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Effects of Planting Density and Manure on Maize (*Zea mays L.*) Agronomic Parameters in Bouaké, Côte d'ivoire

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Authors' contributions

The present study was carried out in collaboration between all authors. Author FGBZ designed, performed and supervised the research. Author FGBZ also analyzed and interpreted the results. Authors JNDK and DHAA drafted and revised the manuscript. Authors VK and KJFE provided technical support. All the authors read and approved the final manuscript.

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ABSTRACT

Aims: The objective of the study was to determine good practices in terms of maize planting density and the effect of manure brought to the cultivated soil on the development of maize.
Place and Duration of Study: The study was conducted in the village of Kongonékro, located 10 km from the city of Bouaké, in Côte d'Ivoire. The period of the study was from March 2016 to May 2017.
Methodology: A Randomized Complete Block Design (RCBD) trial with three replicates was set up. Each block consisted of nine 9 m x 1.5 m ridges. According to the treatments, 27 kg of chicken or sheep manure were brought to the soil of these microparcels, i.e. 20 t/ha. Seeding was performed using three different densities: i) five plants per m^2 with a spacing of 0.3 m between

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plants, ii) four plants per m^2 with a spacing of 0.4 m between plants; and iii) three plants per m^2 with a spacing of 0.5 m between plants.

Results: Organic fertilizer treatment effect significantly improved the studied maize agronomic parameters, namely: the number of leaves, the size and internodes of plants, the number of internodes and the dry weights of cobs and seeds. However, this effect was better expressed with chicken manure when three plants were maintained per m^2 with a spacing of 0.5 m between these plants.

Conclusion: Of the two organic amendments used, chicken manure proves more favorable to the cultivation of maize. On the other hand, high densities of planting seem unfavorable to this crop.

Keywords: Maize cultivation; chicken manure; sheep manure; planting density; agronomic parameters.

1. INTRODUCTION

The rapid population growth observed in Africa in recent decades has led, among other things, to uncontrolled exploitation of cultivated soils. In fact, to cover the growing needs of populations in food resources, producers use soils anarchically. This leads soils to loss their fertility [1]. As a result, yields of food crops are becoming lower [2]. Thus, producers often resort to use synthetic fertilizers. Unfortunately, the costs of these fertilizers are beyond the reach of most of the farmers [3]. Additionally, synthetic fertilizers provide soil only with certain mineral nutrients and are likely to pollute soil and groundwater in the long term [4]. It is therefore, necessary to opt for the use of alternatives such as manures that are available at lower cost and less polluting for soils [5].

In addition to soil fertility, planting density is also critical to achieving good crop yields. It should therefore be increasingly the subject of scientific research to enable African producers to take full advantage of the crop varieties they plant. For example, over the past decade, field crop producers in Quebec, Ontario and the United States of America have tended to increase maize planting densities [6]. In Côte d'Ivoire, where food crops have long been neglected for industrial crops, accurate information on optimal planting densities of food crops is scarce. This study is part of the search for solutions to these many problems that undermine the development of Ivorian food agriculture. The study objectives were: to determine the good practices in terms of maize planting density; and to assess the effect of manures on the cultivated soil and development of maize, which is the staple food for a large part of the Ivorian populations, particularly those in the north.

2. MATERIALS AND METHODS

2.1 Description of the Study Site

The experimental field was set up in the center of Côte d'Ivoire, at precisely 7° 41' north latitude and 5° 02' west longitude, in Kongonékro, village located 10 km from the city of Bouaké, capital of the Gbêkè region. The climate of this region is a tropical climate of humid savannah. Temperatures, at greater amplitude, oscillate between 14°C and 33°C with a humidity of 60 to 70% and an annual rainfall of 1200 mm. This climate is characterized by four seasons: two dry seasons, from November to March and from July to August and two rainy seasons from June to October and from March to May [7]. It is part of the pre-forest of Côte d'Ivoire where we observe blocks and islands of mesophilic dense rain forest and dry dense forest, included in a more or less wooded savanna belonging to the Guinean and sub-Sudanian savannas.

The geological formations that cover the area are mainly granitoids [8]. Soils in the savanna zone are generally ferruginous and lateritic in the forest zone. Most of these soils are slightly acidic and weakly fertile [9].

2.2 Planting Materials

The material used to carry out the study is essentially of three types: maize cultivar, organic fertilizer and tools. In fact, the improved maize variety EV8728 was used as a planting material because of its good vegetative characteristics and the quality of its grain [10]. This variety was provided by the National Center for Agricultural Research [11]. In addition, an organic fertilizer consisting of chicken and sheep manures was also used. This fertilizer material was collected from two farms located less than one kilometer from the experimental plot. Finally, a technical material consisting of tools for measuring distances (a tape measure), clearance (machetes), weeding (dabas) and weight measurement (Roberval balance) were used.

2.3 Field Experiment

The experimental configuration implemented was a Randomized Complete Block Design (RCBD) with three replicates [12]. Each block was a set of nine microparcels of 9 m x 1.5 m. The microparcel consists of two ridges or rows, each ridge measuring 0.3 m wide and 9 m long. Distances between two consecutive blocks and rows are respectively 2 and 0.3 m.

To control the effects of random factors such as soil properties variability, flat terrain that generally favors uniformity of soil properties was chosen for the location of the experimental plot. However, before the ridges were made, chicken or sheep manure was regularly applied to soils at 0 and 20 t/ha, depending on the treatments (control, chicken manure and sheep manure).

To achieve sowing, it was necessary to select the right seeds. It consisted first of pouring seeds into a container of water and shaking the whole to float empty and immature seeds. The good seeds collected at the bottom of the bucket were placed in a container to be hydrated during 24 hours. The seedlings were finally realized by putting two seeds per hole. Fifteen days after germination, we conserved three planting densities on the whole parcel by elimination of plants so as to leave only the most vigorous plant per hole. These planting densities were used:

i) D1: five plants per m^2 or 50,000 plants per ha observing a spacing of 0.3 m between plants;
ii) D2: four plants per m^2 or 40,000 plants per ha observing a spacing of 0.4 m between plants;
iii) D3: three plants per m^2 or 30,000 plants per ha observing a spacing of 0.5 m between plants.

The weeds were removed regularly from the experimental plots. After 112 days (physiological maturity), the plants were kept on the plots for 20 days, then completely dug up and sorted by treatment and density.

2.4 Data Collection

The fertilizing properties of the amendments used were determined before we determine their effects on maize agronomic parameters. To do this, manures sampling was conducted in accordance with existing requirements [13]. It consisted of taking several of their samples and randomly selecting some of these samples for laboratory analyzes. Thus, four samples of each type of manure were kept and packed in plastic bags and kept cool. In the Analysis Laboratory of Soils and Plants of the National Polytechnic Institute "Félix Houphouët-Boigny", their pH was determined using Glass Electrode pH Meter [14] while their contents of total nitrogen, organic carbon, assimilable phosphorus and exchangeable bases were respectively determined by the techniques of Modified Kjeldahl, Walkley and Black, Modified Olsen and Spectrophotometry of Atomic Absorption [15]. At harvest, ten plants were arbitrarily selected by microparcel and labeled from P1 to P10 for the different measures described in Table 1.

To better appreciate the effects of manures and planting density on the evolution of maize plants, it was essential to know the initial conditions of the soil used. These conditions were determined by repeating on four samples of the culture soil the same laboratory analyzes performed on manure samples (Table 2). In addition, the soil contents in sand, silt and clay were determined by the Densimetric Method [15]. The soil sampling points were evenly distributed across the parcel.

2.5 Data Analysis

Mean values of manures properties were compared using Student's t-test at the threshold of 95%. Moreover, mean values of maize agronomic parameters were subjected to a multifactorial analysis of variance (ANOVA) (effects of manures, effects of planting densities and their interaction). When a significant difference ($p<0.05$) is observed between the different factors studied, multiple comparisons were made using the least significant difference (LSD) test to identify the factor (s) that actually causes the observed difference. All these statistical tests were performed using SAS software [16].

3. RESULTS AND DISCUSSION

3.1 Culture Soil and Manures Properties

According to the results in Table 3, the topsoil of the soil of the experimental site was characterized by an acidic pH (6.4). This soil is sandy-loamy with 57.4 ± 2 % of sand, 35.5 ± 2.2 % of silt and 7.1 ± 1.5 % of clay. It contains about 0.19 ± 0.02 g kg^{-1} of carbon and 0.012 ± 0.01 g kg^{-1} of nitrogen. The resulting C/N ratio was 15.83 ± 1.88. Assimilable phosphorus content was 0.0017 g kg^{-1} whereas those in exchangeable bases, namely calcium, magnesium, potassium and sodium were 0.05 ± 0.01, 0.03 ± 0.001, 0, 08 ± 0.01 and 0.07 ± 0.01 cmol kg^{-1}, respectively. In addition, the CEC of this soil was estimated at 11 ± 0.01 cmol kg^{-1}.

The characteristics of chicken and sheep manures used are summarized in Table 4. These characteristics generally revealed significant differences between these two types of manure ($p < 0.001$). In fact, only their pH and sodium content were statistically identical ($p<0.05$). The variables that significantly distinguish these soil amendments are, on the one hand, their organic carbon, nitrogen, assimilable phosphorus, calcium, magnesium and potassium contents and, on the other hand, their C/N ratio. The optimal levels of these variables were observed in chicken manure.

3.2 Effects of Manures Used on Maize Agronomic Parameters

The results presented in Table 5 show that the different fertilizers treatment effects influenced very significantly and differently all the analyzed agronomic parameters ($p<0.001$). Chicken manure, which had higher nutrient levels than sheep manure, appears to have had a greater beneficial effect on maize growth and productivity. In fact, the measured variables were generally optimal with this fertilizer.

Table 1. Summary of methods of measurement of assessed agronomic parameters

Maize agronomic parameters assessed	**Measurement methods**
Plant leaves number	Manual counting of the leaves of each plant, repeated on the ten plants selected by microparcel.
Plants size (cm)	Measurement of the distance separating the collar at the point of insertion of this collar, repeated on the ten plants selected by microparcel.
Internodes size (cm)	Measurement of the internode located below the point of insertion of the cob, repeated on the ten plants selected by microparcel.
Internodes number	Manual counting of internodes of each plant, determined on the 10 plants selected by microparcel.
Cobs dry weight (g)	Measurement of the weight of the dried cob on each plant, repeated on the 10 plants selected per microparcel.
Dry weight of seeds per cob (g)	Measurement of the weight of each dried seeds per cob, repeated on the 10 plants selected per microparcel.

Table 2. Synthesis of laboratory analyses performed on samples of manures and soil used

Variables	**Methods**
pH (1 : 2.5: Soil : Water)Total Nitrogen (N)	Glass Electrode pH Meter [14]
Organic carbon (C)	Modified Kjeldahl Method [14]
Assimilable phosphorus (P.ass)	Walkley and Black Method [14]
	Modified Olsen method [15]
Calcium (Ca^{2+})	Spectrophotometry of Atomic Absorption Method [15])
Magnesium (Mg^{2+})	
Potassium (K^+)	
Sodium (Na^+)	
Cation exchange capacity (CEC)	
Sand (%)	Densimetric Method [15]
Silt (%)	
Clay (%)	

Table 3. Synthesis of the properties of the culture soil

Clay (%)	Silt (%)	Sand (%)	C ($g.kg^{-1}$)	N ($g.kg^{-1}$)	C/N	pH	P.ass ($g.kg^{-}$)	CEC ($cmol.kg^{-1}$)	Ca^{2+} ($cmol.kg^{-1}$)	Mg^{2+} ($cmol.kg^{-1}$)	K^{+} ($cmol.kg^{-}$)	Na^{+} ($cmol.kg^{-1}$)
7	36	57	0.19 ± 0.02	0.012 ± 0.01	15.83 ± 1.88	6.4 ±0.2	0.0017 ± 0.00	11± 1.2	0.05 ± 0.01	0.08 ± 0.01	0.012 ± 0.002	0.07 ± 0.01

Table 4. Synthesis of the properties of manures studied

	C (%)	N (%)	C/N	pH	P.ass ($g.kg^{-1}$)	Ca^{2+} ($cmol.kg^{-1}$)	Mg^{2+} ($cmol.kg^{-1}$)	K^{+} ($cmol.kg^{-}$)	Na^{+} ($cmol.kg^{-1}$)
Chicken manure	25.58 ± 3.32	2.54 ± 0.43	10.06 ± 0.88	7.8 ± 0.11	0.26± 0.04	9.32 ± 0.17	6.88 ± 0.12	2.32 ± 0.09	0.11 ± 0.02
Sheep manure	9.36 ± 0.86	1.25 ± 0.2	7.5 ± 0.10	7.6 ± 0.14	0.03 ± 0.01	2.57 ± 0.3	2.4 ± 0.11	1.21 ± 0.11	0.14 ± 0.02
t	8.580	7.540	6.08	5.58	118.08	11.43	8.020	6.79	4.87
Significance	***	***	**	ns	****	***	***	**	ns
p-value	<0.001	<0.001	<0.01	0.201	<0.001	<0.001	<0.001	<0.01	0.30

– *P.ass: Assimilable phosphorus; ***: Very Highly Significant Difference; **:Highly Significant Difference; Ns: Not Significant Difference*

Table 5. Fertilization effect on maize agronomic parameters

Variables	Control	Sheep manure	Chicken manure	F-values	P-values	Signifiance
PLN	11.86 ± 0.43 c	12.96 ± 0.41 b	15.10 ± 0.4 a	48.28	<0.001	***
PS (cm)	107.40 ± 14.4 c	123.76 ± 14.33 b	180.50 ± 23.07 a	20.00	<0.001	***
IS (cm)	9.86 ± 1.37 c	10.55 ± 1.32 b	12.84 ± 1.8 a	38.83	<0.001	***
IN	11.7 ± 0.46 c	13.00 ± 0.37 b	15.06 ± 0.23 a	95.6	<0.001	***
CDW (g)	35.56 ± 12.7 c	53.45 ± 15.89 b	84.21 ± 30.12 a	62.79	<0.001	***
DWSC (g)	17.44 ± 6.68 c	24.78 ± 7.93 b	46.13 ± 18.59 a	69.00	<0.001	***

– *Means in a same line followed by different letter (s) are significantly different at P≤0.05; PLN: plant leaves number; PS: plants size; IS: internodes size; IN: internodes number; CDW: cobs dry weight per plant; DWSC: dry weight of seeds per cob. ***: very highly significant difference.*

Table 6. Effect of planting density on maize agronomic characteristics

Variables	D1	D2	D3	F-values	P-values	Signifiance
PLN	13.33 ± 1.39 a	13.16 ± 1.49 b	13.43 ± 1.43 a	3.24	0.04	*
PS (cm)	132.06 ± 44.08 b	133.73 ± 25.54 b	146.26 ± 1.96 a	8.10	<0.001	***
IS (cm)	10.64 ± 2.77 b	10.90 ± 1.56 b	11.72 ± 1.96 a	5.03	0.008	**
IN	13.06 ± 1.59 c	13.26 ± 1.31 b	13.43 ± 1.43 a	11.22	<0.001	***
CDW (g)	43.04 ± 19.96 c	56.87 ± 26.25 b	73.31 ± 31.79 a	23.80	<0.001	***
DWSC (g)	21.61 ± 11.36 c	27.85 ± 15.59 b	38.88 ± 19.36 a	23.76	<0.001	***

- *Means in a same line followed by different letter (s) are significantly different at P≤0.05;*
- *D1: 0,7m × 0,3m ; D2 :0,7m × 0,4m ; D3: 0,7 m × 0,5 m; PLN: plant leaves number; PS: plants size; IS: internodes size; IN: internodes number; CDW: cobs dry weight per plant; DWSC: dry weight of seeds per cob. ***: very highly significant difference; **: highly significant difference; *: significant difference.*

Table 7. Effects of fertilization and planting density interaction on maize agronomic parameters

	Control			Sheep manure			Chicken manure					
Variables	D1	D2	D3	D1	D2	D3	D1	D2	D3	F-values	P-values	Signi
PLN	11.90 ±0.31	11.80 ±0.63	11.90 ±0.31	13.00 ±0.42	12.30 ±0.48	13.60 ±0.42	15.10 ±0.56	15.00 ±0.36	15.20 ±0.42	0.66	0.62	ns
PS (cm)	108.80 ±8.63e	110.70 ±10.33e	114.3 ±17.41d	110.3 ±6.65e	127.40 ±10.30c	133.60 ±13.62c	188.70 ±26.47a	163.10 ±17.72b	190.90 ±13.60a	6.38	0.002	**
IS (cm)	8.59 ±0.94 f	10.73 ±0.92 e	10.29 ±1.22e	10.92 ±1.47e	10.09 ±1.22 e	11.00 ±1.21 d	12.83 ±1.87b	11.90 ±1.91 c	13.83 ±1.22 a	3.97	0.005	**
IN	11.20 ±0.42d	12.00 ±0.11 c	11.90 ±0.31d	13.00 ±0.15b	12.80 ±0.42 c	13.20 ±0.42 b	15.00 ±0.11a	15.00 ±0.12 a	15.20 ±0.42 a	7.89	<0.001	**
CDW (g)	22.94 ±5.25	37.96 ±8.62	45.77 ±10.7	41.48 ±7.99	49.99 ±10.10	68.90 ±14.40	64.77 ±14.84	82.66 ±29.25	105.26 ±30.21	0.96	0.43	ns
SDW (g)	11.23 ±1.69	17.74 ±4.62	23.36 ±6.16	18.72 ±3.06	22.02 ±3.12	33.62 ±6.68	34.90 ±8.80	43.81 ±17.83	59.68 ±18.52	1.36	0.25	ns

- *Means in a same line followed by different letter (s) are significantly different at P≤0.05;*
- *D1: 0.7m × 0.3m ; D2 :0.7m × 0.4m ; D3: 0.7 m × 0.5 m;*
- *PLN: plants leaves number; PS: plants size; IS: internodes size; IN: internodes number; CDW: cobs dry weight per plant; DWSC: dry weight of seeds per cob.*
- *** *: very highly significant difference; **: highly significant difference; ns: not significant difference*

3.3 Effects of Planting Density on Maize Agronomic Parameters

Table 6 describes the effects of planting density on maize agronomic parameters. Planting density significantly influenced all the parameters analyzed ($p<0.05$). However, the multiple comparison test showed a total difference in only three parameters, namely: internodes number, cobs dry weight per plant, and dry weight of seeds per cob. For these three parameters evaluated, the highest values corresponded to the lowest planting density (D3: 0.3 m x 0.5 m). For the other three parameters (plants leaves number, plant size and internodes size), the analysis indicates a partial difference in plant size induced by D3 density (0.3 m x 0.5 m). Another partial difference induced by D2 density (0.3 m x 0.4 m) appeared in internodes size and plant leaves number.

3.4 Effects of Fertilization and Planting Density Interaction on Maize Agronomic Parameters

The cumulative effect of planting density and soil fertilization on maize agronomic parameters is presented in Table 7. There is a partial difference between the treatments for plant and internodes sizes and also for internodes number. Regarding cobs dry weight per plant, dry weight of seeds per cob and plants leaves number, no significant difference was observed. However, for all the cases analyzed, the maximum values of the variables were recorded in general on the plots having accumulated the amendment with the chicken droppings and the lowest density of sowing.

4. DISCUSSION

According to [17], maize is a tropical plant that grows well on sandy-loamy and low-acid soils such as the soil of the study site. The same source also reveals that soils used for growing maize must be regularly supplied with water and nutrients, including nitrogen, phosphorus and potassium. Endeed, to complete its cycle, maize mobilizes approximately 240, 90 and 270 kg ha^{-1} of nitrogen, phosphorus and potassium [18]. This latter condition is far from being satisfied by the soil used because its contents in these main nutrients are low (0.012 ± 0.01 g kg^{-1} for nitrogen, 0.0017 ± 0.00 g kg^{-1} for phosphorus and 0.012 ± 0.002 cmol kg^{-1} for potassium) if we refer to their thresholds in soils in general. In addition, the CEC of this soil estimated at 11 ± 1.2 cmol kg^{-1} is low compared to the thresholds [19]. More serious, the little nitrogen found in the soil is hardly available for plants. This is reflected in its high C/N ratio [20]. The combination of all these poor conditions explains the low values of the agronomic parameters of maize found on the control soil. However, spreading manure on this soil has improved the parameters studied. This is proof that the deficits initially observed on the soil have been significantly improved by manures. This result is consistent with the usual situations in which manures, in general, because of their high content of organic matter, are capable of improving not only soil chemical and biological fertility, but also soil structure [21].

The study has shown that of the two amendments used for the agronomic test, chicken manure proved more efficient for the growth of agronomic parameters of maize. This was predictable as nutrient contents in chicken manure were generally more than twice that of sheep manure. The only case of nitrogen is enough to explain this performance of chicken manure. Indeed, nitrogen is the fourth constituent of plants that is used in the development of important molecules such as proteins, nucleotides, nucleic acids and chlorophyll [22]. Poultry manure including chicken manure, which generally contains more than 2% of this element, is classified as one of the most nitrogenous livestock manure [23]. In addition, 60 to 90% of the nitrogen contained in this manure is in mineral form and therefore directly available to the plant. This gives poultry manure in general a higher fertilizer value than most of organic fertilizers [24].

It was also found in this study that the efficiency of fertilizers used as soil amendments is influenced by crop density. Indeed, high planting densities result in faster exploitation of available resources (soil nutrients, water and light) while exacerbating competition for these resources. These types of crop density are therefore not favorable. [25] made similar observations on cotton. These authors noted that seeds sown at very high densities produced plants whose stems were shorter with fewer nodes. The fruit and vegetative branches of these plants were also shorter than those of cotton grown at lower planting densities. Another study realized on okra (*Abelmoschus esculentus*) had a similar result, where lower planting densities favored optimal plant growth [26]. However, [27] and [28] have observed that high plant densities can lead to faster growth of stems, especially when the plant growth period coincides with their flowering time. During this period, the photosynthetic activity of the plant is intense and aims to cover the needs of the plant at the time of flowering initiation. Thus, a competition for light settles between plants: this competition is responsible for their rapid growth.

5. CONCLUSIONS

This study has resulted in the fact that chicken and sheep manures are able to induce significant beneficial effects on maize agronomic parameters. However, of these two fertilizers, chicken manure which had shown a more interesting fertilizing value, made plants grow better. In view of these results, the study appears as a rather interesting contribution to improve maize productivity in Côte d'Ivoire. However, this study needs to be deepened by taking into account a wide range of maize varieties and all the pedoclimatic conditions that characterize this country. It will also be question of evaluating several doses of these manures to determine the optimal dose. The extension of the results obtained to producers would certainly be facilitated by the availability of manures in many farms located in the outlying areas of all major cities of Côte d'Ivoire.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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