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(Research Article)

Nitrogen level impact on the production of double row fodder of maize

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Abstract

Maize is the most important crop in Mexico, being central to the diets of consumers, particularly smallholders, and an undetermined amount is allocated as straw, green fodder, and, to a lesser extent, as silage for animal feed. Nitrogen fertilizer is considered one of the most important factors affecting growth, grain yield, and maize biomass production. In this context, the main objective of this study was to evaluate the effects of different levels of nitrogen fertilizer on maize production. A randomized complete block experimental design consisted of three treatments of nitrogen (180, 160, and 80 kg/ha) with three replications and morphological (plant height, stem thickness, and rate of growth), yield, and yield components (cob weight, length, thickness, number of rows per cob, and plant biomass) variables were used. The results suggest that the increase in nitrogen levels increases all the parameters of maize production. However, at 160 kg/ha, the greatest production of fodder was recorded with 5.99 tons/ha, superior to the one reported at 180 kg/ha, which was 5.47 tons/ha. We conclude that the maize fodder production can be optimized with the use of 160 kg/ha in the conditions of the *altiplano* of San Luis Potosí (Mexico).

Keywords: *Zea Mays*; Plant Biomass; Yield; Animal Feed

1. Introduction

Maize is one of the world's most important crops, coming in third place after wheat and rice in terms of cereal crop production [1]. According to Begam, Ray [2] there are no other cereal crops with such enormous potential, which is why it is known as the "queen of cereals". It is a traditional multipurpose crop that is grown for food, feed, and fodder. Maize is a nutritious food/feed because it contains 72% starch, 10% protein, 9.5 percent fiber, and 4% fat, with an energy density of 365 calories per 100 grams [3, 4].

Maize is the most widely grown cereal in the world (785 million tons), with a grain yield per unit area that is double that of wheat and barley. In Mexico, maize is the most important crop cultivated, being central to the diets of both urban and rural consumers, particularly the poor and an undetermined amount is allocated as straw, green fodder, and to a lesser extent for the silages for animal feed [5]. It occupies the largest planted area in the country devoted to any crop and involves cultivation by a large number of smallholders [6, 7].

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An area of 445,775 ha has been planted in the rainy season and 161,623 ha in irrigation for fodder maize in Mexico in 2015, with yields of 19.29 and 47.55 tons/ha of dry matter and green matter, respectively [8]. Given that agroclimatic heterogeneity has a negative impact on agriculture production and results in variable yields of plant biomass in maize silage [9]. In addition, on average, maize fodder can contain 20.01% crude protein, 18.95% crude fiber, 4.5% ash, and 7.44% ethereal. 88.6% dry matter digestibility, parameters that make these sprouts of high nutritional quality for animal nutrition [10, 11].

Increasing crop productivity while minimizing environmental impact is the most difficult challenge for global food production. In other words, the expansion of intensive crops production and the over use of chemical fertilizers and pesticides cause a slew of issues, including environmental contamination and biodiversity loss. These cultivation, as well as their negative impact on agro-ecosystems, are causing growing problems in agriculture. As a result, we are looking for alternatives that provide high agricultural productivity while also improving efficiency and sustainability [12, 13]. In this context, nitrogen is an essential element that is required for plant growth, leaf area expansion, and photosynthesis, yield, protein, and plant biomass production. Inadequate nitrogen levels in maize can reduce growth and development, resulting in a lower crop yield and biomass. Excess nitrogen value, on the other hand (due to heavy application of nitrogen chemical fertilizer), can reduce yield and biomass production through decreased sugar content and increase diseases and pests [14, 15].

Excessive nitrogen fertilizer application, on the other hand, has negative effects on crops and maize in particular, reduces nitrogen use efficiency and causes significant nitrate leaching losses because it is the primary source of nitrous oxide (N_2O). As a result, nitrogen must be used in ways that meet both economic and environmental goals, which is critical for sustainable agriculture [16, 17]. According to Portillo Vázquez, Pérez Soto [18], optimal fertilization is when the maximum yield: average nitrogen fertilization ratio is reached. In our case, the fertilization optimization is done with the maximum yield and plant biomass production in mind.

The present study had the objective of testing the effects of different levels of nitrogen fertilization on maize fodder production. The above-mentioned, with the hypothesis that different levels of nitrogen can help to optimize maize fodder production by decreasing the quantity of chemical fertilizers used in the fields.

2. Material and methods

2.1. Experimental site

The experiment was established at the Faculty of Agronomy and Veterinary Sciences of the Autonomous University of San Luis Potosí. The geographical coordinates of the locality are 100°01’ 22” west and 22°12’ 27” north latitude, at 1,883 m asl. During the experiment, the mean annual, maximum, and minimum temperatures were 17.6, 27.4, and 9.8 °C, respectively. The annual mean precipitation was 164.08 mm [19].

2.2. Experimental details and cultural practices

A randomized complete block experimental design consisted of three treatments (nitrogen fertilization doses) with three replications (blocks) to form a total of nine experimental units of 1,470 m^2 each. The nitrogen levels were 180, 160, and 80 kilograms of nitrogen per hectare, which were applied in two parts; one to the sowing and the second one to the month after the sowing, which were applied manually. Table 1 shows the experimental design used in this study. Agronomic practices and plant protection measures (daily irrigation to prevent the effect of drought and elimination of the undesirable plants) are accomplished throughout the crops growth period. Irrigation was done immediately after sowing.

Table 1 Experimental design used in the experiment

160-00-00	80-00-00	180-00-00
180-00-00	160-00-00	80-00-00
80-00-00	180-00-00	160-00-00

2.3. Data observation

To evaluate the effect of different level of nitrogen on the production of double-row fodder maize production; data were collected for plant height and stem thickness at 110 days after sowing. Yield and yield attributing characters like cob length, cob weight, cob thickness, number of row per cob were recorded. The weight of the harvested plants in tons per ha was used to estimate plant biomass, which was determined by harvesting all of the plants in each experimental unit. The rate of growth of the maize was estimated using the following equation [20]:

$$RG = \frac{PH2 - PH1}{T2 - T1}$$

Where: PH1 and PH2 are the plant height at 30 and 110 days after sowing, respectively. T1 and T2 the previously indicated times.

2.4. Statistical analysis

All the collected data was processed in MS Excel, and the figures were made in the Paleontological Statistics Software package for education and data analysis (Past). The Statistical Analysis System (SAS, 2003) was used to perform an analysis of variance (ANOVA) on the data. The Tukey test was used to separate the means. The significant differences between the levels of nitrogen were determined using the least significant difference (LSD) test at a 5% level of significance. The data was examined for normality, and no transformation was made because they all presented normality. Correlations and principal component analysis between all the parameters were conducted in Past 4.0.

3. Results and discussion

Significant effects of all the measured variables using analysis of variance were observed (Table 2). That means a significant difference was observed for all the parameters with the use of the different levels of nitrogen for the maize crop.

Table 2 Analysis of variance (ANOVA) of the variables measured on the maize crop fertilized with different levels of nitrogen

Variables	Mean squares	Fvalue	CV (%)
Rate of growth	0.86	9.77**	11.31
Plant height	3977.22	10.61**	9.1
Stem thickness	80.64	88.75***	3.59
Plant biomass	3.61	20.26**	8.25
Cob weight	109634.8	194.74***	7.42
Cob length	28.92	14.95***	5.15
Cob thickness	646.36	41.21***	7.92
Number of rows per cob	12.35	3.72**	10.88
Yield	1813.63	1801.62***	1.42

CV: coefficient of variation; *t-test, $p < 0.05$; **t-test, $p < 0.01$, and ***t-test, $p < 0.001$.

3.1. Morphological variables of the maize crops fertilized with different levels of nitrogen

Figure 1 shows the morphological variables such as plant height, stem thickness, and rate of growth of the maize crop fertilized with different levels of nitrogen. Similar responses were observed for plant height and rate of growth; in both of them, the maximum values were registered with the use of 180 and 160 kg/ha of nitrogen. With 222.87 and 221.2 cm of plant height, respectively, while with 80 kg/ha of nitrogen, they were 193.87 cm. At the same time, the maximum values of the rate of growth with an average of 2.77 and 2.75 m/day were observed for the maximum levels of nitrogen, while at the low level of nitrogen, the maize crops registered an average of 2.35 m/day as a rate of growth. The results suggest that the levels of nitrogen increased the plant height and rate of growth of the maize crops, and significant differences were observed between the first two levels of nitrogen (180 and 160 kg/ha) and the lowest one (80 kg/ha). In addition, with 160 kg/ha of nitrogen, the maize crops registered the maximum average stem thickness, which was statistically higher than the ones observed under 180 and 80 kg/ha of nitrogen. Our results are in concordance with Patel, Patel [21]; Adhikari, Bhandari [22], Hussaini, Nanmwa [23] who stated that the use of higher levels of nitrogen increased the phenology of maize plants. Also related this findings with the use of the higher nitrogen application dose, the more cell division, cell elongation, nucleus creation, green foliage, and hence chlorophyll content, which enhances photosynthesis and stem extension, and thus plant height and rate of growth of the crops. Also Dawadi and Sah [24] reported the increased nitrogen level from 120 kg/ha to 200 kg/ha increased plant height of hybrid maize varieties. An increase in plant height due to high nitrogen may be attributed to better vegetative development that resulted in increased mutual shading and internodal extension [25, 26].

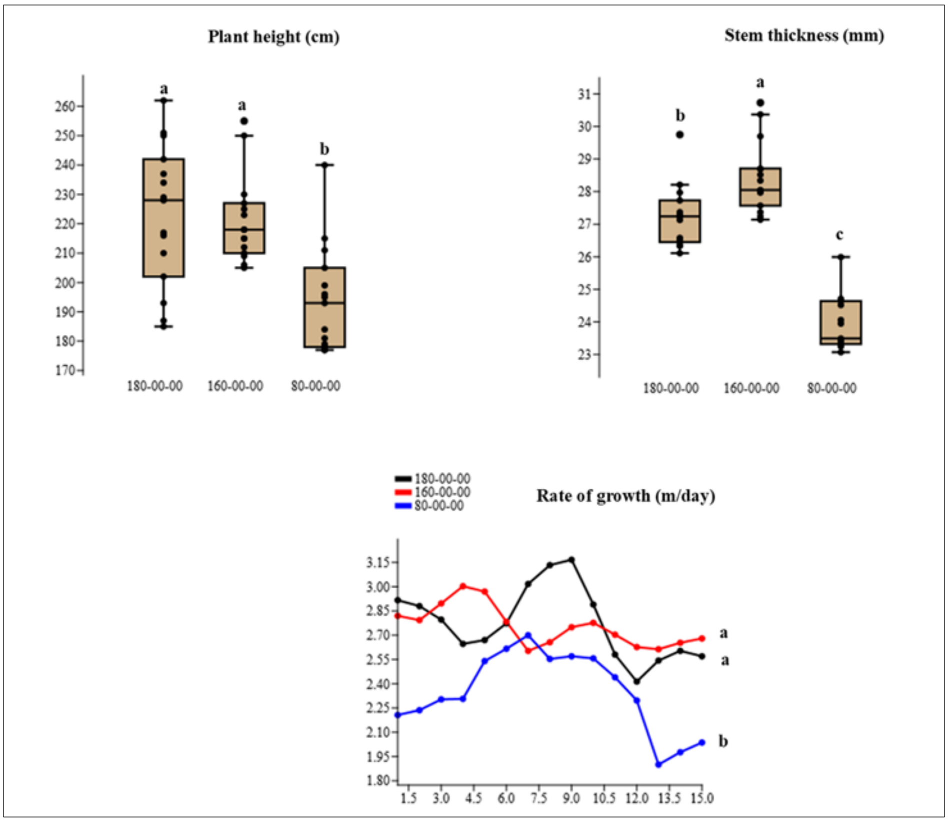

Figure 1 Morphological variables measured from the maize crops fertilized with different levels of nitrogen. Different letters represent significant difference among the means according to Tukey's test ($P < 0.05$). The circles outside the bars represent the outliers

3.2. Yield and yield components of the maize crop fertilized with different levels of nitrogen

Figure 2 shows yield and yield parameters such as cob thickness, length, and weight, number of rows per cob, yield and plant biomass of the maize fertilized at different rates of nitrogen. A significant difference was recorded with the use of different doses of nitrogen for all the parameters. The maximum averages of cob thickness, length, and weight were observed with the use of high levels of nitrogen. However, results observed at 160 kg/ha of nitrogen reported the maximum values of 55.21 mm and 385.77 g for cob thickness and weight, respectively. In addition, no differences were recorded between the highest levels of nitrogen and all of them were statistically higher than the ones reported at a low level of nitrogen (80 kg/ha). This result suggests that the level of nitrogen also affects the yield and yield parameters of the maize crop. At the same time, 160 kg/ha of nitrogen can be an option for optimization of fertilizers because in most of the evaluated parameters, at this level, the maize crop reported equals or was statistically higher than that reported at 180 kg/ha of nitrogen. That was the case of cob thickness, length, weight, number of rows per cob, and plant biomass (Figure 2). Plant biomass being one of the most important parameters for this research, it is important to note that the two highest levels of nitrogen reported the maximum values of 5.47 tons/ha at 180 kg/ha of nitrogen and 5.99 tons/ha at 160 kg/ha of nitrogen. However, maximum yield was reported at the high level of nitrogen (180 kg/ha) and was statistically superior to that reported at the other two levels. In comparison to the lowest level of nitrogen, the yield decreased by up to 51.3%. That is to say, nitrogen fertilizer is critical for maize yield and can significantly increase maize yield and yield parameters. It is important to report that, at 160 kg/ha of nitrogen, the yield was 82.5 tons/ha but was statistically different from the ones observed at 180 kg/ha. These results were similar with finding of Akhtar, Afridi [27] and Asghar, Muhammad [28] who reported higher level of nitrogen enhances the grain yield on account of increased yield component of maize. Also, Gweyi-Onyango, Neumann [29], Agada, Otene [30] said that, the increase in yield and yield components under nitrogen levels could be attributed to the fact that ammonium nutrition is associated with antagonistic uptake of other essential cations at the soil exchange complex, rhizospheric acidification, and osmotic balance changes. Nitrate nutrition, on the other hand, alkalinizes the root system and may have resulted in increased uptake of these important cations due to their adsorption on the soil exchange complex surface. As a result, the favorable synergistic effect with nitrogen to improve yield and yield components may have been amplified [31].

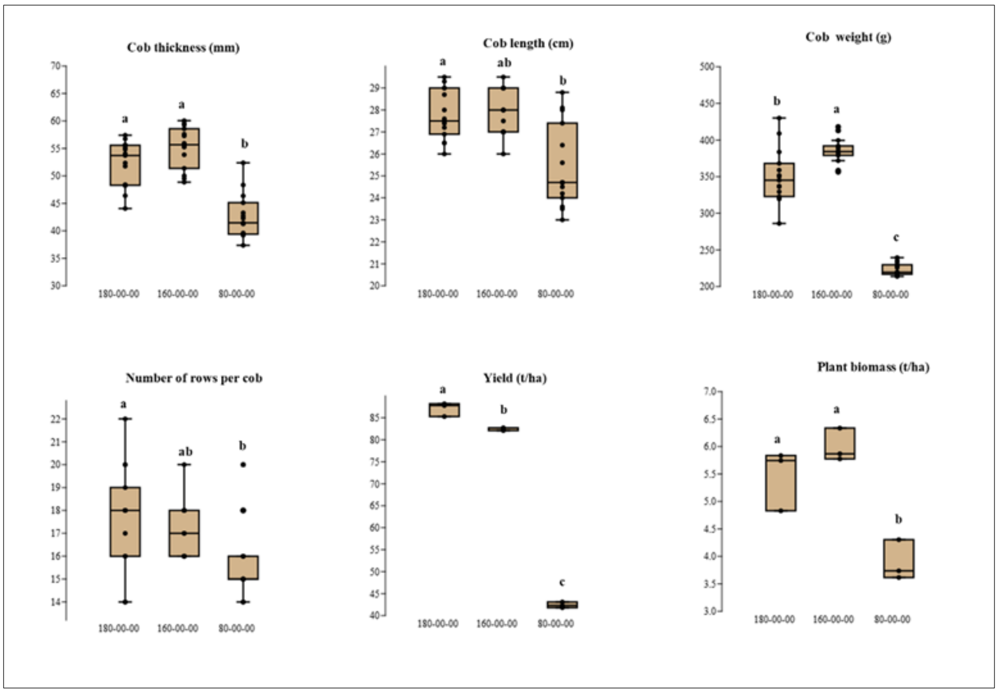

Figure 2 Yield and yield components measured from the maize crops fertilized with different levels of nitrogen. Different letters represent significant difference among the means according to Tukey's test (P < 0.05). The circles outside the bars represent the outliers

3.3. Correlation of Pearson linear (r) and boxplots between Principal Components 1 and 2 show contributions of the measured parameters of the maize fertilized at different levels of nitrogen.

Positive correlations were reported for all the measured parameters. The possible reason may be related to the importance of nitrogen in maize crop growth, development yield and yield components. The increase in nitrogen dose is directly associated with the maize crop production and leads to better growth, development, yield and yield components of the crops (Figure 3A). Plant biomass reported a positive and significant correlation only among the stem thickness of the maize crops, while the yield correlated significantly and positively among the rate of growth and plant height. The results suggest that a better rate of growth and plant height lead to a maximum yield of the maize, while for plant biomass, the stem thickness of the plant is the principal variable, leading to a better biomass of the maize crops (Figure 3A).

A trait biplot of PC1 accounted for a cumulative variance of 97.23% and PC2 with 2.76% (Figure 3B) and identified three major correlation groupings, namely, a group based on yield and plant height; a second group based on cob thickness, length, stem, rate of growth, and number of rows per cob; and lastly, the group comprising only cob weight. It is important to note that the highest nitrogen level correlated significantly and appeared in the first component. The results explain the high cumulative variance of 97.23% for the principal component 1. Also, the tight angles between the number of rows per cob, cob length, plant height and biomass, and yield signified direct association among these parameters. On the other hand, tight angles were reported between cob weight, thickness, and stem thickness. Plants with longer plant height, rate of growth, a greater number of rows per cob and cob length also had better yield and biomass production (Figure 3B). In the context of maize fodder production, our strategy that would explain the existing variation within and between the accumulated desirable characteristics is to optimize the nitrogen fertilizers with the most important parameters measured. In this context, plant biomass and yield were selected as the most important parameters, and they explain the other parameters of collaboration for maize yield and biomass production (Figure 2). The combined high yield, plant biomass, and nitrogen levels present an opportunity for maize crop fertilization optimization. Our results are in concordance with Asare, Tetteh [32] and XING, LI [33], who used similar principal components analysis and reported positive and significant correlations for yield and morphological variables. In our study, plant biomass production and yield are very important because they are the parts used for animals and human nutrition, and they correlated with most of the measured variables. Other studies show that yield is positively related to plant height, rate of growth, cob length, and number of rows per cob, which is linked to the plant biomass production [34, 35]. Our results indicated that plant height and rate of growth have a significant influence on nitrogen level doses in maize crops. XING, LI [33] concluded that plant height is a very sensitive indicator of maize growth and also suggested that improving plant height is an effective measure for maize growth in field managers and maize plant breeders, which helps to select genotypes with a plant height adapted to the conditions of the target environment.

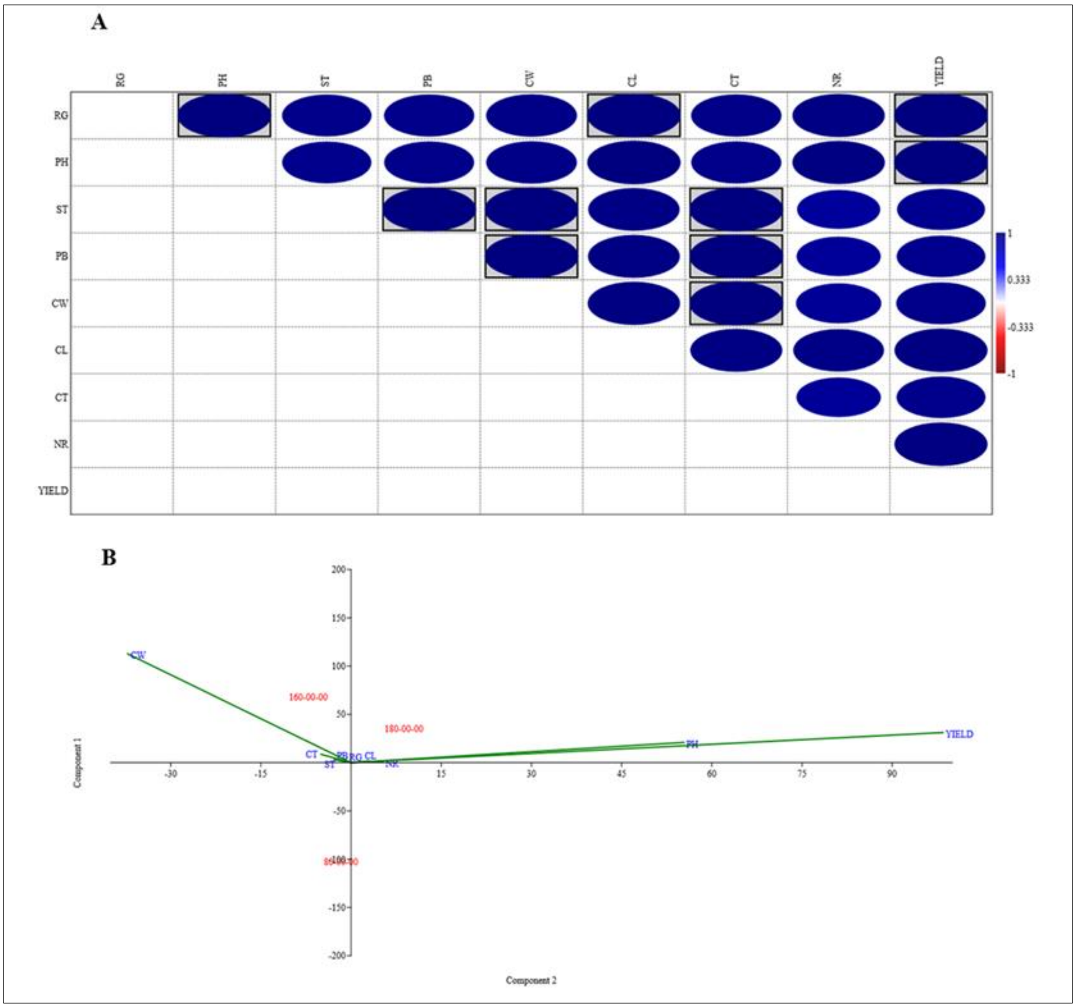

Figure 3 Plots of the statistic correlation of Pearson linear (r) among all the measured variables (A) and boxplots between Principal Component 1 and 2 showing contributions of the measured parameters of the maize fertilized at different levels of nitrogen (B). RG: rate of growth, PH: plant height, ST: stem thickness, PB: plant biomass, CW: cob weight, CL: cob length, CT: cob thickness, NR: number of rows per cob. The boxed plots are significant at $P< 0.05$

4. Conclusion

Nitrogen levels significantly increase the production of double row fodder of maize.

The use of 160 kg/ha of nitrogen can optimize the production of double-row fodder of maize, while with 80 kg/ha, maize production reported the lowest values of all the measured parameters.

The increase in yield and plant biomass correlated significantly and positively with the plant height and rate of growth of the maize fertilized with different levels of nitrogen

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Statement of ethical approval

This article does not contain any studies with human or animal subjects.

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