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Effects of combined mineral and sewage sludge fertilization on soil properties and growth of two *Zea mays* (L.) varieties in Western Highlands of Cameroon

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Historic

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Abstract

This study aimed at evaluating the effects of combined application of dewatered sewage sludge (SS) and mineral fertilizer on the chemical properties of the soil and growth of *Zea mays*. Six treatments: T0, negative control; T1, positive control of 120 kg N/ha; T2, 2 t/ha sewage sludge (SS) + 60 kgN/ha; T3, 4 t/ha SS + 60 kgN/ha; T4, 8t / ha SS+ 60 kgN/ha and T5, 8 t/ha SS were applied in completely randomized block experimental design. The following parameters: height of plants, diameter of stem, number of healthy leaves, leaves area index, root and shoot biomasses were measured on plants at 30, 44 and 58 days after sowing. For the soil parameters, electrical conductivity (EC), redox and hydrogen potentials were measured at the same frequency. The results showed that the height, the stem diameter, the number of leaves, the leaves area index and the biomass of *Zea mays* increased in response to soil supplementation with sewage sludge combined with mineral fertilizers. The treatment that best stimulated the growth of maize was T4 (8t/ha SS+ 60 kgN/ha). The soil chemical properties were modified by sewage sludge application. In general, pH and conductivity decrease with sludge application, while, redox potential increased. This shows that combined sewage sludge to NPK (20 10 10) leads to changes in chemical parameters of the soil and thus, influencing the nutrients uptake by plants to improve their growth.

1. Introduction

Maize is the third most valuable cereal in the world after rice and wheat [1]. This is because all the parts of the plant have an economic value [2]. Approximately 20% of the world's maize production is used directly for human consumption and nearly 2/3 of the world's production is for animal feed. Maize is a staple food for many African countries where it is used as a raw material for feed formulation and in the brewery, soap-making and oil production industries [3]. Despite the availability of improved cultivars, the average yield of maize remains low [4]. In Cameroon, the annual demand for maize is estimated at about 2.8 million tons, for a production of about 2.2 million tons [5]. This low production is attributed to the progressive soil degradation [6] and the low use of agricultural inputs [2]. In addition, African countries are encountering high population expansion which is accompanied by an increase in food demand [7]. Thus, in order to improve their agricultural production, many African countries have increased their cultivated areas and are gradually abandoning fallow practices [8]. However, traditional agricultural practices based on intensive plowing and excessive tillage are the causes of the destruction of soil structure and the reduction of organic matter content and soil porosity [9]. This results in the decrease of soil fertility and thus, lowering of agricultural yield. The mitigation of soil degradation and yield loss through fertilization is well documented [10-12]. According to Voortman and Bindraban [13], mineral fertilization contributes for about 40-60% to global food production. However, the low availability and ever-increasing cost of the fertilizers justify the low-rate of use of fertilizers in sub-Saharan Africa [14]. Furthermore, the exclusive application of chemical fertilizers to improve crop yields is only effective during the first few years of continuous application [15]. In a context of food insecurity, the reduction of soil fertility and the rising prices of fertilizers on the markets, render it necessary to find alternative nutrients available at low cost for agriculture [6]. To this end, sludge from sewage treatment plants have been proven to be rich in organic matter and essential nutrients and could therefore be used to improve soil fertility [16-19]. However, this sludge like any other organic amendment has been used in high concentrations ranging from 25 to 300 t/ha [16, 20-22]. This led to increase accumulation of heavy metals in the soil, which increases with the increase in quantities applied [23]. However, recent studies have shown the effectiveness of sludge combined with mineral amendment on plant growth and on the improvement of microbiological and physicochemical activities of the soil [24, 25]. In addition, studies concerning the combination of organo-mineral amendments have proven that this practice is more advantageous for the plant's growth, maintenance of soil fertility, and ~~it~~ is cheaper [10, 24, 26]. Moreover, this practice contributes to reduce by approximately 80% of total global warming, and 60% of soil acidification and aquatic eutrophication compared to mineral

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fertilization [27]. The objective of this work was to evaluate the effects of small doses of sewage sludge combined with NPK (20 10 10) chemical fertilizer on the growth of two *Zea mays* varieties and the chemical properties of the growing medium.

2. Material and methods

2.1. Location of the study site

The work was carried out at the research farm of the University of Dschang. Dschang is located in the Western Highlands of Cameroon between latitudes 5°25' and 5°30' North, and between longitudes 10°0' and 10°5' East. Its climate is of equatorial type, with an average annual temperature of 20.8°C and thermal amplitude of 2°C (Figure 1).

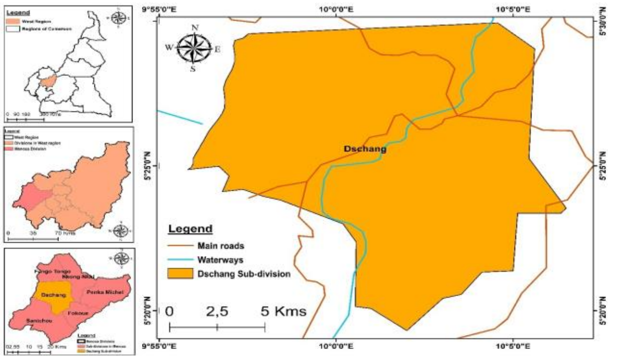


Figure 1: Location of Dschang in the West region of Cameroon

2.2. Maize varieties used

Two composite maize varieties (Kassaï and ATP) which were developed by the Institute of Agricultural Research for Development (IRAD) in 1992 were used in this study. These are varieties adapted to high altitudes (between 800 and 1400 m), offering good yields (4 - 5 tons per hectare) and good resistance to diseases such as maize head smut, curvilariasis, helminthosporiosis, and maize stripe. Their duration cycles are respectively 130 to140 days for Kassaï and 120 to 130 days for ATP.

2.3. Preparation and characterization of sewage sludge and soil

Sewage sludge used in this experiment was collected from the digester of the wastewater treatment plant of the University of Dschang. The primarily treated sludge was dewatered on sand beds, then ground in a mill and passed through coarse particles sieve to remove any inorganic particles. Soil and sewage sludge samples were collected and transported to the soil laboratory of the Faculty of Agronomy and Agricultural Sciences (FASA) of the University of Dschang for analysis. Total carbon was determined by Walkey-Black's method using dichromate solution in the presence of H_2SO_4. Total Phosphorus was determined by Bray II method; total nitrogen was determined using the Kjeldahl method; Ca and Mg were determined using the atomic absorption spectrophotometer; Na and K were determined by flame photometry. pH and electrical conductivity were determined in a mixture obtain by diluting 20 g of dried sample in 100 ml of distilled water and were measured by using pH-meter and conductivity meter.

2.4. Experimental design and treatments

The pots experiment was conducted in a completely randomized block design consisting of 6 treatments, two varieties and 13 replicates. It was conducted for two months under natural conditions. The method used was that described by Ngoran [26] with some modifications. Indeed, the trials were conducted in black polyethylene bags of 30 cm in diameter and 35 cm high and under natural weather conditions. The treatments applied to the different pots were as follows:

T0: negative control.

T1: positive control: 600 kg NPK 20-10-10 (equivalent to 120 kg N/ha)

T2: 2t/ha of powered sewage sludge + 300 kg NPK

T3: 4t/ha of Dried sewage sludge + 300 kg NPK

T4: 8t/ha of Dried sewage sludge + 300 kg NPK

T5: 8t/ha of Dried sewage sludge powder + 0 kg NPK

The quantity of amendment supplied per pot was calculated using the following formula

$$Qp = Qch \times Sp(\frac{1ha}{100000000cm^2}) \quad \text{(Equation 1)}$$

Where, *Qp* = quantity of amendment per pot in g;

Qch = quantity of amendment applied per hectare in tonne;

Sp = area of the pot (πr^2) in cm².

2.4.1. Measurement of growth parameters of maize plants

Parameters such as height, stem diameter, number of leaves, length and width of leaves as well as the roots biomass were measured on 3 plants for each treatment on the 30th, 44th and 58th days after sowing. Plant height, leaf length and width were measured with a graduate meter tape and diameter was measured with a calliper square. The leaf area was calculated from the following formula of Bonhomme *et al.* [28]:

$$Leaf\ Area\ (LA) = L \times l \times 0.75 \quad \text{(Equation 2)}$$

Where L= length of the leaf, l= width of leaf

The leaf area index was determined using the formula from Agba *et al.* [29].

$$LAI = \frac{Y \times Nl \times LAm}{Sp} \quad \text{(Equation 3)}$$

Where *LAI*= leaf area index, *Y*= number of plants per pot, *Nl*= average number of leaves per plant, *LAm*= average leaf area and *SP*= area of pot.

The root system was carefully removed from the pots and washed. Each of the plants was separated into below (roots) and above (stems and leaves) biomass in order to evaluate the biomass distribution. The fresh and dry biomasses were measured before and after the ventilated oven drying at 60°C until obtaining constant biomass.

2.4.2. Chemical characteristic of soil

pH, electrical conductivity and redox potential are the three most important parameters for soil and plant physiology. They are influenced by soil organic matter and nutrients content and they control their availability for plant and their microbiota [30, 31, 32]. Composite soil samples of 100 g from three pots of the same treatment were formed for each of the cultivated varieties. 20 g of dry sample were mixed with 100 ml of distilled water. The soil solution was intermittently homogenized for 2 h and then filtered through Wattman paper N° 3. The pH, the redox potential (*Eh*) and the electrical conductivity were measured on the filtrate using a multi-parameter pH meter and a conductivity meter at 30th, 44th and 58th days after sowing.

2.4.3. Statistical analysis of data

The data collected on *Zea mays* growth parameters as well as the soil parameters were subjected to two-ways analysis of variance (ANOVA) using XL-stat 2016 software. Duncan's multiple comparison test, at 5% significance level was used for means separation when they were different.

3. Results

3.1. Physicochemical characteristics of soil and sewage sludge

The soil used for this study had inherently low nutrient content compared to sewage sludge. Analysis showed that soil was silt-clay-sand with sand content: 58.3±5.75%, silt content: 22.5±4.72%, clay content: 19.2±2.82%; with a moderately acidic pH (6.0±0.12), and C/N ratio of 19.2±8.02contents 5.9% of nitrogen, 0.4% of potassium and 0.3% of Phosphorus (Table 1).

Tableau 1: Physicochemical characteristics of soil and sewage sludge

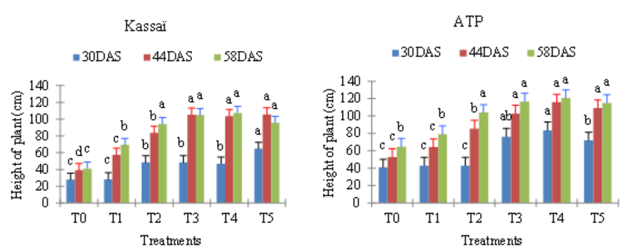
Parameters	Soil	Sewage sludge
Sand (%)	58.3±5.75	/
Silt (%)	22.5±4.72	/
Clay (%)	19.2±2.82	/
pH-H_2O	6.0±0.12	5.5±0.8
CO (%)	4.2±0.59	/
MO (%)	7.2±1.01	/
N (%)	0.2±0.84	5.9±0,6
C/N	19.2±8.02	/
Ca (mg/kg)	2900±460	2520.0±282.8
Mg (mg/kg)	534.6±210.63	5710.2±790.4
K (mg/kg)	312±101.4	3018,3±403.7
Na (mg/kg)	46±16.1	601.2±159.0
P (mg/kg)	22.4±9.84	3913.5±71.6
EC (dS/m)	/	5.9

The chemical characteristics of this sludge showed that the sludge was moderately acidic (pH=5.5) and electrical conductivity value was 5900 µs/cm.

3.2. Effects of different treatments on the growth parameters of the two varieties of *Zea mays*

3.2.1. Plant height

The effects of sewage sludge and combined sewage sludge with NPK on plants height was statistically significant compared to the negative and positive controls (T0 and T1) throughout the experiment excepted for the treatment T2 at 30 DAS for Kassaï variety and at 44 DAS for ATP variety. Following the plants height (Figure 2) for the Kassaï variety, the treatment T5 had the highest heights at 30th DAS (64.43cm). At 44th day, the heigh of plants from treatments T3 (105.37cm), T4 (103.43cm) and T5 (105.7cm) were not statistically different. At 58th DAS plants from all sludge-based treatments had their heights which were not statistically different from each other. Except at 30th DAS, the positive control (T1) had significantly improved height for the Kassaï variety compared to the negative control (T0). For the ATP plant variety, at 30 DAS, the highest height T4 (83.47cm) was recorded in response to the application of treatments T4. At 44th and 58th DAS, all sludge-based treatments had statistically similar responses for height except T2 (85.5cm) at 44th DAS. The plants of the negative and positive controls showed the lowest heights throughout the research period. For the ATP variety, there were no significant differences between positive and negative control.

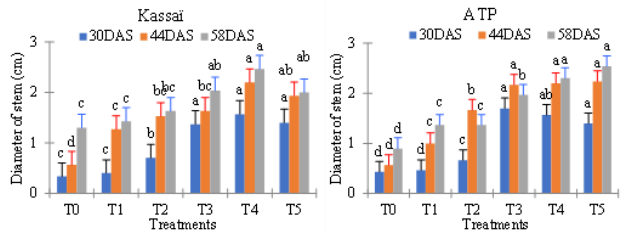


Bar with different letters are significantly differences according to Duncan's multiple comparison test (P<0.05), T1=0 g SS + 4.24g NPK. T2= 14.13 g SS+ 2.12 g NPK, T3= 28.26 g SS+ 2.12 g NPK ; T4= 56.53 + 2.12g NPK and T5= 56.52 g SS + 0 g NPK.

Figure 2: Variation of plants height with time following the different treatments

3.2.2. Plants diameter

All the sewage sludge amendments showed statistical improvement of stems diameter compared to the negative and positive controls throughout the experiment except–those of the treatment T2 for the Kassaï variety. During all the experiment for the Kassaï variety, the T4 treatment presented the largest stem diameter. Despite the fact that the positive control showed higher stems diameter compared to the negative control, there was no significant difference between them. For the ATP maize variety, all amendments showed statistical improvement of stems diameter except for the positive control (T1) at the 30th DAS compared to negative control throughout the experiment. At 30th DAS, the T3 treatment presented the largest stems diameter whereas at 44th and 58th DAS, it was the T5 treatment that showed the largest stems diameter. The positive control had the larger stems diameter compared to negative control except at 30th DAS.

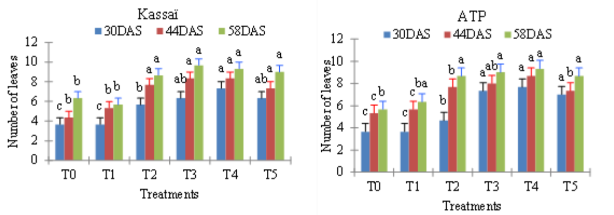


Bars with different letters are significantly differences according to Duncan's multiple comparison test (P<0.05)

Figure 3: Variation of stems diameter with time following the different treatments

3.2.3. Number of leaves

Throughout the experiment, all the sewage sludge treatments significantly improved the number healthy leaves compared to positive and negative controls. At 30th DAS, maize showed healthy leaves count ranging from 4 to 7 for the Kassaï variety (Figure 4).



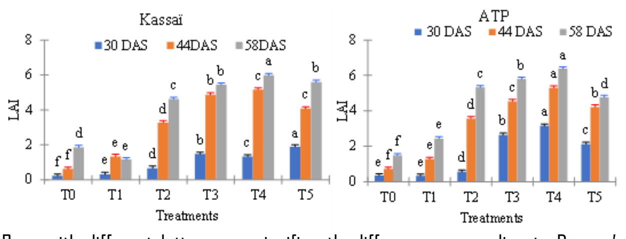
Bars with different letters are significantly differences according to Duncan's multiple comparison test (P<0.05)

Figure 4: Variation of number of leaves with time following the different treatments

At the same period, the T3 treatment presented the highest number of healthy leaves. At 44th DAS, the plants of the T3 and T4 treatments presented the highest number of healthy leaves (8 leaves) and at 58th DAS, the plants of the T3 treatment presented the highest number of healthy leaves (10 leaves). For the ATP variety, the T4 treatment presented the greatest number of healthy leaves throughout the experiment (8, 9 and 9 respectively at 30th, 44th and 58th DAS). There were no significant differences between the number of healthy leaves for the positive (T1) and negative (T0) controls

3.2.4. Leaf area index

Throughout the experiment, all the amendments significantly improved the LAI compared to the negative control (T0). All the sludge-based treatments significantly improved the LAI compared to the positive control (T1). For the Kassaï variety, at 30th DAS, the T5 treatment (1.89) showed the largest leaf area index. At the 44th and 58th DAS, the T4 (5.17) and T5 (5.99) treatments respectively improved most the leaf area indices. For the variety ATP, the LAI increased with increase in the proportion of amendments. The T4 treatment showed the largest leaf area indices throughout the experiment (3.15, 5.32 and 6.38) respectively at the 30th, 44th and 58th DAS (Figure 5).



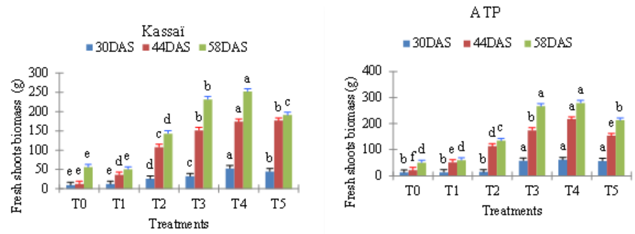
Bars with different letters are significantly differences according to Duncan's multiple comparison test (P<0.05)

Figure 5: Variation of leaf area index (LAI) of *Zea mays* with time following the different treatment

3.3. Biomass distribution on the maize plants

3.3.1. Fresh shoot biomass

The accumulation of fresh shoot biomass was significantly enhanced by the application of sewage sludge (SS) based treatments. In fact, at the 30th, 44th and 58th DAS, the T4 treatment stimulated most the improvement of the fresh shoot biomass for the Kassaï variety (Figure 6).



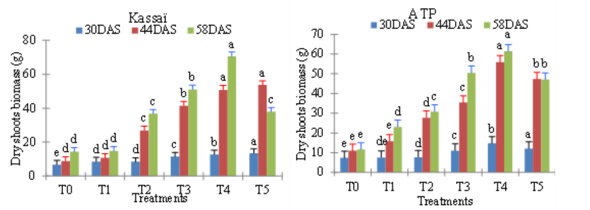
Bars with different letters are significantly differences according to Duncan's multiple comparison test (P<0.05)

Figure 6: Variation of fresh shoot biomass of *Zea mays* with time following the different treatments

This was respectively 52.9, 173.62 and 252g at these different periods of time. For the ATP variety, at 30th, 40th and 58th DAS, the fresh shoot biomass was improved most by the T4 treatment with respectively 61.87, 216.72 and 279.08 g whereas at the 30th DAS, the treatments T3, T4 and T5 did not showed any significant differences. The Positive control (T1) produced more biomass than the negative control except at the 44th DAS for both varieties where the positive control did not show any significant difference with negative control.

3.3.2. Dry shoot biomass

The accumulation of dry shoot biomass was significantly improved by the application of sewage sludge-based treatments. In fact, at the 30th and 44th DAS the T5 treatment improved most the dry shoot biomass production for the Kassaï variety (14.74g and 55.76g respectively). Meanwhile, at the 58th DAS, the T4 treatment stimulated most the improvement of dry shoot biomass (70.61g) while, at the 44th DAS, there was no significant difference between the T4 and T5 treatments. For the ATP variety, at the 30th, 40th and 58th DAS, the T4 treatment improved most the dry shoot biomass (14.74, 55.76 and 61.38 g respectively). Throughout the experiments, the positive control (T1) produced more dry shoot biomass than the negative control (T0) but with no significant differences between the two except at the 30th DAS for Kassaï variety and at the 58th DAS for ATP where, the positive control showed significant differences with negative control (Figure 7).



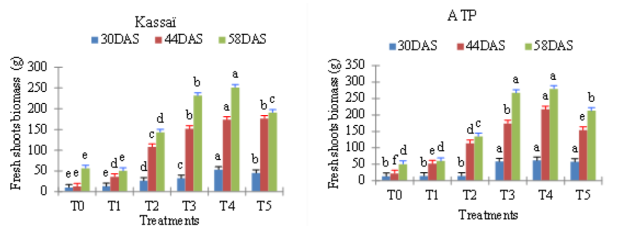
Bars with different letters are significantly differences according to Duncan's multiple comparison test (P<0.05)

Figure 7: Variation of dry shoot biomass of *Zea mays* with time following the different treatments

3.3.3. Fresh root biomass

All treatments significantly stimulated the fresh root biomass production compared to the negative control (T0) except for the positive control (T1) at the 30th DAS for the Kassaï variety and the

T1 and T2 treatments for the ATP variety at the same period. Concerning the ATP variety, the T4 treatment showed the best production of fresh root biomass. All the sewage sludge-based treatments significantly improved the fresh root biomass compared to positive control except the T2 treatment for the ATP variety and the T2 treatment at the 58th DAS for the Kassaï variety. Throughout the experiments, the T4 treatment for the Kassaï variety showed the best improvement of the fresh roots production at the 30th and 44th DAS. Meanwhile, at the 58th DAS the T3 treatment improved most the fresh root biomass (Figure 8).

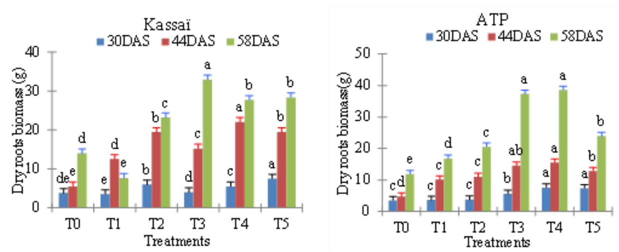


Bars with different letters are significantly differences according to Duncan's multiple comparison test (P<0.05)

Figure 8: Variation of fresh root biomass of *Zea mays* with time following the different treatments

3.3.4. Dry root biomass

At the 30th DAS for the Kassaï variety, dry root biomass was significantly stimulated by all sludge-based treatments compared to the positive and negative controls except for the T3 treatment. Meanwhile, the T5 treatment showed the greatest dry biomass production (7.5g). At the 44th DAS, all the treatments improved the dry roots biomass production compared to negative control (T0) while all the sludge-based treatments significantly improved the dry roots biomass production compared to positive control (T1). The treatment that improved most the dry roots biomass production was T4 (22.02 g). At the 58th DAS, all the treatments improved significantly the dry roots biomass production except the positive control compared to negative control (T0). Concerning the ATP variety, all the treatments significantly improved dry roots biomass production compared to the negative control (T0). Throughout all the experiment, the T4 treatments presented the highest dry roots biomass production (7.59, 15.54 and 38.65g) respectively at the 30th, 44th and 58th DAS.

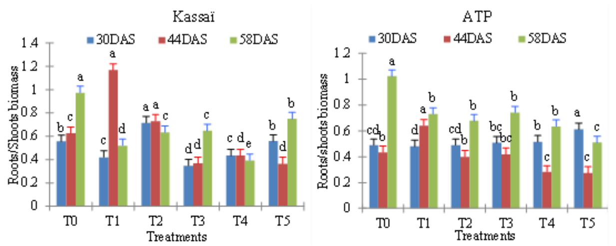


Bars with different letters are significantly differences according to Duncan's multiple comparison test (P<0.05)

Figure 9: Variation of dry roots biomass of *Zea mays* with time following the different treatments

3.3.5. Roots/shoots biomass ratio

The roots to shoots biomass ratio for the Kassaï variety range from 0.35 to 0.72. The positive control (T1) treatment, the T3 and T4 treatments led to the significant decrease of the roots/shoots ratio compared to the negative control (T0). At this same period, the T2 treatment led to the highest increase of the ratio while, the T5 treatment was significantly similar to the negative control (T0). At 44 days after sowing, the T1 and T2 led increase in the ratio while the T3, T4 and T5 treatments led to the reduction of roots/shoots ratio compared to the negative control (T0). The T1 treatment presented the highest roots to shoots biomass ratio (1.16) while the T5 treatment presented the lowest roots to shoots biomass ratio (0.37). At 58 days after sowing, all the treatments led to significant reduction of the roots to shoots biomass ratio compared to the negative control (T0). At the same period, all the sludge-based treatments except the T4 treatment led the increase of the roots to shoots biomass ratio compared to the positive control (T1). Concerning the ATP variety, at the 30th DAS, only the T4 and T5 treatments showed improvement of the roots-shoots biomass ratio compared to the negative control (T0). The T5 treatment presented the highest roots-shoots biomass ratio at this period (0.64). At 44 days after sowing, only the positive control (T1) treatment showed significantly higher roots-shoots ratio compared to the negative control (T0), while the T4 and T5 treatments led to a decrease. At the 58th DAS, all the treatments led to the reduction of roots-shoots biomass ratio compared to the negative control (T0). At the same period, only the T5 treatment showed significant reduction of roots-shoots biomass ratio compared to T1 (Figure 10).



Bars with different letters are significantly differences according to Duncan's multiple comparison test (P<0.05)

Figure 10: Variation of dry root/shoot ratio biomass of *Zea mays* with time following the different treatments

3.3.6. Varieties influence on plant growth parameters

Variety had a significant impact on the height of maize plants. The ATP variety (82.60±27.84a) showed higher heights of plants compared to those of the Kassaï variety (70.58±29.37b). However, despite the fact that the stems diameter, the number of healthy leaves and the leaf area index of the maize plants were higher for the ATP variety compared to the Kassaï variety. Variety did not have any significant impact on these parameters (Table 2).

Table 2: Comparison of growth parameters in the studied varieties of *Zea mays*

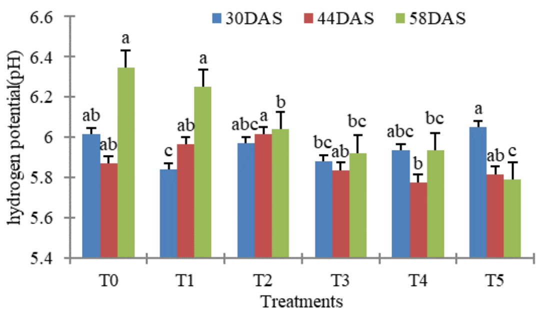
	Maize varieties	
Parameters	**Kassaï**	**ATP**
Plant height (cm)	70.58±29.37b	82.60±27.84a
Stem diameter (cm)	1.43±0,63a	1.47±0.68a
number of leaves	6.83± 1.9a	6.91±1.83a
Leaf Area Index (LAI)	2.77±2.03a	3.05±1.98a
Fresh shoot biomass	97.8±79.75a	108.48±87.49a
Dry shoot biomass	26.62±19.72a	26,54±18.35a
Fresh root biomass	40.98±39.08a	46.35±40.68a
Dry root biomass	14.35±9.45a	13.88±10.40a
Root/shoot ratio	0.591±0.22a	0.548±0.18a

The difference letters in the same row a, b: indicate significant differences tested with Duncan's multiple comparison ($P < 0.05$).

3.4. Effects of the different treatments on the soil chemical properties

3.4.1. Effects of the combination of sewage sludge and chemical fertilizer on soil pH

The soil pH decreased from day 30 to day 44 and increased at day 58, ranging from 5.82 to 6.45. At 30 days after sowing, the positive control treatment with NPK (20 10 10) fertilizer significantly decreased the soil pH compared to the negative control (from 6.02 to 5.84) and all the other treatments. At 44 days after sowing, the pH of soils without amendment (negative control T0) and those treated with T3, T4, and T5 decreased while those treated with positive control (T1) and T2 increased. The T2 treatment had the highest pH (6.01) while T4 had the lowest (5.78). At 58 days after sowing, the negative control (T1), the positive control (T1), T2, T3 and T4 stimulated an increase in pH, while T5 caused a decrease in soil pH. However, negative control (T0) had the highest soil pH (6.35) while T5 had the lowest (5.79). The positive and negative controls did not show any significant difference.

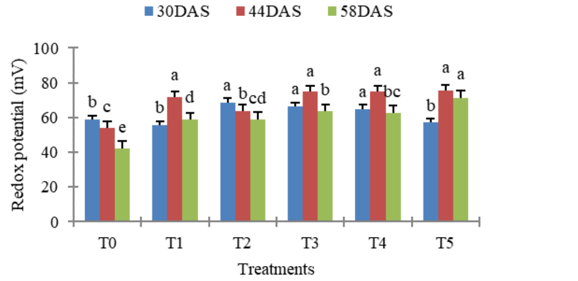


Bars with different letters are significantly differences according to Duncan's multiple comparison test ($P<0.05$)

Figure 11: Variation of the hydrogen potential (pH) with time under the effect of different treatments

3.4.2. Effects of sewage sludge and NKP fertilizer on the evolution of soil redox potential

The redox potential of the soils ranged from 55.5 to 68.75mV at 30 days after sowing. The T2, T3 and T4 Treatments significantly stimulated increase in redox potential compared to the controls T0 and T1. At 44 and 58 days after sowing, all treatments significantly stimulated the increase in Eh compared to the negative control (T0). However, at 44 and 58 days, the redox potentials of the negative control were lowest (54.17 and 42.25 respectively) while those of the T5 treatment were highest (75.25 and 71, 33) (Figure 12).

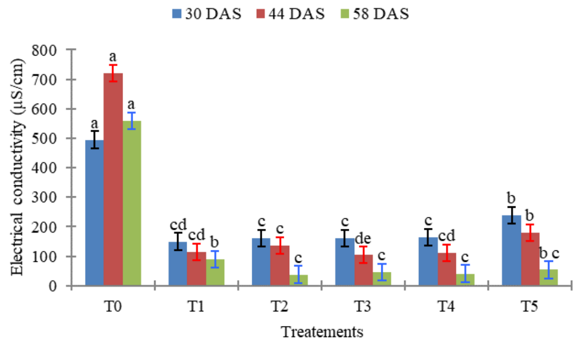


Bars with different letters are significantly differences according to Duncan's multiple comparison test ($P<0.05$)

Figure 12: Variation of the redox potential of the soil with time under the effects of the different treatments

3.4.3. Effects of the combination of sewage sludge and chemical fertilizer on the electrical conductivity of the soil

Soil conductivity decreased from day 30 to day 58 throughout the experiment. All amendments significantly stimulated the reduction of soil electrical conductivity compared to the negative control (without amendment). At 30 days after sowing, all the sludge-based treatments significantly increased the soil conductivity compared to the positive control T1 (115.65 µs/cm). At 44 DAS, the T3 treatment led to the most reduced soil conductivity (103.9). At 58 days, all the sludge fertilizers showed statistically similar responses which were lower than the negative control (Figure 13).



Bars with different letters are significantly differences according to Duncan's multiple comparison test ($P<0.05$)

Figure 13: Variation of electrical conductivity of the soil with time following the different treatments

4. Discussion

4.1. Soil and sewage characterization

Physicochemical analysis showed that the soil had very high organic matter content and high nitrogen, calcium, magnesium and sodium content but was deficient in phosphorus. However, sewage sludge had more than 10 times the K, Mg and Na content; more than 25 times the N content and more than 100 times the phosphorus content of soil.

4.2. Plant growth parameters and biomass

The results showed significantly different responses between the heights of plants of maize varieties studied. Indeed, the heights of plants were higher for the ATP variety compared to the Kassaï variety. This may be explained by the fact that the height of plants is used as discriminatory criterium for *Zea mays* varieties. These results corroborate those obtained by Useni *et al.* [10] and Kimuni *et al.* [33] who found that by applying combined wastes and mineral fertilizers on three different maize varieties, the height of each variety was significantly different. Plant growth parameters (height, diameter, number of leaves and leaf area index) were improved by the application of sludge-based treatments. This could be due to the fact that sewage sludge was rich in essential nutrients that were used by plants for their growth. Indeed; chemical analysis showed that the sewage sludge contained high quantities of nitrogen, phosphorus, potassium, calcium and magnesium. Hussein [16] and Ahckir *et al.* [23] showed that the application of sewage on soil increased their nutrients and organic matter content. However, the positive control T1 had no significant effects on the growth of *Z. mays* plants compared to the negative control without amendment. This may be explained by the chemical composition of the soil, which was formerly containing *Thitonia diversifolia* stands. It may also be explained by the low efficiency of mineral fertilizers in acid soil [34, 35]. It has also been shown that only 10-15% of the phosphorus (P) doses and 10-20% of the nitrogen doses applied to the cultivated soils through fertilizers are taken up by plant, which would suggest nutrients leaching [36]. In addition, during the rainy season, Mi *et al.* [37] showed that mineral fertilization leads to NH_3 volatilization and NO_3^- leaching. Plants height, stems diameter, number of leaves and leaf area index as well as shoots and roots biomasses increased with time and with increase of the sewage sludge doses associated with mineral fertilizer. The highest simple sewage sludge application of 8t/ha (T5) compared to the positive and negative controls without amendment were very high. A similar notice was made by [38, 18, 39, 40] who showed that sludge alone or combined with the mineral amendment stimulated plants growth parameters compared to the negative control without any amendment. This could be explained by the improvement of nutrients supply by sewage, nutrients and water use efficiency, and soil structure properties for better nutrients uptake by *Zea mays* [16, 40]. However, they contradicted the results of Gwenzi *et al.* [18] regarding the effects of mineral amendment, which in his case significantly stimulated the height and number of leaves as well as biomass in the same way as the amendment from sludge combined or not with the mineral amendment. This could be due to the difference in soil used in the different experiments as well as the difference in the climatic conditions where the studies were carried out. Globally, the roots-shoots biomass ratios from the 30^{th} to 58^{th} DAS were lower than 1. This could be explained by the rainfall during the experiment which improved the above-ground biomass production. The roots to shoots biomass ratio at the beginning increased with sewage sludge amendment compared to positive and negative controls. But after 44^{th} DAS, roots to shoots ratio decreased with increase in sewage sludge doses. These results are similar to those of Gwenzi *et al.* [18] which showed that negative control increased roots-shoots ratio compared to positive control and sludge-based treatments.

4.3. Chemical soil parameters

4.3.1. pH

The pH of the soils varied very little throughout the experiment and ranged from 5.78 to 6.34. According to Beernart and Bitondo [41], they ranged from moderately to slightly acidic soils. There is a sort of equilibrium in soil pH. This could be explained by the fact that pH is controlled by the leaching of cationic bases and the release of protons due to humification of organic matter and nitrogen reduction during plant growth [42, 43]. This pH decreases with sewage sludge application from day 30 to day 58. These results are contrary to those observed by Achkir *et al.* [23] which showed that, sewage sludge led to pH decrease. This difference could be due to the difference in dryness of the applied sludge, the latter having disposed of liquid sludge on the soil. The reduction in pH on the NPK-amended soils and on the control, plots can be explained by an increase in root biomass resulting in increase in organic matter, which causes an increase in moisture and a reduction in pH [44, 45]. The decline of pH observed after application of the T3 (4t/ha SS+60kgN/ha) and T4 (8t/ha SS+60kgN/ha) treatments can be explained by the increase in soil organic matter and acid production during decomposition of sludge in the soils [46].

4.3.2. Electrical conductivity

The electrical conductivity of sewage sludge was 5900µs/cm. According to USDA [31] classification, they are slightly salty. However, soil conductivity of the pots ranged from 41.2 to 670 µs/cm throughout the experiment. According to the same author, this range indicates non-salty soil. The application of fertilizer significantly caused a drop of soil electrical conductivity compared to the absolute control without fertilization. This may be because fertilization leads to increased water retention capacity of the soil leading to dilution of soil salinity [40]. In addition, different responses of the soil due to different fertilization types, notably mineral, organo-mineral and organic fertilizations can stimulate different water retention rates by soils. The experiment showed that soil conductivity was significantly reduced. These results are similar to those of [40 and 18]. This reduction with time could be explained by the gradual release of nutrients by fertilizers and their absorption by plants [47, 48]. Indeed, studies by Hussein (16) showed that the application of sludge resulted in an increase in soil conductivity due to the high salt content of the sludge used and high doses applied.

4.3.3. Redox potential (Eh)

Redox potential of the soil during this experiment ranged from 42.25 to 75.25 mv throughout the experiment. According to Kaurichev and Shishova [49], this range indicates reduced state soil type. This low redox potential can be explained by the environmental conditions of the experiment which took place during rainy season and parameters were collected sometimes less than 24 hours after the rains. According to Balakhnina *et al.* [50], redox potential rapidly declines few hours after rains leading to drastic change of state of soil from well aerated to reduced state. The combination of sewage sludge with NPK and the recommended treatment significantly stimulated the increase in soil redox potential compared to the negative control (T0).

However, the T5 treatment which was initially similar to the negative control increased significantly at the end of the experiment compared to all the other treatments. This may be due to the fact that fertilization increases organic matter in soils and that impacts the redox potential [51]. These results corroborate those of Toundou [52] who found that both the mineral and organic amendments stimulated the increase in redox potential of the crops substrates. This could be explained by the nitrification processes of the matter that occurs during growth, generating an increase in redox potential [53, 54].

5. Conclusions

The application of low doses of sewage sludge (between 2 and 8t/ha) combined or not with NPK (20 10 10) at 60 kg/N enhanced the growth of *Zea mays* plants and the production of shoots and roots biomasses. Increasing the doses of sewage sludge led better responses in the plant's growth. Sewage sludge-based treatments also lowered pH reduction compared to positive and negative controls but, they significantly increased redox potential and reduced soil conductivity. Sewage sludge is rich in organic matter and nutrients that have the potentials to improve the chemical properties of the soil and the growth of *Z. mays*. The combined application of sewage sludge T4 treatment (8 t/ha) and NPK (60 kg/ha) had better effects on the growth of both varieties of maize.

Data Availability The data for this research are available with the corresponding author and can be made available to the reviewers or readers of the work on reasonable request. **Conflict of Interest**

The authors declare that they have no conflicts of interest regarding this manuscript.

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