Physiological response of maize under different fertilization management under drought condition

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Abstract

This work was aimed to evaluate the development of maize cultivated under different fertilization management, in order to establish an alternative for mineral fertilization. The experiment was carried out in the experimental area of Chã de Jardim, in Areia, Paraíba, Brazil. Six treatments were used with four replications. Plant height, stalk diameter, leaf number, chlorophyll a, b and total, photosynthetic rate, transpiration, stomatal conductance and internal CO₂ concentration in the leaf were evaluated. In the 30 days after emergence, superiority of treatments was observed in the plants under chemical fertilization for plant height and number of leaves. For diameter of stalk the treatment organic fertilization + P and K showed superiority. At 60 days after planting the chemical fertilization provided the highest averages for plant height and stalk diameter. For the photosynthetic rate, transpiration and internal CO₂ concentration, the treatment that presented the highest average was observed in plants under organic fertilization combined with P and K and N added in top-dressing. For the chlorophyll, the chemical fertilization provided the highest values. Organic fertilization in association with mineral fertilizers provided results close to those observed in mineral fertilization, being an alternative for nutritional management in maize.

Keywords: chlorophyll; organic; plant nutrition; transpiration; Zea mays L.

Introduction

Maize (Zea mays L.) is one of the most important crops worldwide and in Brazil (Almeida et al., 2020), the production in the 2018/2019 was estimated as 27,455.8 thousand tons, with national productivity of 5,379 kg ha⁻¹ (CONAB, 2019), which is below the United States productivity of 11,230 kg ha⁻¹ for this period (USDA, 2018). The Brazilian Northeast is the second region that participates least in the national production of this crop and it is also the region that has the lowest productivity which stands below 2,564 kg ha⁻¹ for the 2018/2019 harvest. The Paraíba state presented one of the lowest productivities with an estimate of 513 kg ha⁻¹ (CONAB, 2019).
In land use at the household level, the use of mineral fertilizers is greatly reduced due to the low purchasing power of small producers (Wiggins, 2014), as well as the risk of rainfall variability. It is also known that the continuous use of chemical fertilizers has resulted in negative results that are reflected in the rapid reduction of the organic matter content, salinization and erosion, resulting in scarcity of nutrient content in the soil (Tian et al., 2012; Smith et al., 2016).

Recently, due to environmental awareness the interest in sustainable agricultural practices has increased (Ardelean et al., 2012; Vastola et al., 2017). A practice commonly adopted to increase yield is the use of manure as an organic fertilizer for the supply of nutrients in the soil, which also provides physical improvements in the soil, such as increased infiltration, increased water storage capacity, higher aggregation of soil particles and reduction of erosive processes (Karami et al., 2012).

The organic fertilization seeks to bring positive effects, thus providing physical-chemical improvements in the soil when compared to mineral fertilization (Gomes et al., 2018). However, the use of nitrogen fertilizer also promotes maize yield gains in the first year of cultivation (Sui et al., 2018; Zhang et al., 2020). It is known that the residual effect of fertilization with animal manure acts in a significant way in the production of biomass in maize cultivation (Fan et al., 2020).

Therefore, the objective of this work was to evaluate the development of maize crop under different fertilization management, aiming to determine an alternative for mineral fertilization.

**Materials and Methods**

**Study site**

This work was carried out in the experimental area of Chã de Jardim, in the Agricultural Sciences Center of Federal University of Paraíba, located in Areia, Paraíba, Brazil, from June to October of 2017. This geographic micro-region called Brejo Paraibano has the climate classified as tropical humid, presenting average temperature of 22 °C and the climate of the region is tropical and classified as Aw according Köppen, hot and humid with rainfall from autumn to winter, relative humidity of approximately 80% and rainfall of 1.400 mm annually (Ribeiro et al., 2018). The climatic data during the period of the experiment are presented in Figure 1.

![Figure 1](image-url)
The soil of the experimental area is Oxisol, of which chemical properties are presented in Table 1.

### Table 1. Chemical properties of the soil, in the depths of 0 - 20 cm

| Property | pH | P | K | Na | H+Al | Al | Ca | Mg | CEC | O.M. |
|----------|----|---|---|----|------|----|----|----|-----|------|
| In KCl   |    |   |   |    |      |    |    |    |     | 4.8  |
| mg dm⁻³  |    | 2.40 | 28.40 | 0.05 | 5.49 | 0.10 | 0.81 | 0.30 | 6.72 | 36.72 |

P and K Mehlich-1 extraction. SB: sum of bases. CEC: cation exchange capacity. OM: organic matter

**Experimental design and treatments**

The experimental design was complete randomized blocks (CRB), with six treatments (Table 2) and four replicates, totalling 24 experimental plots. Each plot consisted of five rows of five meters in length, with a spacing of 0.8 m between rows and 5 plants per row, totalling a population of 65,000 plants per hectare.

### Table 2. Description of the treatments used in the experiment carried out in the experimental area of Chã de Jardim, Areia, Paraíba, Brazil

| Treatment | Composition | Treatment code |
|-----------|-------------|----------------|
| T1        | No fertilization | NFE            |
| T2        | Chemical fertilization (NPK) | CF             |
| T3        | Organic fertilization | OF             |
| T4        | Organic fertilization + P and K | OF+CF          |
| T5        | Organic fertilization + N Top-dressing | OF+TD          |
| T6        | Organic fertilization + P and K + N Top-dressing | OF+CF+TD       |

**Implementation and conduct of the experiment**

The fertilization was performed according to Cavalcanti (2008), based on the soil chemical properties (Table 1). In the whole experimental area, the soil acidity was corrected by the saturation method, aiming to raise the saturation to 60%, for that the dolomitic limestone (PRNT 80%) was used. The liming was performed 70 days before planting, then the incorporation of lime was performed at 0.20 m depth. Forty days before planting, a non-selective herbicide Roundup®, in doses of 1.5 l / 100 l of water application was performed.

The application of the treatments was carried out in the rows of approximately 0.08 m depth in which fertilizers were applied and covered. Depth of seeding was 0.03 m. Three seeds were sown every 0.2 m and after 10 days of the emergence (DAE) the thinning was performed, left each 1 plant per seed.

The ‘Potiguar’ (EMPARN®, RN, Brazil) maize cultivar was used. Nutrients were provided with commercial sources: Potassium Chloride (60% KCl); Urea (N 45%); mono-ammonium-phosphate MAP (P2O5 48%; N 12%); and bovine manure as a source of organic fertilizer, chemical properties of the bovine manure have in its composition 15.58 g N kg⁻¹, 5.07 g P kg⁻¹ and 11.82 g K kg⁻¹.

**Parameter determinations**

For the biometric evaluation the following variables were evaluated: plant height (PH), Stalk diameter (SD) and the number of leaves (NL). To evaluate the gas exchange, the IRGA equipment (LI-6400XT LI-COR®, Nebraska, USA) was used to obtain the photosynthesis (A) rate, transpiration (E), stomatal conductance (gs) and internal carbon (Ci). Chlorophyll data were obtained with the use of chlorophyll electronic metering equipment (ClorofiLOG-Falker®).

**Statistical analysis**

Data were tested for normality by the Shapiro-Wilk test, homogeneity of variances by the Bartlett test and analysis of variance by F test (p ≤ 0.05) and the means were compared by the Tukey's test at 5% of probability, according to the criteria of Banzatto and Kronka (2011). All analyses were conducted in R software 3.6.3 (R Core Team, 2020).
Results and Discussion

The different fertilization managements significantly interfered in the growth of maize plants, at plant height (PH) the treatment no fertilization (NFE) was statistically inferior to the other treatments during the 30 and 60 days after emergence, probably due to the lack of nutritional demands necessary for this crop, while the greatest means were found with the use of chemical fertilization (CF), not differing from the treatments organic fertilization (OF), organic fertilization + P and K (OF + CF), organic fertilization + N Top-dressing (OF + TD) and organic fertilization + P and K + N Top-dressing (OF + CF + TD) for PH at 30 DAE and OF + CF + TD for PH at 60 DAE (Table 3).

Table 3. Plant height (PH), stalk diameter (SD) and the number of leaves (NL) of the corn cv. ‘Potiguar’ under different organic-mineral fertilization management evaluated at 30 and 60 DAE.

| Treatments       | PH (cm)  | SD (cm)  | NL       |
|------------------|----------|----------|----------|
|                  | 30 DAE   |          |          |
| NFE              | 7.80b    | 0.62c    | 4.05c    |
| CF               | 19.35a   | 1.41a    | 5.70a    |
| OF               | 17.18ab  | 1.25ab   | 4.80abc  |
| OF+CF            | 18.70a   | 1.36a    | 5.20ab   |
| OF+TD            | 15.90ab  | 1.19b    | 4.70bc   |
| OF+CF+TD         | 19.40a   | 1.39a    | 5.25ab   |
|                  | 60 DAE   |          |          |
| NFE              | 22.75d   | 1.72c    | 6.80d    |
| CF               | 85.25a   | 2.43a    | 11.20ab  |
| OF               | 66.95c   | 2.27ab   | 10.35bc  |
| OF+CF            | 73.70bc  | 2.30ab   | 10.75bc  |
| OF+TD            | 64.40c   | 2.24b    | 10.05c   |
| OF+CF+TD         | 79.85ab  | 2.39ab   | 11.75a   |

Means followed by the same letter in the column do not differ by the Tukey test at 5% probability

Therefore, the evaluation at 60 DAE shows that there is variation in the efficiency of the management of fertilization for the height of corn, perhaps the addition of phosphorus and potassium together with organic compost and nitrogen fertilization in cover has contributed to the PH at 60 DAE because it is a time that the plant needs high concentrations of N, P and K. When the fertilizer dose is increased, the amount of nutrients available increases thus increasing corn plant height, up to a certain limit (Ullah et al., 2020).

Likewise, in the stem diameter (SD) the NFE treatment showed the lowest average and differed statistically from the others at 30 and 60 DAE, while the highest values were obtained in the CF treatment, probably due to the faster nutritional availability, however not differing from the OF, OF + CF and OF + CF + TD treatments at 30 and 60 DAE (Table 3). Phosphate and nitrogen fertilization may have contributed to this result, since the nutritional requirements of nitrogen by the maize crop change with the different stages of plant development. In the initial stages these requirements are minimal and increase as the plant growth rate increases reaching its maximum during the flowering until the beginning of grain formation (Mansouri-Far et al., 2010).

While phosphorus is responsible for the development of roots and hence seedlings at the beginning of the plants’ development, contributing to the increase of plant resistance for drought (Gouda et al., 2018). The soil initially had a low P content of 2.4 mg dm$^{-3}$ (Table 1), together with this natural phosphorus deficiency and due to the high levels of oxides of iron and aluminum contained in the Oxisols, there could be a high adsorption capacity of this element.

Leaf emission at 30 DAE was lower in the NFE and OF + TD treatments, with the highest incidences in the CF, OF, OF + CF and OF + CF + TD treatments (Table 4). At 60 DAE, the NFE treatment was
statistically inferior to the others, with a greater number of leaves in the CF and OF + CF + TD treatments. Increased organic fertilization with nitrogen fertilization in phosphate and potassium cover (OF + CF + TD) obtained results similar to CF, due to the addition of nutrients in the mineral form N, P and K to the organic input, which requires more time for mineralize the nutrients to a form assimilable by the plant, in relation to the nutrients provided by the mineral input.

The treatment that promoted the highest photosynthetic rate (A) was OF + C + TD, differing significantly from the OF treatment, with the lower photosynthetic rate (Table 4). This can be explained by the extraction of nitrogen from the maize. A higher nitrogen supply results in an increase in the rate of photosynthesis, leading to greater accumulation of biomass (Bender et al., 2013).

**Table 4.** Photosynthetic rate (A), transpiration (E), stomatal conductance (gs) and internal CO$_2$ concentration (Ci) in the leaf of maize 'Potiguar' under organo-mineral fertilization

| Treatment       | A (µmol CO$_2$ m$^{-2}$ s$^{-1}$) | E (mmol H$_2$O m$^{-2}$ s$^{-1}$) | gs (mmol m$^{-2}$ s$^{-1}$) | Ci (µmol m$^{-2}$ s$^{-1}$) |
|-----------------|-------------------------------|----------------------------------|-----------------------------|-----------------------------|
| NFE             | 24.19ab                       | 0.12b                            | 130.44a                     | 3.08a                       |
| CF              | 27.12ab                       | 0.19ab                           | 137.31a                     | 4.11ab                      |
| OF              | 23.59b                        | 0.13b                            | 135.14a                     | 2.92b                       |
| OF+C            | 24.05ab                       | 0.13b                            | 132.50a                     | 3.13b                       |
| OF+TD           | 26.37ab                       | 0.14b                            | 131.57a                     | 3.41b                       |
| OF+C+TD         | 29.07a                        | 0.23a                            | 137.30a                     | 4.90a                       |

Means followed by the same letter in the column do not differ by the Tukey test at 5% probability.

For the transpiration (E) a significant difference was observed, where the OF + C + TD treatment presented the highest values, not differing statistically from the treatment CF. It is probable that, the high transpiration rates to be associated with stomatal conductance. The OF + C + TD treatment had the highest transpiration rate, thus not differing from the CF, which is fundamental in the stomatal opening process, aggregated with the top-dressing with nitrogen, which is essential for the synthesis of proteins such as H$^+$ - ATPase, that is used for the flow of K$^+$ and Cl$^-$ for the opening and closing of the stomata (Heidari and Jamshid, 2010).

**Figure 2.** Falker Chlorophyll Index of the maize cv. 'Potiguar' under different fertilization management

Means followed by the same letter in the series do not differ from each other by the Tukey test at 5% probability.
There was no significant difference for the stomatal conductance parameter (gs) among the treatments. The internal CO₂ concentration in the leaf (Ci) had a significant difference, with the highest values observed in the OF + C + TD treatment (Table 5). There was no significant difference in the stomatal gas conductance (gs) among the treatments, what is related to the water scarcity at critical periods of the crop (Figure 1). The plant in the stress condition tends to close its stomata in order to minimize water loss and maintain turgescence (Pinto et al., 2014).

Regarding the chlorophyll index, highest values were in the CF treatment, but no significant difference was observed from the treatment OF + TD for chlorophylls a, b and total. In general, the treatment with addition of phosphorus and potassium associated with the organic compound (OF + C) showed the lowest values for chlorophylls a, b and total (Figure 2).

Conclusions

The organic fertilization associated with mineral fertilization promoted results close to those observed for mineral fertilization, thus, being considered an alternative of nutritional management for the maize crop in the Brejo region conditions of the state of Paraíba. Organic fertilization along with the fertilization of P and K plus N in top-dressing promoted a great performance in the parameters evaluated.

Authors’ Contributions

Conceptualization: FM and MAB; Data curation: MAB and TRSC; Formal analysis: MAB and JEC; Funding acquisition: FM and MBA; Investigation: MAB, JEC, VFOS and TRSC; Methodology: MAB and FM; Writing - original draft: TRSC, MAB and JEC; Writing - review and editing: FM, MBA, JEC and VFOS. All authors read and approved the final manuscript.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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