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Effect of Quail Dropping and Compost on Soil Biological and Chemical Fertility, Growth and Biomass Production of Maize

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A B S T R A C T

In Burkina Faso, maize (*Zea mays* L.) is the second most cultivated cereal. However, yields remain low due to the decline in soil fertility inherent to several factors. This study was carried out in order to valorize compost and quail droppings in maize production. It was carried out in a greenhouse vegetation vase at French Research Institute for Sustainable Development in Ouagadougou. The methodology used was based on a randomized block agronomic trial with 04 treatments repeated 5 times. The trial consisted of comparing compost (3 t ha^{-1}), quail droppings (3 t ha^{-1}) and NPK (14-23-14-3B-1S) (200 kg ha^{-1}) with a control. The chemical and biological parameters of the soil after harvest and the production of maize biomass were measured. The results showed that soil amendment with compost significantly increases (P = 0.006) biomass production (125.44 ± 17.13 g) compared to NPK. Compost-treated soils significantly (P = 0.0001) improved plant height (101.22 ± 8.34 cm) and number of ears per plant (0.67 ± 0.14) compared with other treatments. Plant diameter was significantly (P = 0.0001) increased under quail droppings (13.67 ± 0.51 mm). The soil treated with quail droppings improved microbial life with increased CO_2 release (2715 ± 648.81 ppm) throughout the incubation period compared with the other treatments. The quail droppings amendment provided more soil organic carbon and nutrients that were easily mineralized and assimilated by plants. At result, the quail droppings improve soil biological and chemical activities or the compost increase maize biomass yield.

Introduction

Maize (*Zea mays* L.) is the most important cereal crop in the world after wheat and rice in terms of arable land and total production (Osagie and Eka, 1998). Despite the numerous uses of maize, its yield in Africa has been steadily declining to 1 t ha^{-1} due to factors such as rapid reduction in soil fertility and neglect of soil amendments (Dipa, 2006; Enujeke *et al*., 2013). Maize productivity depends mainly on soil nutrient management (Sharma *et al*., 2008). French). More than 40% of soils in the sub-Saharan African region are nutrient depleted (Barbier and Hochard, 2018; Ntinyari *et al*., 2022). Moreover, average annual fertilizer consumption in African countries ranges between 8.3 and 10 kg ha^{-1} (Sanginga and Woomer, 2009). These rates are reportedly the lowest in the world due to high prices, untimely availability, and insufficient supply of fertilizers (Chianu *et al*., 2012). In Burkina Faso, nitrogen and phosphorus levels in most soils are generally below 0.06% (AU/SAFGRAD, 2010). This partly explains the low crop productivity, with a yield gap of more than 30% between actual production and achievable potential (Joseph *et al*., 2020). Given farmers' low purchasing power, there is a need to develop accessible fertilization techniques that increase yields while preserving long-term soil fertility (Bado, 2002). Although the application of supplemental nitrogen fertilizers can prevent nitrogen stress and increase yields, excess nitrogen can lead to contamination of groundwater and surface water (Lehrsch *et al*., 2000; Yang *et al*., 2012).

Sonetra (2002) suggested that subsistence farmers should apply organic manure directly to the soil as a natural way of recycling nutrients to improve soil fertility and crop yield. The use of poultry practices in soil fertility management on farms is now an alternative to crop-livestock integration. Indeed, the results of Coulibaly *et al*., (2018) showed that poultry can contribute nearly 30% of organic substrate production on farms. It can also allow farms that strongly integrate poultry farming with agriculture to fertilize nearly 5% of their field compared to 0.52% for agro-pastoralists who integrate more livestock farming (Coulibaly *et al*. 2018). Thus, the application of livestock manure with a high C/N ratio can lead to nitrogen immobilization in the soil, limiting nitrogen uptake by maize and short-term yield (Nyamangara *et al*., 2003). Many studies have shown that the application of compost or quail droppings on farms can increase maize yield and nitrogen uptake, decrease soil NO_3^- and nitrogen emissions, restore crop productivity and sustainability, and reduce apparent nitrogen surplus (Wen *et al*., 2016; Geng *et al*., 2019). Therefore, the valorization of quail droppings and compost as organic fertilizers could sustainably improve soil productivity and optimize crop yields. Although the effects of different types of compost inputs in maize production have been the subject of several research studies, investigations on the use of quail droppings in maize production are poorly documented in the Burkinabe context. This study was therefore initiated to evaluate the effects of quail droppings and compost on maize production.

Materials and Methods

Experimental sites

The soil sampling site used in the experiment is located in the village of Gampéla, more precisely in the district of Godin. Gampéla is located at 12°25' north latitude and 1°21' west longitude in the commune of Saaba, 25 km east of Ouagadougou, the capital of Burkina Faso. The greenhouse experiment was conducted from February to November 2023 at the French National Research Institute for Development (IRD) located in Ouagadougou. The greenhouse reproduces the same climatic conditions as the city of Ouagadougou, which has a Sudano-Sahelian climate, with an average annual rainfall of 569 mm and an average temperature of 28.6 °C.

Characteristics of the experimental soil

The soil used in the test is classified as *Lixisol* (WRB 2015). This soil has a sandy-loamy surface texture. The characteristics of the soil used are shown in Table (1).

Fertilizers and plant material

Compost made in a peasant way by the women of the NABONSWENDE association in Niessega in the North region of Burkina Faso. Quail droppings composed of cattle manure and NPK mineral manure (14-23-14-3B-1S) were used as fertilizer. The quail droppings are made up of livestock effluents (droppings, feather and shell debris, dead quail, etc.) from the farm "Prestige du Centre" in Patte d'oie in Ouagadougou (Burkina Faso). The droppings were spread in the open air, then watered and turned regularly for 33 days to reduce their ammonia content and purify them. The plant material used was the *Barka* maize variety, characterized by a semi-maturity cycle of 88 days and a grain yield potential of 5.5 t ha^{-1} in a peasant environment. The chemical characteristics of the fertilizers used are given in Table (2).

Soil sampling and preparation

Soil samples were collected from the 0 -14 cm layer. The samples were collected using a pickaxe. The samples were air-dried for 7 days and then sieved to 2 mm. After sieving to 2 mm, fine soil was used to conduct the experiment.

Determination of humidity at field capacity

The moisture content at field capacity (HFC) of the test soil was determined before setting up the test in a growing vessel. This measurement was obtained using the formula for percentage moisture content at field capacity by mass. The bottom of the pot was perforated and closed with a nylon sieve with a mesh size less than 2 mm, which was used to determine the dry weight (DW). The soil was then saturated with water and the pot was allowed to dry for 24 hours. The wet weight (WW) was then determined. Applying the formula HFC = (WW - DW) / DW, the moisture content at field capacity was 0.150 kg (150 ml) of water per kg of soil.

Experimental design, treatments and culture management

The experimental set-up consisted of a completely randomized vase-grown block using plastic pots of 5 liters each. The experiment was conducted over a period of 63 days, with five replicates for each treatment, making a total of 20 pots in the experimental set-up. The treatments applied were as follows:

- T0 = absolute control without any input

- T1 = 200 kg ha^{-1} NPK (14-23-14-3B-1S) (Rate recommended by research for the *Barka maize variety*)

- T2 = 3 t ha^{-1} of quail droppings

- T3 = 3 t ha^{-1} of compost

Substrate preparation consisted of mixing 500 g of compost or quail droppings per pot with 4 kg of soil. For the controls, only 5 kg of soil was added to the pots. NPK was applied to the soil at a rate of 6 g per pot (200 kg ha^{-1}) on the 15th day after sowing (DAS). Organic fertilizers were incorporated as basal fertilizer and the plants were sown at a rate of 4 grains per pot after pre-irrigation one day before sowing, using 450 ml of water for treatments (T0 and T1) and 750 ml of water for treatments (T2 and T3), respectively. From the 3rd DAS, the plants were watered every other day with 150 ml of water; from the 5th to the 45th DAS, irrigation was carried out with 450 ml of water, and from the 48th to the 63rd DAS, 750 ml of water was applied. To control the amount of water supplied to the system, a transparent polyane film was placed over the experimental system to prevent any atmospheric runoff, knowing that we were at the beginning of the rainy season. The quantities of water supplied were adjusted according to the vegetative stage of the crops and the climatic parameters. Felling consisted of leaving two plants per pot at the 7th DAS.

Data collection

Data collection focused on morphological and physiological parameters during the vegetative phase of maize plants, as well as biomass production at harvest depending on the treatments. Morphological and physiological parameters were assessed weekly for each plant. These parameters included seed emergence rate (SER) at 5th DAS; plant height (PH), crown diameter (CD); and the number of leaves (NL), flowering plants (FP), flowers per plant (FPP), panicles per plant (PPP), and ears per plant (EPP). SER at 5th DAS represents the percentage of emerged maize plants per pot. Plant PH was measured using a ruler from the base of the crown to the last ligule. Plant CD was measured using a caliper at crown level. The evaluation of PH, CD, NL, FP, FPP, PPP, EPP consisted of counting leaves, flowering plants, panicles and spikes respectively. Biomass production at harvest, separating the root and root biomass of plants per treatment. Shoot fresh weight (SFW) and root fresh weight (RFW) as well as plant fresh weight (PFW) were determined by weighing. These different biomasses were then dried in an oven at 40 °C until a constant weight was obtained and weighed. Shoot dry weight (SDW), root dry weight (RDW) and plant dry weight (PDW) in g were measured.

Soil sample analysis

Of soil were collected at the harvest of maize biomass. Five (05) elementary samples were taken from the rhizosphere of the plants per treatment. A composite sample was made by taking and mixing 50 g of soil from the 5 elementary samples per treatment. Then, the soil samples were dried in the air and at room temperature, and sieved at 2 mm for analysis. A total of 4 soil samples corresponding to the 4 treatments were analyzed. The soil water content (DM) in (%) was determined by the formula DM = (WW – DW) x 100/ WW where WW is the wet weight of the soil and DW is the dry weight of the soil after drying in an oven at 70 °C until a constant weight is obtained. The analysis of soil parameters included the determination of: the pH of the water according to the principle of Conyers and Davey (1988) and the pH KCl according to the method of Pansu and Gautheyrou (2006). Acidity was measured in a soil suspension with a soil/distilled water or KCl (1N) ratio equal to 2/5 using a combined electrode pH meter; organic carbon (C) using the method of Walkley and Black (1934). Organic matter (OM) content was obtained by multiplying the carbon content value by a coefficient equal to 1.724; total nitrogen (N) by colorimetry after digestion by the Kjeldahl method (1883); total phosphorus (P), carried out according to the method of Kitson and Mellon (1944) and available phosphorus according to the Bray method 1 of Bray and Kutz (1945); total potassium (K), according to the method of Ahenkorah (1970) using 6N HCl and available potassium, extracted using a mixed solution of 0.1 N HCl and H_2CEO_4 measured using the flame photometer after mineralization; microbial respiration by release of CO_2 from incubated soil samples by the method of Dommergues (1960).

Statistical Analysis

Data were entered into EXCEL (2021) spreadsheet. The Shapiro-Wilk test was used to assess the normality of the collected data. Graphs were developed to evaluate the evolution of maize morphological and physiological parameters as well as soil respiration under the different treatments over time. Analysis of variance (ANOVA) and Tukey's HSD mean separation test at the 5% threshold were performed on the mean values of maize morphological, physiological and biomass production parameters according to the treatments. XLSTAT 4.1, 2023 (ADDINSOFT, 2023) software was used for these analyses.

Results and Discussion

Effects of treatments on biological and chemical fertility of soils

Effect on biological parameters

Table 3 summarizes the effects of treatments on soil CO_2 release as a function of incubation times. Analysis of variance (ANOVA) and Tukey's HSD mean separation test at the 5 % level showed that there was no significant difference between the mean CO_2 release values under the different treatments from one hour after incubation to the 19th day after incubation.

The control soil T0 showed higher values (450 ± 42.16 ppm) compared to treatments T1 and T3 followed by treatment T2 (410 ± 51.64 ppm) which produced a fairly high CO_2 release from the first hour after incubation. On the 21st day after incubation, statistical analysis revealed a highly significant difference ($P = 0.001$) in CO_2 release marked by a value of (800 ± 81.12 ppm) under T2 significantly higher than those obtained under the other treatments (T0; T1; T3). In addition, the T3 treatment significantly increased the release of CO_2 from the soil compared to T1 on the 21st day after incubation.

Effect on Soil Chemical Parameters

Table (4) summarizes the soil test results at harvest of maize. Soil moisture at harvest (SM) fluctuated between 15.50% under treatment T1 and 16.54% under treatment T2. Soil chemical values ranged from 1.61% to 2.77% under treatment T2 to 0.08% under treatment T0 and 0.14% under treatment T2.

Total phosphorus (P) levels ranged from 107.04 ppm under T1 to 560.64 ppm under T3 and potassium (K) levels from 112.13 ppm under T0 to 160.03 ppm under T2. Soil water pH fluctuated between 5.95 under T0 and 7.85 under T3 and KCl pH between 4.78 under T0 and 7.67 under T3. Similarly, the C/N ratio increased from 11 under T3 to 12 under T2. Available phosphorus contents ranged from 3.10 ppm at T0 to 4.90 ppm at T2 and available potassium ranged from 61.25 ppm at T1 to 149.35 ppm at T2.

The T3 treatment resulted in an increase of 32; 36; 16; 24; 24% and 38% respectively in the contents of OM, N, available phosphorus, available potassium, water pH and pH KCl compared to those recorded under the T0 treatment. The C/N ratio was reduced by 6% at T3 compared to T0. The contents of OM, N, available P, available K, water pH and pH KCl were improved by 7; 9; 5; 18; 2 and 3% at T1 and by 42; 40; 37; 51; 16% and 28% at T2 compared to T0.

Effects of treatments on morphological, physiological and biomass parameters of maize plants

Table (5) presents the effects of the treatments on the mean values of morphological and physiological parameters of maize plants at harvest.

Maize plant emergence rates (TXL) ranged from 80 ± 6% under T2 to 100 ± 7% under T3. Analysis of variance (ANOVA, 5%) did not reveal a significant difference between T0 treatments (absolute control); T1 (NPK input); T2 (quail droppings) and T3 (compost input) for maize seed emergence rates (SER). Mean height of plant (HP) values fluctuated between 40.40 ± 7.91 cm under T0 treatment to 101.22 ± 8.34 cm under T3 treatment.

Applying compost (T3) to the soil significantly improved ($P < 0.0001$) the HP compared to other treatments (ANOVA and Tukey's test at the 5 % threshold). The Tukey HSD mean separation test at the 5% threshold showed that the T3 treatment increased the HP by 60% compared to the T0 treatment. Diameter at root collar (DRC) of plant ranged from 8.52 ± 0.51 mm under the T1 treatment to 13.67 ± 0.51 mm under the T2 treatment. Quail droppings (T2) significantly increased ($P < 0.0001$) the DRC of plant compared to T1, T0 and T3 treatments. The Tukey HSD mean separation test at the 5% threshold showed that with the T2 treatment, plant diameters increased by 38% compared to the T1 treatment.

The T3 treatment increased the DRC by 26% and 22% compared to the T1 and T0 treatments, respectively. As for the mean number of leaves per plant (NL), the values ranged from 14.40 ± 0.59 under T0 to 16.44 ± 0.62 under the T3 treatment. The NL increased significantly ($P = 0.031$) under T3 and T2 treatments compared to T0 and T1 treatments. Number of plants flowering (NPF) fluctuated between 0.80 ± 0.11 in T2 to 1.00 ± 0.11 in T3.

The analysis of variance (ANOVA, 5%) did not reveal a significant difference between T0 treatments; T1; T2 and T3 for the number of plants that flowered. Number of flowers per plant (NFP) varied to 0.90 ± 0.19 under T0 to 1.67 ± 0.20 under T3. T3 treatment significantly improved the NFP by 46% compared to T0 treatment. Number of panicles per plant per plant (NPP) ranged from 0.70 ± 0.11 in T1 to 1.00 ± 0.12 in T3.

The analysis of variance did not reveal a significant difference between T0 treatments; T1; T2 and T3 for the number of panicles per plant (NPP). Number of spikes per plant (NSP) ranged from 0.00 ± 0.13 under T0 to 0.67 ± 0.14 under T3. T3 treatment significantly increased ($P = 0.009$) the NSP compared to T0.

Effects of treatments on maize plant biomass production

The effects of the treatments on maize biomass production at harvest are reported in Table (6). Shoot fresh weight (SFW) ranged from 23.40 ± 15.21 g under T0 to 98.86 ± 13.60 g under T3. Soil treatment with compost (T3) significantly ($P \leq 0.005$) increased maize shoot fresh weight (SFW) at harvest compared to control treatment (T0) and NPK application (T1) according to ANOVA at 5% level. A 76% improvement in shoot fresh weight (SFW) was recorded under T3 compared to T0 and T1. Root fresh weight (RFW) ranged from 10.00 ± 3.75 g in T1 to 26.58 ± 3.75 g in T3.

The T3 treatment significantly ($P = 0.026$) increased maize root fresh weight (RFW) at harvest compared with the T1 treatment according to ANOVA and Tukey's HSD mean separation test at the 5% level. Shoot dry weight (SDW) fluctuated between 6.38 ± 3.42 g under T0 and 22.68 ± 3.06 g under T3. The T3 treatment significantly ($P \leq 0.007$) improved maize shoot dry weight (SDW) at harvest compared with the T0 and T1 treatments. Tukey's HSD mean separation test at the 5% level shows that treatment T3 promoted a 72% increase in shoot dry weight (SDW) compared to the control T0 and a 69% increase compared to T1.

Root dry weight (RDW) ranged from 1.60 ± 0.55 g in T1 to 3.82 ± 0.55 g in T3. Soil treatment with compost (T3) significantly ($P = 0.034$) increased root dry weight (RDW) of maize at harvest compared to treatments T0 and T1 (ANOVA and Tukey's HSD mean separation test at the 5% level). Plant fresh weight (PFP) ranged from 34.03 ± 19.15 g in T0 to 125.44 ± 17.13 g in T3.

The T3 treatment significantly improved the plant fresh weight (PFW) of maize at harvest by 73 % ($P \leq 0.006$) compared to T0 and T1 according to ANOVA and Tukey HSD mean separation test at the 5% level.

The plant dry weight (PDW) fluctuated between 7.98 ± 3.98 g under T0 and 26.50 ± 3.56 g under T3. T3 treatment significantly improved maize PDW ($P < 0.008$) by 68% to 70% ($P < 0.008$) compared with T0 and T1, respectively.

Table.1 Characteristics of the soil

Soil Variables	Values
Clay (%)	14.5
Limon (%)	28.05
Sand (%)	38.49
Texture	sandy-loam
C (g kg^{-1})	0.73
N (g kg^{-1})	0.05
C/N	14
P total (ppm)	1257
Available P (ppm)	1.3
Calcium (Cmoles Kg^{-1} soil)	1.81
Magnesium (Cmoles kg^{-1} soil)	1.85
Potassium (Cmoles kg^{-1} soil)	0.11
Sodium (Cmoles kg^{-1} soil)	0.04
S (Cmoles kg^{-1} soil)	3.81
CEC (Cmoles kg^{-1} soil)	7.28
Saturation rate	52
pH water	5.46

C = total carbon; N = total nitrogen; P Total = total phosphorus; available P = assimilable phosphorus; S = sum of cations; CEC = cation exchange capacity.

Table.2 Chemical characteristics of the organic materials used

Parameters	Quail droppings	Compost
Total Organic Matter (%)	34.83	47.28
Total Carbon (%)	20.20	27.42
Total nitrogen (%)	2.84	1.42
C/N	7	19
N-NH_4^+ (mg/kg)	180.69	139.60
N-NO_3^- (mg/kg)	89.04	4648
Mineral N (mg/kg)	269.73	186.08
Total Phosphorus (%)	6.68	1.29
Available Phosphorus (g/kg)	52.38	12.13
Total Potassium (%)	3.59	1.45
available Potassium (mg/kg)	2142	679

C = total carbon; N = total nitrogen; N-NH_4^+ = ammoniacal nitrogen; N-NO_3^- = nitrate nitrogen; P Total = total phosphorus; available P = assimilable phosphorus.

Table.3 Effect of treatments on soil respiration according to incubation times

Treatments	1 HAI	24 HAI	4 DAI	7 DAI	11 DAI	13 DAI	17 DAI	19 DAI	21 DAI
				CO_2 (ppm)					
T3	283.33 ± 42.16 a	490.00 ± 127.75 a	1043.33±361.43 a	1600.00±361.43a	2010 ±529.75 a	1213.33 ±205.68a	856.66±206.36 a	483.33 ±132.98 a	430.00 ± 66.23 b
T2	410.00 ± 51.64 a	920.00 ± 156.46 a	1525.00±292.34 a	2145.00±442.66a	2715 ±648.81 a	1575.00 ±251.91a	965.00±252.74 a	710.00 ±162.87 a	800.00 ± 81.12 c
T1	263.33 ± 42.16 a	456.66 ±127.75 a	900.00±361.43 a	1353.33±361.43a	1760 ±529.75 a	953.33 ±205.68 a	390.00±206.36 a	346.66 ±132.98 a	83.33 ± 66.23 a
T0	450.00 ± 42.16 a	446.66 ±127.75 a	910.00±361.43 a	1393.3 ±361.43 a	1570 ±529.75 a	1266.66 ±205.68a	560.00±206.36 a	313.33 ±132.98 a	133.33 ± 66.23 ab
P	0.05	0.161	0.402	0.549	0.591	0.365	0.311	0.316	0.001
Significance	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**HS**

T0 = control without any input; T1 = 200 kg ha $^{-1}$ NPK; T2 = 3 t ha $^{-1}$ of quail droppings; T3 = 3 t ha $^{-1}$ of compost; HAI = hour after incubation; DAI = day after incubation. The numbers are the means ± standard errors of the parameters evaluated; P = ANOVA probability at the 5% significance level; the means ± standard errors of the same column with the same letter do not differ significantly according to the Tukey HSD test at the 5 % significance level; P ≤ 0.001 (HS): highly significant; P ≥ 0.05: not significant (NS).

Table.4 Effects of treatments on soil chemical fertility

Treatments	SM	C	MO	N	P	K	pH water	pH KCl	C/N	Available P	Available K
	%	%	%	%	ppm	ppm				ppm	ppm
T3	16	1.36	2.35	0.13	560.64	157.02	7.85	7.67	11	3.70	95.68
T2	17	1.61	2.77	0.14	193.74	160.03	7.10	6.65	12	4.90	149.35
T1	16	1.00	1.73	0.09	107.04	132.31	6.07	4.93	11	3.27	61.25
T0	16	0.93	1.61	0.08	112.13	112.47	5.95	4.78	11	3.10	72.34

T0 = control without any input; T1 = 200 kg ha $^{-1}$ of NPK; T2 = 3 t ha $^{-1}$ of quail droppings; T3 = 3 t ha $^{-1}$ of compost; SM = soil moisture at harvest; C = total carbon; OM = total organic matter; N = total nitrogen; P = total phosphorus; K = total potassium; Available P = Available phosphorus; Available K = Available potassium.

Table.5 Effect of treatments on morphological and physiological parameters of maize plants

Treatments	SER (%)	HP (cm)	DRC (mm)	NL	NPF	NFP	NPP	NSP
T3	100 ± 7 a	101.22 ± 8.34 b	11.47 ± 0.54 b	16.44 ± 0.62 a	1.00 ± 0.11 a	1.67 ± 0.20 b	1.00 ± 0.12 a	0.67 ± 0.14 b
T2	80 ± 6 a	68.35 ± 7.91 a	13.67 ± 0.51 c	16.40 ± 0.59 a	0.80 ± 0.11 a	1.20 ± 0.19 ab	0.80 ± 0.11 a	0.40 ± 0.13 ab
T1	90 ± 6 a	45.00 ± 7.91 a	8.52 ± 0.51 a	14.70 ± 0.59 a	0.80 ± 0.11 a	1.00 ± 0.19 ab	0.70 ± 0.11 a	0.20 ± 0.13 ab
T0	100 ± 6 a	40.40 ± 7.91 a	8.99 ± 0.51 a	14.40 ± 0.59 a	0.90 ± 0.11 a	0.90 ± 0.19 a	0.90 ± 0.11 a	0.00 ± 0.13 a
P	0.088	<0.0001	<0.0001	0.031	0.537	0.042	0.321	0.009
Significance	NS	HS	HS	S	NS	S	NS	VS

T0 = control without any input; T1 = 200 kg ha $^{-1}$; NPK; T2 = 3 t ha $^{-1}$ of quail droppings; T3 = 3 t ha $^{-1}$ of compost; SER = seed emergence rate at the 5th day after sowing; HP= heights of plant; DRC = diameter at root collar; NL = number of leaves; NPF= number of plants flowering; NFP = number of flowers per plant; NPP = number of panicles per plant; NSP = Number of spike number per plant. P = ANOVA probability at the 5% significance level. The means ± standard errors of the same column with the same letter do not differ significantly according to the Tukey HSD test at the 5% significance level. P < 0.05: significant (S); P ≤ 0.01: very significant (VS); P ≤ 0.001 (HS): highly significant; P ≥ 0.05: not significant (NS).

Table.6 Effect of treatments on maize plant biomass production

Treatments	SFW (g)	RFW (g)	SDW (g)	RDW (g)	PFW (g)	PDW (g)
T3	98.86 ± 13.60 b	26.58 ± 3.75 b	22.68 ± 3.06 b	3.82 ± 0.55 ab	125.44 ± 17.13 b	26.50 ± 3.56 b
T2	61.02 ± 13.60 ab	18.02 ± 3.75 ab	14.52 ± 3.06 ab	2.94 ± 0.55 ab	79.04 ± 17.13 ab	17.46 ± 3.56 ab
T1	26.06 ± 13.60 a	10.00 ± 3.75 a	7.00 ± 3.06 a	1.60 ± 0.55 a	36.06 ± 17.13 a	8.60 ± 3.56 a
T0	23.40 ± 15.21 a	10.63 ± 4.19 ab	6.38 ± 3.42 a	1.60 ± 0.61 a	34.03 ± 19.15 a	7.98 ± 3.98 a
P	0.005	0.026	0.007	0.034	0.006	0.008
Significance	VS	S	VS	S	VS	VS

T0 = control without any input; T1= 200 kg ha $^{-1}$ of NPK; T2 = 3 t ha $^{-1}$ of quail droppings; T3 = 3 t ha $^{-1}$ of compost; SFW = Shoot fresh weight; RFW = Root fresh weight; SDW= Shoot dry weight; RDW = Root dry weight; PFW = Plant fresh weight; PDW = Plant dry weight; The numbers are the means ± standard errors of the parameters evaluated. P: ANOVA probability at the 5% significance level. The means ± standard errors of the same column with the same letter do not differ significantly according to the Tukey HSD test at the 5% significance level. P < 0.05: significant (S); P ≤ 0.01: very significant (VS).

Effects of treatments on biological and chemical fertility of soils

Microbial activity in soil: Soil results showed a general increase in biological activity (CO_2 release) in soils treated with quail droppings, compared to other treatments (control, NPK and compost), regardless of incubation time. This improvement represents an increase of 40%, 45% and 23% respectively in microbial activity in the soil under quail droppings (T2) compared to treatments T0, T1 and T3. At day 21 after incubation, CO_2 release was significant under treatment T2 compared to the other three treatments. This observation could be explained by an abundance of microorganisms in the soil treated with quail droppings, attributable to its higher content of labile nutrients (180.69 mg kg $^{-1}$ N-NH_4^+; 89.04 mg kg $^{-1}$ N-NO_3^-; 52.38 g kg $^{-1}$ available phosphorus; and 2142 mg kg $^{-1}$ available potassium) conducive to the proliferation of microorganisms in the soil. The supply of easily metabolizable nutrients in the organic medium of quail droppings was probably the most influential factor contributing to the increase in microbial activity. These results are consistent with those of Marin (2004), who found that the nutrient content (N and P) was higher with the addition of poultry manure than with the addition of compost to the soil; these nutrients could have increased the quantity and activity of microorganisms. The soils in the control and NPK treatments recorded the lowest values in terms of microbial activity throughout the 21-day soil CO_2 measurement experiment. These results can be explained by the low levels of organic matter (1.61 % and 1.73%) and nutrients (0.93% and 1.00% C; 0.08 % and 0.09% N) contained in these treatments T0 and T1 respectively, which are important for microbial metabolism. Thus, the low number of soil fauna in the control treatment may be due to the absence of an external carbon source (Dijkstra *et al*., 2009). This is in line with the findings of Garcia *et al*., (1996), who suggested in their study that the low microbial activity in the control soil throughout the experiment was probably due to the low organic matter content of the soil and the resistance to decomposition of this type of organic matter.

Changes in soil chemical parameters: The addition of organic resources (compost or quail droppings) led to an improvement in soil chemical parameters. Indeed, it has been proven that, in general, organic inputs contribute to the improvement of soil properties (Mando, 1998; Ouédraogo *et al*., 2001). Soil amended with quail droppings contained higher levels of nitrogen (N) (2.84%) and total potassium (3.59%) than soil amended with compost, which contained 1.42% nitrogen (N) and 1.45% total potassium. Poultry manure should therefore mineralize more quickly than cattle manure used in compost (Chadwick *et al*., 2000; Qiu, McComb and Bell, 2008). Although the compost was richer in carbon (C) by 27.42%, its incorporation into the soil resulted in soils less rich in carbon (C) by 1.36% than soils amended with quail droppings (C) by 1.61%. This behavior is attributable to the sandy-loam texture of the soil, where the proportion of silt was not negligible (28.05%), but also to the very high colloidal power of the quail droppings. The residual soil contents of total nitrogen (0.05 g kg $^{-1}$), available phosphorus (1.3 ppm) and available potassium (0.11 Cmoles $^{(+)}$ kg $^{(-1)}$ soil) were increased by 99%, 73% and 94% respectively under quail droppings compared to the control (T0). Similar results were reported by Sanon *et al*., (2023), who demonstrated an increase in soil phosphorus and nitrogen contents with the application of chicken droppings, attributable to an increase in biological activity. The increase in biological activity is thought to have resulted in the decomposition of organic forms of phosphorus, leading to the availability of residual available phosphorus in the soil. The high nitrogen concentration in poultry droppings could be explained by the quality of the manure, which varies depending on the type of animal, age, diet, and management system (Chadwick *et al*., 2000). The water pH was neutral to slightly alkaline under quail droppings and compost applications of 7.1 and 7.85, respectively. pH is a critical indicator of the chemical nature of the soil, which affects the availability and uptake of essential plant nutrients. This neutrality or alkalinity of soil pH under application of manure or compost with high concentrations of organic matter indicates that organic matter has a significant ability to improve soil acidity.

The increase in soil pH may be caused by a decomposition process that produces humus and releases bases contained in quail droppings and compost, so it can increase the concentration of OH^- ions and ultimately increase soil pH Andayani *et al*., (2019). According to Van Zwieten *et al*., (2008), decomposed organic matter can increase the activity of OH - ions from the carboxyl group (-COOH) and hydroxyl group (OH^-). OH^- ions will neutralize H^+ ions in the soil solution. These results confirm those of Melero *et al*., (2007) and Bacye *et al*., (2019), who showed that, compared to mineral inputs, organic inputs significantly improve soil pH.

Effect of treatments on the morphological and physiological performance of maize plants

The results showed that the strongest growth and development of maize plants were observed in soils amended with organic substrates (compost or quail droppings) compared to the absolute control soil and the addition of NPK mineral fertilizer. These positive effects on growth are related to the additional inputs of 27.42% C, 1.42% N, 1.29% P and 1.45% K from compost or 20.2% C, 2.84% N, 6.68% P and 3.59% K from quail droppings, but also to their indirect effect on the physical and biological properties of the soil. Indeed, the organic matter contained in organic manure increases the soil's capacity to buffer pH variations, improves cation exchange capacity (CEC), reduces phosphate fixation and acts as a reservoir of secondary nutrients and micronutrients (Lehmann *et al*., 2011; Singh *et al*., 2023). Our results corroborate those found by Gomgnimbou *et al*., (2019) under experimental station conditions, which indicated that chicken droppings inputs increased organic matter levels under maize cultivation. This could be attributable to the labile effect of organic matter in poultry droppings, which mineralizes faster than that of compost. In addition, the results of the study show that the mineral input (NPK), although at the recommended dose for growing the Barka maize variety, had little mineral influence on the morphology and physiology of the plant. This could be due to the low cation exchange capacity (CEC = 7.28 Cmoles kg^{-1} soil) of the soil used, which regulates the exchanges between the soil and its environment, thus avoiding the leaching of nutrients. Contrary to our results, the application of mineral fertilizers is a source of nutrients immediately usable by the plant for its nutrition, as indicated by Hien (2004); and Efthimiadou *et al*., (2010), which should improve the vegetative growth of crops.

Effects of treatments on maize plant biomass production

The application of compost to the soil had a beneficial effect on the soil mineral pool, making minerals available to plants and positively impacting biomass production. Above-ground and root biomass, fresh and dry; and total fresh and dry biomass of maize at harvest were significantly influenced by the T3 compost treatment. These results are explained by the addition of 27.42% C, 1.42% N, 1.29% P and 1.45% K of compost to the initial soil. These inputs thus improved the soil solution of the mineral elements necessary to promote the production of above-ground and root biomass by maize plants. These observations are in agreement with the findings of LagBrotons *et al*., (2014) who demonstrated through various field studies that the addition of compost to bioenergy crops had positive effects on biomass production over different seasons and that growth was also positively impacted. Furthermore, non-significant increases in plant biomass production parameters were observed in maize treated with quail droppings (T2). This can be explained by the lack of correlation between maize plant biomass production parameters and quail droppings (T2). The results diverge from the findings of Munyabarenzi's (2014) study which observed a significant increase in maize grain yield, 1000-grain weight and stalk biomass following the application of poultry droppings. The results of this study indicate that optimal maize biomass productions are obtained with soil amendment with compost and to a lesser extent with quail droppings when growing maize on this lixisol.

The lack of significant response of maize crop in the control treatment shows that this type of soil has marginal suitability for maize cultivation and therefore requires fertilization maintenance for better yields. Ouedraogo *et al*., (2007) concluded that in semi-arid West Africa, without organic resources or nitrogen inputs, soil organic matter is essential for nitrogen nutrition of crops. In addition, the physical improvement (structure, porosity, aeration, etc.) of the soil through composting would contribute to a better exchange between the soil and its environment, thus providing a favorable environment for the root development of crops. These results are consistent with previous findings by Jindo *et al*., (2012) who found that humic acids from composted and non-composted urban organic waste induced the proliferation of lateral root emergence sites in maize seedlings.

In Conclusion, the evaluation of the effects of quail droppings and compost on the biomass yield performance of the Barka maize variety revealed that applications of 3 t ha^{-1} of organic manure (compost) significantly improved plant growth parameters compared to applications of 3 t ha^{-1} of quail droppings. However, applications of 3 t ha^{-1} of quail droppings had a more pronounced impact on the biological and chemical fertility of the soil. Thus, these treatments were more effective both agronomically and pedologically in maize production. On the other hand, the incorporation of quail droppings into the soil was positively effective in terms of dry matter production, compared to fertilization with NPK fertilizer. The best agronomic performances were obtained under compost application.

To achieve this, soils amended with quail droppings and compost must be complementary for better productivity and conservation of *lixisol* fertility. These results show that the addition of compost would be effective for maize production in the short term, but that quail droppings would be more effective in the long term. For maize production on a *Lixisol,* the application of quail droppings or compost to the soil remains effective, reducing the use of chemical fertilizers while increasing crop yield and nutrient assimilation by plants and soil fauna. To better understand the agronomic and pedological impact of these organic amendments, it would be necessary to: i) evaluate the dynamics of organic matter in these soils; ii) evaluate the effectiveness of the coupling of manure + compost, compost + NPK and manure + NPK; iii) conduct experiments in an agricultural environment over several years; iv) carry out a technical and economic assessment of the different fertilization practices in order to determine which is technically effective and economically sustainable.

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Authors Contribution

Mahamadi KYELEM: Investigation, formal analysis, writing - original draft. Koulibi Fidèle ZONGO: Resources, investigation writing - review and editing. Daouda GUEBRE: Supervision, writing - review of the final version of the manuscript. Boussa Tockville MARE: Validation, methodology, writing - review. Aboubacar COULIBALY: Formal analysis, writing - review. Edmond HIEN: Conceptualization, methodology, data curation, supervision, writing - review of the final version of the manuscript.

Declarations

Ethical Approval: Not applicable.

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