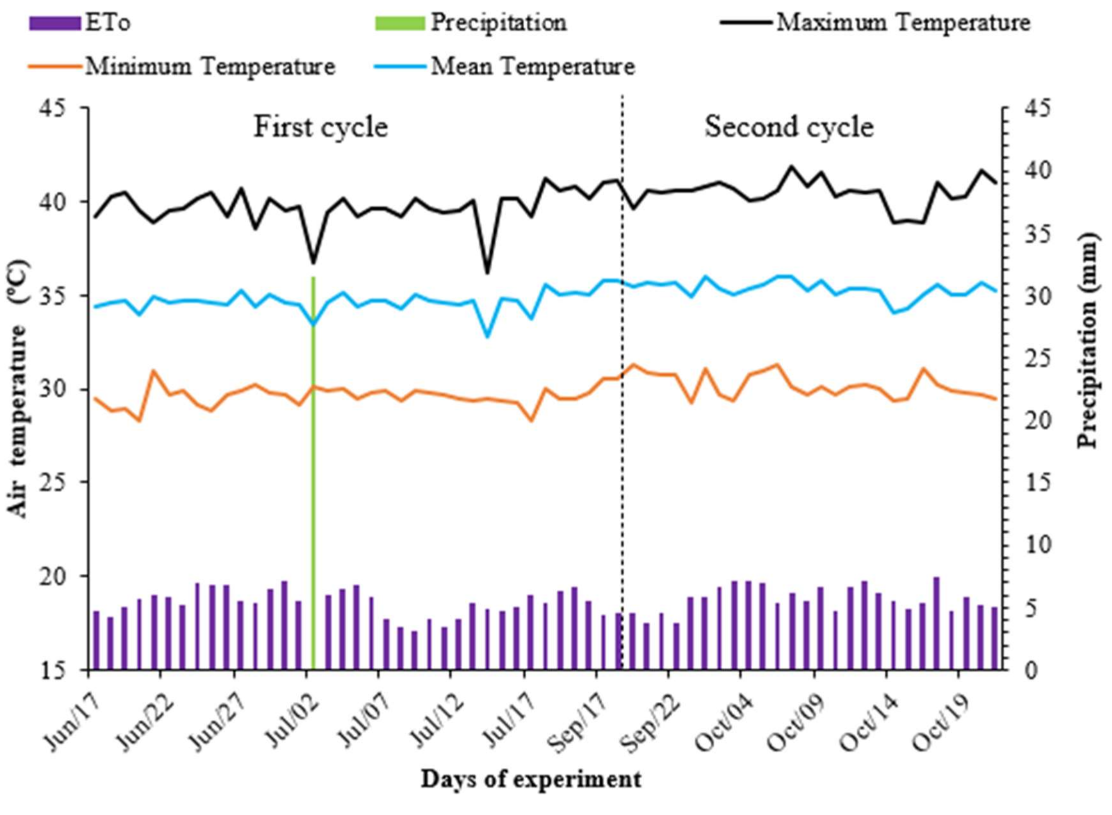


FIGURE 1. Maximum, mean, and minimum temperatures and precipitation at PRECE in Pentecoste-CE, recorded during the experimental period in the first and second production cycles.

The experiment was conducted in randomized blocks arranged in a split-plot design composed of four blocks arranged in the subplots. The plots consisted of irrigation depths (ID) with 50, 75, 100, 125, and 150% of the localized crop evapotranspiration (ETc_{loc}) applied by a drip irrigation system with a flow rate of 2.0 L h^{-1} and a service pressure of 10 MWC. The subplots consisted of five different bagana mulch levels (ML) (0, 25, 50, 75, and 100%), with the 100% level being equivalent to 16 t ha^{-1} (Souza et al., 2017).

Each plot had an area of 10 m^2 (1.0 × 10.0 m) whereas the subplot had an area of 2.0 m^2 (1.0 × 2.0 m), with 60 plants, of which the 10 central ones were considered the useful area. The spacing between plants was 0.1 m and between rows was 0.2 m, totaling 100 experimental subplots.

Experiment set up

Coriander was sown on June 17, 2018 (1st Cycle), and September 17, 2018 (2nd Cycle), directly in the planting rows of all beds. Each bed had three planting rows. The area underwent a previous preparation, with the plant residues being removed. Subsequently, 20 kg of an organic compost (P = 314.7 mg kg^{-1}; K = 1690 mg kg^{-1}; Ca = 14 $cmol_c$ dm^{-3}; Mg = 9.2 $cmol_c$ dm^{-3}; Na = 1.14 $cmol_c$ dm^{-3}; Fe = 26.9 mg dm^{-3}; Cu = 0.4 mg dm^{-3}; Zn = 20.4 mg dm^{-3}; Mn =100.3 mg dm^{-3}) was distributed per m^2 30 days before sowing. The soil was tilled to incorporate the compost and eliminate clods in the area to be worked. The compost was incorporated at a depth of 0–0.30 m.

Irrigation was estimated based on the reference evapotranspiration (ETo), obtained through a class A tank, where evaporation readings were taken daily to estimate ETo (Bernardo et al., 2019). ETc_{loc} was determined using the Kc used by Silva et al. (2018), a location coefficient, which considers the wetted area and total area (Bernardo et al., 2019), and the fractionation of the applied water depth according to the treatment (50, 75, 100, 125, and 150%).

Variables obtained during the experiment

The biometric response variables of the experiment consisted of productivity, shoot fresh mass (SFM), shoot dry mass (SDM), root fresh mass (RFM), and root dry mass (RDM). Productivity (t ha^{-1}) was obtained by weighing the SFM of each treatment, correlating its useful area (2 m^2) relative to an area of 1 ha. The variables SFM (g $plant^{-1}$), SDM (g $plant^{-1}$), RFM (g $plant^{-1}$), and RDM (g $plant^{-1}$) were obtained by weighing separately the shoots and roots on a 0.01 precision scale. Subsequently, the plant material was packed in paper bags and dried in an oven at a temperature of 65 °C until reaching a constant weight.

The growth variables were plant height, root length, and the number of roots. The variables plant height (cm) and root length (RL, cm) were obtained using a ruler with scales in centimeters, while the variable number of roots was obtained by manual counting.

Modeling of the neuro-fuzzy system

A neuro-fuzzy mathematical model with an adaptive-network-based fuzzy inference system (ANFIS) consisting of eight output variables and two input variables (Figure 2) was developed to model the output variables. An appropriate number of input membership functions (five for water depths and five for mulch levels) was selected in line with the experimental procedure. The number of rules (25 rules) was also accurately sized so that the combinations between the experimental treatments of the input variable could be contemplated in each rule.

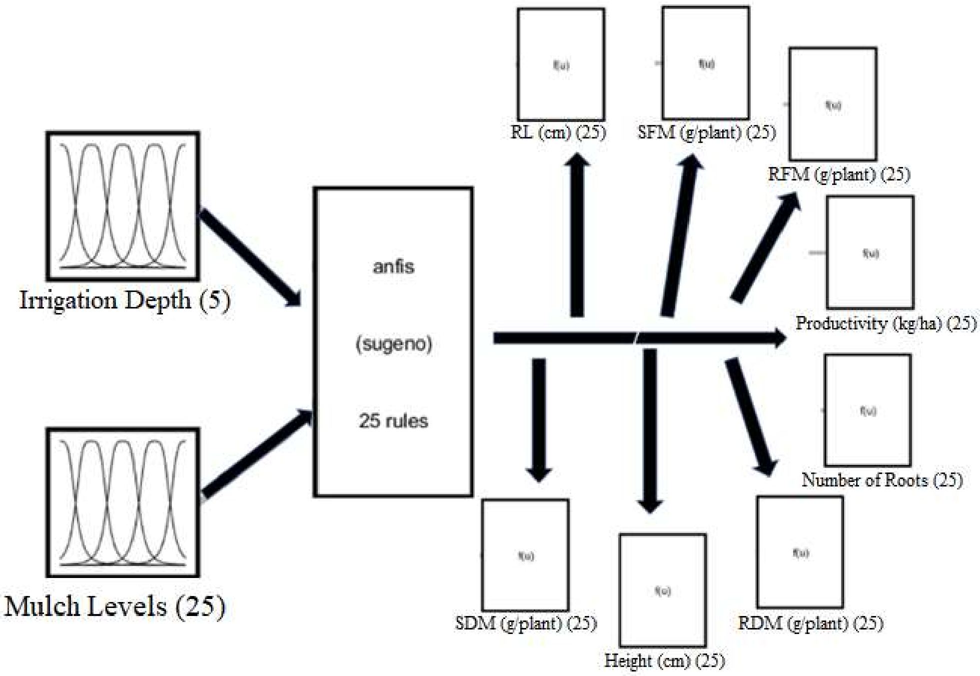


FIGURE 2. Fuzzy system of biometric variables of the coriander crop according to different irrigation depths and mulch levels.

Altogether, 100 experimental subplots were considered, and each plot provided eight pieces of information (data) regarding the variables, totaling a database of 800 measurements. Regarding the models, the domain information of each function was composed of 25 ordered pairs related to the studied combinations.

The developed neuro-fuzzy system values each independent interaction, thus generating the most satisfactory point for coriander production, which is related to the best water conservation considering irrigation depths and mulch levels. It allows for determining the situations in which soil moisture can be maintained for a longer time, thus delaying evapotranspiration.

Five fuzzy sets related to the input variable ID of 50, 75, 100, 125, and 150% of ETc_{loc} were created. Moreover, five fuzzy sets were also defined for the second input variable ML, associated with the different bagana mulch levels (0, 25, 50, 75, and 100%).

Figure 3A shows the generalized bell-shaped membership functions for the “Irrigation Depth” data (Input 1), and Figure 3B shows the “Mulch Levels” (Input 2), where the fuzzy sets C1, C2, C3, C4, and C5 and their respective delimiters were considered, as shown in Table 1. The membership functions of these fuzzy input sets used in the model consisted of the generalized bell-shaped membership function (The MathWorks, 2021), according to [eq. (1)].

$$f(x) = \frac{1}{1 + \left|\frac{x-c}{a}\right|^{2b}} \quad (1)$$

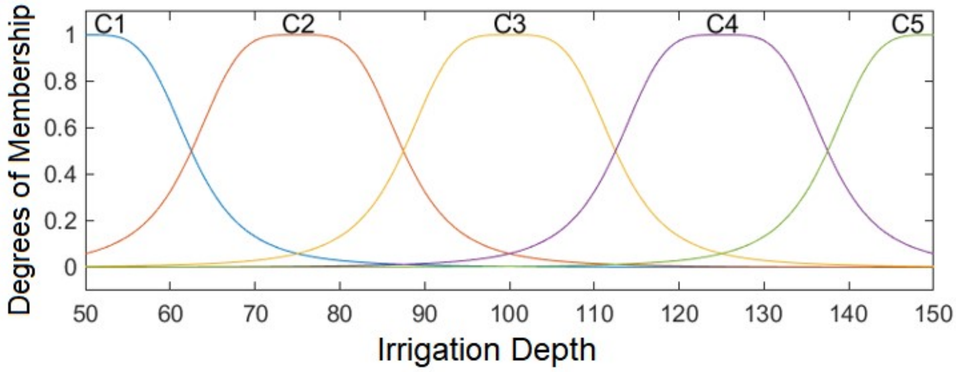
Where:

a defines the width of the membership function, in which a larger value creates a wider membership function;

b sets the shape of the curve on either side of the central plateau, where a larger value creates a sharper transition, and

c defines the center of the membership function.

A.



B.

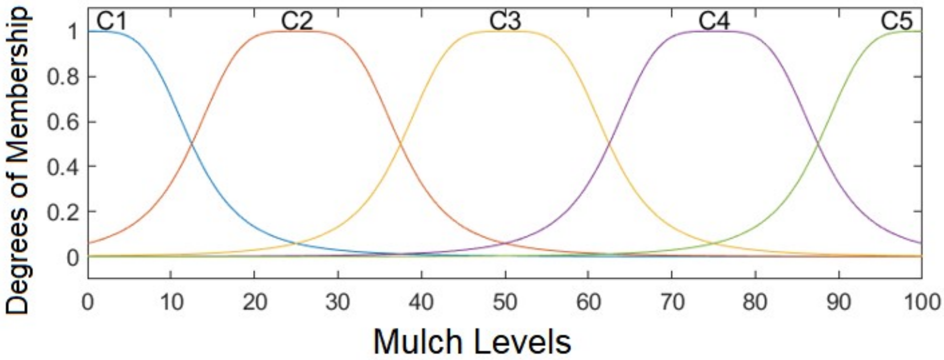


FIGURE 3. Generalized bell-shaped membership function of the input variables (a) Irrigation Depths and (b) Mulch Levels.

TABLE 1. Definition of the generalized bell-shaped membership functions of the input variables.

Variable	Fuzzy set	Delimiter 1	Delimiter 2	Delimiter 3
Irrigation depth	C1	12.5	2	50
	C2	12.5	2	75
	C3	12.5	2	100
	C4	12.5	2	125
	C5	12.5	2	150
Mulch levels	C1	12.5	2	0
	C2	12.5	2	25
	C3	12.5	2	50
	C4	12.5	2	75
	C5	12.5	2	100

The rule-based fuzzy system was generated by the software MATLAB® using the Neuro-Fuzzy Designer Toolbox of Fuzzy Logic.

Model validation

A quadratic polynomial regression model, which is one of the most used multivariate techniques in social (Bartholomew, 2010) and agricultural sciences, was used to analyze and validate the efficiency of the fuzzy models and compare the data. The multiple quadratic polynomial regression models determined for each variable were obtained according to [eq. (2)].

$$z = a_0 + a_1x + a_2y + a_3xy + a_4x^2 + a_5y^2 \quad (2)$$

Where:

z is the biometric variable;

x is the irrigation depth level;

y is the bagana mulch level, and

$a_i \in \mathbb{R},\ i = 1,2, \dots ,5.$

After adjustment, the neuro-fuzzy and polynomial models were evaluated using some of the common indicators for evaluating the accuracy of a regression model. For this purpose, three performance metrics were used to measure and compare the precision of the algorithms, namely mean absolute error (MAE), mean square error (MSE), and root mean square error (RMSE). The better the model fits, the smaller these errors.

RESULTS AND DISCUSSION

This discussion refers to each specific factor relating to the two crop cycles, considering the parameters mulch levels and irrigation depths and taking into account three-dimensional surfaces and contour maps.

Yield variables

The variable productivity (t ha^{-1}) in the interaction between ML and ID showed production values ranging from 5 to 9 t ha^{-1} in the 1st cycle (Figures 4A and 4C) when ID was close to 55% of ETc_{loc} and ML ranging from 20 to 60% and 90 to 100%. Production values equal to or higher than 9.5 t ha^{-1} were observed with an ID of 150% and ML of 100%, thus indicating that soil moisture maintenance favors coriander development. However, the neuro-fuzzy model under water scarcity conditions demonstrates, as previously mentioned, the possibility of making production feasible by reducing ID to 55% of ETc_{loc} and using ML values lower than 100%.

Importantly, the use of natural resources to mitigate drought is an important and often economically viable strategy despite the high temperatures in the region and water scarcity (Almeida et al., 2021). Thus, the use of carnauba bagana can be a good option, as this residue retains moisture in the soil when used as mulch, favoring increased coriander productivity. Similarly, Almeida et al. (2020) used mulch and obtained a radish production of 9.6 t ha^{-1} in the Northeast of Brazil. Moreover, Kassu et al. (2018) found a maximum coriander production of 8.0 t ha^{-1} in Ethiopia and indicated the possibility of using different types of mulch.

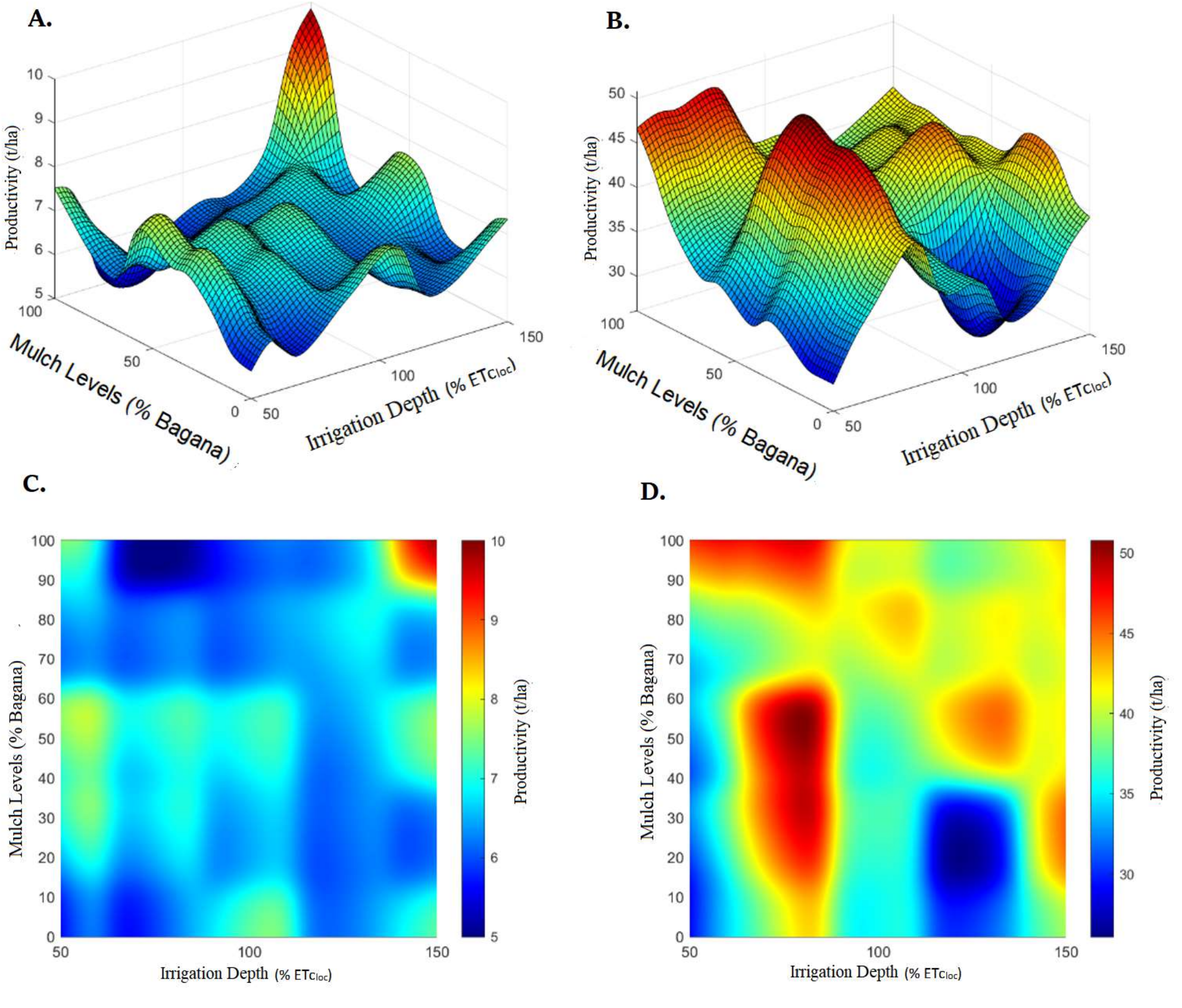


FIGURE 4. Three-dimensional surfaces and contour maps for the variable productivity (kg ha^{-1}) in the first (A and C) and second cycles (B and D) of coriander cultivation as a function of bagana mulch levels and irrigation depths.

Productivity for the 2nd cycle (Figure 3B and 3D), according to the proposed model, presents higher values (45 to 50 t ha^{-1}) when using an ID of 80% of ETc_{loc} and ML between 40 and 60%. The lower productivity in the first cycle (9 t ha^{-1}) compared to the second cycle (50 t ha^{-1}) may be related to several factors, such as the cultivation system, which consisted of an organic system with the use of organic fertilizers that may have increased nutrient availability in the 2nd cycle due to slow release. Another factor may be related to the carnauba bagana, which may have favored soil fertility for the 2nd cycle due to its incorporation during the 1st cycle. Similarly, Martins et al. (2018) studied planting densities in coriander production in São Manuel-SP and observed productivities of 45 t ha^{-1} using one plant per pit and chemical fertilizers.

The proposed model pointed out the highest value of SFM (96 g $plant^{-1}$) when using ML above 90% and ID between 135 and 150% of ETc_{loc} in the 1st cycle (Figures 5A and 5B). In contrast, SFM values ranging from 60 and 75 g $plant^{-1}$ were obtained when using ML between 30 and 60% (% carnauba bagana) and 100% of ETc_{loc}.

The 2nd cycle (Figures 4B and 4C) showed a decrease in SFM (75 g $plant^{-1}$) when varying ML values from 10 to 30% with ID values above 100% of ETc_{loc}. According to the proposed model, the optimal point in this cycle was when ID was close to 80% of ETc_{loc}, with 30 and 55% of carnauba bagana. This fact may be important for decision-making by producers, as the optimal levels suggested by the neuro-fuzzy model may assist in reducing input costs (carnauba bagana) and the use of water.

The variable RFM had the highest values (10 g to 12 g $plant^{-1}$) in the 1st cycle (Figures 5E and 5F) for an ID between 45 and 60% of ETc_{loc}, which was also observed from 140 to 150% of ETc_{loc}, and ML of 90 to 100% of carnauba bagana. Possibly, the accuracy of the proposed neuro-fuzzy model demonstrates that, in addition to the high soil moisture provided by irrigation, protecting the soil with mulch reduces evaporation and, as a consequence, maintains water storage that is conducive to root development.

The highest RFM values (60 g $plant^{-1}$) in the 2nd cycle (Figures 5G and 5H) were observed for an ID ranging from 52 to 60% of ETc_{loc} and ML between 60 and 50%. The values indicated by the proposed neuro-fuzzy model may be related to the behavior of the roots, which often develop in search of water at higher soil depths, as also discussed by Almeida et al. (2020).

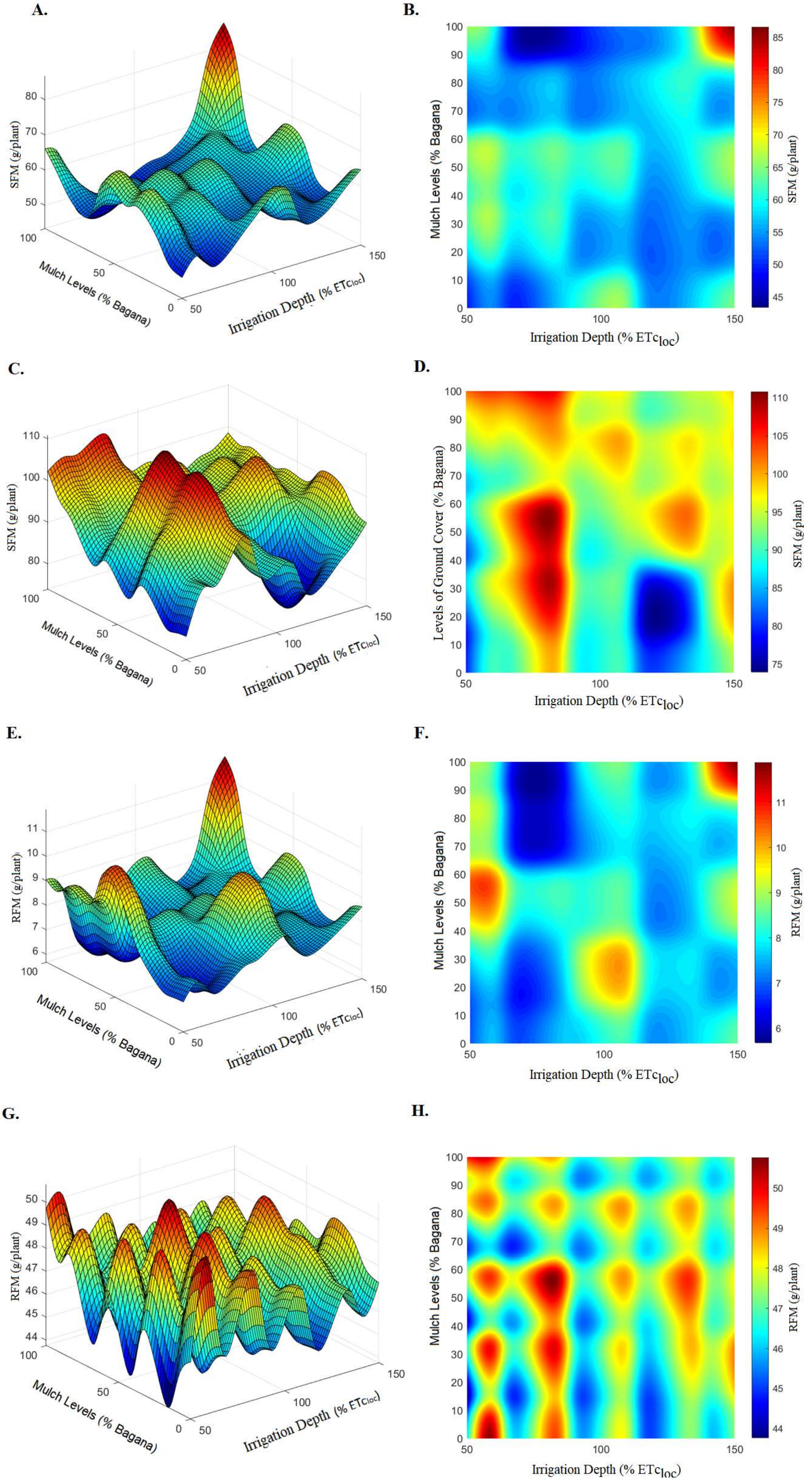


FIGURE 5. Three-dimensional surfaces and contour maps for the variables SFM and RFM in the first (A, B, E, and F) and second cycles (C, D, G, and H) of coriander cultivation as a function of bagana mulch levels and irrigation depths.

In the 1st cycle (Figures 6A and 6B), the variable SDM reached values above 8.5 g $plant^{-1}$ for ML values between 30 and 40% associated with ID values close to 55 and 100% of ETc_{loc}, and 8 g $plant^{-1}$ for an ML of 40% and ID of 100% of ETc_{loc}. However, an increase in irrigation depths above 145% of ETc_{loc} leads to a need for an increase in mulch levels, reaching a maximum production of 9 g $plant^{-1}$. In the 2nd cycle (Figures 6C and 6D), the optimal point for the variable SDM was reached when using 90% of ETc_{loc} associated with 30% of ML, resulting in values above 9 g $plant^{-1}$.

ID values close to 100% of ETc_{loc} and 100% of ML in the first cycle (Figures 6E and 6F) resulted in RDM levels above 4.5 g $plant^{-1}$. Levels lower than 100% for both factors led to a downward trend in RDM values, which may be related to the high crop evapotranspiration for that specific period.

In the 2nd cycle (Figures 6G and 6H), the variable RDM presented values above 4.6 g $plant^{-1}$ for an ID ranging from 55 to 85% of ETc_{loc} and ML between 20 and 40%. Therefore, the variable RDM was higher in the 2nd cycle, possibly due to the need to deepen the root system in search of soil moisture (Almeida et al., 2020). Similarly, Pereira (2018) found an RDM value of 5.2 g $plant^{-1}$ using 62 t ha^{-1} of Java-bean mulch, while Aguiar et al. (2016) obtained a production of 16.1 g $plant^{-1}$ with the application of 60 t ha^{-1} of organic compost, proving the superiority of results compared to the present study.

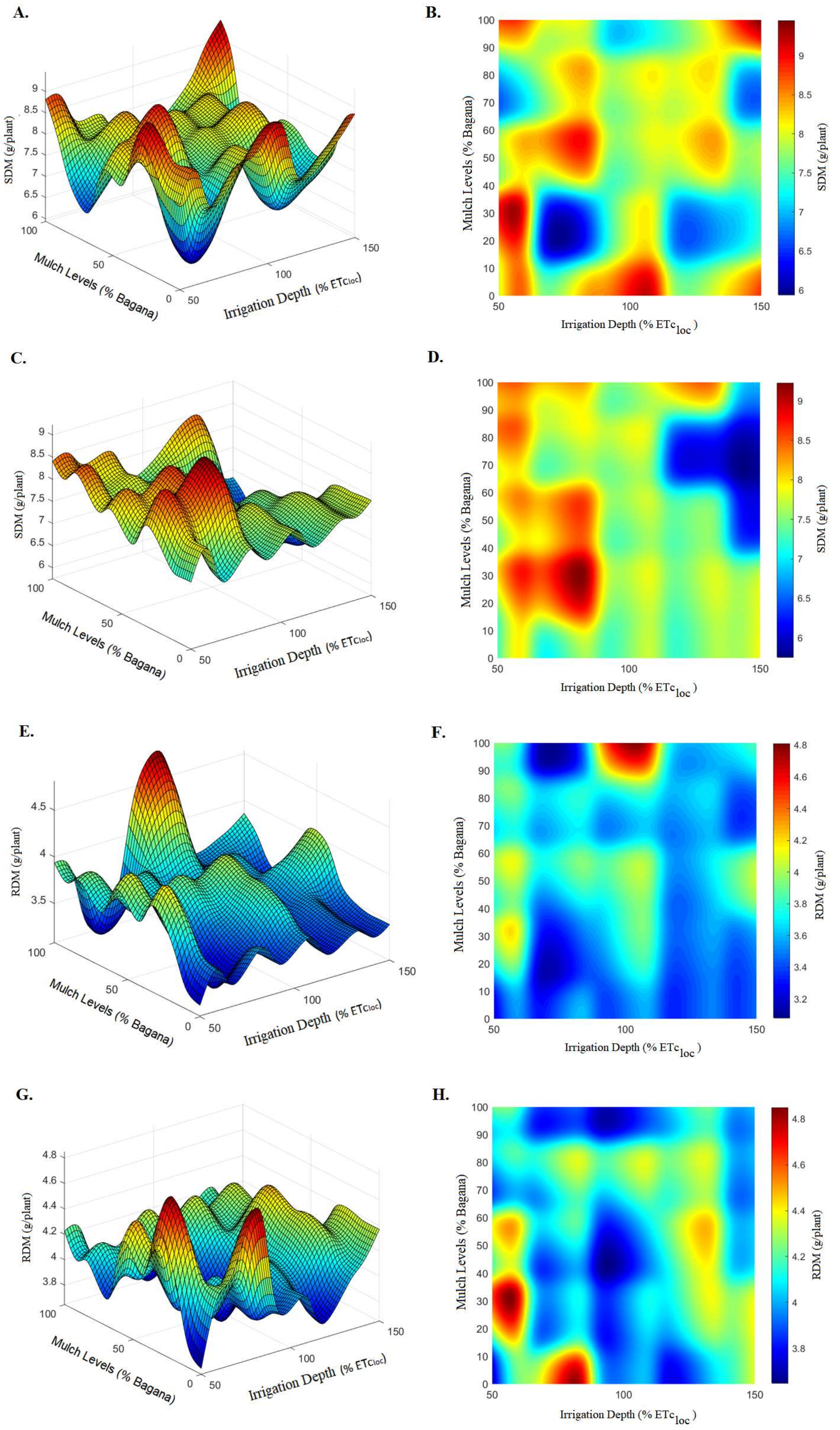


FIGURE 6. Three-dimensional surfaces and contour maps for the variables SDM and RDM in the first (A, B, E, and F) and second cycles (C, D, G, and H) of coriander cultivation as a function of bagana mulch levels and irrigation depths.

Growth variables

The highest values for the variable height (cm) in the 1st cycle (Figures 7A and 7B) were observed with ID above 145% of ETc_{loc} and ML ranging from 40 to 60% of carnauba bagana. The proposed neuro-fuzzy model indicates that height is related to the high soil water availability and low evaporation, reduced by the use of mulch.

However, high values for the variable height in the 2nd cycle (Figures 7C and 7D) occurred when ML was above 90% and ID was close to 100% of ETc_{loc}. This increase may be related to the semi-arid climate, with high evapotranspiration (Nogueira et al., 2023). A high soil temperature makes it difficult to maintain moisture, which is lost through evaporation, therefore requiring a mulch that provides a reduction in soil temperature.

Pereira (2018) obtained values of 20.84 cm for the variable height in coriander plants, using 48 t ha^{-1} of Java-bean mulch. Cunha et al. (2018) evaluated the height of coriander intercropped with mint under different doses of manure and jitirana and found a maximum value of 13.14 cm when it was cultivated single and 8.1 cm when intercropped. The same authors also reported that plant height is of paramount importance for coriander producers due to commercial issues. Linhares et al. (2014) obtained positive results with the use of carnauba straw incorporated into the soil, with average height values of 22 cm plant^{-1} when using values close to 16 t ha^{-1} of the studied mulch.

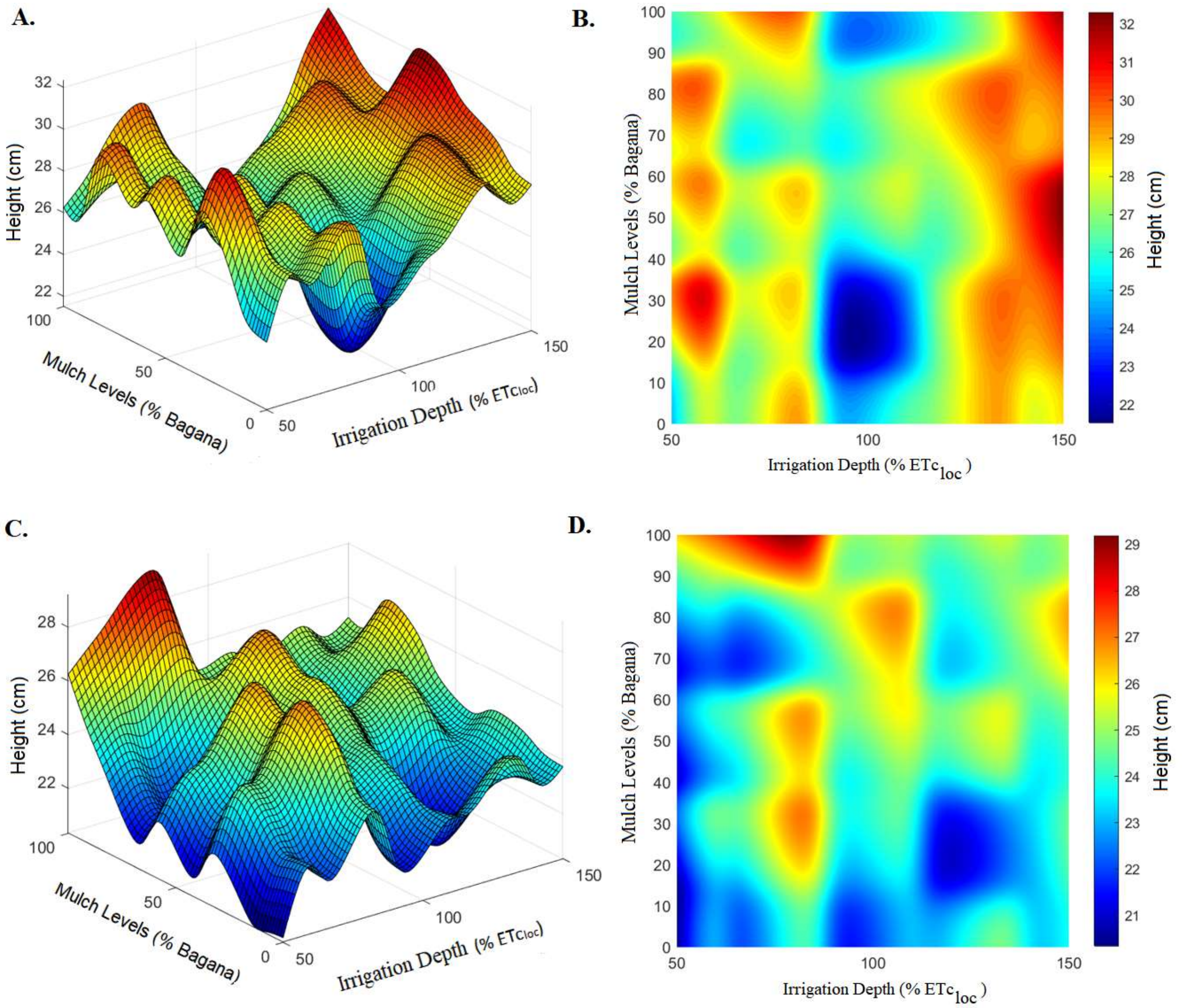


FIGURE 7. Three-dimensional surfaces and contour maps for the variable plant height in the first (A and B) and second cycles (C and D) of coriander cultivation as a function of bagana mulch levels and irrigation depths.

The variable number of roots in the 1st cycle (Figures 8A and 8B) showed the highest values (37 to 47 roots) for an ML between 30 and 65% of carnauba bagana associated with an ID ranging from 50 to 60% of ETc_{loc}. A similar number of roots (37 to 40) were observed when there was a variation in ID from 65 to 80% and 145 to 150% of ETc_{loc} together with ML values from 65 to 85%, 0 to 10%, and 90 to 100% of carnauba bagana. This variability demonstrates the options obtained by the neuro-fuzzy model to optimize decision-making depending on the situation, considering the availability of water and natural resources.

The results behave differently for the 2nd cycle (Figures 8C and 8D), with acceptable levels for the number of roots (between 29 and 31) occurring for ML values ranging from 90 to 100% and 15 to 40% and ID from 50 to 60% of ETc_{loc}, ranges that stood out among the other values. The range of ID from 60 to 100% of ETc_{loc} and ML from 70 to 100% of carnauba bagana provided a number of roots close to 27.

The variable RL in the 1st cycle (Figures 8E and 8F) showed a disparity in ID levels from 80 to 90% and 145 to 150% of ETc_{loc} (higher water consumption) with ML values of 10 to 35% and 10 to 60% of carnauba bagana, respectively. In the 2nd cycle (Figures 8G and 8H), RL presented values ranging from 10.5 to 11.5 cm with ID values from 60 to 95% of ETc_{loc} and ML between 40 to 60%. Almeida et al. (2019) observed similar results in a study on the agroeconomic viability of coriander, with RL values of approximately 14 cm with a planting density of 2 g m^{-1}.

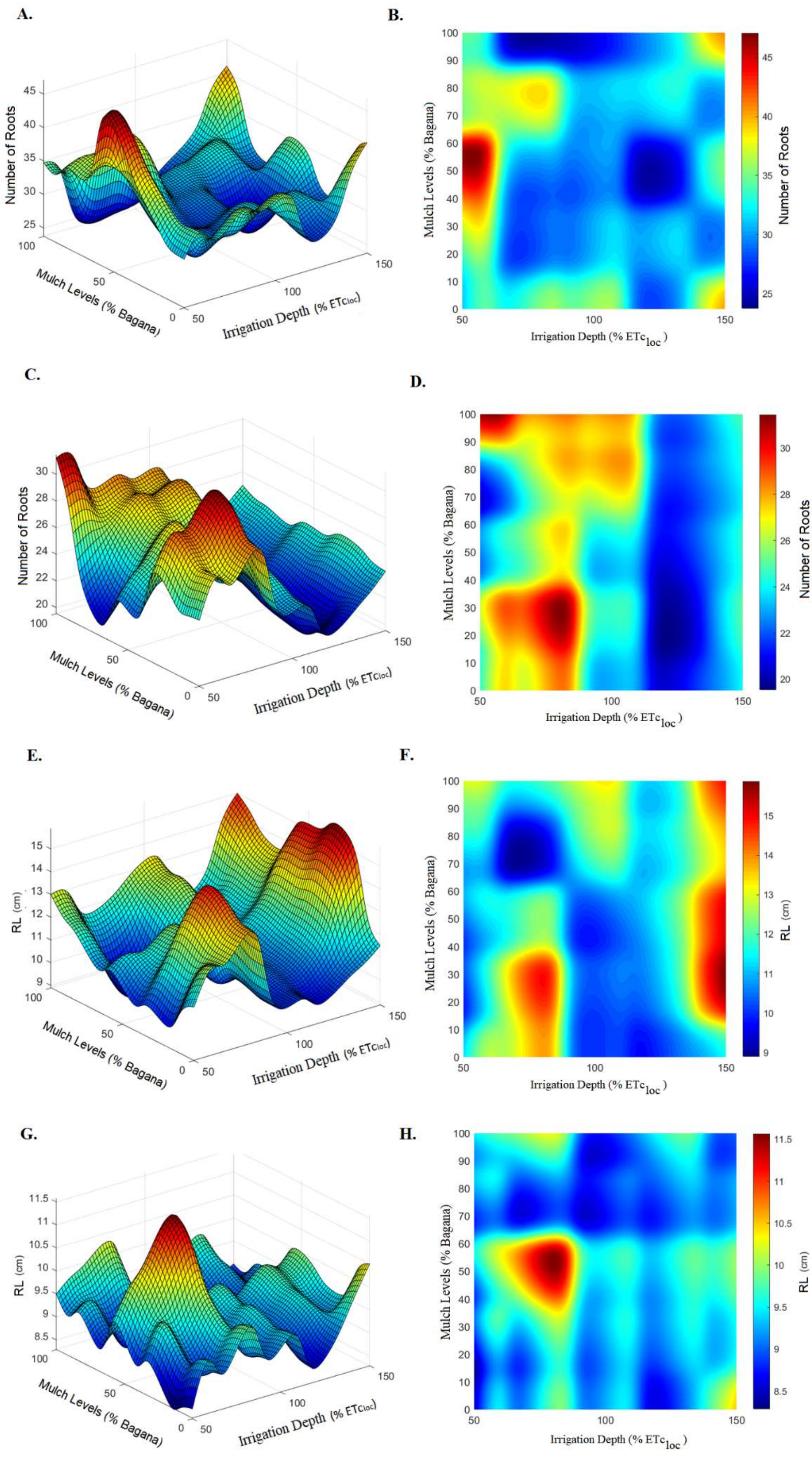


FIGURE 8. Three-dimensional surfaces and contour maps for the variable number of roots (A, B, C, and D) and root length (E, F, G, and H) in the first and second cycles of coriander cultivation as a function of bagana mulch levels and irrigation depths.

The MAE, MSE, and RMSE fit errors of all models were calculated as a form of validation (Table 2). Neuro-fuzzy models always have smaller fit errors than multiple quadratic polynomial regression models. MAE, MSE, and RMSE reached values 9, 22, and 10% smaller for the proposed neuro-fuzzy models relative to the regression models, thus demonstrating the accuracy of the tested model.

Gabriel Filho et al. (2022) demonstrated the efficiency of fuzzy models for decision-making and their accuracy. The authors reported that fuzzy systems explain implicit rules in the agronomic experiment, as well as present models that allow adequate comparison between different factors in irrigated agriculture, such as the use of different cultivars and irrigation depths.

TABLE 2. Mean absolute error (MAE), mean square error (MSE), and root mean square error (RMSE) of neuro-fuzzy (F) and regression (R) models for the 1st and 2nd cycles of coriander cultivation and a comparative percentage between the models for the variables productivity, shoot dry mass, root dry mass, height, shoot fresh mass, number of roots, root length, and root fresh mass.

Variable	Model	Cycle 1			Cycle 2		
		MAE	MSE	RMSE	MAE	MSE	RMSE
Prod.	**F**	1,303	2,802,388	1,674	7,416	89,872,208	9,480
	R	1,425	3,429,471	1,852	8,373	115,890,392	10,765
	%	*-9%*	*-22%*	*-11%*	*-13%*	*-29%*	*-14%*
SDM	**F**	1.0	1.7	1.3	1.0	1.5	1.2
	R	1.2	2.3	1.5	1.1	1.8	1.4
	%	*-15%*	*-33%*	*-15%*	*-11%*	*-19%*	*-9%*
RDM	**F**	0.40	0.39	0.62	0.35	0.21	0.46
	R	0.42	0.48	0.69	0.37	0.26	0.51
	%	*-4%*	*-23%*	*-11%*	*-6%*	*-25%*	*-12%*
Height	**F**	5.5	56.6	7.5	3.1	13.9	3.7
	R	5.6	59.6	7.7	3.1	16.0	4.0
	%	*-2%*	*-5%*	*-3%*	*-2%*	*-15%*	*-7%*
SFM	**F**	11.8	232.9	15.3	10.4	173.6	13.2
	R	12.9	282.9	16.8	11.7	222.3	14.9
	%	*-9%*	*-21%*	*-10%*	*-12%*	*-28%*	*-13%*
NR	**F**	7.9	118.8	10.9	4.5	31.2	5.6
	R	8.5	137.6	11.7	4.8	37.9	6.2
	%	*-7%*	*-16%*	*-8%*	*-6%*	*-21%*	*-10%*
RL	**F**	1.8	6.3	2.5	1.1	1.8	1.3
	R	2.2	8.5	2.9	1.2	2.1	1.5
	%	*-22%*	*-35%*	*-16%*	*-9%*	*-18%*	*-9%*
RFM	**F**	1.7	5.6	2.4	1.4	3.2	1.8
	R	1.9	7.1	2.7	1.6	3.9	2.0
	%	*-11%*	*-25%*	*-12%*	*-11%*	*-23%*	*-11%*

CONCLUSIONS

The neuro-fuzzy model can be a viable option for decision-making in irrigated crops, being able to optimize the use of natural resources and available water in semi-arid regions.

According to the proposed model and aiming at the need to reduce the use of water resources in semi-arid regions, the use of 55% of irrigation depth associated with a range between 40 and 50% of mulch levels can be an interesting strategy for higher water use efficiency. The use of 100% of ETc_{loc} and 100% of mulch is recommended to maximize production when the availability of natural resources is not an issue.

The potential of carnauba bagana as a mulch to mitigate water scarcity is a reality, in which new studies with different crops and amounts of mulch should be explored.

The need for further research regarding the interference of carnauba bagana absorption with the availability of water through irrigation is necessary, as there was a need for higher levels of irrigation depths that exceed 100% of the crop requirements, and fuzzy application in the results to maximize the interactions.

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