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REGULAR ARTICLE

# *Fuzzy* modeling of the effects of the use of mineral and organic fertilizers on the productivity of second crop corn

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## Abstract

A high productivity in a culture mainly the corn it is associated with many factors, like technological application, integrated management of plagues and diseases, soil fertility, primarily for the disponibility in soil nutrients. The present study has a its objective to analyze statistically the corn productivity with a different dosage of the 5-10-10 mineral fertilizers and organic bovine composting and develop a logic-based system *Fuzzy* of the agronomic parameters. The experiment measured corn productivity in five different dosages of mineral and organic fertilizers, being developed in the field at Colégio Agrícola de Toledo (CAET), Toledo/PR, Brazil. The results showed that a specific range of fertilizer dosages (mineral and organic) can increase corn productivity in the second crop. With the *Fuzzy* model developed, it was possible to verify the importance of the use of optimization tools that can assist in the analysis of experimental data and allow performing simulations capable of inferring points that have not been determined experimentally in the field.

## Keywords

Artificial intelligence; optimization; Fertilizer 5-10-10; bovine composting.



## Introduction

Corn is one of the main cereals produced in Brazil with about 14 million hectares and an average productivity of 3.9 tons hectare$^{-1}$ (CONAB, 2022). With great prominence in the results of the national GDP (National Gross Domestic Product), with approximately 715 billion reais (CNA, 2021).

High productivity is related to several factors, such as applications of technologies, integrated pest and disease management, soil fertility, among others (Araújo et al., 2019). Like any plant, corn requires essential nutrients for its growth, development and production, with the emphasis on macronutrients nitrogen (N), phosphorus (P) and potassium (K) (EMBRAPA, 2009). According to Malavolta et al. (1997), the deficiency or excess in the application of a nutrient can generate a nutritional imbalance in the plant, causing symptoms of nutritional deficiency and "weakening" the plant in a possible defense against pathogens and mainly reducing productivity.

Therefore, optimization in the agricultural production process is fundamental, because it seeks to mathematically model data so that they are applied to the field in order to reduce waste and/or excess of products that can impact production costs and the environment (Godinho et al., 2021).'

Mathematical modeling is an important methodology to optimize productive processes, such an industrial, agricultural, economic, etc., Caneppele et al. (2021), describe that the logic *Fuzzy* is a modeling that has stood out when looking for optimization in production chains. cites that an efficient method is the applicability of *Fuzzy* logic. Godinho & Caneppele (2022), report that *fuzzy* or nebulous logic is standing out in organizational structures because it works with algorithms, these being close to human reasoning.

The present study aims to statistically analyze corn productivity with different dosages of mineral fertilizers 5-10-10 and organic cattle composting and establish a system based on *Fuzzy* Logic helping farmers assess their possible productivity in corn.

## Materials and methods

### *Agronomic experiment*

The experiment was conducted in field conditions without use of screens on the experimental beds, was carried out in the period from August to November 2019, in the experimental area of the State Agricultural College of Toledo (CAET - PR), located in the municipality of Toledo/PR, with an altitude of 240 m, south latitude 24°47'16" and west latitude 53°43'29" in

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the southern region of Brazil. According to Belusso and Serra (2006), the region of western Paranaense, where the type 3 soil is predominant (> 35% clay), the region's climate is characterized (mesothermal Cfa), under the influence of a humid temperate climate with high summer temperatures.

***Management and cultivation practices***

Soil samples were taken from the experimental beds and forwarded to be processed and analyzed at the Laboratory of Chemistry and Soil Fertility State University of Western Paraná (UNIOESTE), according to Pauletti & Motta (2019). The soil of the western region of Paraná was classified as eutrophic Latossolo Vermelho with a very clayey texture (Giarola et al., 2009).

The soil of the site as shown below shows that the soil did not require corrections with limestone and/or with a specific fertilisation, with the following characteristics: K = 1,06 $cmol_c$ $dm^{-3}$; Ca = 10,81 $cmol_c$ $dm^{-3}$; Mg = 2,10 $cmol_c$ $dm^{-3}$; P = 49,40 mg $dm^{-3}$ by Mehlich extractor; $Al^+$ = 0,2 $cmol_c$ $dm^{-3}$; H + Al = 3,71 $cmol_c$ $dm^{-3}$; pH in $H_2O$ = 5,54 and base saturation = 76,06%. The beds had as experimentation area, being 3 m long with 2.8 m, with 8.4 m².

The sowing was carried out on August 15, 2019 with the harvest on December 10 of the same year, the flowerbed was divided into 5 lines of corn variety DK255 with spacing of 15 cm between plant and 45 cm between lines, leaving 0.5 m distance between the edges of the flowerbed.

The experimental design used was an experimental planning (5 × 5) in a completely randomized block (IHD). The treatments were related to applications of 5 different dosages (150, 200, 250, 300 and 350) kg $ha^{-1}$ of mineral fertilizer 5-10-10 (NPK) and 5 different dosages (25, 50, 75, 100 and 125) kg $ha^{-1}$ of organic fertilizer (bovine manure), the applications were carried out with the aid of a shovel on the flowerbed. The experiment was performed in quadruplicate.

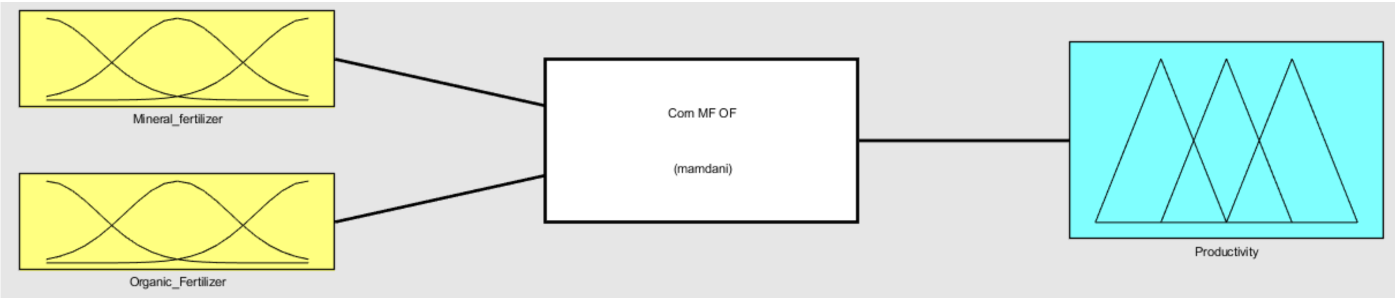
The harvest was performed with grain moisture reaching approximately 14% of moisture. Seven plants were collected randomly within each row. After the manual harvesting, the ears were manually threshed and weighed in an analytical balance of precision of 5 houses after the comma in grams. For the final productivity calculation, the grain moisture was adjusted to 14%.

The averages of the data obtained were compared, using Tukey's test analysis, to 5% probability, later applied to ANOVA and the Anderson-Darling test.

***Fuzzy model***

A system based on *fuzzy* logic was developed with an input processor, a set of language rules, a diffuse inference method and an output processor (defuzzifier), which generates a real output number (Figure 1).

**Figure 1**. *Fuzzy* logic-based system for evaluation of radish bulb, with 2 inputs and 1 output.




The input variables are composed of two different types of fertilizers, Mineral fertilizer 5-10-10 (MF) and bovine organic composting fertilizer (OF). Table 1 and Figure 2 show the five pertinence functions called MF1, MF2, MF3, MF4 and MF5 for the Mineral Fertilizer variable. For the Organic Fertilizer variable, Figure 3 shows the five pertinence functions called OF1, OF2, OF3, OF4 and OF5.

**Table 1.** Definitions of the degree of relevance for the variables Mineral Fertilizer and Organic Fertilizer.

| **Variables** | ***Fuzzy*** | **Delimiters** |
|---|---|---|
| Mineral Fertilizer | MF1 | [100 150 200] |
| | MF2 | [150 200 250] |
| | MF3 | [200 250 300] |
| | MF4 | [250 300 350] |
| | MF5 | [300 350 400] |
| Organic Fertilizer | OF1 | [0 25 50] |
| | OF2 | [25 50 75] |
| | OF3 | [50 75 100] |
| | OF4 | [75 100 125] |
| | OF5 | [100 125 150] |

**Figure 2**. *Fuzzy* set membership functions of the Mineral Fertilizer input variables.

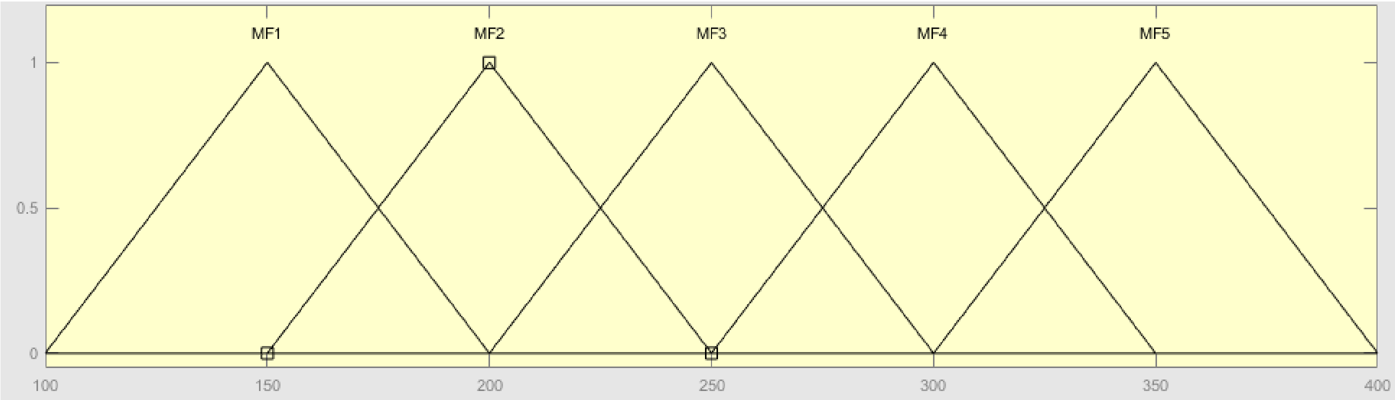
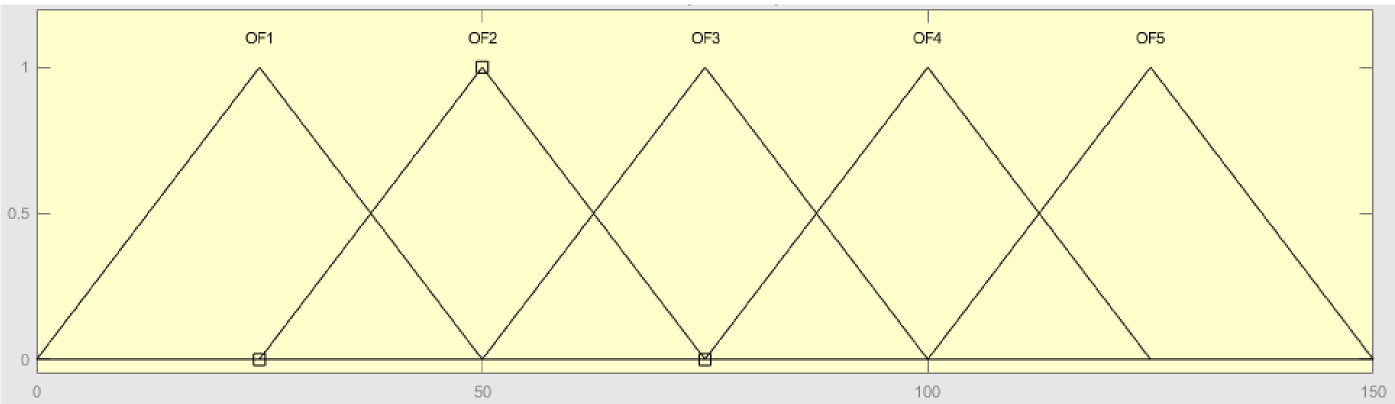



**Figure 3**. *Fuzzy* set membership functions of the Organic Fertilizer input variables.

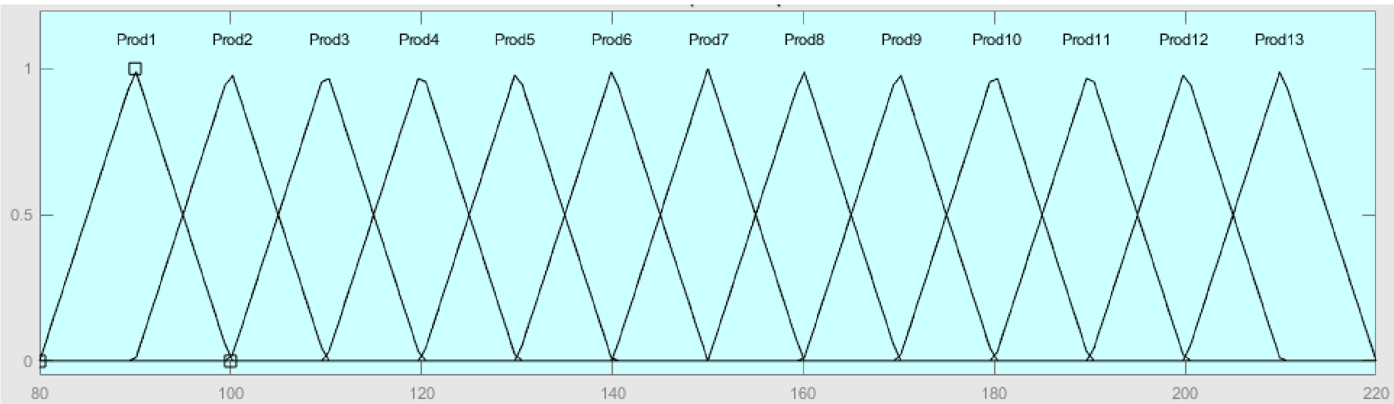



The output variable consisted of corn productivity (Prod), where a diffuse response to the variables analyzed (MF and OF) was developed. The degree of relevance was established in 13 levels, i.e., Prod1, Prod2, Prod3, Prod4, Prod5, Prod6, Prod7, Prod8, Prod9, Prod10, Prod11, Prod12 and Prod13 (Table 2 and Figure 4).

**Table 2.** Definition of parameters of triangular relevance functions for the output variable.

| ***Fuzzy* Set** | **Type** | **Delimiters** |
|---|---|---|
| Prod1 | triangular | [80 90 100] |
| Prod2 | triangular | [90 100 110] |
| Prod3 | triangular | [100 110 120] |
| Prod4 | triangular | [110 120 130] |
| Prod5 | triangular | [120 130 140] |
| Prod6 | triangular | [130 140 150] |
| Prod7 | triangular | [140 150 160] |
| Prod8 | triangular | [150 160 170] |
| Prod9 | triangular | [160 170 180] |
| Prod10 | triangular | [170 180 190] |
| Prod11 | triangular | [180 190 200] |
| Prod12 | triangular | [190 200 210] |
| Prod13 | triangular | [200 210 220] |

**Figure 4**. Fitting functions of *Fuzzy* sets of the output variable.




Twenty-five (5 × 5) combinations between the *Fuzzy* sets of the two input variables were considered for the system's rule base. The model was developed based on Mamdani's inference rules, this method employs calculations of the pertinence functions of the output variable. This methodology was similarly used by Putti et al. (2017), Viais Neto et al. (2019), Godoy et al. (2020) and Góes et al. (2020).

## 3 Results and discussion

### *Agronomic results*

Table 3 and Figures (5 – 6) show the results regarding the effects of application levels of mineral fertilizer and organic fertilizer on the corn crop. The highest productivity levels were detected (MF2 and OF5) and (MF4 and OF5), that is, when 200 kg ha$^{-1}$ of MF was applied with 125 kg ha$^{-1}$ of OF and 400 kg ha$^{-1}$ of MF with 125 kg ha$^{-1}$ of OF. Silva et al. (2012), concluded in a study with mineral fertilization in corn, that there is a great relation in the application of NPK with productivity, besides leaving the soil with a high fertility level, it tends to increase the release of micronutrients to the plant.

**Table 3**. Definition of parameters of triangular relevance functions for the output variable.

| Productivity | OF1 | OF2 | OF3 | OF4 | OF5 | Average |
|---|---|---|---|---|---|---|
| **MF1** | 100.00 Cd | 122.50 Cc | 137.50 Bbc | 150.00 Cab | 160.00 Aa | **134.00** |
| **MF2** | 137.50 Bc | 135.00 Cc | 187.50 Ab | 205.00 Aab | 215.00 Aa | **176.00** |
| **MF3** | 137.50 Bd | 160.00 Bc | 187.50 Ab | 207.50 Aa | 212.50 Aa | **181.00** |
| **MF4** | 175.00 Ac | 195.00 Ab | 195.00 Ab | 187.50 Bbc | 215.00 Aa | **193.50** |
| **MF5** | 180.00 Ab | 190.00 Aab | 195.00 Aab | 180.00 Bb | 207.50 Aa | **190.50** |
| **Average** | **146.00** | **160.50** | **180.50** | **186.00** | **202.00** | |

The averages followed by the same letter do not differ statistically; uppercase in the column and lowercase in the row by Tukey's test at 5% probability. Caption: Mineral Fertilizer (MF) and Organic Fertilizer (OF)

**Figure 5.** Regression graph of the interactions between mineral fertilizer (MF) and organic fertilizer (OF).

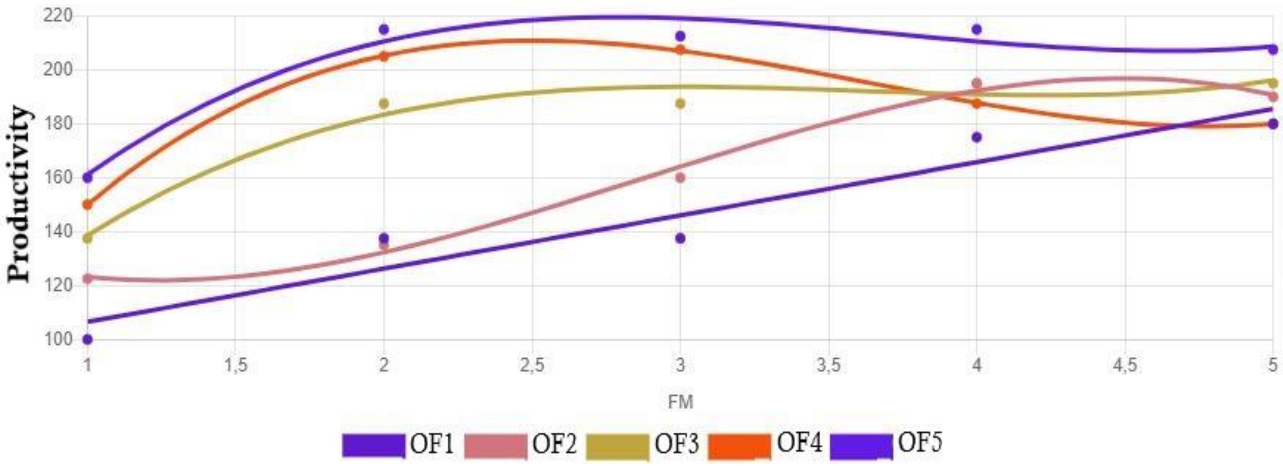
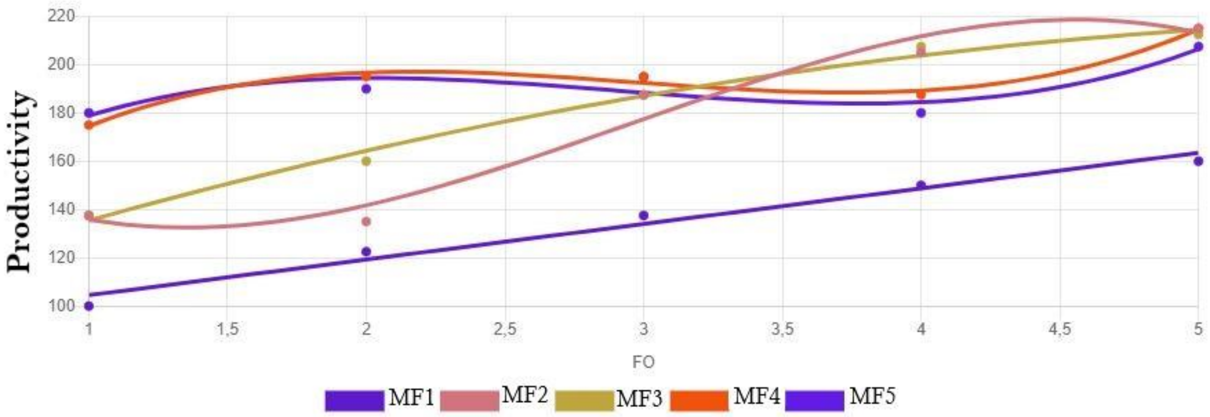



**Figure 6**. Regression graph of the interactions between organic fertilizer (OF) and mineral fertilizer (MF).




The regression equations of the models are shown in Chart 1.

**Chart 1**. Regression equations of the MF x OF interaction.

| | |
|---|---|
| OF → MF1 | $y = 89.750 + 14.750x \rightarrow R^2 = 0.9745$ |
| OF → MF2 | $y = 191.000 - 96.130x + 46.160x^2 - 5.20833x^3 \rightarrow R^2 = 0.9651$ |
| OF → MF3 | $y = 100.500 + 37.964x - 3.0357x^2 \rightarrow R^2 = 0.9901$ |
| OF → MF4 | $y = 98.500 + 112.2020x - 40.714x^2 + 4.5833x^3 \rightarrow R^2 = 0.9848$ |
| OF → MF5 | $y = 118.000 + 91.488x - 34.553x^2 + 3.958x^3 \rightarrow R^2 = 0.8381$ |
| MF → OF1 | $y = 89.750 + 14.750x \rightarrow R^2 = 0.9745$ |
| MF → OF2 | $y = 191.000 - 96.130x + 46.160x^2 - 5.208x^3 \rightarrow R^2 = 0.9651$ |
| MF → OF3 | $y = 100.500 + 37.964x - 3.035x^2 \rightarrow R^2 = 0.9901$ |
| MF → OF4 | $y = 98.500 + 112.202x - 40.714x^2 + 4.583x^3 \rightarrow R^2 = 0.9848$ |
| MF → OF5 | $y = 118.000 + 91.488x - 34.553x^2 + 3.958x^3 \rightarrow R^2 = 0.8381$ |

The increase in corn productivity was affected by the increase in the application of organic fertilizer in due points (OF5, OF4 and OF2 125, 100 and 25 kg ha$^{-1}$) (Figure 5), while the best result presented in (Figure 6) was the use of mineral fertilizer at 200 kg ha$^{-1}$ (MF2). Grohskopf et al. (2019) using in one experiment two different fertilizers (mineral and organomineral), observed that when applying the organomineral the response in the release of phosphorus was higher in the soil.

Reinforcing the results presented in Figures 5 and 6, Silva et al. (2012), proved that corn achieved better productivity responses when it was being planted in areas with organomineral fertilizer with green cover.

***Results of the nebulous model***

After the statistical analysis applied to the agronomic results, the modeling was performed in the logic *Fuzzy*, using the mineral fertilizer and the organic fertilizer an inputs variable with the corn productivity as output variable.

Figure 7 presents the functions of relevance of the *Fuzzy* set of the output variable corn productivity using the parameters of Chart 2.

**Figure 7.** Set pertinence functions *Fuzzy* of the corn productivity output variable.

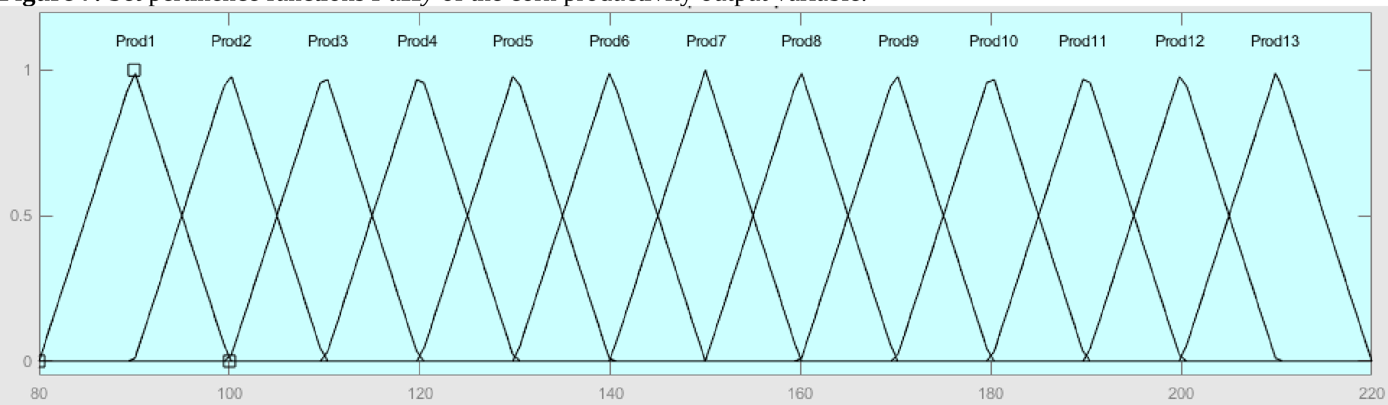


**Chart 2.** Rules base of the *Fuzzy* model

| Mineral Fertilizer | Organic Fertilizer | Productivity |
|---|---|---|
| MF1 | OF1 | Prod1 |
| MF1 | OF2 | Prod3 |
| MF1 | OF3 | Prod4 |
| MF1 | OF4 | Prod5 |
| MF1 | OF5 | Prod6 |
| MF2 | OF1 | Prod4 |
| MF2 | OF2 | Prod6 |
| MF2 | OF3 | Prod11 |
| MF2 | OF4 | Prod12 |
| MF2 | OF5 | Prod13 |
| MF3 | OF1 | Prod4 |
| MF3 | OF2 | Prod6 |
| MF3 | OF3 | Prod9 |
| MF3 | OF4 | Prod10 |
| MF3 | OF5 | Prod10 |
| MF4 | OF1 | Prod7 |
| MF4 | OF2 | Prod9 |
| MF4 | OF3 | Prod9 |
| MF4 | OF4 | Prod9 |
| MF4 | OF5 | Prod10 |
| MF5 | OF1 | Prod9 |
| MF5 | OF2 | Prod10 |
| MF5 | OF3 | Prod10 |
| MF5 | OF4 | Prod9 |
| MF5 | OF5 | Prod10 |

Caption: Mineral Fertilizer (MF) and Organic Fertilizer (OF)

Chart 2 shows the rules base of the *Fuzzy* system, where the first five lines show the rules:

- If (mineral fertilizer is MF1) and (organic fertilizer is OF1), then (corn productivity is prod1);
- If (mineral fertilizer is MF1) and (organic fertilizer is OF2), then (corn productivity is prod3);
- If (mineral fertilizer is MF1) and (organic fertilizer is OF3), then (corn productivity is prod4);
- If (mineral fertilizer is MF1) and (organic fertilizer is OF4), then (corn productivity is prod5);
- If (mineral fertilizer is MF1) and (organic fertilizer is OF5), then (corn productivity is prod6);
- And so on.

The basic rules were developed based on the identification of the highest degree of adherence for each point in the field of function. With 25 pairs correlating the input variables (MF and OF). The detailed rule base for the *Fuzzy* system is shown in Chart 2.

The response surface and contour map of the results are shown in Figures 8 and 9, respectively, according to the dosages of mineral and organic fertilizer applications.

**Figure 8.** Surface of the output variable Corn productivity a functions of the input variables mineral fertilizer and organic fertilizer.

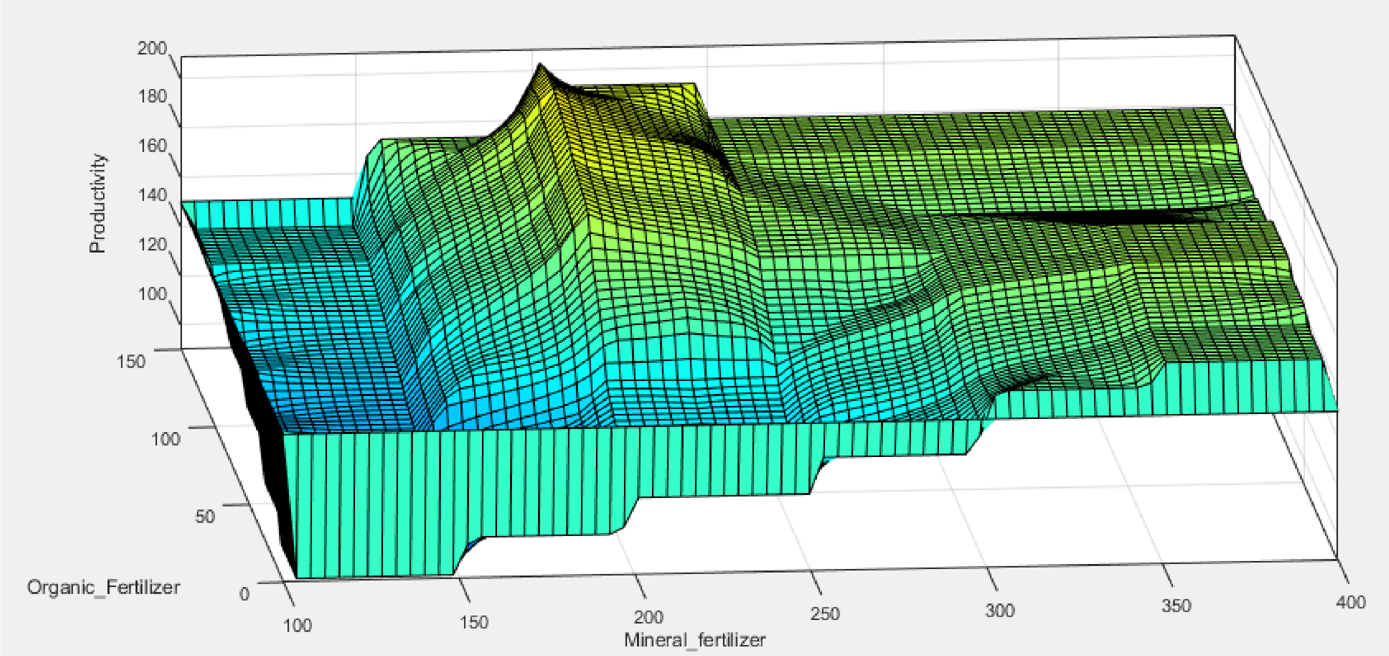
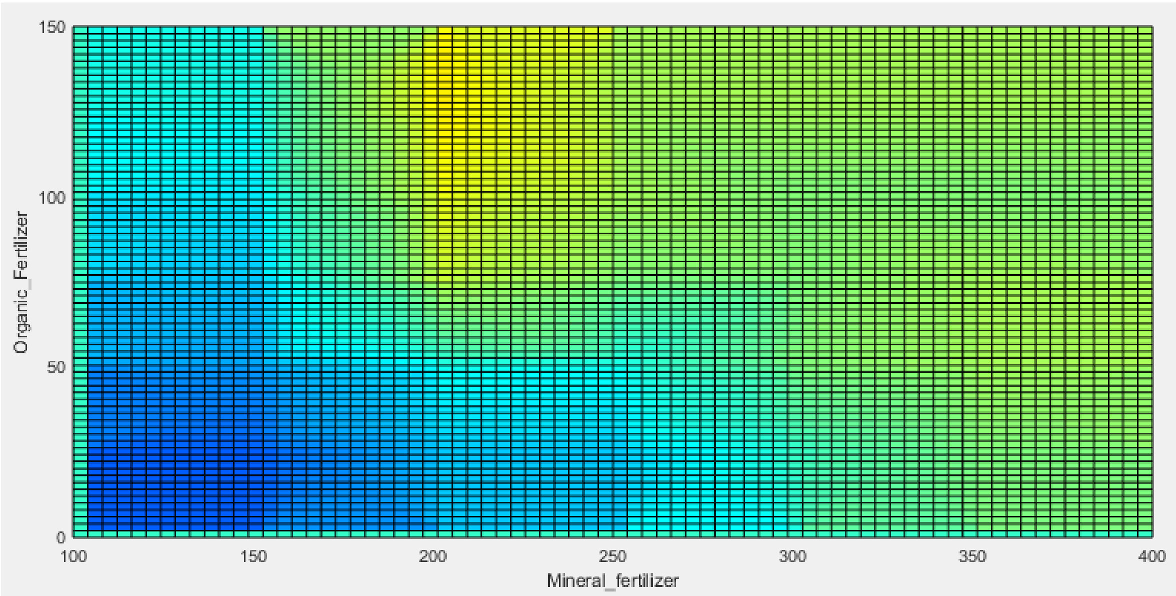



**Figure 9.** Contour map of the output variable Corn productivity as a functions of the input variables mineral fertilizer and organic fertilizer.




Figures 8 and 9 show the best ranges obtained along mineral and organic fertilizer, where for mineral fertilizer the range was 200 to 250 kg $ha^{-1}$ with organic fertilizer between 100 to 150 kg $ha^{-1}$. Where corn productivity varied statistically to different dosages of fertilizers. Such results may be associated with the application and release of the main macronutrients (NPK) having as main focus the immediate release of N to the plant roots, as cited by Alves et al. (2008).

The medium dosage application (not high and not low), shows that for a plant when it is well nourished is when it has the minimum of the maximum nutrient applied, as shown in Figures 8 and 9. Relates plant growth to the amount of the element in the soil. Reinforcing these data Raij (1981) and Russel & Russel (1973), where according to them, the growth of a plant is limited by that nutrient that is in a smaller proportion in the soil, in relation to the physiological need of a plant.

## Conclusions

The statistical conclusions showed that corn productivity is directly related to a specific fertiliser dosage. The current experiment established a mathematical and computational model that monitors corn productivity in relation to various dosages of mineral and organic fertilizers. The method covered different dosages of mineral (5-10-10) and organic (bovine) fertilizer. This resulted in a mathematical system of easy understanding to help rural entrepreneurs to measure possible productivity.

This study used a mathematical method capable of interpreting the productivity of corn using several dosages of a mineral fertilizer (5-10-10) and an organic fertilizer (bovine composting). Having as best intervals in the dosages of MF between 200 to 220 kg $ha^{-1}$ and OF between 100 to 150 kg $ha^{-1}$. In this way, it can be observed that proper management with a specific dosage can provide a high agronomic performance in corn cultivation in the second crop.

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