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Comparative Effect of Mineral (NPK) and Organic (Poultry Manure) Fertilization on the Agronomic Parameters of Millet on an Arenosol in the Dakar Region

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ABSTRACT

This study was conducted to analyze the influence of an organic residual product (ORP) and an inorganic fertilizer on the growth parameters of millet, in the context of climate change and declining soil fertility in Senegal. A greenhouse experiment was conducted on a carbon-poor arenosol (A) to study the behavior of a high root exudation millet variety (M+) under the effect of poultry manure and NPK fertilizer. The experimental design consisted of a complete randomized block with 2 treatments (T1: NPK (AM+) and T2: poultry manure with urea and K2O supplements (AM+PM)) with 5 repetitions each, over 12 crop cycles of 45 days. Agronomic parameters (number of leaves NL, plant height PH, aerial biomass AB and root biomass RB) were measured at the end of each cycle. The results showed that fertilization with poultry manure (PM) did not significantly increase NL, PH, AB and RB compared to NPK fertilization. However, it showed an upward trend in the middle of the experiment through to the end. These results confirm the importance of PM in fertilizing carbon-poor soils. They also affirm that PM could be an alternative in the fight against soil degradation and constitutes an important element in animal waste recycling policies in agriculture.

Keywords: Poultry manure, growth, millet, recycling, waste, soil degradation

INTRODUCTION

In a context of massive population growth, sub-Saharan Africa faces the challenge of sustainably developing its agricultural production (1). In the Sudano-Sahelian zone of West Africa, agricultural productivity is strongly affected by climate variability and change (2). Farmers often resort to agricultural intensification in order to increase yields and maximize returns on investment. However, this practice does not necessarily ensure increased productivity (3). Furthermore, the excessive use of mineral fertilizers is not without long-term consequences for soil fertility. In this context, in West Africa, agroecological techniques have been recognized by many farmers, NGOs and farmer organizations as a promising solution to slow down the persistent degradation of soil fertility in arid areas (4). In Senegal in particular, beyond environmental and soil degradation (5), over the past 20 years, rural populations have increased, leading to greater agricultural intensification and the use of marginal land poorly suited to farming (6). Various predictive models have concluded that climate change would reduce the production of major cereal crops, with the exception of millet due to its ability to grow under variable climatic conditions and in dry areas thanks to a strong root system (7). Pearl millet (Pennisetum glaucum [(L.) R. Br.]), one of the most important cereals in West Africa, was probably domesticated once in the Sahelian zone of West Africa (8). In addition, millet is a C4 crop, meaning it has the capacity to fix carbon even under conditions of high temperatures and low nitrogen content due to its low transpiration rate (9). In addition to contributing to food security, millet has enormous potential to reduce the impact of agriculture on global warming and should be cultivated worldwide as an alternative to major cereals and grains (7). In Senegal, the main millet production areas are predominantly the groundnut basin, eastern Senegal and Upper Casamance. In these areas, particularly the groundnut basin, the limited availability of organic residual products such as poultry manure (PM) in small farms justifies the use of inorganic fertilizers to maintain or increase agricultural yields. This can be explained by the fact that the highest PM production is in the Dakar region due to intensive poultry activity (10). Indeed, according to the 4 poultry sectors defined by the (11), Dakar concentrates sectors 1 and 2 with an intensive and commercial system (more than 80% of poultry stocks) (12). This production serves as a fertilizer or soil amendment in market gardening ((13), (14)). Studying the role of this organic residual product in millet cultivation would be an asset in an agroecological approach to replacing or combining it with mineral fertilizers.

The objective of this work is to determine the effects of applying poultry manure and NPK chemical fertilizer on the growth of millet cultivated on a low organic matter arenosol in Senegal.

MATERIALS & METHODS

The experiment was carried out at the École Nationale Supérieure des Mines et de la Géologie of Cheikh Anta Diop University in Dakar. It took place over 12 crop cycles of 45 days each and began in February 2021.

Origin and chemical composition of fertilizers

The organic residual product (ORP) used in this study is of agricultural origin. It consists of poultry manure (PM) collected in the Dakar region. The interest in the ORP lies first in its fertilizing and soil-amending properties, but also in its availability in sufficient quantities. Added to this is its degree of mineralization compared to other ORPs such as sewage sludge. Indeed, studies have shown that PM is more reactive than sewage sludge (15).

The poultry manure comes from the ISRA experimental station located in the rural community of Sangalkam (Latitude 14° 46' 44.30" N, Longitude 17° 13' 33.65" W, Altitude 19 m), in the Rufisque department (Figure 1). This site is located in the Niayes ecological zone. The total quantity of raw poultry manures potentially produced per year in the Dakar region is estimated at 9,072 tonnes (10). The PM samples were analyzed at the IMAGO laboratory of the IRD in Dakar. The chemical characteristics are given in Table 1.

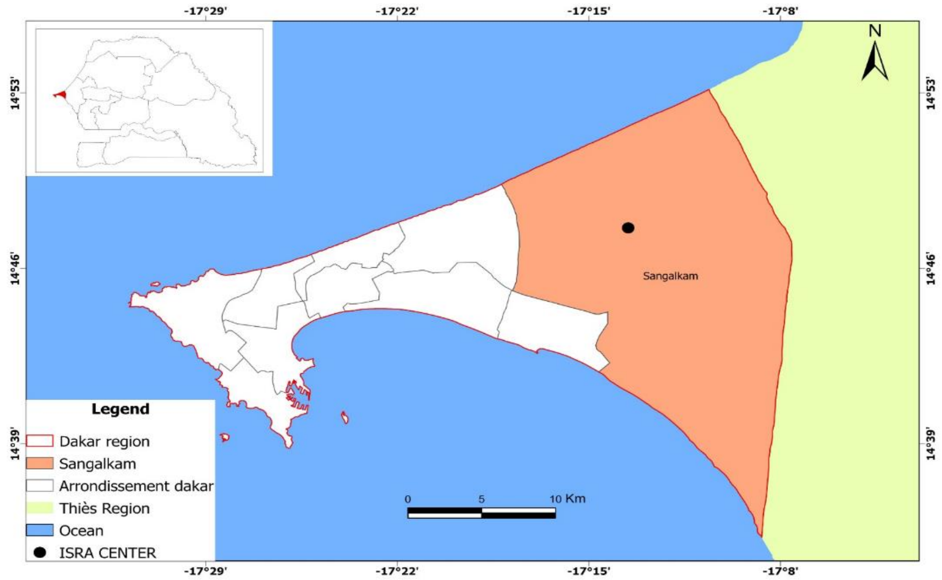

Figure 1: Location of the PM sampling site at the Sangalkam research centre ISRA, in the Dakar region

Tableau 1: Chemical characteristics of the PM used

ORP	Total Carbone Organic (g/kg)	Total N (g/kg)	Total P (mg/kg)	K (mg/kg)
Poultry manure	2,2 ± *0,8*	0,25 ± *0,1*	8573 ± *1687*	10469 ± *2798*

In treatments without PM addition, mineral fertilizers (urea and K2O) were added to supplement the N, P and K inputs. The different doses applied are recorded in Table 2.

Equations 1, 2 and 3 were used to calculate the quantity of products to be applied per pot. Let CE (%): the fertilizer equivalence coefficient for each product applied; T: content of the element in the product; Consp (kg/kgDM): concentration of N, P and K in the product; F (kg/ha): the fertilization to be applied corresponding to the plant's needs; QP (kg/ha): the quantity of product to be applied at field scale and Qp (g/pot): the quantity of product to be applied per pot.

The fertilizer equivalence coefficient is used to estimate the fertilizing value for an element present in an organic material. CE corresponds to the fraction of this element that acts like a mineral fertilizer, i.e. directly available to the crop.

We have:

- Equation 1: Cons.p = T/1000
- Equation 2 : QP = F/ (Cons.p × CE)
- Equation 3: Qp = QP × pot surface × 1000

Thus, we applied 7 g of poultry manure and 0.4 g of NPK fertilizer (15-15-15) per pot.

Tableau 2: Calculation of fertiliser quantities applied

Quantity	Elements	Units	Mineral fertiliser	poultry manure
CE	N		1	0,6
	P	%	1	0,65
	K		1	1
Cons.p	N		0,15	0,0244
	P	kg/kg MS	0,15	0,0173
	K		0,15	0,0066
F	N		60	
	P	kg/ha	30	
	K		30	
QP	N		400	4098
	P	kg/ha	200	2668
	K		200	4545

Qp	N		1	10,4
	P	g/pot	0,5	6,8
	K		0,5	11,6

Experimental design

The experimental design consisted of a factorial randomized pot block (2 × 1), comparing 2 types of fertilization (PM and NPK) and a high root exudation millet variety, in 5 repetitions, for a total of 10 pots.

Soil preparation and application of fertilizers and plants

Soil samples were also collected at the Sangalkam research center at a depth of 0–20 cm. This is an arenosol very low in organic matter (<0.5% carbon). Its particle size analysis shows a composition of >90% sand. A mass of 600 g was used in the growing pots. The soil was sieved to 2 mm at the end of each crop cycle and mixed with the various fertilizers. Its return to the pot was accompanied by compaction to respect the original bulk density (1.33). Several millet seeds were planted and the pots were watered with an input equal to 5 pore volumes. Thinning (removing plants from the seedlings to optimize yield) was carried out 10 to 15 days after sowing (vegetative phase), leaving only 3 millet plants per pot.

Data collection

At the end of each crop cycle, the plants were removed from the pots in order to take measurements. These consisted of counting the number of leaves and measuring plant height. Aerial biomass and root biomass were determined once the plants were freed from their rhizospheric soil. They were dried in envelopes for 72 hours at 65°C. Once dried, they were weighed and stored for possible analyses.

Statistical Analysis

Data processing and analysis were carried out using Rstudio (R-4.3.1) and XLSTAT (version 2021) software. The Grubbs test was first applied to detect extreme values, and outliers were then removed using Box-plots. After examining the independence between variables, testing data normality (Shapiro test, $p < 0.05$) and variance homoscedasticity (Levene test, $p < 0.05$), ANOVAs were performed to compare variable means (Tukey test) to test the effects of treatments (ORP and NPK) on the various measured variables. The ranking of means for each treatment level was carried out using Newman-Keuls significance tests (SNK) at the 5% threshold with a 95% confidence interval. A graphical representation using histograms (means from 5 repetitions) and error bars (standard deviation) was used to visualize significant differences (*) between treatments.

RESULT

Effect of poultry manure on the number of leaves

Figure 2 shows the variations in leaf number according to the two types of fertilization. The results showed that poultry manure produced higher leaf numbers, without significant difference ($p>0.05$), in all cycles except cycles C3, C4 and C12, where the number of leaves was significantly lower in C3 and C4. In C9, however, a significant increase was recorded.

Effect of poultry manure on plant height

The evolution of plant height is shown in Figure 3. Analysis of variance (ANOVA) at the 5% threshold revealed no significant difference between the various measured heights. In PM treatments, plant height was greater in cycles C1, C2, C9, C10, C11 and C12. In contrast, mineral fertilization treatments recorded greater plant heights in cycles C3, C4, C5, C6, C7, C8 (significantly) and C12.

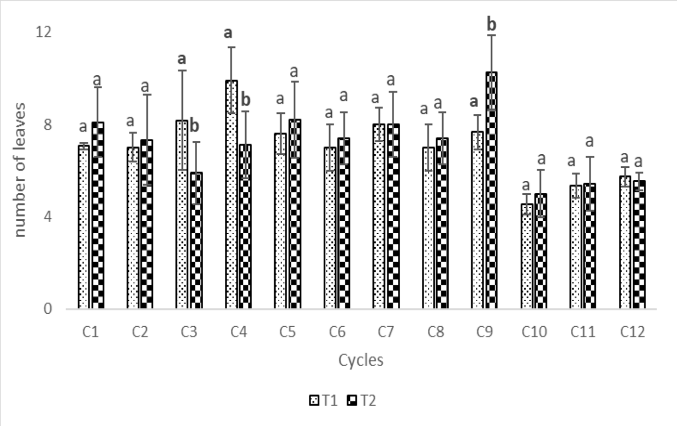

Figure 2: Effect of poultry manure on the number of leaves, with cycles on the x-axis and the average number of leaves per treatment on the y-axis. Each histogram represents the average of five replicates, and the error bars represent standard deviations. Different letters indicate significant differences between T1 (NPK) and T2 (PM)

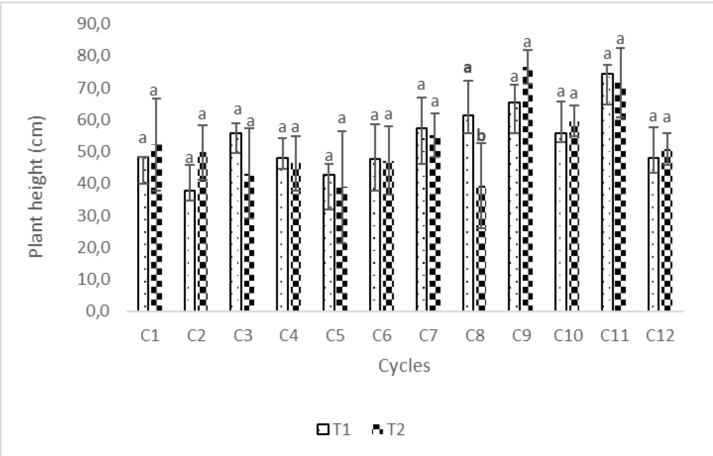

Figure 3: Effect of poultry manure on the plant height, with cycles on the x-axis and the average number of plant height per treatment on the y-axis. Each histogram represents the average of five replicates, and the error bars represent standard deviations. Different letters indicate significant differences between T1 (NPK) and T2 (PM)

Effect of poultry manure on aerial biomass

Biomass measurements reported higher aerial biomasses in PM treatments from C7 to C12, with significant differences in cycles C9, C10 and C11. These results are illustrated in Figure 4 and show the absence of interaction between the two types of fertilization.

Effect of poultry manure on biomass

The same trend observed with root biomasses is also noted at the level of root biomasses. Indeed, they increase from C7 to C12 but without significant difference with poultry manure. However, significant decreases are noted in cycles C3 and C4 (Figure 5). Similarly, these results also show the absence of interaction between the 2 types of fertilization.

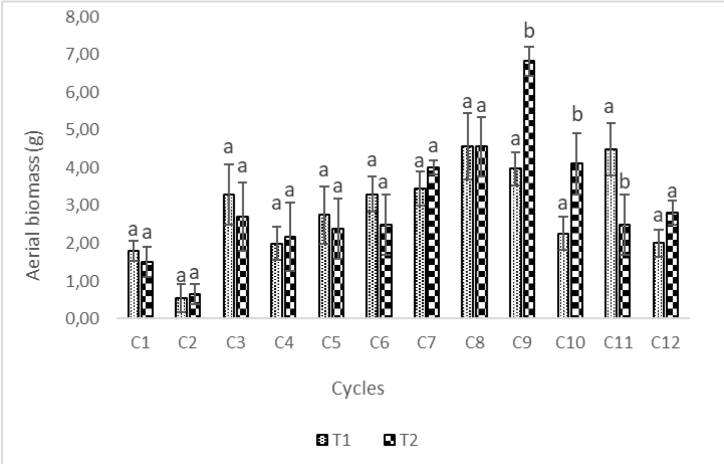

Figure 4: Effect of poultry manure on the aerial biomass, with cycles on the x-axis and the average number of aerial biomass per treatment on the y-axis. Each histogram represents the average of five replicates, and the error bars represent standard deviations. Different letters indicate significant differences between T1 (NPK) and T2 (PM).

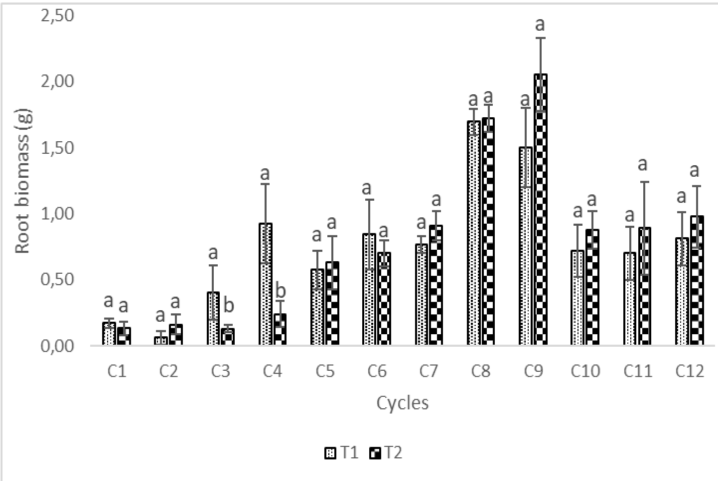

Figure 5: Effect of poultry manure on the root biomass, with cycles on the x-axis and the average number of root biomass per treatment on the y-axis. Each histogram represents the average of five replicates, and the error bars represent standard deviations. Different letters indicate significant differences between T1 (NPK) and T2 (PM).

DISCUSSION

Effect of PM on growth parameters

Our results showed that there is no major interaction between PM treatments and NPK treatments. PM treatments showed upward trends and maintenance from C7 for the number of leaves and from C9 for plant height. Conversely, in NPK treatments, the number of leaves and plant height were greater during the first crop cycles. This observation seems to indicate a residual effect of the manure in the soil. Indeed, PM is a very rich organic fertilizer that rapidly releases nitrogen, phosphorus, potassium and calcium, while improving soil structure and increasing its pH. Its organic matter content (and consequently its carbon content) allows soil fertility to be improved after several crop cycles (16).

On the other hand, the absence of a significant effect of poultry manure can also be explained in part by its application method. Indeed, since PM was applied during soil preparation, a significant quantity could have been lost through leaching upon first watering. In fact, studies have shown that applying organic fertilizers around clods during the tillering period allowed for better yields (17). Furthermore, the low quantities of PM applied could affect agronomic performance, given the low organic matter content of our soil and

also the number of millet plants per pot (3). Moreover, there are certain concerns regarding the long-term viability of microdosing due to potential soil nutrient depletion, particularly without joint application of organic matter or crop residue return (18).
However, other studies have shown conflicting results. For example, (19) showed that soil amended with PM resulted in greater plant growth, greater root biomass, increased root exudation and greater microbial activity. Similarly, the results obtained by (20) showed that the mineral fertilization treatment (N-P-K 10-10-20, 150 kg ha^{-1} and urea 100 kg ha^{-1}) significantly influenced height growth ($p=0.056$), aerial ($p=0.0281$) and root ($p=0.0374$) biomasses and millet grain yield ($p=0.0015$) compared to the control (T0) at the 5% threshold.

Effect of NPK fertilizer

The application of inorganic NPK fertilizer showed good performance at the beginning of the experiment, but this effect appeared to slow down from cycle C7 onwards until the end of the study. This effect seems to indicate a long-term decline in soil fertility. Indeed, studies have shown that in the Niayes zone (Dakar Region), prolonged use of mineral fertilizers for agricultural intensification has led to a decrease in soil fertility (21). To address this, it would be recommended to review NPK fertilizer doses and also to consider PM + mineral fertilizer combination formulas. In terms of dosing, studies have shown that low doses of fertilizer can lead to good yields. For example, (22) showed that millet yield was highest with the recommended fertilizer rate, but the yield response per unit of fertilizer applied (i.e., agronomic use efficiency) was greater for the reduced rate than for the recommended rate. The reduced fertilizer rate increased yield by 110% compared to the control, while the recommended rate increased yield by 16% compared to the reduced rate. Similarly, micro-doses of NPK fertilizer (17-17-17) of 0.3, 0.6 and 0.9 g increased millet yield by 31.3%, 30.7% and 47% respectively in the studies of (23).

Effect of PM + mineral fertilizer combination

In this study, the urea and K2O added to compensate for nutrient needs in PM treatments did not produce a significant effect on agronomic parameters. These results are consistent with those of (24), who showed that the interaction between the amendment and mineral fertilization had no effect on the growth parameters of sanio millet. Furthermore, an in-depth analysis of a 25-year fertility experiment showed that combining organic and inorganic fertilizers provided no yield advantage over applying the same quantities of nutrients from exclusively organic or inorganic sources (25). Moreover, a study by (26) revealed that the appropriate application of inorganic fertilizers in combination with organic manure increases soil fertility compared to values obtained with organic or inorganic fertilizers used separately.

CONCLUSION

This study demonstrated that the prolonged use of inorganic fertilizers can lead to a decline in soil fertility. In addition, the use of organic residual products, particularly poultry manure, would play a key role in agroecological practices for restoring degraded soils by contributing organic matter. Moreover, poultry manure, combined with other synthetic products (chemical fertilizers for example), could contribute doubly to sustainable development policies. First by enabling carbon to be stored in the soil for its fertility and the fight against climate change. Then for its recycling as agricultural waste in order to reduce pollution, limit chemical inputs, promote the circular economy and preserve natural resources.

Declaration by Authors

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