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Residual effect of the waste product derived from termite trapping on the physical and chemical properties of soils in Central-Western Côte d'Ivoire

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Abstract

The objective of this study is to determine the influence of termite waste amendment on the physicochemical properties of soil after rice production in Daloa, Côte d'Ivoire. The experiment was conducted using a randomized complete block design (RCBD) with three replicates, each comprising ten treatments. A sandy soil was amended with the waste product Termisol. Six doses of Termisol and four controls (zero fertilizer, NPK fertilizer, manure, and natural termite mound soil) were tested. Observations focused on physicochemical properties, infiltration, soil moisture, and temperature after the second cycle. The results showed that plots amended with 87.30 to 175 t ha^{-1} of Termisol retained higher levels of carbon, organic matter, available phosphorus, exchangeable bases, and (clay + silt) than the other plots and the control soil at the test site. The 4% Termisol treatment (116.5 t ha^{-1}) showed the best residual effect with a clay + silt content of 28.35%, an organic matter content of 1.68%, an assimilable phosphorus content of 48 mg kg^{-1} and a base sum of 1.57 mg kg^{-1}. The addition of Termisol to this sandy soil helped improve soil moisture and therefore its water retention capacity, as a result of its effect on soil permeability. These results showed that the effect of the Termisol amendment can allow for at least two consecutive crop cycles. This study deserves to be extended in order to determine the effect of this product when applied continuously over two to three cycles.

Keywords: Residual effect; Termisol; Rice; Daloa; Côte d'Ivoire

1. Introduction

In sub-Saharan Africa, most crop residues are either collected by farmers for domestic use or destroyed by bush fires. These practices result in the export of nutrients without replenishment to the soil, disrupting the natural cycle of soil organic matter renewal. This unsustainable soil management leads to rapid soil depletion [1, 2]. In addition, the use of fallow land, once essential for restoring soil fertility, is becoming less and less common due to the strong pressure on arable land caused by the growing needs of a growing population [3]. Thus, to improve yields, farmers are forced to resort to modern agricultural techniques such as varietal selection and the rational use of pesticides and chemical fertilizers [4]. While chemical fertilizers have a rapid beneficial effect on crop productivity, justifying their use, their misuse leads to soil degradation through loss of organic matter and acidification. Furthermore, their high cost makes them almost inaccessible to small farmers [5, 6], while the risks of environmental pollution and water eutrophication pose a threat to biodiversity and endanger the lives of local populations. As a result, it is essential to identify alternative and sustainable solutions for soil fertility management. With this in mind, various studies have reported on certain soil macroinvertebrates such as termites and earthworms and the use of agricultural residues to improve soil properties [7]. For example, the work of [8] highlighted the contribution of termites to restoring the fertility of degraded soils by

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examining their contribution of nutrients through the on-site decomposition of residues from a few plant species, while the work of [9] demonstrated the fertilizing capacity of waste products from artificial termite mounds and their potential use in rainfed rice cultivation. These results open up an opportunity to initiate the formation by termites of a waste product that retains the characteristics of the natural termite mound in a semi-controlled environment. The overall objective of this study is to contribute to improving rainfed rice productivity by amending the soil with the waste product Termisol, which is produced by termites digesting agricultural residues in an artificial termite mound. The specific objective is to determine the after-effect of amending with the waste product "Termisol" on the physicochemical properties of the soil in rainfed rice cultivation after two production cycles.

2. Material and methods

2.1. Location of the study site

The agronomic trial took place at Camp Zongo (Figure 1).

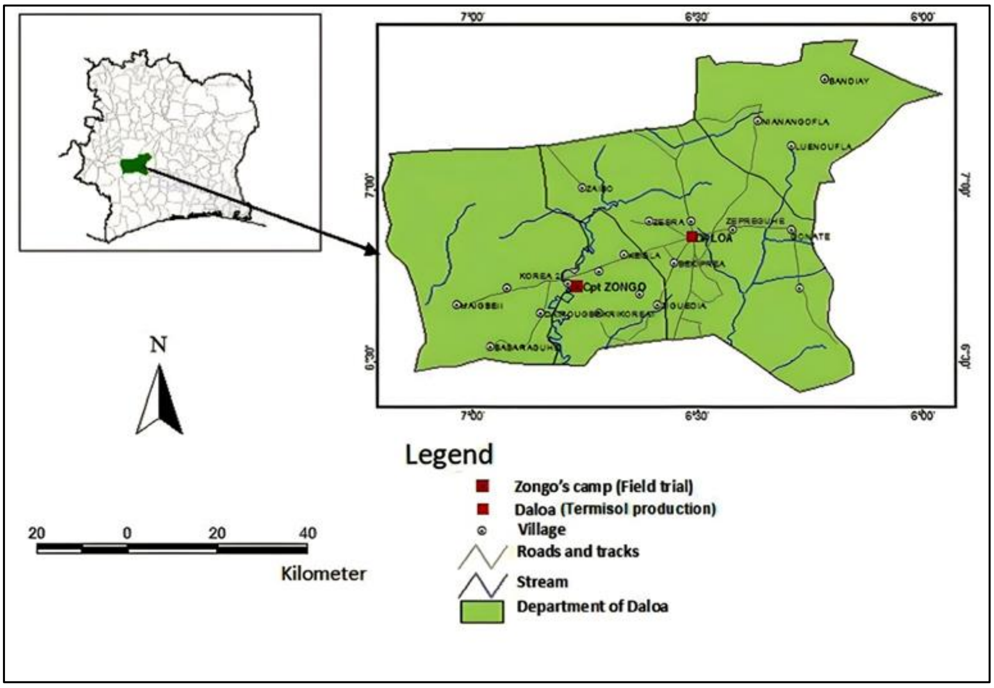

Figure 1 Location of the evaluation test of the termite waste product ''Termisol''

2.2. Material

2.2.1. Biological material

The biological material used in this study consists of rice plants grown from seeds of the IDSA 10 variety. This is a rainfed rice variety with a cycle of 105 days and an average yield of 2.5 t ha^{-1}. It also has good drought tolerance [10].

2.2.2. Technical equipment

The technical equipment used included an auger for taking soil samples for analysis, an infiltrometer for determining soil permeability, a barrel for storing water for infiltration assessment, a stopwatch used to evaluate water infiltration time; and a FieldScout TDR 350 moisture meter used to measure soil moisture and surface temperature.

2.2.3. Fertilizers, and soil amendments

The fertilizers and soil amendments used were:
The termite waste product "Termisol". This was obtained through the degradation of corn residues and the uptake of mineral constituents by termites in an artificial termite mound [9].

Poultry manure (organic fertilizer) is characterized by nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) contents of 1.40%, 0.45%, 1.72%, 2.44%, and 0.32%, respectively. As for trace elements, the copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) contents were 5.03 mg kg-1, 10.11 mg kg^{-1}, 5.09 mg kg^{-1}, and 7.19 mg kg^{-1}, respectively.

NPK (15-15-15) and urea (46% N);

Termite mound soil characterized by a sandy loam texture, low in organic matter (1.16%), slightly acidic with a CEC of 7.2 cmol kg^{-1}. It is a desaturated soil with a saturation rate (V) of 34.44% and a base sum equal to 2.48 cmol kg^{-1}.

2.3. Methods

2.3.1. Experimental design

The experimental design is completely randomized blocks (CRB) with three replicates of ten (10) treatments each (Figure 2). The treatments consist of six (6) doses of Termisol and four controls.
The doses of Termisol applied were calculated based on the mass of soil contained in one square meter at a working depth of 22 cm in the plot to be treated [9].

Thus, the doses of Termisol used were:

- 29.1 t ha^{-1}, or 1% Termisol (T1);
- 58.30 t ha^{-1}, or 2% Termisol (T2);
- 87.30 t ha^{-1}, or 3% Termisol (T3);
- 116.50 t ha^{-1}, or 4% Termisol (T4);
- 145.50 t ha^{-1}, or 5% Termisol (T5);
- 175 t ha^{-1}, or 6% Termisol (T6).

The control treatments are:

- ZeroF: absolute control without fertilizer (T0);
- NPK: application of 0.15 t ha^{-1} of NPK (15-15-15): mineral control (T7);
- TermNat: application of 116.50 t ha^{-1} of natural termite mound soil (T8) taken from the trial site [11];
- Manure: application of chicken manure at a rate of 7 t ha^{-1}: organic control (T9).

The treatments were applied once as basal dressing in cycle 1. During the vegetative phase, top dressing with urea (46% N) at a rate of 0.07 t ha^{-1} was applied 40 days after sowing on all plots during both cycles.
The basic plot is rectangular, measuring 1.25 m long and 1 m wide.

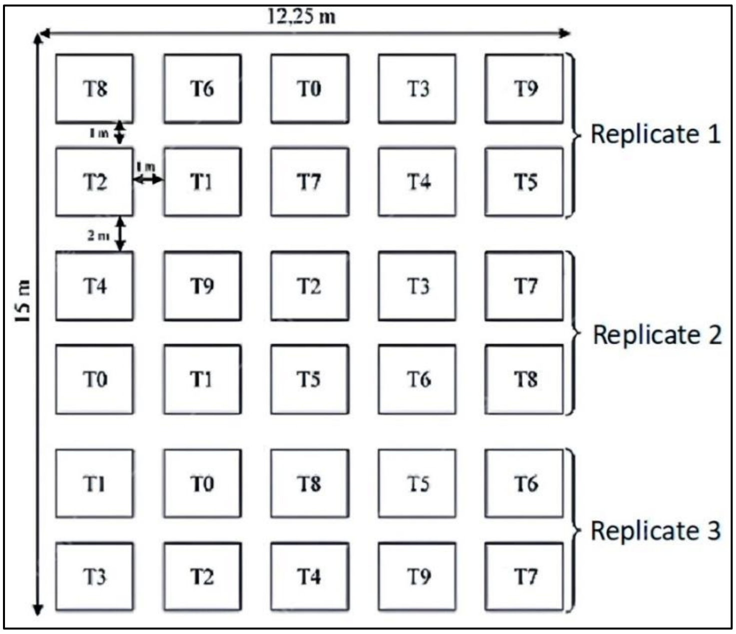

Figure 2 Experimental design applied to the field

2.3.2. Effect of Termisol on the physical and chemical properties of soil.

A composite soil sample was taken from the site before the first trial was set up in order to determine the fertility level of the plot. At the end of the second crop cycle without fertilizer application, composite samples were taken according to the various treatments for physicochemical characterization. All analyses were carried out at the Plant and Soil Analysis Laboratory (LAVESO) of the Félix Houphouët-Boigny National Polytechnic Institute in Yamoussoukro (INPHB). The parameters analyzed were:

Particle size distribution determined by the densimetric method using a Robinson pipette [12]. This method involves separating soil particles according to their size. It provides a weight-based distribution of mineral particles less than 2 mm in diameter according to different texture classes;

The pH of soil samples, measured by direct reading on a pH meter according to a soil/distilled water ratio of 1:2.5 after stirring the suspension [13];

Organic carbon was measured after calcination of soil samples in a muffle furnace using the Walkley & Black method [14]. This determination was made using the cold sulfochromic acid attack method after oxidation with potassium dichromate ($K_2Cr_2O_7$) in a strongly acidic medium (H_2SO_4). The carbon content was used to calculate the organic matter (OM) content:

$$OM = C \times 1{,}724$$

Where

OM: Organic matter content (%)

C: Organic carbon content (%)

Nitrogen is measured using the Kjeldahl method [15]. Mineralization consists of converting organic nitrogen into a mineral form (ammonium sulfate) in a concentrated medium (sulfuric acid (H_2SO_4)), in the presence of a catalyst. Distillation allows $(NH_4)_2SO_4$ to be converted into NH_4OH in the presence of an excess of soda, which alkalizes the reaction medium. The solution obtained is distilled, then the ammonium is recovered in a boric acid solution that has been titrated using a sulfuric acid solution.

Available phosphorus was determined using the modified Olsen method [16] and total phosphorus by colorimetry after extraction with perchloric acid [17];

Exchangeable bases (Na^+, K^+, Ca^{2+}, Mg^{2+}) were extracted with 1 M ammonium acetate buffered at pH=7. Calcium and magnesium were quantified by atomic absorption spectrophotometry. Potassium was measured using flame spectrophotometry [18]. Cation exchange capacity (CEC) corresponds to the sum of the bases in the exchange complex.

2.3.3. Effect of Termisol on soil infiltration

At the end of cycle 2, the soil infiltration rate was assessed. A double-ring infiltrometer was used. The outer and inner rings have diameters of 32 cm and 11 cm, respectively, and are 18 cm high. A graduated ruler was placed against the inner face of the inner ring to facilitate reading the water level. The rings are arranged concentrically and sunk vertically 5 cm into the soil. The initial water level was 12 cm high and the height of infiltrated water was read every 2 minutes. The variation in water level in the inner ring (ΔH) and the infiltration time (Δt) were used to calculate the infiltration velocity (V):

$$V = \frac{\Delta H}{\Delta t}$$

Where

ΔH is in millimeters (mm);

Δt is in hours (h).

The permeability coefficient (K) was calculated using the following formula:

$$K = (D/2 \times \ln\frac{h1}{h2}) \div 2 \times (t2 - t1)$$

Where:

(D/2) represents the radius of the inner ring in meters;

ln represents the logarithm;

h1 and h2 are the initial and final heights measured in meters;
(t2– t1) expresses, in seconds, the time elapsed between two consecutive measurements.

2.3.4. Effect of Termisol on soil moisture and temperature

After the second cycle harvest, soil moisture and temperature are measured at field capacity using a moisture meter. For the measurements, the probes are inserted into the soil to a depth of 3.8 cm and the two parameters are read on the screen.

2.3.5. Data processing

The data were processed using XLSTAT software. The normality of the sample distributions was verified using the Shapiro-Wilk test and the homogeneity of variances was verified using Levene's test. If the variable from which the sample originates follows a normal distribution and the variances are homogeneous, an ANOVA is performed; otherwise, the nonparametric Kruskal-Wallis test is applied. The analysis of variance was supplemented by the Newman-Keuls test, which allowed the means to be ranked using the smallest significant difference (p-values) at a 5% probability threshold. A principal component analysis (PCA) was then performed using R software.

3. Results

3.1. Physicochemical characteristics of the soil before cultivation and of Termisol

The results of the physical and chemical analyses carried out on soil samples from the plot and from Termisol showed that Termisol has the physical characteristics of sandy loam, rich in organic matter (5.86% OM), nitrogen (0.26% Nt), and assimilable phosphorus (78 mg kg^{-1} P.ass) with a neutral pH (7.12). This fertilizing substance is generally saturated with bases with V = 74.14%. The control soil is a silty sand poor in OM (1.38%) and Nt (0.05%) with an acidic pH (5.23) and moderately saturated with V = 47.29% (Table 1).

Table 1 Physicochemical characteristics of the control soil and Termisol (threshold [19])

Parameters		Control soil	Termisol	Thresholds
Particle size distribution	A (%)	3.42	11.25	
	L (%)	19.65	26.08	
	A+L (%)	23.07	37.33	
	S (%)	75.55	59.26	
Bioorganic	C (%)	0.8	3.41	1.6 - 2.5
	Nt (%)	0.05	0.26	1.5 – 2.5
	C/Nt	15.48	12.48	9 - 12
	OM (%)	1.38	5.86	3 - 6
Chemicals	pH	5.23	7.12	5.5 - 6
	P.ass (mg kg^{-1})	40.67	78	50 - 100
	Ca^{2+} (cmol kg^{-1})	0.75	2.24	2.5 – 3.5
	Mg^{2+} (cmol kg^{-1})	0.5	1.65	1 – 1.5
	K^{+} (cmol kg^{-1})	0.03	3.41	0.15 – 0.40
	Na^{+} (cmol kg^{-1})	0.06	0.12	0.3 – 0.7
	CEC (cmol kg^{-1})	2.83	9.92	3 - 8
	Sb (cmol kg^{-1})	1.34	7.4	3 - 6
	V%	47.29	74.14	50 – 80

A: clay; L: silt; S: sand; pH: hydrogen potential; C: carbon; C/N: carbon-nitrogen ratio; Nt: total nitrogen; OM: organic matter; P.ass: available phosphorus; CEC: cation exchange capacity; Ca^{2+}: calcium; Mg^{2+}: magnesium; Na^{+}: sodium; K^{+}: potassium; Sb: sum of bases; V: saturation rate.

3.2. Changes in the physical and chemical parameters of soils

3.2.1. Particle size distribution

After cycle 2, the textures of the 2%Termisol, 4%Termisol, and 6%Termisol and manure treatments changed to silty sand, while the NPK and TermNat treatments remained sandy loam (Table 2).
The clay + silt (A+L) content of the soils varied overall between 19.05% (ZeroF) and 38.35% (Manure). The highest contents were obtained in the 2%Termisol, 4%Termisol and Manure treatments, with 26.55%, 28.35%, and 38.35%, respectively. The ZeroF, 5%Termisol, and TermNat treatments had the lowest (A+L) contents, with values of 19.05%, 19.50%, and 21.35%, respectively (Table 2).

3.2.2. Soil acidity

The soil pH varied between the two crop cycles. However, the treatments changed it from an acidic pH (5.23) on the initial plot to a pH ranging from slightly acidic (6.1–6.5) to neutral (7.1) after cycle 1. After cycle 2, the treatments changed the pH from acidic (5.23) on the initial plot to slightly acidic, ranging from 5.4 to 5.7. Fertilizer was applied before the first cycle in a single application (Table 2).

3.2.3. Bioorganic parameters

The addition of Termisol with 3.41% carbon (carbon-rich) did not significantly improve soil status after two crop cycles (Table 2). After the second cycle, carbon levels ranged from 0.61% to 1.01%. The TermNat, 4%Termisol, and 2%Termisol treatments, with 0.96%, 0.98%, and 1.01% respectively, had the highest carbon levels after this last cycle. The threshold values range from 1.6% to 2.5%.

The organic matter content of the soil was insufficient on all plots compared to the standard range of 3% to 6%. Following cycle 2, the OM content remained low, ranging from 1.05% (Manure) to 1.74% (2%Termisol). However, OM levels appeared to have improved slightly on the 3%Termisol, 4%Termisol, 6%Termisol, and TermNat plots, with respective levels of 1.55%, 1.68%, 1.58%, and 1.65% (Table 2).

Following cycle 2, the Nt content decreased significantly and ranged between 0.04% (manure) and 0.08% (2%Termisol). The threshold values range from 1.2% to 2.2%. Nt levels appeared to be slightly improved on plots treated with 1%, 2%, 3%, 4%, and 6%Termisol compared to the pre-test soil level of 0.05%.

After cycle 2, the C/Nt ratio of the soil in the plots varied between 12.54 (1%Termisol) and 17.43 (4%Termisol). The highest ratios were obtained in the 5%Termisol and 4%Termisol treatments, with 17.10 and 17.43 respectively (Table 2).

3.2.4. Chemical parameters

After cycle 2, the assimilable phosphorus content varied between 39 mg kg^{-1} (2%Termisol) and 48 mg kg^{-1} (4%Termisol). The threshold values for assimilable phosphorus are between 50 mg kg^{-1} and 100 mg kg^{-1}. The phosphorus content of all treatments except 2%Termisol was improved compared to that of the site soil before cultivation, which was 40.67 mg kg^{-1} (Table 2).

The cation exchange capacity varied very slightly after cycle 2 (Table 2). The CEC ranged from 1.4 cmol kg^{-1} (ZeroF) to 2.4 cmol kg^{-1} (2%Termisol). The standard values for CEC range from 3 to 8 cmol kg^{-1}. All Termisol treatments showed values lower than the soil's CEC before the test.

Table 2 Physicochemical parameters of the soil after cycle 2

Parameters		**Treatments**										**Soil before cultivation**
		Zero F	**1%Termisol**	**2%Termisol**	**3%Termisol**	**4%Termisol**	**5%Termisol**	**6%Termisol**	**NPK**	**Term Nat**	**Manure**	
Particle size distribution	A (%)	3.5	3.5	3.5	4.5	4.5	4.25	4.5	4	5	4	3.42
	L (%)	15.55	18.50	23.05	19.20	23.85	15.25	19.52	18.60	16.35	34.35	19.65
	A+L (%)	19.05	22.00	26.55	23.70	28.35	19.50	24.02	22.60	21.35	38.35	23.07
	S (%)	79.57	76.55	71.71	74.75	69.97	79.18	74.40	76.28	77.00	60.60	75.55

Bioorganic	C (%)	0.80	0.84	1.01	0.90	0.98	0.77	0.92	0.65	0.96	0.61	0.8
	Nt (%)	0.06	0.07	0.08	0.07	0.06	0.04	0.06	0.05	0.07	0.04	0.05
	C/Nt	13.4	12.54	12.68	13	17.43	17.1	16.41	13.03	13.67	13.68	15.48
	M.O (%)	1.38	1.45	1.74	1.55	1.68	1.32	1.58	1.12	1.65	1.05	1.38
Chemicals	pH	5.4	5.4	5.5	5.4	5.6	5.6	5.6	5.6	5.7	5.7	5.23
	P.ass (mg kg^{-1})	47	44	39	47	48	46	45	45	44	44	40.67
	Ca^{2+} (cmol kg^{-1})	0.702	0.694	0.896	1.041	1.001	0.939	0.994	0.871	0.982	0.844	0.75
	Mg^{2+} (cmol kg^{-1})	0.466	0.418	0.451	0.474	0.465	0.404	0.426	0.400	0.431	0.383	0.5
	K^{+} (cmol kg^{-1})	0.034	0.032	0.031	0.051	0.059	0.057	0.057	0.061	0.052	0.054	0.03
	Na^{+} (cmol kg^{-1})	0.049	0.051	0.043	0.05	0.046	0.039	0.047	0.045	0.038	0.042	0.06
	CEC (cmol kg^{-1})	1.4	1.2	2.4	1.7	1.6	1.5	1.7	1.7	1.7	1.4	2.83
	Sb (cmol kg^{-1})	1.251	1.195	1.421	1.616	1.571	1.439	1.524	1.377	1.503	1.323	1.34
	V (%)	92.8	91.6	59.1	94.5	93.7	93.3	88.2	82.3	88.2	92.8	47.29

ZeroF: control without fertilizer; TermNat: natural termite mound; A: clay; L: silt; S: sand; pH: hydrogen potential; C: carbon; C/Nt: carbon-nitrogen ratio; Nt: total nitrogen; OM: organic matter; P.ass: available phosphorus; CEC: cation exchange capacity; Ca^{2+}: calcium; Mg^{2+}: magnesium; Na^{+}: sodium; K^{+}: potassium; Sb: sum of bases; V: saturation rate

The calcium content varied slightly compared to the threshold values, which range between 2.5 and 3.5 cmol kg^{-1}. Thus, after cycle 2, the calcium content dropped significantly and varied between 0.69 cmol kg^{-1} (1%Termisol) and 1.04 cmol kg^{-1} (3%Termisol). However, all treatments showed values higher than those of the soil before the test.

The magnesium content remained low compared to threshold values between 1 and 1.5 cmol kg^{-1}. Thus, after cycle 2, this content varied between 0.383 cmol kg^{-1} (manure) and 0.474 cmol kg^{-1} (3%Termisol). The Manure, NPK, and 5%Termisol treatments had the lowest contents, with values of 0.383, 0.400, and 0.404 cmol kg^{-1}, respectively. The soil prior to the trial had a magnesium content of 0.5 cmol kg^{-1}.

The soil remained very low in potassium after the trial. The 2%Termisol, 1%Termisol, and ZeroF treatments had the lowest levels, with values of 0.031 cmol kg^{-1}; 0.032 cmol kg^{-1}; and 0.034 cmol kg^{-1} in cycle 2, respectively. However, these levels remain higher than those in the soil before the trial (0.03 cmol kg^{-1}). The threshold values for potassium are between 0.15 and 0.40 cmol kg^{-1}.

The sodium content was low in the soil after the trial (Tables 2). However, the different treatments contributed to lowering this sodium content in the trial soils. Thus, after cycle 2, the sodium content varied between 0.038 cmol kg^{-1} (TermNat) and 0.051 cmol kg^{-1} (1%Termisol). The threshold values for sodium are between 0.3 and 0.7 cmol kg^{-1}.

The sum of exchangeable bases remained low on the plots during the trial compared to threshold values between 3 and 6 cmol kg^{-1}. In cycle 2, it decreased on all plots and varied between 1.195 cmol kg^{-1} (ZeroF) and 1.616 cmol kg^{-1} (3%Termisol). The 1%Termisol, ZeroF, and Manure treatments had the lowest sum of bases, with values of 1.195, 1.251, and 1.323 cmol kg^{-1}, respectively (Table 2). The 2%, 3%, 4%, 5% and 6% Termisol treatments had values higher than those of the soil before the trial.

All treatments showed saturated complexes. However, only the soil from the 2%Termisol treatment showed a moderately saturated complex with a saturation rate of 59.10%. The saturation rate threshold values range from 50% to 80%.

3.3. Effect of Termisol on permeability, humidity, and temperature

No significant differences were recorded between treatments for infiltration rate, permeability coefficient, and field capacity temperature. However, moisture varied significantly (P = 0.02) between treatments in cycle 2 (Table 3).

The permeability coefficient varied overall between $1.71\times10^{-5}\pm0.5\times10^{-5}$ m s^{-1} (6%Termisol, cycle 2) and $70.52\times10^{-5}\pm30\times10^{-5}$ m s^{-1} (1%Termisol, cycle 1). After cycle 1, the highest permeability coefficients were obtained for the manure and NPK treatments, with values of $58.18\times10^{-5}\pm6\times10^{-5}$ m s^{-1} and $64.54\times10^{-5}\pm9\times10^{-5}$ m s^{-1} respectively, below 1%Termisol. After cycle 2, the permeability coefficient decreased on all plots and varied between $1.71\times10^{-5}\pm0.5\times10^{-5}$ m s^{-1} (6%Termisol) and $4.63\times10^{-5}\pm2\times10^{-5}$ m s^{-1} (manure). The 3%Termisol and 2%Termisol treatments had the lowest permeability coefficients, with values of $2.09\times10^{-5}\pm0.2\times10^{-5}$ m s^{-1} and $2.11\times10^{-5}\pm0.8\times10^{-5}$ m s^{-1} above 6%Termisol for this cycle, respectively.

After cycle 1, the moisture content at field capacity varied between 6.30±1.47% (6%Termisol) and 4.66±0.57% (1%Termisol). After cycle 2, moisture content improved on all plots, with the highest values obtained for the 6%Termisol, 4%Termisol, and 3%Termisol treatments, with values of 8.23±0.57%, 8.56±1.52%, and 8.90±0%, respectively (Table 3).

The field capacity temperature varied overall between 34.20±2.07 °C (NPK, cycle 2) and 37.30±0.26 °C (5%Termisol, cycle 1). Between these extremes, the highest temperatures were obtained in the 3%Termisol and Manure treatments, with values of 37.16±0.65 °C and 37.23±0.64 °C, respectively, in cycle 1 (Table 3). The Manure and 4%Termisol treatments had the lowest temperatures, with values of 34.46±1.27 °C and 34.56±1.19 °C, respectively, in cycle 2.

Table 3 Permeability coefficient, humidity, and temperature according to treatment

Treatments	**Parameters**					
	K (m s^{-1})		**Hcc (%)**		**Tcc (°C)**	
	Cycle 1	**Cycle 2**	**Cycle 1**	**Cycle 2**	**Cycle 1**	**Cycle 2**
ZeroF	40.24E-05±4E-05^{a}	3.72E-05±1E-05^{a}	5.00±1^{a}	7.56±0.57^{ab}	36.76±0.73^{a}	34.73±0.64^{a}
1%Termisol	70.52E-05±30E-05^{a}	4.05E-05±2E-05^{a}	4.66±0.57^{a}	6.60±0.51^{b}	36.93±0.80^{a}	34.66±0.80^{a}
2%Termisol	5.070E-05±1E-05^{a}	2.11E-05±8E-06^{a}	5.96±1.95^{a}	8.90±1^{a}	36.93±0.75^{a}	34.70±1.12^{a}
3%Termisol	28.00E-05±3E-05^{a}	2.09E-05±2E-06^{a}	6.30±0.51^{a}	8.90±0^{a}	37.16±0.65^{a}	34.70±1.04^{a}
4%Termisol	27.61E-05±20E-05^{a}	2.38E-05±1E-05^{a}	6.30±0.51^{a}	8.56±1.52^{ab}	36.96±0.60^{a}	34.56±1.19^{a}
5%Termisol	11.02E-05±7E-05^{a}	4.22E-05±8E-06^{a}	5.63±1.09^{a}	8.56±0.57^{ab}	37.30±0.26^{a}	34.80±0.6^{a}
6%Termisol	25.59E-05±20E-05^{a}	1.71E-05±5E-06^{a}	6.30±1.47^{a}	8.23±0.57^{ab}	37.00±0.65^{a}	34.70±0.52^{a}
NPK	64.54E-05±9E-05^{a}	3.09E-05±1E-05^{a}	5.33±1.15^{a}	7.56±0.57^{ab}	37.06±0.58^{a}	34.20±2.07^{a}
TermNat	35.25E-05±20E-05^{a}	3.27E-05±2E-05^{a}	6.30±0.51^{a}	7.90±1^{ab}	37.06±0.68^{a}	34.63±0.68^{a}
Manure	58.18E-05±6E-05^{a}	4.63E-05±2E-05^{a}	5.66±0.57^{a}	7.23±0.57^{ab}	37.23±0.64^{a}	34.46±1.27^{a}
Cv	1.1064	0.523	0.1784	0.1213	0.015	0.0261
P	0.6221	0.3547	0.4942	0.0268	0.9944	0.9998
Effect	ns	ns	ns	*	ns	ns

ZeroF: Control without fertilizer; TermNat: Natural termite mound; K: permeability coefficient; Hcc: field capacity moisture content; Tcc: field capacity temperature; * significant difference P < 0.05; ns: non-significant difference P > 0.05; CV: coefficient of variation.

3.4. Correlation between the parameters studied

3.4.1. Relationship between soil parameters

The physicochemical parameters of the soil establish positive or negative relationships between themselves (Table 4).

Thus, organic matter (OM) content is positively correlated with magnesium (Mg^{2+}) content (P < 0.01, r = 79), clay (A) content with P < 0.05 and r = 75, and moisture (Hcc) content (P < 0.05, r = 64), but negatively correlated with saturation level (V) with P < 0.05 and r = 69. The granulometric clay content is positively correlated with magnesium content (P < 0.05, r = 66). Silt (L) is positively correlated (P < 0.05 and r = 72) with sand (S). Assimilable phosphorus (P.ass) and calcium (Ca^{2+}) are negatively correlated (P < 0.05; r = 69). CEC is strongly positively correlated with calcium (P < 0.001; r = 87). Soil moisture at field capacity is weakly but positively correlated with organic matter content (P < 0.05; r = 64), calcium (P < 0.05; r = 76) and clay (P < 0.05; r = 65).

Table 4 Correlation matrix of soil parameters

Variables	OM	P.ass	CEC	Ca^{2+}	Mg^{2+}	K^+	V	A	L	S	Hcc
OM	1										
P.ass	0.29	1									
CEC	0.20	-0.43	1								
Ca^{2+}	-0.13	-0.65	0.87	1							
Mg^{2+}	0.79	0.32	0.32	-0.04	1						
K^+	-0.05	-0.13	-0.29	-0.28	0.05	1					
V	-0.69	-0.14	-0.51	-0.06	-0.52	0.20	1				
A	0.75	0.31	-0.19	-0.48	0.66	0.34	-0.29	1			
L	-0.42	-0.55	0.10	0.32	-0.62	-0.43	0.13	-0.58	1		
S	-0.15	0.41	0.001	-0.004	0.17	0.26	0.11	-0.14	-0.72	1	
Hcc	0.64	0.13	0.30	-0.07	0.76	0.44	-0.60	0.65	-0.58	0.14	1

3.4.2. Relationship between soil parameters and rice production parameters

The projection on the 1-2 factorial plane positively associates, on axis 1, the production parameters (total number of tillers (TalTot), number of fertile tillers (Talfert), thousand-grain weight (PMG), and fresh yield (Rendfrais)), organic matter (MO), Mg^{2+}, field capacity moisture (Hcc), and clay content (A) of the soil. It positively and negatively associates silt (L) and the sum of clay + silt (A+L), sand content (S) and assimilable phosphorus (P.ass) on axis 2 (Figure 3A).

The factorial design defines three groups (Figure 3B). Group 1, organic and medium productivity, is characterized by soils dominated by silt (S) and clay+silt (A+L). This group consists solely of the poultry manure treatment. Group 2, mineral and low-yielding, would be characterized by soils with a high concentration of sand (S) and low in organic matter (MO) and clay (C). It includes the ZeroF, NPK, TermNat, and 1%Termisol treatments. Group 3, organomineral and high productivity, is characterized by soils with good organic matter and clay content and good water retention capacity. This group includes treatments based on Termisol at a dose of 2 to 6%.

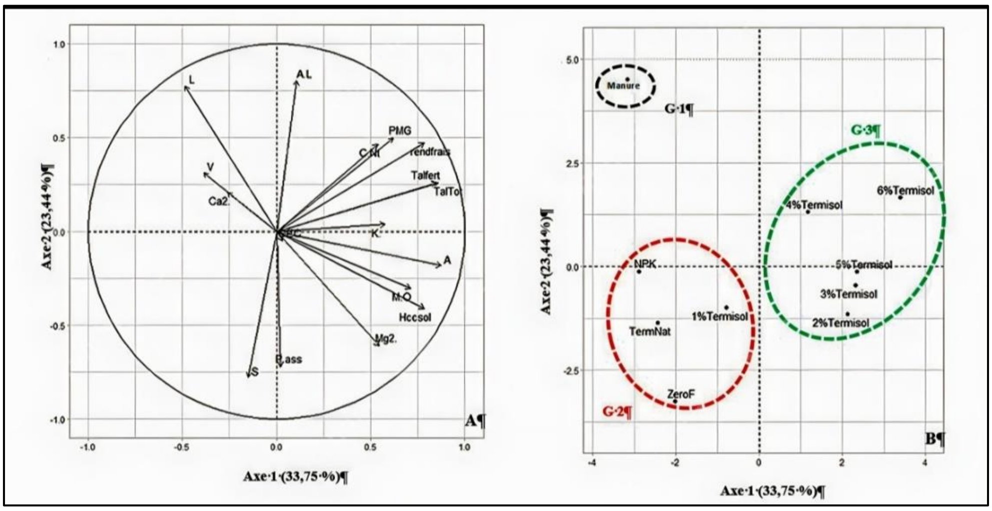

Figure 3 ACP combining soil and rice production parameters

4. Discussion

The results of the physical and chemical analyses of the soil and Termisol prior to cultivation showed that the pH of Termisol (7.12) is higher than that of the soil on the plot (5.23). Termisol has a good total organic nitrogen content (0.26%), total organic carbon content (3.41%), organic matter content (5.86%), assimilable phosphorus content (78 mg kg^{-1}) and a C/N ratio of 12.48, which is favorable for good mineralization of organic matter. These results corroborate those of [9] on termite mound waste and [20] on termite mound soil (*Cubitermes* spp). These authors showed that these substrates were richer in minerals and had a neutral pH. The low values of the characteristics of the soil to be amended are due to its origin and climatic conditions. Indeed, the lithological origin and tropical pedogenesis conditions make most soils low in fertility [21, 22]. In addition, these soils are cultivated using farming systems that expose them to erosion and/or depletion [23].

The pH is an important parameter in soil dynamics because it influences three key components of soil fertility: nutrient bioavailability, biological activity, and structural stability [24]. When the pH tends towards neutrality, this accelerates microbial biomass activity and improves the availability of organic matter to soil microorganisms [25]. According to [26], at low pH values, much of the organic matter remains inactive because microbial activity is severely limited. The addition of Termisol to plots therefore helps to reduce soil acidity.

The C/N ratio of 12.48 in Termisol is very favorable for good mineralization of organic matter [27]. The quality of soil amendments and their ability to supply nitrogen are generally assessed by the C/N ratio [28]. According to this author, amendments with a C/N ratio of less than 20 decompose more quickly, nitrogen mineralizes rapidly, and are considered to be of good quality. Termisol has a high organic matter content. This organic matter has played a physical role in the soil, a chemical role in plant nutrition through degradation and mineralization processes, and has also played a biological role in stimulating biological activity [29].

The good content of available phosphorus, exchangeable bases, and cation exchange capacity (CEC) of Termisol provided good nutrition for crops. These results are similar to those obtained by [30] and [31], who concluded that the main soil types are characterized by the state of their complex and the nature of the fixed cations. The chemical characteristics of this product, obtained by trapping termites in pots, are similar to those of the soil from termite mounds described by [26]. Termisol would therefore appear to be one of the main factors responsible for the improvement in rice growth parameters observed in this study.

Physicochemical analyses of the soil after the trials show a loss of organic matter and exchangeable cations in the soil in almost all treatments after the second crop cycle. The results obtained are consistent with those of [11], who attributes these losses to percolation, runoff, and the use of organomineral matter by plants.

The initial pH values (5.23) of the upper horizons of the study site indicate acidic soil. These low pH values could promote low nitrification, phosphorus deficiency, aluminum and manganese toxicity, high availability of certain heavy metals [31] and induce low assimilation of nutrients such as nitrogen, phosphorus, potassium, magnesium, and sulfur [33]. The addition of Termisol significantly raised the pH through the mineralization of the organic matter it contains [34]. The calcium content also varied within normal ranges after the two test cycles, and this content was higher in the treatments amended with Termisol despite the uptake of this cation by the plants. This calcium enrichment is attributable to the activity of termites. Calcium ions neutralize the ions responsible for soil acidity by displacing them from the clay-humic complex. The higher the Ca^{2+} content, the greater the neutralization of H^+ and Al^{3+} ions and, consequently, the lower the acidity [35]. Ca^{2+} in soils increases the amount of mineralized nitrogen and improves soil aeration and water retention [36, 37, 38].

In cycle 2, the total nitrogen content in the treatments decreased. This decrease could be due to a considerable reduction in the stock of organic molecules that become difficult for soil organisms to degrade, to the extinction or reduction of microorganism colonies, or to soil desiccation [11]. Indeed, the addition of Termisol to the soil influences the proliferation of microorganisms. These microorganisms become active and degrade large organic molecules to varying degrees. The by-products of this degradation (C, N, P_2O_5, K^+, and other mineral elements) are released into the soil and made available to other organisms and plants. At the end of a crop cycle, microorganism activity in the soil decreases if the amendment is not renewed, as was the case with the addition of Termisol (before the first cycle). [39] also noted that with each crop cycle, nitrogen mineralization in the soil decreases by almost half, reaching low values at the end of the experiment.

Low doses of Termisol induce satisfactory responses on certain fertility factors in certain treatments. These results confirm those of [40], who state that termite mound soil can have an indirect effect on plant nutrition by inducing the proliferation of a symbiotic mycorrhizal fungus on plant roots, which is responsible for mineralizing nitrogen.

The low C/N ratios on plots amended with Termisol indicate increased activity of soil-decomposing microorganisms and high nitrogen availability in the soil [41].

Plots amended with 3% to 6%Termisol retain high levels of certain organic and mineral elements compared to other plots. However, the 4%Termisol treatment showed the best after-effect, with physicochemical values superior to those of the other treatments. This treatment had the highest clay and silt content (28.35%), an OM content of 1.68%, a C/N ratio of 17.43, a CEC of 1.6 cmol kg^{-1} and a complex saturation rate of 93.70%. However, this improvement in the proportion of silt remains significant with the addition of manure.

At the end of the work, permeability and field capacity moisture content had improved. This could be explained by calcium levels remaining normal after the two cycles, linked to higher organic matter content and enrichment with clay and silt. Organic matter and clay have a greater capacity for water retention. The addition of Termisol to this sandy soil helped reduce permeability and thus improve the soil's water retention capacity. Indeed, the work of [37] has shown that calcium greatly influences soil properties by acting as a binder for soil aggregates, clay fractions, and organic matter. It thus ensures the cohesion of aggregates and adhesion with other aggregates in the formation of soil structure and porosity [42].

Termites, with their ability to dig and build, explore deep horizons and transport fine particles such as clay, silt, and even fine sand grains to surface horizons. It is this ability that was exploited in this study to improve the texture of this sandy soil and its agronomic properties. Indeed, [43] had already established that in coastal areas, by drawing on deeper horizons, termites increased the clay content of sandy soils. The termite trapping developed by humans would promote the production of Termisol, dominated by fine soil and termite droppings, whose fertility potential would facilitate agronomic use by contributing to the physical and chemical fertility of the soil.

5. Conclusion

The overall effect of the amendment was to increase the mineral and organic nutrient reserves in the soil and improve rice production. Following their use for two consecutive cycles, nutrient stocks were reduced, but to varying degrees depending on the type of treatment.

Treatments amended with 3% to 6%Termisol retained relatively high levels of certain organic and mineral elements compared to other treatments. However, the 4%Termisol treatment had a more interesting residual effect, showing that the effect of the Termisol amendment can persist in the soil even two years after application.

In light of these results, Termisol can be used as an amendment to improve soil fertility.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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