Comparative Evaluation of Mineral and Organo-Mineral Nitrogen Fertilization and the Role of Amino Acids as Plant Growth Promoters in Maize Cultivation

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Abstract: The challenge to increase nitrogen uptake efficiency in intensively cultivated soils without runoffs and atmospheric release has been difficult to handle and usually leads to the excess application of mineral fertilizers. In the present study, four combinations of two different N fertilizers and a control were used in maize cultivation to evaluate the use of different types of N fertilization in the case of agronomic and plant physiology characteristics, as well as the quantity and quality characteristics of maize’s yield. The results show that, when the full rate of mineral fertilization with the addition of half rate of organo-mineral fertilizer with amino acids (MF+OMAA/2) was used, maize presented a 16% yield increase in comparison with the control, followed by mineral fertilization (MF) with a 10% increase. Protein content was increased in all treatments by 3–6% compared to the control, with the conventional fertilization and the alternates with lower rates of mineral fertilization not differing significantly. The nitrogen content in the leaves of maize increased in both measurements (11–23% and 19–40% at 70 and 107 days after sowing, respectively) of the different fertilizer treatments compared to the control. The results of this study confirm that the organo-mineral fertilizer containing amino acids can be used as an alternative or additive N fertilization that can decrease the use of conventional mineral fertilizers or can result in improved seed productivity and protein content in maize farms.

Keywords: nitrogen fertilization; amino acids; plant growth promoters; protein; maize

1. Introduction

Maize (Zea mays L.) is a major crop worldwide and it has many uses as food, feed and industrial raw material. At the same time, climate change made it clear that the variability in its yield worldwide should be examined and adapted in order to tackle the imminent danger of lack of food [1]. Macronutrients and especially N adequacy in plants are the factors that can make a difference in their production and tackle the problem of food demand when used cautiously [2,3]. N fertilization for maize cultivation can be very crucial to provide a good development and growth of maize plants [4]. Nitrogen uptake efficacy in fully cultivated soils has always been a difficult task in farming because the N flow in an ecosystem can vary from runoff to surface waters to N atmospheric release [5–7]. The excessive and careless use of N fertilization is the main cause of this problem. Plants are most likely to take up dissolved organic N instead of inorganic [8]. Moreover, it has been
observed that N uptake can be improved when organic fertilizers, such as natural compost and seaweed compost, are used instead of conventional fertilization [9].

There is an increasing effort for the rational use of N fertilization by applying relatively low rates aiming to reduce the negative effects on the environment from N loss. This effort would be more difficult without the use of innovative and environmentally friendly products, such as amino acids, organo-mineral fertilizers and other plant growth promoters, microbial or non-microbial [10–12]. In the particular case of amino acids, their role in plants is crucial since they are precursors of various N compounds [13]. Their role as a salinity stress reliever has been reported on fava bean plants when used as a foliar application, improving the decreased parameters of saline stress [12]. Products containing amino acids along with other organo-mineral compounds report that this combination can also help in drought stress situations in tomato plants [14]. Amino acids as plant growth regulators in tomatoes in certain concentrations have been found also to improve yield and nutrients [15]. The enrichment of organic fertilizers with nutrients and biologically active substances, such as amino acids, which are known to stimulate plant growth even at very low concentrations, sustainably increases the productivity of maize [16]. Organo-mineral fertilizers started to emerge as an alternative proposal to conventional fertilizers. It is now established knowledge that the combination of organic and inorganic fertilization increases the productivity of crops such as maize [17]. Different combination rates of organic and mineral fertilizers have been tested in Jerusalem artichoke, and yield and growth characteristics were observed in cases of half-organic and half-mineral fertilization [18]. Moreover, animal-based products have been also tested as fertilizers; in spinach, for example, the combination of fish manure and N supplement produced better results over conventional N applications in growth characteristics and yield [19]. Studies show that animal byproducts can positively affect the habitat of the indigenous bacteria in the rhizosphere in various crops [20,21]. Liquid fish-based fertilizers have been used even in greenhouses that do not use soil as substrate in order to become an alternative to inorganic fertilizers [22,23].

This study aims to evaluate the use of an organo-mineral fertilizer enriched with amino acids at different doses and mixes with urea, which is the fertilizer that is used in common agricultural practice. The evaluation of the use of different types of N fertilization in-season was conducted along with agronomic and plant physiology measurements, as well as the quantity and quality characteristics of the yield of maize.

2. Materials and Methods
2.1. Experimental Site and Design
The field experiment was conducted at Oropos, in the region of Attica, Greece (38°18′ N, 23°45′ E, Altitude 45 m). The maize hybrid DKC 6980 (DEKALB, K&N Efthymiadis Single Member S.A., Sindos, Thessaloniki, Greece) was used. It is a FAO 700 hybrid, with a production cycle of approximately 130–136 days, and it is highly productive. The sowing was conducted on 12 April 2021 and the harvest was conducted on 8 September 2021. The main weather conditions during the cultivation period are presented in Figure 1. The temperature, relative humidity and precipitation data were recorded by a weather station Weatherhub (TFA Dostmann GmbH & Co. KG, Wertheim-Reicholzheim, Germany), which was placed in the experimental area. The cultivation was irrigated using drip irrigation during the growing season according to soil needs.
The experiment followed a completely randomized design with five treatments (four combinations of fertilizers and the control) and three replications. Every experimental plot was 9 m². The distance between rows was 80 cm and the within-row distance from plant to plant was 20 cm. The physical and mineral properties of the soil of the experimental site at the depth of 0–30 cm were determined as described in Table 1.

Table 1. Soil physical and chemical properties.

| Parameters          | Values  | Method                           |
|---------------------|---------|----------------------------------|
| Sand (%)            | 46      | Bouyoucos [24]                   |
| Silt (%)            | 34      |                                  |
| Clay (%)            | 20      |                                  |
| Soil Texture        | Loam    |                                  |
| pH                  | 7.2     | pH-meter                         |
| Electrical Conductivity (mS cm⁻¹) | 1.01 | ISO 11265:1994 [25]              |
| Total salts (%)     | 14      | calculation                      |
| Organic Matter (%)  | 4.1     | ISO 14235:1998 [26]              |
| Total Nitrogen (mg g⁻¹) | 1.93 | ISO 11261:1995 [27]             |
| Available K (cmol + kg⁻¹) | 0.92 |                                  |
| Available Ca (cmol + kg⁻¹) | 22 | atomic absorption spectrometry [28] |
| Available Mg (cmol + kg⁻¹) | 7.7 |                                  |
| Available P (mg kg⁻¹) | 67 | ISO 11263:1994 [29]              |
| Fe-DTPA (mg kg⁻¹)   | 19      |                                  |
| Cu-DTPA (mg kg⁻¹)   | 3       | DTPA [30]                        |
| Zn-DTPA (mg kg⁻¹)   | 5.2     |                                  |
| Mn-DTPA (mg kg⁻¹)   | 21      |                                  |
| Available B (mg kg⁻¹) | 1.1 | Bingham [31]                     |

The base application of the granular fertilizer (Nutrimore 30-6-6, Gavriel D.S. & Co., Ltd., Athens, Greece) was conducted on the same day as the seeding at the rate of 200 kg per ha and it was common to all the experimental plots, including the control. The in-season application of nitrogen was conducted using different split applications of a common mineral fertilizer (Utec 46-0-0, Eurochem S.A., Athens, Greece), and an organo-mineral fertilizer with amino acids (Vitamin Sea 18-0-0, Ikorganic P.C., Kifisia, Greece), and two combinations of the abovementioned fertilizers (Table 2). The organo-mineral fertilizer is a fish-based product with amino acids.
Table 2. Different split applications of N to maize cultivation.

| Treatments               | At Seeding | In-Season 42 DAS | In-Season 56 DAS | In-Season 70 DAS |
|--------------------------|------------|------------------|------------------|------------------|
| T1 (Control)             | 200 kg/ha 30-6-6 | -                | -                | -                |
| T2 (OMAA)                | 200 kg/ha 30-6-6 | 30 lt/ha 18-0-0  | 30 lt/ha 18-0-0  | 30 lt/ha 18-0-0  |
| T3 (MF)                  | 200 kg/ha 30-6-6 | 140 kg/ha 46-0-0 | 140 kg/ha 46-0-0 | 140 kg/ha 46-0-0 |
| T4 (MF/2 + OMAA/2)       | 200 kg/ha 30-6-6 | 70 kg/ha 46-0-0  | 70 kg/ha 46-0-0  | 70 kg/ha 46-0-0  |
|                          |             | + 15 lt/ha 18-0-0 | + 15 lt/ha 18-0-0 | + 15 lt/ha 18-0-0 |
| T5 (MF + OMAA/2)         | 200 kg/ha 30-6-6 | 140 kg/ha 46-0-0 | 140 kg/ha 46-0-0 | 140 kg/ha 46-0-0 |
|                          |             | + 15 lt/ha 18-0-0 | + 15 lt/ha 18-0-0 | + 15 lt/ha 18-0-0 |

OMAA: organo-mineral fertilizer with amino acids; MF: mineral fertilizer. DAS: Days After Sowing.

2.2. Measurements

Fresh and dry weight measurements were conducted 58, 98 and 120 days after sowing (DAS). Three plants per plot were collected from the middle lines. Fresh weight was measured with a precision balance right after the destructive measurement, while for the measurement of the dry weight, the samples were oven-dried at 70 °C for three days. For the physiology measurements (photosynthetic rate, transpiration rate and stomatal conductance), a LCI Leaf Chamber Analysis System (ADC, Bioscientific, Hoddesdon, UK) was used. The physiology measurements were conducted at midday, with a clear sky, on fully expanded leaves at 65 and 106 DAS. At every plot, three measurements with the LCI Leaf Chamber Analysis System were conducted. For the maize plant tissue analysis, fully expanded leaves were collected at 70 and 107 DAS. The samples were oven-dried at 70 °C for 24 h and the total nitrogen was determined by the Kjeldahl method. For the yield measurement, ten plants per plot were harvested.

2.3. Quality Characteristics of Harvested Corn Grains

Total protein (%), moisture (%), fat (%) and starch (%) content were determined using Infratec™ 1241 whole grain analyzer (FOSS, Hillerød, Denmark) after harvest. The scanning temperature range was controlled at 21–25 °C. A sample of 0.5 kg was used, and the mean value of ten subsamples was recorded.

2.4. Statistical Analysis

A one-way analysis of variance (ANOVA) was performed to evaluate the effect of the in-season N fertilization. IBM SPSS software ver. 24 (IBM Corp., Armonk, NY, USA) was used to analyze the experimental data. Duncan test at 5% level of significance \((p \leq 0.05)\) was used for the comparisons of means.

The examination of the dataset was achieved with Python 3.8, the Scikit Learn library and the Pinguin library, with the aim of extracting the predictive importance of the dataset. This was achieved by testing ten different algorithms in 10-fold cross-validation experiments. In total, over 15,000 models with different hyperparameters were tested. The data were saved on JSON format in the MongoDB database.

3. Results

3.1. Plant Growth

Dry weight measurements presented statistically significant differences in all the measurements that were performed (Table 3). In the first measurement (58 DAS), T5 treatment (39.50 g per plant) was the best among the treatments, followed by the T4 treatment (37.14 g per plant). In the second measurement (98 DAS), T5 treatment (379.35 g per plant) along with T3 treatment (400.72 g per plant) were significantly better than the others, with the control treatment (269.36 g per plant) being the worst. In the third
measurement (120 DAS), all fertilization treatments performed significantly better than the control (328.88 g per plant), but no significant differences were present among the different fertilization treatments.

Table 3. Effect of different fertilization combinations on dry weight per plant at 58, 98 and 120 DAS.

| Treatment | 58 DAS | 98 DAS | 120 DAS |
|-----------|--------|--------|---------|
| T1        | 33.76 ± 2.47 b | 269.36 ± 32.87 c | 328.88 ± 14.37 b |
| T2        | 35.02 ± 1.95 b | 324.76 ± 7.38 b  | 369.76 ± 7.00 a  |
| T3        | 36.07 ± 1.57 b | 400.72 ± 4.51 a  | 386.71 ± 5.59 a  |
| T4        | 37.14 ± 1.33 ab| 338.75 ± 12.03 b | 367.72 ± 14.64 a |
| T5        | 39.50 ± 1.07 a | 379.35 ± 26.75 a | 383.63 ± 1.41 a  |

F<sub>treat</sub> = 4.694 * 19.399 *** 15.844 ***

DAS: days after sowing; T1: control; T2: organo-mineral fertilizer with amino acids (OMAA); T3: mineral fertilizer (MF); T4: (MF/2 + OMAA/2) and T5: MF + OMAA/2. Means followed by the same letter for treatments are not significantly different according to Duncan test (p < 0.05). The values presented are mean values of three replicates ± standard deviation. Significance levels: * p < 0.05 and *** p < 0.001.

3.2. Physiology Measurements

Statistically significant differences were present in photosynthetic rate, transpiration rate and stomatal conductance measurements at 65 and 106 DAS (Table 4). In particular, the photosynthetic rate at 65 DAS for T3 mineral fertilization performed the best (32.08 µmol CO₂ m⁻² s⁻¹), followed by the T2 treatment of the organo-mineral fertilizer with amino acids (31.12 µmol CO₂ m⁻² s⁻¹). However, in the second measurement of the photosynthetic rate, the two combinations T4 and T5 were significantly better than the T2, and T3 fertilizations and the control. In particular, T4 treatment had 29.74 (µmol CO₂ m⁻² s⁻¹) and T5 treatment had 30.98 (µmol CO₂ m⁻² s⁻¹). In the case of the transpiration rate in both measurements (65 and 106 DAS), all fertilization treatments performed significantly better than the control; however, among them, nonsignificant differences were observed. Concerning stomatal conductance in both measurements (65 and 106 DAS), the T3 treatment (0.29 and 0.28 mol m⁻² s⁻¹, respectively) had values with no statistically significant differences from the T4 (0.28 and 0.27 mol m⁻² s⁻¹, respectively) and T5 treatments (0.28 and 0.29 mol m⁻² s⁻¹, respectively).

Table 4. Effect of different fertilization combinations on the photosynthetic rate, transpiration rate and stomatal conductance per plant at 65 and 106 DAS.

| Treatment | Photosynthetic Rate (µmol CO₂ m⁻² s⁻¹) | Transpiration Rate (mmol H₂O m⁻² s⁻¹) | Stomatal Conductance (mol m⁻² s⁻¹) |
|-----------|---------------------------------------|--------------------------------------|-------------------------------------|
|           | 65 DAS | 106 DAS | 65 DAS | 106 DAS | 65 DAS | 106 DAS |
| T1        | 28.02 ± 1.03 c | 24.28 ± 0.77 b | 3.32 ± 0.14 b | 2.99 ± 0.13 b | 0.21 ± 0.01 c | 0.24 ± 0.01 b |
| T2        | 31.12 ± 0.87 ab | 25.37 ± 0.44 b | 3.70 ± 0.15 a | 3.56 ± 0.09 a | 0.23 ± 0.01 b | 0.25 ± 0.01 b |
| T3        | 32.08 ± 0.27 a | 26.00 ± 0.45 b | 3.84 ± 0.91 a | 3.53 ± 0.20 a | 0.29 ± 0.01 a | 0.28 ± 0.02 a |
| T4        | 29.58 ± 0.98 bc | 27.94 ± 0.49 a | 3.84 ± 0.05 a | 3.56 ± 0.20 a | 0.28 ± 0.01 a | 0.27 ± 0.01 a |
| T5        | 30.07 ± 1.75 abc | 30.98 ± 2.02 a | 3.88 ± 0.17 a | 3.83 ± 0.42 a | 0.28 ± 0.01 a | 0.29 ± 0.01 a |

F<sub>treat</sub> = 6.064 * 23.995 *** 9.791 ** 5.019 * 62.150 *** 14.731 ***

DAS: days after sowing; T1: control; T2: organo-mineral fertilizer with amino acids (OMAA); T3: mineral fertilizer (MF); T4: (MF/2 + OMAA/2) and T5: MF + OMAA/2. Means followed by the same letter for treatments are not significantly different according to Duncan test (p < 0.05). The values presented are mean values of three replicates ± standard deviation. Significance levels: * p < 0.05, ** p < 0.01 and *** p < 0.001.

3.3. Yield

All fertilization treatments that were applied presented higher values than the control (Figure 2). The highest among them was the T5 treatment, the combination of mineral fertilization with the addition of half organo-mineral fertilizer with amino acids, which
recorded a yield of 266.7 g per plant, followed by the T3 (252.9 g per plant) and T2 treatments (246.6 g per plant), which did not present statistically significant differences. Significantly lower were the T4 treatment (242.3 g per plant) and the control (230 g per plant), because of the reduction in the half rate of the mineral fertilizer of the T4 treatment and the absence of in-season mineral fertilizer of the control. The full rate of OMAA and MF, as well as full rate of MF along with half rate of OMAA, had the highest yield per plant.

![Figure 2. Effect of different fertilization combinations on yield per plant. T1: control; T2: organo-mineral fertilizer with amino acids (OMAA); T3: mineral fertilizer (MF); T4: (MF/2 + OMAA/2) and T5: MF + OMAA/2. Means followed by the same letter for treatments are not significantly different according to Duncan test (p < 0.05). The values presented are mean values of three replicates ± standard deviation. ANOVA F Value: 4.466.](image)

### 3.4. Grain Quality Measurements

Protein content and starch were the only grain quality measurements that presented significant statistically differences, while moisture and fat content did not differ significantly (Table 5). In the case of protein content, all fertilization treatments (combinations and solo) performed significantly better than the control; however, among them, nonsignificant differences were observed. In particular, T4 had 6.8% of protein content, T5 6.71%, T2 6.7%, and T3 6.62%, while in the significantly lower T1 control treatment, a protein content of 6.39% was observed. On the other hand, the T3 treatment was the only treatment that had significantly higher values (64.90%) in starch compared to the rest of the treatments. Notably, T1 (64%), T2 (63.70%), T5 (63.63%) and T4 (63.57%) had significant lower starch than T3, but without significant differences among them.

### Table 5. Effect of different fertilization combinations on protein content, moisture, fat, starch and nitrogen percentages of maize grains.

| Treatment | Protein (%) | Moisture (%) | Fat (%)   | Starch (%) |
|-----------|-------------|--------------|-----------|------------|
| T1        | 6.39 ± 0.06^b | 12.94 ± 0.71 | 2.93 ± 0.15 | 64.00 ± 0.17^b |
| T2        | 6.70 ± 0.12^a | 13.08 ± 0.68 | 3.10 ± 0.20 | 63.70 ± 0.36^b |
| T3        | 6.62 ± 0.07^a | 12.52 ± 0.70 | 3.03 ± 0.21 | 64.90 ± 0.10^b |
| T4        | 6.80 ± 0.20^a | 13.42 ± 0.30 | 3.00 ± 0.10 | 63.57 ± 0.25^b |
| T5        | 6.71 ± 0.14^a | 13.39 ± 0.70 | 3.00 ± 0.10 | 63.63 ± 0.25^b |
| F treat   | 4.91 *       | 1.215 ns     | 0.434 ns   | 15.348 *** |

T1: control; T2: organo-mineral fertilizer with amino acids (OMAA); T3: mineral fertilizer (MF); T4: (MF/2 + OMAA/2) and T5: MF + OMAA/2. Means followed by the same letter or no letter for treatments are not significantly different according to Duncan test (p < 0.05). The values presented are mean values of three replicates ± standard deviation. Significance levels: * p < 0.05, *** p < 0.001 and ns: non-significant.
3.5. Plant Tissue Analysis

Leaf nitrogen content presented statistically significant differences among the treatments at 70 DAS and 107 DAS (Figure 3). At 70 DAS, when fertilization was applied, the nitrogen content of the leaves was significantly better than the nitrogen content of the control. In particular, T3 treatment presented 2.38% of leaf nitrogen content, T2 treatment presented 2.34%, T4 treatment presented 2.31% and T5 treatment was 2.26%, while the statistically significantly lower control had 2.10%. In the second measurement (107 DAS), the leaf nitrogen content was lower. The higher nitrogen content was observed in the plot with T3 mineral fertilization (2.07%), followed by the plot with T5 fertilization treatment (2%). Significantly lower were the T2 (1.8%) and T4 treatments (1.75%). The control plot (T1), once again, presented the lowest value of nitrogen content (1.47%), significantly lower than all treatments.

![Figure 3. Effect of different fertilization combinations on leaf nitrogen content at 70 and 107 DAS.](image)

3.6. Feature Coefficiency Using Machine Learning Models

Machine learning (ML) models can be used in order to find a correlation between variables. In our case, 10 different machine learning models were analyzed, in 10 different metrics, to find the most efficient model for our data.

As shown in Figure 4, the Bayesian Ridge model had the best results. The correlation of the variables was extracted using this model, in an attempt to find the plant growth and physiology measurements that are highly correlated with the yield, protein, starch, moisture and fat of the corn. The dataset contains six measurements, two of which were taken in three timestamps and four were taken in two timestamps. The Bayesian Ridge algorithm is based on linear regression, meaning that feature coefficiency is used to extract correlations. The feature coefficiency adds weights to every feature based on the algorithm. Each feature comprises the measurements for all the treatments and replications. Positive values of feature coefficiency show that the features are vital for the algorithm, while negative values of feature coefficiency show that the measurements are inversely proportional to the algorithm.
In Figure 4, the feature coefficient using the Bayesian Ridge algorithm was extracted. Measurements SC 65 DAS, SC 106 DAS and Nitrogen 70 DAS have the highest absolute value. All three of them have a high correlation with the fat of the maize. The Nitrogen 70 DAS variable has a positive correlation, while SC 65 DAS and SC 106 DAS have a negative correlation. In terms of yield, Nitrogen 107 DAS and TR 65 DAS appear to have the highest correlation. Lastly, SC 65 DAS, SC 106 DAS, TR 65 DAS and TR 106 DAS are correlated with starch, with SC 65 DAS and SC 106 DAS having a negative correlation and TR 65 DAS and TR 106 DAS having a positive correlation.

In Figure 5, the feature coefficient using the Bayesian Ridge algorithm was extracted. Measurements SC 65 DAS, SC 106 DAS and Nitrogen 70 DAS have the highest absolute value. All three of them have a high correlation with the fat of the maize. The Nitrogen 70 DAS variable has a positive correlation, while SC 65 DAS and SC 106 DAS have a negative correlation. In terms of yield, Nitrogen 107 DAS and TR 65 DAS appear to have the highest correlation. Lastly, SC 65 DAS, SC 106 DAS, TR 65 DAS and TR 106 DAS are correlated with starch, with SC 65 DAS and SC 106 DAS having a negative correlation and TR 65 DAS and TR 106 DAS having a positive correlation.

Figure 4. Comparison of normalized error metrics and STDs of the 12 algorithms used.

Figure 5. Feature coefficient of the Bayesian Ridge algorithm. DAS: days after sowing; DW: dry weight; FW: fresh weight; PR: photosynthetic rate; SC: stomatal conductance; TR: transpiration rate. DAS: Days After Sowing.
4. Discussion

The use of organo-mineral fertilization shows promising results. Maintaining high yield, growth and seed quality characteristics while decreasing the use of pure mineral fertilization shows potential for this practice. There is considerable discussion around the use of biostimulants as substitute or addition to mineral fertilization and how their use affects different crops [32]. Amino acids such as L-tryptophane are among the leading debate subjects in agriculture as eco-friendly plant growth regulators [33]. However, many different biostimulant categories are being evaluated to answer the question “which biostimulants and how can they be implemented to improve the current situation in agriculture?” [34]. In our study, the organo-mineral fertilizer with amino acids that was used presented promising results on its own compared to the control and, in combination with a low dose rate of conventional mineral fertilization, it was equal to pure mineral fertilization. This result agrees with the study of Ahmad et al. [16], in which they found that the addition of enriched compost to a low dose of mineral fertilizer can provide significantly better yield results in maize than conventional mineral fertilization. In addition, when the amino acid L-tryptophan was used as an addition to mineral fertilizer, the uptake of sulfur and nitrogen was significantly increased while also contributing to chlorophyll biosynthesis [35].

When organo-mineral fertilization with amino acids was used in our study with a lower dose of mineral fertilizer, protein content of maize grains was as high as in the full dose of mineral fertilization, whereas ash and moisture content were not affected. However, the starch content of the grains was significantly higher in the treatment of mineral fertilization compared to all the other treatments. Popko et al. [36] used also amino-acid-enhanced compounds and found that protein content and yield were increased in winter wheat plants as well; however, in their experiment, the ash content was increased too. In a greenhouse experiment, almost all foliar applications of amino acid fertilizers showed better results that the control, especially the 200 mg L\(^{-1}\) dose of L-methionine that excelled in the chlorophyll content, root weight and leaf area of broccoli plants [37]. Similarly, in a lettuce root application experiment, L-methionine performed better than the other amino acids tested with an approximately 23% increase in growth from the control. When different doses of the L-methionine were evaluated, lettuces with lower dose applications had a better performance [38].

Amino acids have been also reported to help in water stress conditions in crops. Hammad and Ali [39] tested different biostimulants in water stress conditions in wheat and their results showed that the biostimulants used were able to assist up to a point to drought tolerance by presenting better growth and quality characteristics compared to the control. In another wheat experiment when a combination of organic and inorganic N was used, the N uptake of plants was similar to the N uptake of pure inorganic N [40]. This is in agreement with our experiment, in which similar results were confirmed in maize plants at the early stages; the leaf nitrogen content of pure mineral fertilization and the ones with half the amount of mineral fertilizer, but with the addition of the amino acid compounds, did not differ significantly. In addition to the use of non-microbial fertilizers, there has been a recent tendency to explore microbial fertilizers, such as plant growth-promoting bacteria. Different combinations of fertilizers have been also evaluated in the past for maize. Efthimiadou et al. [17] found that organic and inorganic fertilization, when used together, can result in the improvement of maize’s yield; however, it was also noted that the cow manure treatment presented higher growth results, such as plant dry weight and height.

Machine learnings models can extract important data by corresponding weights to every variable in the dataset [41]. The extraction of the correlation between features has proven to be important in various fields of study, such as logistics [42], healthcare [43], engineering [44] and agriculture [45]. Understanding the relations and importance of the variables in the dataset allows us to understand the correlation between cultivation and measurements. The adoption of this technology is continuously increasing because it can be considered a method to find highly correlated features from the field in addition to
understanding the dataset and finding the most convenient model for it [46]. In a recent study, the Bayesian Ridge algorithm was selected in order to extract the importance of the measurements in sweet corn. The results showed that the measurement of stomatal conductance at 98 DAS appeared to be the most important measurement [47].

5. Conclusions

Two different types of N fertilizers that were applied as split in-season fertilization, separately and as a mix at full and half rates, were used via soil application in maize cultivation and presented significant results in the cases of plant growth, physiology characteristics, yield, grain’s protein and starch content as well as leaf nitrogen content. The results of dry weight showed that the N fertilization, as the maize plants grow, had a positive effect; however, what is interesting is that the applications of organo-mineral fertilizer presented the same values of plant biomass as the conventional mineral fertilization. Following the same pattern, the physiological characteristics of the applications with less mineral fertilization showed results as good as the conventional fertilization. In most cases, the combination of increased physiological characteristics measurements and high biomass through the growth of the maize plant contributed to a better yield. The full rate of mineral fertilization with the addition of a half rate of organo-mineral fertilizer with amino acids (MF + OMAA/2) presented a 16% yield increase in comparison to the control, followed by mineral fertilization (MF) with a 10% increase, half mineral and half organo-mineral fertilizer with amino acids (MF/2 + OMAA/2) that presented a 7.2% increase and organo-mineral fertilizer with amino acids (OMAA) with 5.3% increase compared to the control. In all treatments, the protein content was increased by 3–6% compared to the control. On the other hand, mineral fertilization (MF) was the only treatment that had significantly higher values (64.90%) in the starch content. Noteworthy, the nitrogen content of the maize leaves was increased in both measurements (11–23% and 19–40% at 70 and 107 DAS, respectively) for all treatments, compared to the control, proving that the maize plants utilized the N from the different fertilizer treatments.

This study supports the general idea of investigating new types of N fertilization, which could decrease, in the future, the use of conventional mineral fertilizers. Organomineral fertilizers with amino acids could contribute to a more sustainable nitrogen fertilization management. The role of amino acids as plant growth promoters at a wide range of concentrations could sustainably increase the productivity of maize, when combined with reduced quantities of mineral fertilizers, in order to promote a sustainable yet profitable production.

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