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EFFECTS OF MICRODOSE FERTILIZATION AND PLANT DENSITY ON MAIZE (*Zea mays* L.) PRODUCTION IN THE CENTRE-WEST REGION OF SENEGAL

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ABSTRACT

Microdosing fertilization is aimed at reducing the investment in mineral fertilizers while increasing crop yield without harming the environment. However, only a few studies investigated the interactive effect of microdose and plant density on crop production, particularly in the maize-grown Centre-West region of Senegal. This work aimed to study the effects of the microdose and plant density interactions on maize's growth and yield components. The experiment was carried out at the experimental station of the National Higher School of Agriculture (ENSA) of Thies, Senegal. Two factors were studied in a factorial design with three replications: microdose with two levels (M1: 0.5 g hill^{-1} of NPK + 0.5 g hill^{-1} of urea; and M2: 1 g hill^{-1} of NPK + 0.5 g hill^{-1} of urea) and sowing density with three levels (D1: 125,000; D2: 83,333; and D3: 62500 plants ha^{-1}). The microdose × plant density interaction was insignificant for plant height, number of leaves, and weight of ears. For each density, the two microdoses showed non-significant differences for these parameters. The interaction was also insignificant for grain and straw yields. However, the plant density highly significantly affected the grain and straw yields, with the higher density D1 leading to the best grain (1607 kg ha^{-1}) and straw yields (2396 kg ha^{-1}). The study shows that under microdosing fertilization, sowing maize in higher densities is recommended for better production and efficient use of fertilizer.

Key words: microdose, sowing density, yields, maize, Senegal

INTRODUCTION

Soil nutrient depletion is severe in sub-Saharan Africa, where low-input small-scale farming systems are predominant (Ibrahim *et al.,* 2016). The decline of soil fertility strongly reduces crop productivity (Christopher and Lea, 2015; Vanlauwe *et al.,* 2015), which maintains populations in chronic poverty. Hence, research on management systems affecting soil fertility and crop productivity in degraded and highly weathered tropical soils is paramount (Obalum *et al*., 2012). Mineral and organic fertilizers effectively enhance soil fertility, but each has some limitations. Although mineral fertilizers show immediate and beneficial effects on yields, most smallholder farmers in sub-Saharan Africa have limited access to them (Bagayoko *et al.,* 2011) due to low availability, high prices, difficulties in accessing credits, and lack of appropriate technologies for field application.

Microdosing of mineral fertilizers has been suggested as a fertilization technique to overcome these constraints. It consists of applying small quantities of a given mineral fertilizer at the hill of the sown crop, aiming to minimize the investment in fertilizer while optimizing productivity. Applying a small amount of 6 g or less per hill (depending on the type of fertilizer and crop) opposes the microdosing to the conventional broadcast or row fertilizer applications where higher amounts of chemical fertilizer are required. Microdosing has proven to increase agricultural productivity under different soil types and crops, leading to higher economic returns (Tabo *et al.,* 2007). Other reports highlighted the positive role of microdosing in improving nutrient use efficiency by concentrating nutrients in the root system (Tabo *et al.,* 2006, Palé *et al.,* 2009). Implementing the microdosing technique across the Sahel region has shown a considerable short-term increase in yields and income (Sani *et al*., 2020). In Senegal, microdosing of fertilizers increased yields by 132% and 36% compared to the control and the recommended rate, respectively (Rabi *et al.,* 2020).

In Burkina Faso, Mali, and Niger, two years of on-farm trials showed an average increase of millet and sorghum grain yields by 44 and 120%, and an increase of farmer's incomes of 52 and 134% when using hill application of fertilizer compared to the recommended fertilizer broadcasting methods and farmers' practice, respectively (Tabo *et al.,* 2007).

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Since the amount of fertilizer during microdosing is defined per hill, the application rates of fertilizer increase with increasing plant densities (Rosy, 2019). There have been studies showing the influence of plant density on productivity of non-cereal crops (Adubasim *et al*., 2017; Obalum *et al*., 2017; Umeugokwe *et al*., 2021; Obi *et al*., 2024), but its interaction with micro-dosing is unclear especially for cereals. To fill this gap, this study was carried out to evaluate the agronomic effect of microdosing on maize growth and yield as influenced by plant density.

MATERIALS AND METHODS

Study Site

The experiment was conducted at the experimental station of the National Higher School of Agriculture (ENSA) of Thies, located 70 km East of Dakar, Senegal (14° 46’ N and 16° 57’ W) (Figure 1). The climate is typical of the Sahelian zone (Le Houérou, 1989), characterized by a rainy season from June to October and a dry season for the rest of the year. The annual rainfall is fairly low, ranging from 300 to 500 mm (Sarr *et al.,* 1999). The soil is the leached tropical ferruginous type, classified as Lixisol (FAO, 2006).

Plant Material

Hybrid maize variety Gaaw Na was used as the planting material. It is a variety selected by IITA and ISRA in Ibadan, Nigeria. It is a rainfed crop generally grown in the Fatick and Kaolack regions of Senegal and has a short growth cycle (75-80 days). The grains are white with a horny texture with a potential average yield of 2 t ha^{-1}.

Experimental Design

The experimental design was a completely randomized factorial block design with three replications consisting of two fertilizer levels (M1: 0.5 g hill^{-1} of NPK + 0.5 g hill^{-1} of urea, and M2: 1 g hill^{-1} of NPK + 0.5 g hill^{-1} of urea), and sowing densities (D1, D2, and D3 were 125,000 plant ha^{-1}; 83,333 plant ha^{-1}; and 62,500 plant ha^{-1} respectively). Each replication consisted of three sub-blocks (corresponding to the three sowing densities D1, D2, D3) of two elementary plots of 2.4 m × 2 m each (corresponding to the two fertilizer rates), giving 18 plots for the whole set-up. There was a space of 2 m between the blocks and 1.5 m between the sub-blocks, while 0.90 m separated the elementary plots.

Experimental Setting

The trial was conducted during the 2019 cropping season on a plot where maize was cultivated the previous season. The physicochemical characteristics of the soil in the experimental plot before implementation of treatments at a depth of 20 cm (Table 1) show that the soil has a grain size dominated by sand and silt, thus giving it a sandy-loamy type texture. The pH of 7.5 indicates a slightly alkaline soil. Its CEC (14 meq 100-g^{-1}) shows that it has a low element exchange potential. Its organic matter content is also very low and the C/N ratio (10) indicates that it is poorly mineralized. The nitrogen and phosphorus contents are low. The calcium and magnesium contents are high while those of potassium and sodium are low. Flat sowing at 2 grains per hill was

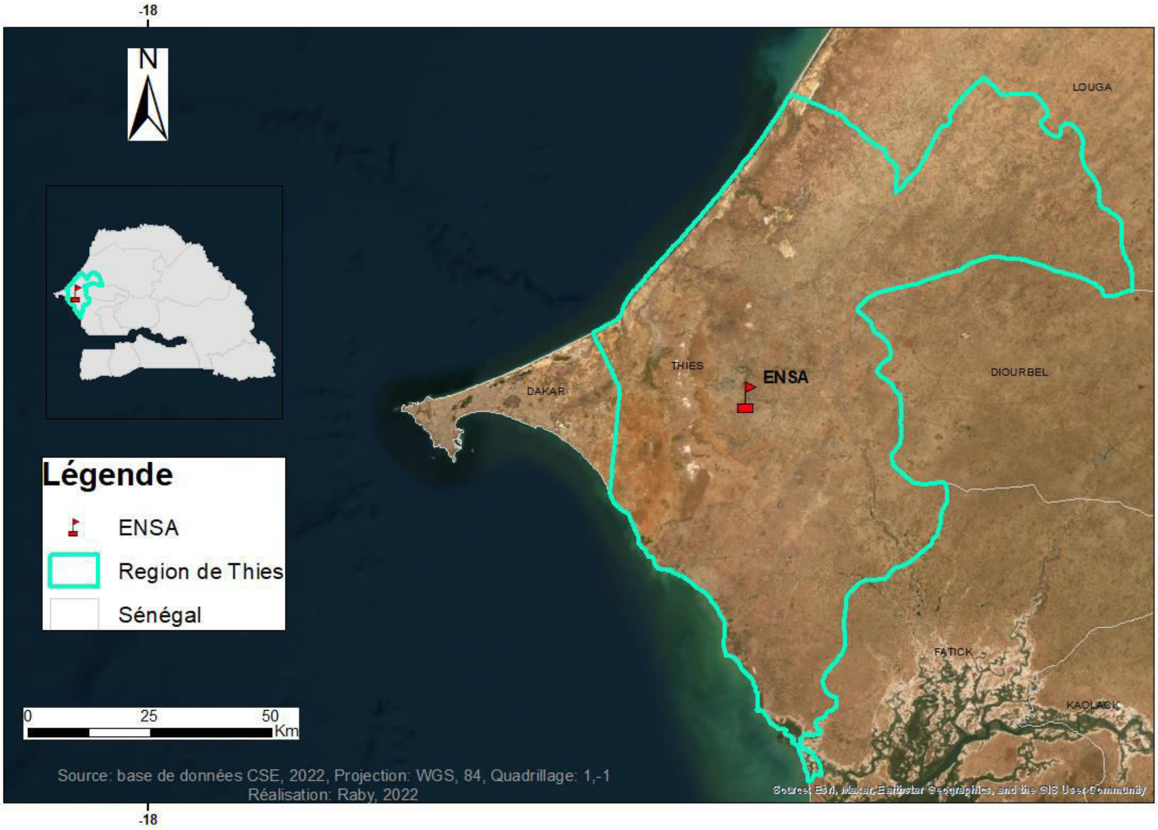

Figure 1: Location of the study site (ENSA, Thies-Senegal)

Table 1: Physicochemical characteristics of the soil

Granulometry (%) Clay	3.52
Silt	48.2
Sand	48.3
Chemical elements	
pH-water	7.5
% Carbon, C	0.554
% Nitrogen, N	0.053
C/N	10
Phosphorus, P (ppm)	0.6402
Potassium, K (meq 100-g^{-1})	0.3612
Calcium, Ca (meq 100-g^{-1})	3.75
Magnesium, Mg (meq 100-g^{-1})	2.25
Sodium, Na (meq 100-g^{-1})	0.333
CEC meq 100-g^{-1}	14

CEC - cation exchange capacity,
ppm - part per million, meq - milliequivalent

carried out on August 21, 2019. Thus, once the hill was opened, maize seeds were first placed in the hole, then the doses of NPK were placed surrounding the seeds while avoiding any contact with them to protect them from burning. Seedlings were thinned to one plant per hill two weeks after sowing, and hills with non-emerged seedlings were subjected to transplanting during the thinning period. Urea was applied at the 7-10 leaf stage 30 days after sowing. The growth parameters were analyzed on the six individual plants of the two central lines of each elementary plot. The analysis of yields and yield components was done on the five plants of the central line of each elementary plot. Data were collected on plant height, number of leaves, insertion height of ears, ear weight, hundred-grain weight, number of grains per ear, number of rows per ear, straw yield, and grain yield.

Statistical Analysis of the Data

The Shapiro-Wilk normality test using GenStat v.17 first verified the normal distribution of the data because of the sample size (*n* < 50). The two-factor analysis of variance (ANOVA) was used to compare the mean scores of the variables that showed a normal distribution after the normality test. The ANOVA model included the treatment × density interaction. Without a significant interaction, the average values of the two microdoses or the three seed densities were considered. Means were compared using the less significant difference (LSD) and the SNK (Student Newman Keuls test) at the 5% level when a significant effect of the factor was found.

RESULTS

Shapiro-Wilk Normality Test

Table 2 shows the Shapiro-Wilk normality test, with a normal distribution for plant height (PH), number of leaves (NL), ear weight (EW), grain yield (GY), and straw yield (SY) as indicated by the > 5% probability level. Therefore, only these variables were then subjected to the ANOVA for further interpretation.

Variation in Plant Growth and Ear Weight

The two-way ANOVA indicated a non-significant effect of the microdose × sowing density interaction for plant height, number of leaves, and weight of ears, with probability levels of 0.761. 0.176. and 0.130, respectively. Therefore, the averages of the two microdoses for each density are shown in Figure 2 for these three parameters. The results show that the plant height, number of leaves, and ear weight are statistically equivalent at the three seeding densities.

Table 2: Shapiro-Wilk normality test

Variables	GY	SY	PH	IHE	NL	NGE	NRE	HGW	EW
Probability	0.304	0.106	0.184	0.018	0.055	0.002	0.003	0.003	0.564

PH - plant height, NL - number of leaves, IHE - insertion height of ears, EW - ear weight, HGW - hundred-grain weight, NGE - number of grains per ear, NRE - number of rows per ear, SY - straw yield, GY - grain yield

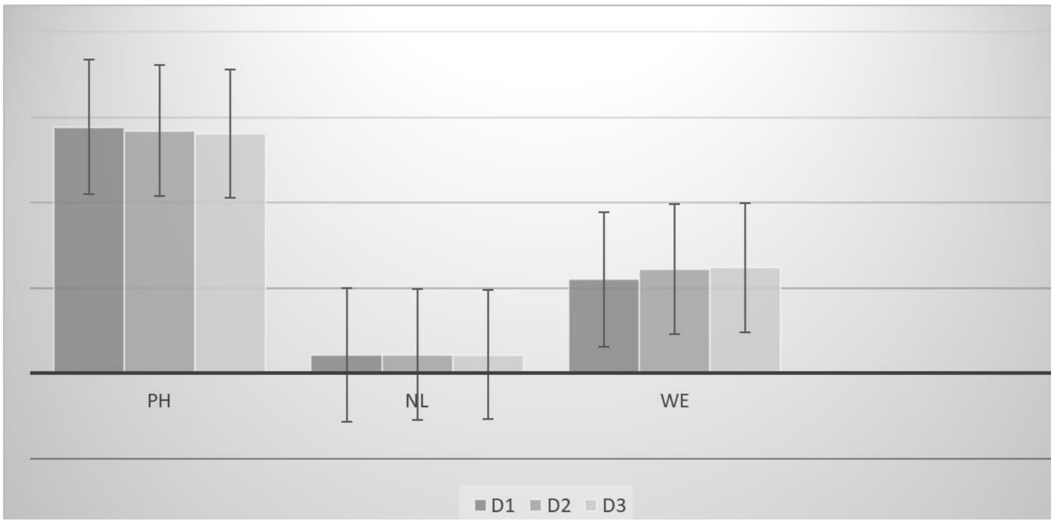

Figure 2: Effects of plant density on plant growth and ear weight
PH (cm) - plant height; NL - number of leaves, WE (g) - weight of ears, D1 - Density 1; D2 - Density 2, D3 - Density 3

Variation in Grain and Straw Yields

The two-way ANOVA also revealed a non-significance of the interaction between microdose ×sowing density for the grain and straw yields, with probability levels of 0.611 and 0.799, respectively. Figure 3 shows the average grain and straw yields obtained from the two microdoses for the three-plant density. It indicates highly significant differences between densities for both parameters. Increasing the sowing density increases the grain and straw yields, although there was no significant difference between D1 (125,000 plants ha^{-1}) and D2 (83,333 plants ha^{-1}). For the grain yield, the increase was only 14% (not significant) from D2 to D1, while it was 52.44% (significant) from D3 (62,500 plants ha^{-1}) to D2 (83,333 plants ha^{-1}). There was no significant difference in these parameters for all densities between M1 and M2 (data not shown).

DISCUSSION

The microdosing technique has proven its positive effect in improving nutrient use efficiency and crop yield while minimizing the amount of chemical fertilizer and its adverse environmental effects (Tabo *et al.,* 2006, Palé *et al.,* 2009). However, the interaction between crop densities and the microdose rates on growth and yield parameters still needs to be clarified. The present study investigated this aspect and found a non-significant effect of the microdose × sowing density interaction for plant height, number of leaves, and ear weight using the Gwana maize variety. The plant height, number of leaves, and ear weight were similar among all three densities (125,000 plants ha^{-1}; 83,333 plants ha^{-1}; 62,500 plants ha^{-1}). Moreover, there was no significant difference between the two microdoses (0.5 g $hill^{-1}$ of NPK + 0.5 g $hill^{-1}$ of urea, 1 g $hill^{-1}$ of NPK + 0.5 g $hill^{-1}$ of urea) for these parameters at each sowing density. The result indicates that the two microdoses affect the plant growth similarly, regardless of the sowing density, and all three densities influence the plant growth to the same extent. These results align with the work (Irmak and Djaman, 2016), which reported that plant density did not significantly affect maize plant height. However, this contradicts the results of Siene *et al.* (2010), who found a higher plant height when the population density increases. Numerous authors (Dieye, 2004; Rosiane *et al.,* 2016) explained this increase in height by a more intense vegetative development occurring at higher plant densities because of light competition during bolting. Therefore, the non-significant difference observed between densities in our study may indicate an absence of competition for light, likely because of lower densities than those reported in (Dieye, 2004; Rosiane *et al.,* 2016) studies or because of ambient sun lightning in the study area. Moreover, the microdose × sowing density interaction also had a non-significant effect on grain and straw yields. Therefore, the averages of the two microdoses were considered for each density.

The ANOVA showed highly significant effects of the density for both grain and straw yields. These results align with the work of Joseph *et al.* (2021), which showed the advantages of plant density and N combinations as grain yield increased in improved sorghum varieties. The increase in grain yield of the Gwana variety relied on the increased plant density. As reported by (Dieye, 2004), the greater grain yields obtained in the plots with higher densities are explained by the higher number of plants. In the present study, the D1 density had twice the number of plants in D3 and 1.5 times than in D2. Furthermore, other reports (Wei *et al.,* 2019; Zhilong *et al.,* 2019; Ullah *et al.,* 2020) explained this increase in grain yield by an adaptation of varieties to agronomic practices such as plant density. Numerous studies have also shown that sowing density is vital to enhanced crop yields (Esechie, 1992; Akbar *et al.,* 2002; Moradpour *et al.,* 2013; Obalum *et al.,* 2017; Obi *et al.,* 2024). The differences in straw yields, which followed a similar trend as those of the grain yields, were also explained by the high number of plants per hectare.

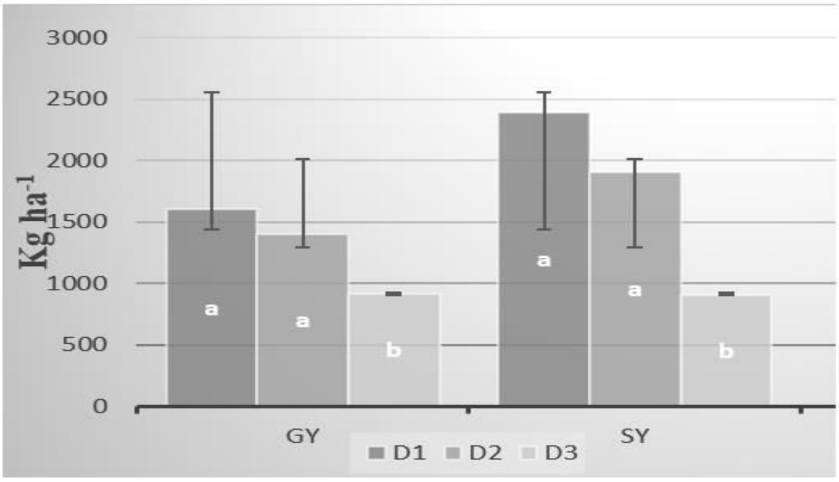

Figure 3. Effects of plant density on grain and straw yield

GY (kg ha^{-1}) - grains yield, SY (kg ha^{-1}) - straw yield, D1 - Density 1, D2 - Density 2, D3 - Density 3

CONCLUSION

This study shows that the three sowing densities of the maize variety Gwana did not significantly influence the number of leaves, plant height, and ear weight, regardless of the microdose. For each given density, the two microdoses also influenced these parameters similarly. The highest grain and straw yields (1,607 kg ha^{-1} and 2,396 kg ha^{-1}, respectively) are recorded at the higher sowing density D1 and D2, and the lowest are from the low sowing density D3. We conclude that the highest sowing densities are the most appropriate to obtain increased maize production. Since the two microdoses did not show significant differences in maize production, we suggest the lower microdose to minimize further the amount of chemical fertilizer for economic and environmental means.

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AUTHOR CONTRIBUTIONS

Rabi Housseini Malam Laminou, Saliou Ndiaye, Aliou Guissé: Conceptualization; Data curation; Formal analysis; Funding acquisition; Methodology; Writing-original draft. Djibril Diallo: Formal analysis; Methodology; Writing-review & editing. Papa Saliou Sarr: Data curation; Formal analysis, Writing-review & editing.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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