Fuzzy Modeling of Development of Sheets Number in Different Irrigation Levels of Irrigated Lettuce with Magnetically Treated Water

Fernando F. Putti[1,2], Luís Roberto A. G. Filho[1,2], Camila P. Cremasco[1,2] and Antonio E. Klar[2]

[1]*FCA, UNESP – Univ. Estadual Paulista, Botucatu,*
Rua Doutor José Barbosa de Barros, 1780, CEP 18610-307, Botucatu – SP, Brazil
[2]*CET, UNESP – Univ. Estadual Paulista, Campus of Tupa,*
Avenida Domingos da Costa Lopes, 780, CEP 17602-496, Tupa-SP, Brazil

Keywords: Growth, Water Stress, Foggy, Uncertain, Precision, Curves.

Abstract: In the wake of the worldwide water supply crisis, several methods are being used to optimize the use of water, mainly in agriculture, which is the main consuming factor. Magnetically treated water for agriculture is beneficent due to an increase in quality and productivity. Current assay evaluates the effects of magnetically treated water in lettuce cultivations throughout its cycle and determines the intermediate rates by fuzzy models submitted at different reposition rates and assessed throughout the cycles. The assay was conducted in randomized blocks with a 4 x 5 factor scheme, with 5 reposition laminas and 4 dates after transplant. Development was evaluated by fuzzy mathematical modeling and by multiple polynomial regressions. Results were compared with data collected on the field. The highest development occurred for treatments irrigated with magnetically treated water, featuring a greater green aerial phytomass and number of leaves throughout the cycle. The fuzzy model provided a more exact adjustment when compared with results from statistical models.

1 INTRODUCTION

The lettuce culture is the most consumed vegetables in Brazil. It is highlighted its economic and social importance because it is grown by small and medium producers. Its consumption has increased by its extensive use in fast-food (Hirata et al, 2014; Sala and Costa, 2008) and by presenting low calories and being a source of vitamins and minerals (Figueiredo et al, 2012.; Oshe et al., 2001).

Recently, studies have shown that satisfactory results are those that use magnetically treated water for irrigation. Several researches indicate the significant increase in productivity, as well as the qualitative issue. Can be highlighted research involving the celery crop, bean and pea (Maheshwari and Grewal, 2009), wheat (Hozayn and Qados, 2010), jatropha (LOPES et al., 2007), corn (AODA; Fattah 2011).

However, often the inaccuracy of the model makes the response does not play indeed what was found. Buckley (2006) found that this inaccuracy could be reduced across the application of fuzzy logic, in which responses were more accurate.

Statistical analyzes for proving trials, as would naturally be the proposal for the analysis of the above aspects have been improved by the use of computational methods capable of predicting with greater accuracy the estimates values.

Furthermore, in general, the greater the complexity of the phenomenon, the lower the accuracy of the model that describes it. Ross (2010) infers that the more imprecise or inaccurate information are we to characterize the fuzzy model, the greater the precision degree will be output.

In recent years, for inaccuracy, nebulae situations in various areas have been explained with application of fuzzy logic, which has sections in applications such as, for example, expert systems seeking specific knowledge extraction and translated into an algorithm. Also the application is to automate processes, known as fuzzy controllers. And the fuzzy modeling seeks to explain certain cases through a system based on fuzzy rules.

Putti, F., Filho, L., Cremasco, C. and Klar, A..
Fuzzy Modeling of Development of Sheets Number in Different Irrigation Levels of Irrigated Lettuce with Magnetically Treated Water.
In *Proceedings of the 7th International Joint Conference on Computational Intelligence (IJCCI 2015) - Volume 2: FCTA*, pages 162-169
ISBN: 978-989-758-157-1

The objective of this study was to develop a fuzzy modeling to estimate the values of the biometric variables of lettuce in all intermediate values between the minimum and maximum rates of water replacement levels adopted and days after transplanting. It was also developed a specific methodology for modeling of realized experiment in proposed fuzzy system.

The model proposed in this work aims to use fuzzy rule based system to also model the response curves, but seeking a higher precision than traditional regression analysis commonly used in agronomic sciences.

However, it should be noted that the use of models based on fuzzy rules has been of great importance in various areas (social, exact, agrarian) to explain facts which classical mathematics cannot. So the fuzzy rule-based systems feature a range of applications to solve these facts even before not explained.

Be advised that papers in a technically unsuitable form will be returned for retyping. After returned the manuscript must be appropriately modified.

2 MATERIAL AND METHODS

Was analyzed previously in all datasets considered in this study, the data normality test was conducted by Anderson-Darling test and found to homocedasticity to analyze the constant variance of the errors of the data with testing the equation of variance (or Bartlett test) (Pagano and Gauvreau, 2012). Developed a prediction model using known data of independent variable $(x_1, x_2, x_3, \dots, x_k)$ and estimate the value of the dependent variable (y) (HAIR et al, 2006; ZAVALA, 2007), in which the general model may be given by the equation:

$$y = \beta_0 + ax_1 + a_1x_2 + a_2x_2^2 + a_3x_2^3$$

where β_0 is the linear coefficient, x_1 is the type of water treatment ($x_1 = 0$ for conventional treatment and $x_1 = 1$ for magnetic treatment), x_2 is a level percent of irrigation, $x_2 \in [25; 125\%\ da\ ETc]$.

The fuzzy mathematical modeling proposed in this work sought to explain the agronomic production characteristics of the lettuce due to irrigation management in the use of magnetic treatment water in the intermediate intervals the levels of agronomical factors experiment performed, namely $]25k\%, 25(k+1)\%;\ 1 \leq k \leq 4[$. In levels $25k\%, 1 \leq k \leq 4$, being evaluations also the cycle long (14, 21, 28 and 35 days after transplanting) , was held in one que modeling way analogous paragraph each cycle . if considering hum agronomic characteristics model, thus have- se $f: \mathbb{R}^2 \to \mathbb{R}$, with $y = f(\bar{x})$, wherein $\mathbb{R}$ is the set of real numbers; in que $x = (x_1, x_2)$ is defined by por $x_1 =$ fluid replacement rate (% of ETc) and $x_2 =$ days after transplanting, with$x_2 \in \{14\ ,35\}$;and $y = (y_1, \dots, y_5)$ is defined by the mean values of biometric characteristics , namely $y_1 = \overline{NF}$.

This system is based on fuzzy rules function is the $F: [14,35] \times [25,125] \to \mathbb{R}, F(x,y) = (f_1(x,y), f_2(x,y), f_3(x,y), f_4(x,y), f_5(x,y))$, where the Cartesian product that represents the reviews of field over the cycle (14 a 35 days after transplanting) and levels irrigation (25 to 125% , etc.) wherein codomain $\mathbb{R}$ response variable is evaluated in the experiment.

For the input variable " Irrigation Blades " , they considered five fuzzy sets denoted by $L_i, i = 1, 2, 3, 4, 5$. This definition is due to the fact that the agronomic experiment , there were five dimensioned irrigation water according to the Etc levels , namely $(25i)\%, i = 1, 2, 3, 4, 5$. Membership functions were adopted (trapezoidal) of L_i sets because according Yet (2009), because it is a set that features a continuous variable , the trapezoidal model fits better in the model answer. With this, such functions are set so that each ratio (% of Etc) has degree of membership equal to 1 when its corresponding fuzzy set $(u_{L_i}(25i\%) = 1)$ and $u_{L_i}(x) < 1$ para $x \neq 25i$.

The output variables were chosen electing the variables of biometric analysis , observed that no significant differences (p < 0.001) , according to Putti (2013) .

Results are presented in two surfaces responses , one for each type of water, and for each cycle as follows:

Group 1 - graphs of functions $F_1^0: [14,35] \times [25; 125] \to \mathbb{R}$, $F_1^0(0,y) = f_1(0,y)$, wherein the codomain of F_1^0 E on the number of sheets ; $F_1^1: [14,35] \times [25; 125] \to \mathbb{R}$, $F_1^1(0,y) = f_1(1,y)$, wherein the codomain of F_1^1 1is on the number of sheets ;

The rule base of the fuzzy system developed shows how the results are modeled. Assuming the fuzzy rule that :

- If " premise (antecedent) " " conclusion (consequent) "

it was possible to calculate the model inputs , from the combination of the factors set as outputs.

From the input variables , it was possible to create twenty pairs of rules ($Blade\ irrigation \times Days\ After\ Transplanting$) and associated with five output variables. The basic rules created for the proposed fuzzy model was created using the methodology proposed in Cremasco et al . (2010) and Gabriel Filho et al. (2011), in which, after the construction of fuzzy sets output , the highest degree of relevance of each median of the treatments were calculated by linking the input variables to the output.

The calculated values of the output variables with membership degree 1 were determined by associations with the fuzzy sets of the output variables. Accordingly , from the necessity of calculating the delimiters 19 , as performed in the method for preparing the fuzzy sets output , it was determined percentile leve 1 0 % (minimum) and 5,36. i, with i = 1,2 , ..., 18,19 the data of output.

variables S, enabling the subsequent classification of the output variable of the points with membership degree 1 , characterized the rule base of fuzzy systems:

- If $S \leq P(5{,}26\%)$ then VS é "$C1$";
- If $P(10{,}52\%) \leq S \leq P(15{,}78\%)$ then VS é $C2$;
- If $P(21{,}04\%) \leq S \leq P(26{,}3\%)$ then VS é $C3$;
- If $P(31{,}56\%) \leq S \leq P(36{,}82\%)$ then VS é $C4$;
- If $P(42{,}08\%) \leq S \leq P(47{,}34\%)$ then VS é $C5$;
- If $P(52{,}6\%) \leq S \leq P(57{,}86\%)$ then VS é $C6$;
- If $P(63{,}12\%) \leq S \leq P(68{,}38\%)$ then VS é $C7$;
- If $P(73{,}64\%) \leq S \leq P(78{,}9\%)$ then VS é $C8$;
- If $P(84{,}16\%) \leq S \leq P(89{,}42\%)$ then VS é $C9$;
- If $VS \geq P(94{,}68\%)$ then VS é $C10$,

For preparing the system based on fuzzy rules and multiple regression equations, it was possible to analyze the degree of association intensity, being held the analysis of the data collected in fields with SBRF and the regression equations, using the following tests:

1. Mean square error:

$$EQM = \sum_{i=1}^{n} \frac{(y_{obs} - y_{fuzzy})^2}{n}$$

2. Pearson Correlation (r):

$$r = \frac{\sum_{i=1}^{n}(y_{fuzzy} - \bar{y}_{fuzzy})(y_{obs} - \bar{y}_{obs})}{\left[\sum_{i=1}^{n}(y_{fuzzy} - \bar{y}_{fuzzy})^2 (y_{fuzzy} - \bar{y}_{fuzzy})^2\right]^{1/2}}$$

3. Index the Willmott et al. (1985):

$$d = 1 - \left[\frac{\sum_{i=1}^{n}|y_{fuzzy} - y_{obs}|^2}{\sum_{i=1}^{n}(|y_{fuzzy} - \bar{y}| + |y_{obs} - \bar{y}|)^2}\right]$$

where, y is the average of the observed values; y is the data observed in the field; x is the average of data modeled former is given modeled.

The closer to 1 the better r² value is the model fit. For the analysis of Willmott index, the closer to 1 the "d" the greater the accuracy of the model.

So this methodology sets up a way to compare ways of curve fitting that in this work were established by fuzzy system and regression analyzes. So this methodology sets up a way to compare ways of curve fitting that in this work were established by fuzzy system and regression analyzes. After the implementation in Matlab software, it was possible to develop a program in Toolbox Fuzzy Logic environment to simulate different scenarios of discrete fuzzy rule -based system within the predetermined intervals in the input sets.

3 RESULTS AND DISCUSSION

From the verification of the assumptions of normality and homoscedasticity, where were accepted, there was the need for data transformation. Thus, it was possible to determine the adjustment equations to model the response variable as a function of irrigation depths and evaluations throughout the cycle. Table 1 shows the setting equations of the model in which one can observe that the adjustment occurs by means of 3rd degree equation (Table 1).

The construction methodology of the model membership functions output can be seen in Figure 1. The development was made possible by the determination of the percentiles of each output variable , so we can see the shape of fuzzy sets for biometric variables in their respective cycle in appendix tables enabling the determination of the vertices of the graphs below .

Defined the membership functions, the fuzzy sets of biometric variables were developed, combining the highest degree of membership for each assessment carried out for the lettuce crop when submitted to irrigation with ATM and AC, similarly for each cycle.

The fuzzy models developed intermediate situations allowed to check more accurately, when compared with the curves generated from the multiple polynomial regression models for the development of the culture of lettuce subject at different water depths, they were separately analyzed types of water and cycles. From the implementation of Matlab computational environment, it was possible to perform simulations of intermediate levels of irrigation and also for intermediate levels of evaluations. The simulations were implemented using the *evalfi*s function. Thus enable the preparation of surfaces for answers to the biometric evaluations.

In the analysis of leaf number was verified that the treatments irrigated with ATM showed higher development compared to irrigated with AC (Figure1).

Table 1: Coefficients of regression and determination of the multiple polynomial equations for growing lettuce submitted in different irrigation evaluated over the cycle.

$$y = \beta_0 + \sum_{j=1}^{2} \sum_{i=1}^{3} a_{ij} x_j^i$$

	NF -1ºCycle		NF -2ºCycle	
	WM	WP	WM	WP
β_0	30,33*	-23,71*	30,4*	-43,23*
ax_1	-0,184*	0,47*	- 0,224*	6,86*
ax_1^2	0,002*	0,0074*	0,0027*	0,12
ax_1^3	- 0,000006	- 0,000033*	- 0,0000009	- 0,31
a_1x_2	- 0,184*	4,92*	- 2,75*	- 0,002*
$a_2x_2^2$	0,1*	- 0,19*	0,1*	0,005*
$a_3x_2^3$	0,00068	0,0027*	- 0,00059	0,000001*
R^2	0,98*	0,89*	0,94*	0,94*

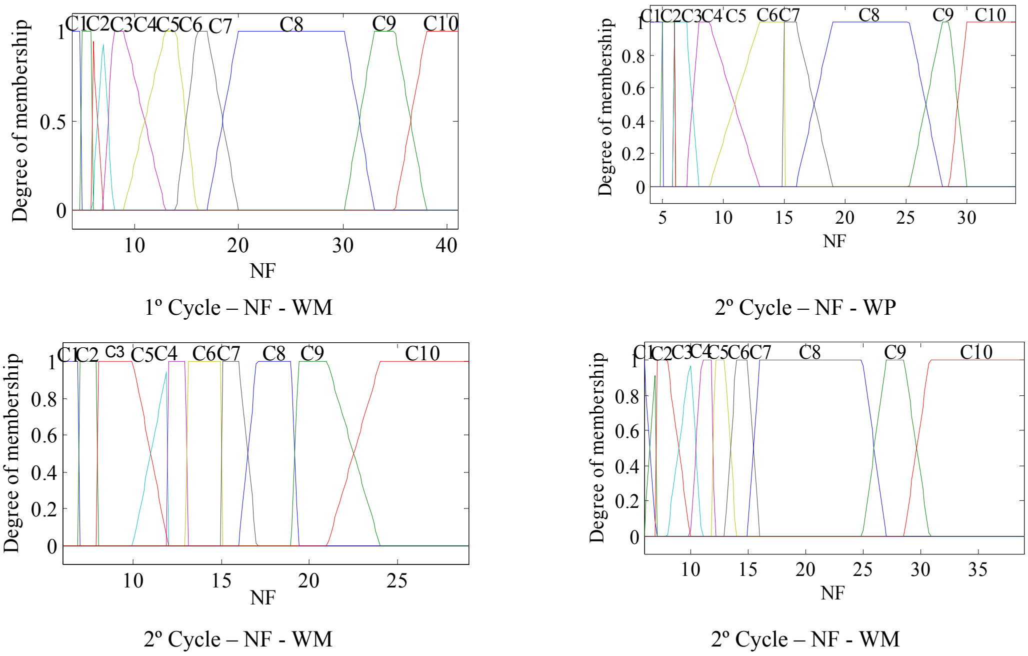

Figure 1: Membership functions of fuzzy sets for the output variables of the lettuce crop under irrigation levels and ATM, over the cycle to the 1st cycle.

In general for the 1st cycle, the greater the number of leaves accumulation occurred when irrigated with ATM, which treatments for the replacement rates of 75% and 100% etc. The development has occurred in a milder way. When comparing with other blades, the more abrupt development for the past few weeks was observed (Figure 2a), reaching maximum production around 35 sheets.

By analyzing the treatments irrigated with AC, it was noted the less marked development over the cycle, but arriving to accumulate 32 sheets at the end of the cycle (Figure 2c).

In the 2nd cycle, it is very similar to the 1st cycle behavior when subjected to irrigation with ATM, in which there was less pronounced in development rate of 75% etc and the other, occurring more protruding shape (Figure 2b), reaching a maximum 33 sheets.

But when used with irrigation AC noted, in general, held the mildest development throughout the cycle, and produced a maximum of 26 sheets when subjected to irrigation 125% ETC

With fuzzy model developed and the multiple polynomial regression equations, it was possible to verify the degree of association intensity of the models with the data collected in the field, which were used as parameters analyzes the Pearson correlation (r), mean square error (EQM) and the index " d " Willmott. Given our results, it can be

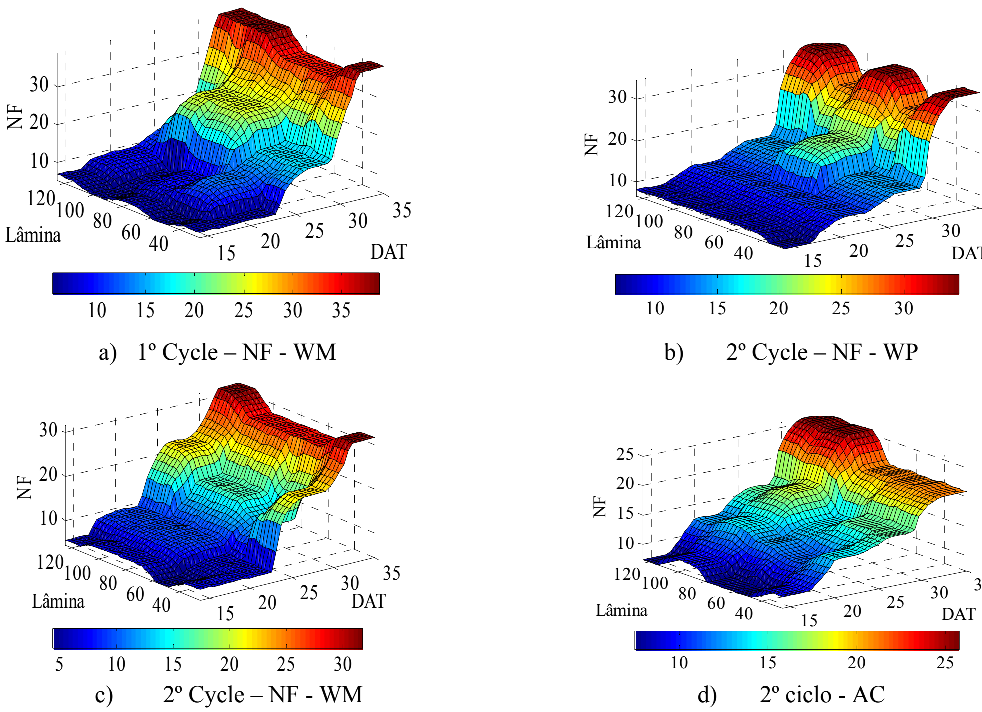

Figure 2: Number of lettuce leaves under different irrigation levels and types of water being evaluated throughout the cycle.

Table 2: Association intensity analysis of fuzzy models and regression to the data collected in the field, to biometric variables of lettuce, under different irrigation levels and assessed throughout the cycle for each type of water.

Cycle	Variable	Model	1° cycle		
			MSE	r	d
1	ATM	*fuzzy*	1,20	0,99*	0,986
		regressão	1,46	0,98*	0,773
	AC	*fuzzy*	4,44	0,98*	0,947
		regressão	5,61	0,83*	0,932
2	ATM	*fuzzy*	1,86	0,96*	0,999
		regressão	2,15	0,94*	0,998
	AC	*fuzzy*	7,53	0,95*	0,998
		regressão	50,67	0,73*	0,978

Legend: NF: number of leaf ; FVA : air green fitomasa; FSA: air dry mass; FVR: Green root biomass; FSR: dry mass of roots and " d " Willmott, * significant at α = 5%.

inferred that the fuzzy models were more accurate (Table 2).

From the response surface method, it was possible to draw up contour maps for better visualization of development (Figure 3).

In the 1st cycle, submitted to irrigation with ATM there was a greater number of leaves at 35 DAT in the region A (Figure 3a) and being higher than the production in the region B. In the region, noted the range of irrigation between 80 to 125% of ETc, producing the same amount. Thus, it can be inferred that as reduction in the volume of water applied by irrigation, as well as a reduction in the days of the cycle.

Irrigation using AC, the region had the highest number of leaves compared to the region B, which produced 32 leaves (Figure 3a and c). For the 2nd cycle, it was found that when the irrigation ATM have much production close to 35 DAT. By analyzing the highlighted spots it turns out that the region had the highest production A very close and also the region B, demanding higher volume of water. It should be noted that most production was reached before 35 DAT; thereby there is a possibility of an earlier harvest (Figure 3a and b).

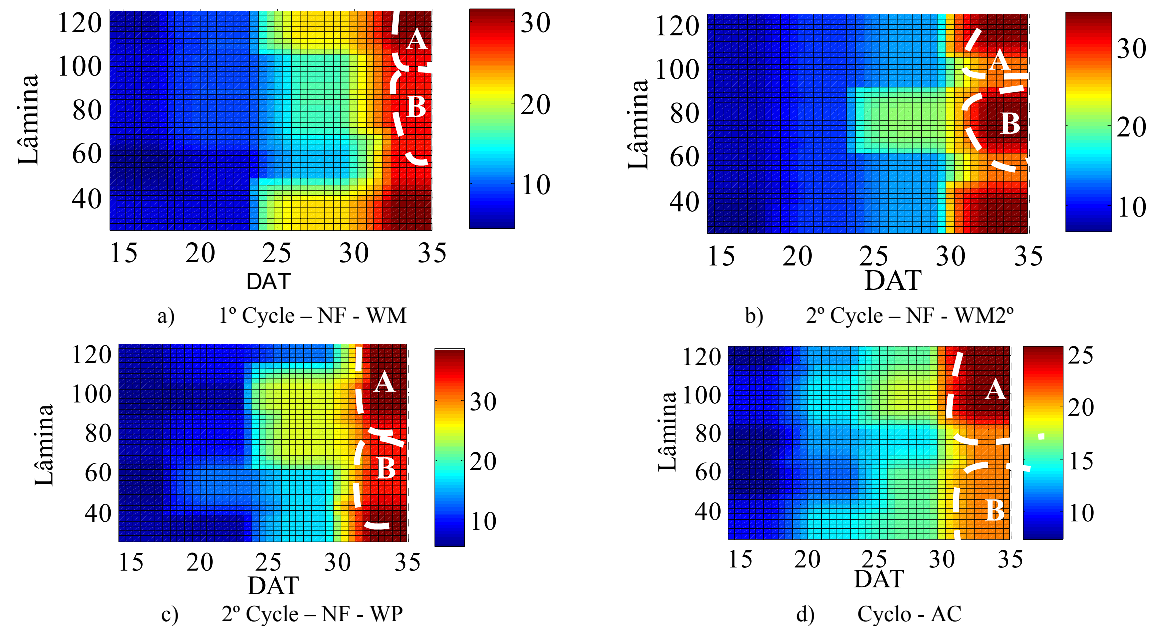

Figure 3: Contour map for the development of the number of sheets subjected to the culture of different irrigation lettuce.

In the 2nd cycle when irrigated with AC, it was found that the region A showed higher accumulation of the number of sheets occurring close to 35 DAT compared with the region B. It should be noted that the region between 90 to reset Etc was 125% of the largest number of sheet, thus the optimum range for maximum yield of the number of sheets contained in the region A.

By analyzing the behavior of water in contact with magnetic fields, it was found that changes occur in their properties, and the main research has been observed in the adsorption of water on surfaces (Ozeki et al., 1996), solubility of some minerals (Bogatin et al., 1999; Gehr et al, 1995;. Hasson et al, 1985; Herzog et al, 1989), surface tension (Joshi et al 1966) and crystallization and precipitation of salts (Katsuki et al... 1996; Kronenberg, 1985).

Bogatin et al. (1999) observed that by subjecting the water to the magnetic field degassing occurred, resulting in an increase in soil permeability, which leads to increased irrigation efficiency. Khoshravesh et al. (2011) to submit the ATM, they found that there was greater soil moisture, compared to AC. Such changes in soil moisture provided by irrigation with ATM favored the absorption of macro and micronutrients by the culture of lettuce.

The changes cause the biggest development in lettuce, which found the same production value with lower irrigation volume of ATM compared with AC irrigation, reducing the total volume of water applied. Furthermore, it was found that there was the possibility of reducing the cycle, because the treatments irrigated with ATM have reached the same air green matter irrigated with water from the conventional DAT 35 before completing even 35 DAT (Table 2).

The fuzzy models showed a higher degree of association with the data collected in the field than the multiple polynomial regression, being that it was possible to verify these results from the statistical tests applied, which proved such a setting. For the value of the mean square error, it was noted that for both types of water, as in the two cycles, the lowest value occurred.

The correlation coefficient was value closer to 1, therefore, closer to the collected data and the value of the model's accuracy by calculating the value of "d" of "Wilmott" also showed the highest values. P value was also determined to verify the significance of the models. In all cases analyzed, it was found value p <0.005.

Carozzi et al. (2013) used the fuzzy model for the determination of producing maize response occurred and found that the lowest error when compared with the regression analysis. Zhang et al. (2013) inferred fuzzy model that achieved the most accurate results in determining the uptake of phosphorus by plants. Polat et al. (2015) found that the application of fuzzy logic enabled determining more precisely the areas with contamination risks. Weber et al. (2014) observed that the fuzzy model for the determination of the hardness of maize showed more accurate results.

4 CONCLUSIONS

From the statistical models we found that irrigation, using ATM, showed higher development for the number of sheets. Was the possible reduction in the volume of wastewater to achieve the same production when subjected to the AC supply. Thus, the technology enables increased food productivity, and optimizing water resource without bringing any harm to health or the environment.

The fuzzy model developed showed a better fit when compared to the strength of the association results of the statistical models of multiple polynomial regression with the data collected in the field, it has been observed that reducing the MSE and the increase in value of re "d" of Wilmott .

So it turns out that the fuzzy modeling provides less error adjustment curves, presenting as a behavior analysis modeling of the variables tested experimentally in the field of agricultural sciences.

Was the possible reduction in the volume of waste water to achieve the same production when subjected the irrigation with AC. Thus, this technology enables increased productivity of food.

The method developed in this work is aimed at preparing the system based on fuzzy rules, without the presence of espcialista. Thus, such a method is innovative in the area of experiments assessments.

REFERENCES

Aoda, M. I; Fattah, M. A. (2011). The Interactive Effects of Water Magnetic Treatment and Deficit Irrigation on Plant Productivity and Water Use Efficiency of Corn (Zea Mays L.). *The Iraqi Journal of Agricultural Sciences*, 42, 164-179.

Bogatin, J., Bondarenko, N. P., Gak, E. Z., Rokhinson, E. E., & Ananyev, I. P. (1999). Magnetic treatment of irrigation water: experimental results and application conditions. *Environmental science & technology*, 33(8), 1280-1285.

Buckley, J. J. 2006. *Fuzzy Probability and Statistics. Studies in Fuzziness and Soft Computing.* 1. ed. vol.196. New York: Springer, 270 p.

Carozzi, M., Bregaglio, S., Scaglia, B., Bernardoni, E., Acutis, M., & Confalonieri, R. (2013). The development of a methodology using fuzzy logic to assess the performance of cropping systems based on a case study of maize in the Po Valley. *Soil Use and Management*, 29(4), 576-585.

Cremasco, C. P., Gabriel Filho, L. R. A., & Cataneo, A. (2010). Metodologia de determinação de funções de pertinência de controla-dores fuzzy para a avaliação energética de empresas de avicultura de postura. *Energia na agricultura*, 25(1), 21-39.

Figueiredo, C. C., Ramos, M. L. G., McManus, C. M., & de Menezes, A. M. (2012). Mineralização de esterco de ovinos e sua influência na produção de alface. *Horticultura Brasileira*, 30(1), 175-179.

Gabriel Filho, L. R., Cremasco, C. P., Putti, F. F., & Chacur, M. G. (2011). Application of fuzzy logic for the evaluation of livestock slaughtering. *Engenharia Agrícola*, 31(4), 813-825.

Gehr, R., Zhai, Z. A., Finch, J. A., & Rao, S. R. (1995). Reduction of soluble mineral concentrations in CaSO 4 saturated water using a magnetic field. *Water Research*, 29(3), 933-940.

Hair, J. F. Anderson, R. E.; Black, W.C.; Tatham, R.L. 2005. *Análise Multivariada de Dados*. Porto Alegre: Bookman, 5th. edition

Hasson, D., & Bramson, D. (1985). Effectiveness of magnetic water treatment in suppressing calcium carbonate scale deposition. *Industrial & Engineering Chemistry Process Design and Development*, 24(3), 588-592.

Herzog, R. E., Shi, Q., Patil, J. N., & Katz, J. L. (1989). Magnetic water treatment: the effect of iron on calcium carbonate nucleation and growth. *Langmuir*, 5(3), 861-867.

Hirata, A. C. S., Hirata, E. K., Guimarães, E. C., Rós, A. B., & Monquero, P. A. (2014). Plantio direto de alface americana sobre plantas de cobertura dessecadas ou roçadas. *Bragantia*, 73(2), 178-183.

Hozayn, M., & Qados, A. M. S. A. (2010). Irrigation with magnetized water enhances growth, chemical constituent and yield of chickpea (Cicer arietinum L.). *Agriculture and Biology Journal of North America*, 1(4), 671-676.

Joshi, K. M., & Kamat, P. V. (1966). Effect of magnetic field on the physical properties of water. *J. Ind. Chem. Soc*, 43, 620-622.

Katsuki, A., Tokunaga, R., Watanabe, S. I., & Tanimoto, Y. (1996). The Effect of High Magnetic Field on the Crystal Growth of Benzophenone. *Chemistry Letters*, (8), 607-608.

Khoshravesh, M., Mostafazadeh□Fard, B., Mousavi, S. F., & Kiani, A. R. (2011). Effects of magnetized water on the distribution pattern of soil water with respect to time in trickle irrigation. *Soil Use and Management*, 27(4), 515-522.

Kronenberg, K. J. (1985). Experimental evidence for effects of magnetic fields on moving water. Magnetics, *IEEE Transactions on*, 21(5), 2059-2061.

Lopes, G. N., Kroetz, V. J., Alves, J. M. A., & Smiderle, O. J. (2010). Irrigação Magnética. *Revista Agro@ mbiente* On-line, 1(1), 1-8.

Maheshwari, B. L., & Grewal, H. S. (2009). Magnetic treatment of irrigation water: Its effects on vegetable crop yield and water productivity. *Agricultural water management,* 96(8), 1229-1236.

Mamdani, E. H., & Assilian, S. (1975). An experiment in linguistic synthesis with a fuzzy logic controller. *International journal of man-machine studies*, 7(1), 1-13.
Ohse, S., Dourado-Neto, D., Manfron, P. A., & Santos, O. S. D. (2001). Qualidade de cultivares de alface produzidos em hidroponia. *Scientia Agrícola*, 58(1), 181-185.
Ozeki, S., Miyamoto, J., Ono, S., Wakai, C., & Watanabe, T. (1996). Water-solid interactions under steady magnetic fields: Magnetic-field-induced adsorption and desorption of water. *The Journal of Physical Chemistry*, 100(10), 4205-4212.
Pagano, M.; Gauvreau, K. 2012. Princípios de Bioestatística. São Paulo: Pioneira Thomson Learning.
Polat, S., Aksoy, A., & Unlu, K. (2015). A Fuzzy Rule Based Remedial Priority Ranking System for Contaminated Sites. *Groundwater*, 53(2), 317-327.
Ross, T. J. (2009). *Fuzzy logic with engineering applications*. John Wiley & Sons.
Sala, F. C., & Costa, C. P. D. (2008). Gloriosa': cultivar de alface americana tropicalizada. *Horticultura Brasileira*, 26(3), 409-410.
Weber, C., Dai Pra, A. L., Passoni, L. I., Rabal, H. J., Trivi, M., & Poggio Aguerre, G. J. (2014). Determination of maize hardness by biospeckle and fuzzy granularity. *Food science & nutrition*, 2(5), 557-564.
Yeh, C. T. (2009). Weighted trapezoidal and triangular approximations of fuzzy numbers. *Fuzzy Sets and Systems*, 160(21), 3059-3079.
Zavala, A. A., Bolfarine, H., & de Castro, M. (2007). Consistent estimation and testing in heteroscedastic polynomial errors-in-variables models. *Annals of the Institute of Statistical Mathematics,* 59(3), 515-530.
Zhang, T., Page, T., Heathwaite, L., Beven, K., Oliver, D. M., & Haygarth, P. M. (2013). Estimating phosphorus delivery with its mitigation measures from soil to stream using fuzzy rules. *Soil Use and Management*, 29(s1), 187-198.