Effects of organic compost and *Trichoderma harzianum* spores on soil fertility and agronomic performance of soybean (*Glycine max* (L.) Merr.)

ABSTRACT

The food supply has grown steadily over the years, while production has been hampered by the increased use of synthetic fertilizers, leading to pollution and degradation of soil physico-chemical properties. It is imperative to advocate for the promotion of sustainable farming techniques that can enhance crop yields while improving soil fertility, without the excessive utilisation of chemical fertilizers. Hence the interest of this study, which involved the use of organic compost enriched or not with *Trichoderma Harzianum* spores as an alternative method to assess their effect on the physico-chemical soil and agronomic parameters of the « *TGX 1910-14F* » soybean variety being tested in a greenhouse growing vase. The study was carried out at the Institute of Research Development (IRD) in Ouagadougou (Burkina Faso), on a completely randomized block trial with four fertilizers repeated five times. The trial consisted of comparing soil parameters and soybean yields under four fertilization regimes: T1 (1 l m^{-3} of *Trichoderma harzianum* spores); T2 (3 t ha^{-1} of compost); T3 (3 t ha^{-1} of compost + 1 l m^{-3} of *Trichoderma harzianum* spores), T0 (absolute control with no inputs). 4 kg of fine soil from a lixisol and sieved to 2 mm with a field capacity moisture of 150 ml kg^{-1} of soil were added to each treatment. The results showed that T2 and T3 fertilization regimes improved the organic status, total N, P and K content, absorbable P and available P of the soils. T3 significantly ($P < 0.001$) increased plant height (146.80 ± 9.92 cm) and the number of soybean plant leaves (46.20 ± 2.41) compared with treatments T0 and T1. T0 and T1 fertilization regimes significantly increased ($P < 0.001$) the number and weight of soybean nodules compared with T2 and T3. Total soybean biomass was significantly improved ($P < 0.001$) under T2 and T3 compared with T1 and T0. Thus, the T2 and T3 fertilization regimes was more effective in improving soil fertility and soybean biomass production. *Trichoderma harzianum* and fine soil stimulated nodulation of soybean, while compost combined with *Trichoderma harzianum* spores had an effect on vegetative growth. It may be posited that the latter treatment could serve as an alternative means of improving soil fertility and increasing soybean yields.

Keywords: Lixisol, Biofertilizer, Microorganism, Agro-pedology, soybean, Yield, Burkina Faso.

1. INTRODUCTION

The economy of Burkina Faso, a Sahelian country with a predominantly semi-arid climate, is predominantly based on agriculture and livestock farming. Agriculture and livestock farming, including forestry, employ 85% of the population and generate 2/3 of national wealth. The rural sector remains the basis of socio-economic development and depends on the exploitation of the main natural resources, in particular water, soil, forests and pastures [1]. The agricultural sector is the most important and reliable pillar of the world economy [2].

Agricultural cropping systems around the world use large quantities of chemical fertilizers, insecticides and herbicides to improve crop profitability [2]. However, this type of agricultural production is now facing challenges such as water scarcity, reduced soil organic matter, soil degradation, lower crop yields, lower incomes, fertilizer build-up and pesticide pollution of environment. Land degradation jeopardizes the entire economy and hence the country's socio-political stability. More than 34% of the national territory, i.e. 9,234,500 ha of agricultural land, is degraded, with an estimated increase of between 105,000 and 250,000 ha per year over the last 10 years, according to [1]. Soil degradation remains a crucial and growing problem worldwide [3]. It is reported that 40% of soils in sub-Saharan Africa are depleted of nutrients [4, 5]. These same authors suggest average annual nutrient depletion rates in 37 African countries of 22 kg N ha^{-1}; 2.5 kg P ha^{-1}; and 15 kg K ha^{-1}. Annual soil nutrient extractions of the order of -43 kg NPK ha^{-1} in the Sudano-Sahelian zone of Burkina Faso in mining farming systems result in declining soil fertility and poor harvests [1]. It will therefore be necessary to diversify fertilizer sources in order to enhance crop yields in general, and legumes in particular, and improve soil fertility. Burkina Faso's agro-ecosystems are dominated by leguminous crops such as soybean, which play an important role. According to Zongo et al. [6], legumes improve the nitrogen balance in cropping systems and increase the yield of subsequent cereals. However, vegetable crops, particularly soybean, are highly dependent on nutrients, especially N and P [7], and are faced with a low level of soil fertility. These mineral elements can come from compost used as a biofertilizer. It is important to note that legumes fix nitrogen at the beginning of their development cycle, but additional nitrogen fertilizer in poor soils is likely to improve their yield. Legumes are also very sensitive to P deficiency because of its role in nodulation, biological N_2 fixation and energy reactions [8, 9]. New technologies have therefore been scientifically developed to improve productivity, reduce the cost of resources and the environmental problems associated with agricultural production. These technologies include the use of biofertilizers such as compost and micro-organisms [10, 11]. *Trichoderma harzianum* spores have been shown to increase the bioavailability of insoluble forms of P to promote plant growth [2, 12]. This promotes P uptake from the soil solution. Based on these findings, the use of compost and biostimulants such as *Trichoderma harzianum* should be explored as ways of improving soil fertility and legume yields. In fact, the use of compost in combination with fungal micro-organisms as biofertilizers is a good approach that not only increases the efficiency of nutrient use by improving soil fertility, but also minimizes the leaching of these nutrients into groundwater. Zeinabou et al. [13] and Zraibi et al. [14] have shown that the use of biofertilizers can increase crop yields, reduce the use of chemical fertilizers and promote environmentally sustainable agriculture. It is in this context that the present study was carried out. The aim of the study is to evaluate the effect of compost associated or not with

Trichoderma harzianum on soil fertility and the agronomic performance of soybean under greenhouse growing conditions.

2. MATERIAL AND METHODS

2.1. Study area

The study was carried out in pots experiments under greenhouse conditions at the Institute of Research for Development (IRD) in Ouagadougou (Burkina Faso, West Africa). The soil used for the experiment was taken from a field in Gampéla, a rural village of Saaba commune, 25 km East of Ouagadougou, with geographical coordinates 12°25‘N and 1°21’W (Fig. 1). The greenhouse has the same climatic conditions as Ouagadougou, which has a Sudano-Sahelian climate, with an average rainfall of 569 mm and an average temperature of 28.6°C each year.

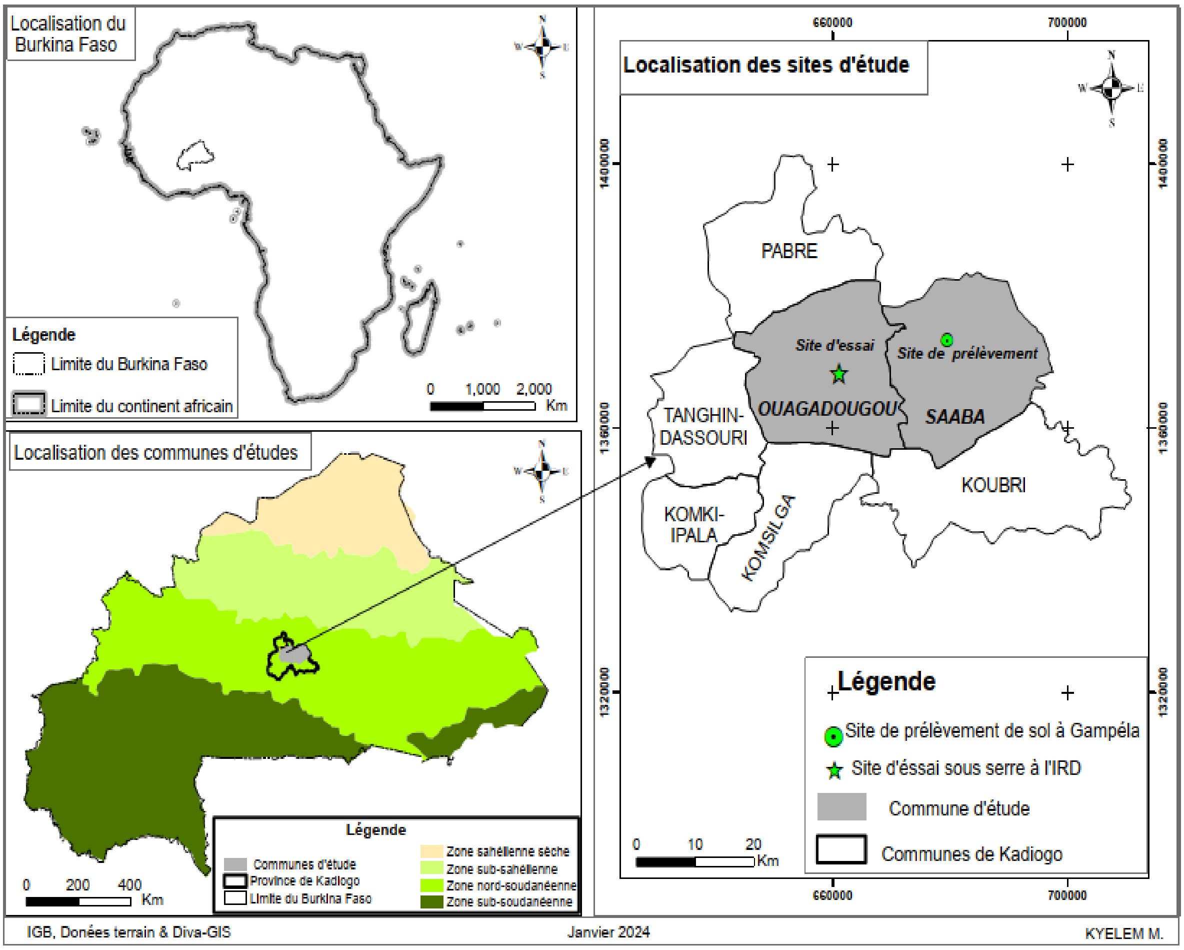

Fig. 1. Location of the study site.

2.2. Characteristics of the experimental soil

The soil used in the trial is of the Lixisol type according to the [15] classification. It was taken from the surface horizon of approximately (0-14 cm). It has a sandy-loam texture. The characteristics of the soil used are given in table 1.

Table 1. Characteristics of the soil used to set up the experiment.

Soil variables	Units	Values
Argil	%	14.5
Silt	%	28.25
Sand	%	57.25
Texture	-	Sandy-silt
C	g kg^{-1}	0.73
N	g kg^{-1}	0.05
C/N		14
P total	ppm	1257
Assailable P	ppm	1.3
Calcium	Cmoles $^{(+)}$ kg^{-1}	1.81
Magnesium	Cmoles $^{(+)}$ kg^{-1}	1.85
Potassium	Cmoles $^{(+)}$ kg^{-1}	0.11
Sodium	Cmoles $^{(+)}$ kg^{-1}	0.04
S	Cmoles $^{(+)}$ kg^{-1}	3.81
CEC	Cmoles $^{(+)}$ kg^{-1}	7.28
Saturation rate		52
Water pH		5.46

C = Total Carbon ; N = Total Nitrogen; Total P = Total Phosphorus; Assimilable P = Assimilable Phosphorus; S = Sum of cations; CEC = Cation Exchange Capacity.

2.3. Plant material and fertilizers

The plant material used is the soybean variety « *TGX 1910-14F* » from northern Togo. Its production cycle is 90-110 days. It is an upright line that is resistant to pests.Its average yield is 2.5 t ha^{-1} with a potential of 4 t ha^{-1}. This variety produces small, oval, light yellow seeds. Its growing zone is 600 to 1500 mm. The fertilizers used are organic compost and biofertilizer based on *Trichoderma Harzianum* spores. The organic compost was made by the women of the NABONSWENDE association in Niessega, part of the NGO the Association for Research and Training in Agroecology (ARFA). It was produced from substrates consisting of bush grass straw (60% of *Loudetia togoensis*, 30% of *Andropogon pseudapricus* and 10% of *Andropogon gayanus*), cow dung and wood ash, composting lasted 45 days. The organic and chemical characteristics of the compost used are given in table 2.

Table 2. Organic and chemical characteristics of organic compost.

Parameters	Units	Values
Total Organic Matter	%	47.28
Total carbon	%	27.42
Total nitrogen	%	1.42
$N\text{-}NH^4$	mg/kg	139.60
$N\text{-}NO_3$	mg/kg	46.48
Mineral N	mg/kg	186.08
C/N		19
Total phosphorus	%	1.29
Assailable phosphorus	g/kg	12.13
Total potassium	%	1.45
Available potassium	g/kg	679

The *Trichoderma harzianum* spores were supplied in liquid form called “Solsain”, from the BIOPROTECT-Burkina Economic Interest Group. Solsain is a liquid biofertilizer enriched with a high concentration of *Trichoderma harzianum* spores (at least $5{,}10^8$ spores per ml). It is a ‘starter’ fertilizer with a triple action: fertilization, bio-control and plant stimulant. The recommended dose is 100 ml for a 10 m^2 plant bed.

2.4. Determination of field capacity of soil moisture

The field capacity of soil moisture (HCC) of the soil in the trial was determined before the trial was set up in a growing vase. It was determined using the formula for moisture at field capacity expressed as a percentage by mass. The bottom of the pot was perforated and closed with a nylon screen with a mesh size of less than 2 mm. The dry weight Ps was determined. The soil was then saturated with water and the pot allowed to dry for 24 hours. The wet weight pH was then determined. Using the equation HCC = (Ph - Ps) / Ps, the moisture at field capacity was 0.150 kg (150 ml) of water per kg of soil.

2.5. Experimental design and treatments

The experimental design under greenhouse conditions at the IRD included the following fertilization regimes: 4 fertilization regimes were used. The total number of pots was 20. Each pot had a capacity of 5 litres. The different fertilization regimes were:

T0 = control with no input (4 kg of fine soil)

T1 = 1 l m^{-3} of *Trichoderma harzianum* spores + 4 kg of fine soil

T2 = 3 t ha^{-1} of compost + 4 kg of fine soil

T3 = 3 t ha^{-1} of compost + 1 l m^{-3} of *Trichoderma harzianum* spores + 4 kg of fine soil

2.6. Crop management

This study was conducted 6 March to 6 June 2023. Five hundred grams (500 g) of compost was placed in each pot mixed with 4 kg of fine soil. For the controls, the pots contained only 4 kg of fine soil. Five (05) ml of *Trichoderma harzianum* spores were mixed with the fine soil for treatments T1 and T3. Four seeds were sown per pot. After the plants had emerged, weeding consisted of leaving 2 plants per pot. On the 1st, 2nd and 3rd days after sowing (DAS), the pots were watered every day with 150 ml of water per pot. After the 3rd DAS, the plants were watered every two days with 150 ml per pot. From the 5th to the 45th day, 450 ml of water was added per pot/2days and from the 48th to the 63rd day, the plants were watered with 750 ml/2 days. Once the experimental set-up had been established, the crops were exposed to daylight on a daily basis. Thereafter, as the insolation was heterogeneous, the pots were regularly moved in order to keep them in the same conditions of exposure to daylight. All pots received the same irrigation treatment. One week after sowing, the emergence rate was assessed, followed by a demarcation.

2.7. Agronomic data collection

The following morphological and physiological parameters of the plants were assessed each week: plant height (HP), diameter of the base of the crown (DP) in mm; number of leaves (NF), number of plants having flowered (NPF), flower per plant (NFP), fruit per plant (NFR). The emergence rate at 4 days after planting (TXL) is the percentage of soybean plants that have emerged per pot. Plant heights (HP) in cm were measured using a graduated ruler from the base of the crown to the terminal bud. The

DP in mini meters of the plants was measured with a caliper at the level of the plant collar. The assessment of NF, NPF, NFP and NFR consisted of counting leaves, plants that had flowered, flowers per spike plant and fruits per plant. Biomass at harvest was assessed by counting each treatment and each crop. After soaking in water, the root parts were carefully cleaned and rinsed thoroughly to remove the soil from the roots. The nodules were then detached from the roots, counted and preserved in filter paper to be dried in the laboratory and weighed. The weights of the total fresh biomass (BTF) in g were obtained by weighing. They were then wrapped in aluminium foil and dried in an oven at 40°C until a constant weight was obtained, then weighed again to obtain the weights of the total dry biomass (BTS). The detached nodules were preserved in filter paper and air-dried in the laboratory until a constant weight was obtained. Nodule biomass weights (PDN) in mg were assessed.

2.8. Soil sampling and chemical analysis at soybean harvest

Soil samples were taken when the soybean biomass was harvested. Five (05) primary samples were taken from the rhizosphere of each crop depending on the fertilizer. A composite sample was then formed by combining the 5 incremental samples per fertilization regime. A total of 4 samples were analyzed. The composite soil samples were then air-dried at room temperature, crushed and sieved through a 0.2 mm sieve for analysis. Soil parameters were analysed by determining:

- ✓ pH H_20 and KCl according to the [16] Method. The pH H_20 and KCl were respectively measured in a soil suspension with a ratio of soil to distilled water or KCl (1N) equal to 2/5 using a pH meter with a combined electrode;
- ✓ soil organic carbon (C) was measured using the [18] Method. The determination of organic matter (OM) was obtained by multiplying the value of the carbon content by a coefficient equal to 1.724;
- ✓ total phosphorus (P), using the [19] method and assimilable phosphorus (Pass) using [18] method;
- ✓ total potassium (K), according to the method of [20] using 6N HCl and available potassium (K disp), extracted using a mixed solution of 0.1N HCl and H_2CeO_4 measured using a flame photometer after mineralisation [21] method;
- ✓ of total nitrogen (N) using the [22] Method.

2.9. Statistical analysis

Excel 2021 was used to enter the data. The Shapiro-Wilk test was used to test the normality of the data collected. For each of the parameters measured, a comparison of the means according to the treatments was carried out using an analysis of variance (ANOVA) and a Tukey HSD test for the separation of means at 5% threshold. XLSTAT 4.1, 2023 [23] was used for these analyses.

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Effect of fertilization regimes on soil fertility

The effect of fertilization regimes (T3, T2, T1, T0) on the chemical fertility of soil à soybean harvest is shown in table 3. The pH of H_20 and KCl range from 5.77 and 4.93 at T1 to 7.95 and 7.78 at T2. The total organic matter (OM) content ranges from 1.45% in T0 to 2.22% in T3; the N (total nitrogen) content from 0.09% in T1 to 0.11 in T2 and T3; and the soil C/N ratio from 9 in T0 to 13 in T1. Soil total phosphorus levels range from 91.79 ppm in T0 to 542.84 ppm in T2 and assailable P (P_ass) from 1.93 ppm in T0 to 4.04 ppm in T2. The K (total potassium) and K disp (available potassium) contents vari respectively from 94.9 and 40.84 under T0 to 153.57 ppm under T2 and 107.34 ppm under T3.

T3 fertilization regime increased pH H_20 by 21%: 29% pH KCl; 34% OM; 34% C; 9% N; 82% P; 38% P_ass; 17% K and 62% K disp; fertilizer T2 increase pH H_20 by 22%: 30% pH KCl; 35% OM; 35% C; 9% N; 83% P; 52% P_ass; 38% K and 60% K disp; and T1 of 23% OM; 23% C; 12% P; 49% P_ass; 10% K and 53% K disp compared with the absolute control.

Table 3. Effect of fertilization regimes on residual soil fertility.

Fertilization regimes	**pH H_20**	**pH KCl**	**MO**	**C**	**N**	**C/N**	**P**	**P_ass**	**K**	**K disp**
			%				ppm			
T3	7.83	7.77	2.21	1.28	0.11	12	499.62	3.10	115.01	107.34
T2	7.95	7.78	2.22	1.29	0.11	12	542.84	4.04	153.57	102.68
T1	5.77	4.93	1.88	1.09	0.09	13	104.50	3.78	105.25	87.51
T0	6.22	5.48	1.45	0.84	0.10	9	91.79	1.93	94.90	40.84

T0 = Control with no input; T1 = 1 litre m^{-3} of *Trichoderma harzianum* spores (Solsain); T2 = 3 t ha^{-1} of organic compost; T3 = 3 t ha^{-1} of organic compost + 1 litre m3 of *Trichoderma harzianum* spores (Solsain); OM = Organic matter; C = Total carbon; N = Total nitrogen; P = Total phosphorus; P_ass = Assailable phosphorus; K = Total potassium; K disp = Available potassium.

3.1.2. Effects of fertilization régimes on morphological parameters of soybean

At soybean harvest, the results showed that plant heights (HP) and numbers of leaves (NF) were significantly different depending on the fertilization regimes (Table 4). T3 fertilizer significantly ($P = 0.002$) increased HP with an average height of 146.80 ± 9.92 cm, unlike treatments T1 and T0 with HP of 94.90 ± 9.92 and 100.44 ± 10.45 cm respectively. NF were significantly improved ($P = 0.001$) under T3 with 46.20 ± 2.41 cm compared to T1 with 32.00 ± 2.41 cm. Also, T2 fertilization regime significantly favored the gain in NF with a production of 44.00 ± 2.41 compared with T1. The seed emergence rate (TXL) at 7 days after planting, plant diameter (DP), number of flowering plants (NPF), number of flowers per plant (NFP) and number of soybean fruits per plant (NFR) were not significantly different under the different fertilization regimes.

Table 4. Effects of fertilization regimes on soybean morphological parameters (means ± standard errors).

Fertilization regimes	TXL (%)	HP (cm)	DP (mm)	NF	NPF	NFP
T3	70±9a	146.80±9.92b	3.67±0.16a	46.20±2.41c	1.00±0.05a	14.90±2.92a
T2	70±9a	130.60±9.92ab	3.60±0.16a	44.00±2.41bc	1.00±0.05a	14.00±2.92a
T1	81±10a	94.90±9.92a	3.56±0.16a	32.00±2.41a	0.90±0.05a	13.30±2.92a
T0	90±9a	100.44±10.45a	3.38±0.17a	34.67±2.54ab	1.00±0.05a	12.67±3.08a
P	0.353	**0.002**	0.659	**0.000**	0.421	0.958
Significance	NS	**TS**	NS	**HS**	NS	NS

T0 = Control with no input; T1 = 1 litre m^{-3} of *Trichoderma harzianum* spores (Solsain); T2 = 3 t ha^{-1} of organic compost; T3 =3 t ha^{-1} of organic compost + 1 litre m3 of Trichoderma Harzianum spores (Solsain); TXL= Seed emergence rate; HP= Plant height; DP = Plant diameter; NF = Number of leaves; NFP = Number of flowering plants; NFP = Number of flowers per plant; NFR = Number of fruits per plant; P: Probability according to ANOVA at 5% significance level. 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).

3.1.3. Effects of fertilization regimes on nodulation and biomass of soybean

The number of soybean nodules (NN) varied from 0.00 ± 1.75 in T3 to 15.20 ± 1.57 in T1, the nodule weight (PDN) from 0.000 ± 76.59 mg in T3 to 960.00 ± 68.51 mg in T1, total fresh biomass (BTF) from 21.90 ± 2.67 g at T1 to 46.00 ± 2.67 g at T2 and total dry biomass (BTS) from 6.56 ± 0.85 g at T1 to 12.08 ± 0.85 g at T2 (Table 5). NN, PDN, BTF of soybean and BTS were significantly different according to the fertilizer according to ANOVA at the 5% threshold. Fertilizers T0 and T1 significantly (P < 0.0001) increased NN compared with fertilization regimes T2 and T3 according to the Turkeys test of separation of means at the 5% threshold. T1 and T0 fertilization régimes significantly (P < 0.0001) and differently increased NDP compared with T2 and T3 fertilization regimes. BTF and BTS of soybean were significantly improved (P < 0.0001) under T2 and T3 compared to T1 and T0.

Table 5. Effect of fertilization regimes on soybean nodulation and biomass production (means ± standard errors).

Fertilization regimes	NN	PDN (mg)	BTF(g)	BTS(g)
T3	0.00±1.75a	0.000±76.59a	43.60±2.98b	11.70±0.96b
T2	0.20±1.57a	60.00±68.51a	46.00±2.67b	12.08±0.85b
T1	15.20±1.57b	960.00±68.51c	21.90±2.67a	6.56±0.85a
T0	9.40±1.57b	620.00±68.51b	23.24±2.67a	7.26±0.85a
P	**<0.0001**	**<0.0001**	**<0.0001**	**0.000**
Significance	**HS**	**HS**	**HS**	**HS**

T0 = Control with no input; T1 = 1 litre m^{-3} of *Trichoderma harzianum* spore (healthy soil); T2 = 3 t ha^{-1} of organic compost; T3 =3 t ha^{-1} of organic compost + 1 litre m^{-3} of Trichoderma Harzianum spore (healthy soil); NN = Number of nodules; PDN = Nodule weight; BTF = Total fresh biomass; BTS = Total dry biomass; P: Probability according to ANOVA at 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. ($P < 0.05$): $P \leq 0.001$ (HS): highly significant.

3.2. Discussion

The purpose of this study was to assess the effects of organic compost, with or without *Trichoderma Harzianum* spores, on soil fertility and the agronomic performance of soybean. The results showed that treatment T2 (3 t ha^{-1} of compost) and treatment T3 enriched with *Trichoderma Harzianum* spores were more effective in improving the chemical fertility of the soil. Organic compost at a dose of 3 t ha-1 and compost enriched with *Trichoderma* on a lixisol improved soil fertility. Compost maintains and improves the organic status of the soil by improving its fertility through its various properties. In fact, the increase in organic matter (compost) content following its application is due to the fact that compost helps to improve the structure and structural stability of the soil and that organic matter improves the physico-chemical and biological properties of the soil [24]. Compost also helps to improve porosity by reducing bulk density [25], and increases the soil's water retention capacity. *Trichoderma* increases soil fertility by metabolizing trace elements and minerals such as Mn, Fe and Mg, which are important for plant growth [26]. The same authors state that the production of certain organic acids such as citric acid, gluconic acid and/or fumaric acid by *Trichoderma harzianum* reduces soil pH, leading to the solubilization of phosphates [26]. In addition, the improvement in soil fertility through the use of manure results in a reduction in acidity and exchangeable aluminum levels due to the increase in exchangeable element reserves and CEC, the accumulation of organic matter and the improvement in biological properties [27]. The improvement in total nitrogen and total phosphorus content observed in soils following the application of fertilizers T2 and T3 respectively is a function of the availability of mineral elements provided by the compost [28], in addition to the biostimulant and biofertilizing effects of *Trichoderma*. Abidet and Djabil [29] has shown that under cowpea cultivation, treatment with compost generally contributes to an increase in organic carbon, total nitrogen and assailable phosphorus content. Compost also improves the physicochemical and biological qualities of the soil, and organic matter is an important source of mineral elements (N, P, K). In addition, organic matter improves growth by lowering the pH of the rhizosphere, resulting in better solubilization of nutrients and greater availability to plants [30].

T3 fertilizer significantly increased plant height compared with T0 (control with no fertilizer applied). Thus, the T3 treatment contributes to soybean growth through its growth stimulating and competitive actions against soil-borne phytopathogenic fungi [31]. The number of leaves was significantly affected under T3 fertilizer compared with T1 (1 liter m^{-3} of *Trichoderma harzianum* spores) and T0 fertilizers. This result is thought to be due to the action of the nutrients contained in the compost, as most of the positive effects of organic fertilizers are due to the nutrients released after the decomposition of organic waste, which leads to an increase in yield [32, 33]. Fertilizer T2 significantly increased the number of leaves compared with fertilizer T1. Fruit number was significantly improved under T3 compared with fertilizers T0, T1 and T2. This shows that, independently of the crop, organic compost input associated with *Trichoderma harzianum* spores was more effective for foliar proliferation and crop fruiting. This result is the combined action of compost and *Trichoderma* on the one hand, the application of organic fertilizers on soybeans leads to a significant increase in the characteristics of the number of pods according to Lestari Sri et al. [32]. *Trichoderma* spores not only stimulate growth in soybean plants but also help to eradicate certain pathogens [31]. The significant increase in leaf numbers under T3 compared to T1 reflects that the inputs of organic compost associated with *Trichoderma Harzianum* were more efficient than the *Trichoderma Harzianum* only. This shows that the mineral elements contained in compost play an essential role in the agronomic performance of the fungi of the genus *Trichoderma Harzianum*.

The T0 and T1 treatments significantly increased the number and weight of soybean nodules (NN) compared to T2 (organic compost inputs) and T3 (organic compost inputs associated with *Trichoderma Harzianum* fertilizers. The inputs of organic compost associated or not with *Trichoderma* (T2, T3) favored the production of soybean biomass contrary to the inputs of *Trichoderma* and the control. The results show that soybeans respond to low nitrogen levels in the soil for their nodulation unlike their biomass production. By their ability to bind atmospheric nitrogen, legumes can improve soil nitrogen availability and increase crop yields. Also, the importance of phosphorus in improving cowpea production and biological nitrogen fixation has been demonstrated [34, 35, 36]. Most tropical acid soils have low P availability due to soluble inorganic P being fixed by Al and Fe in an acidic soil [37]. Thus, fungi of the genus *Trichoderma* hydrolyse phosphorus making it available for nodulation and therefore correlated for symbiotic nitrogen fixation. Biomass production under the inputs of compost combined or not with *Trichoderma* would be due to the mineralization of the compost which releases the mineral elements available for the plants. It has also been shown that by neutralizing the low acidity of soils and providing nutrients to plants, manure improves mineral nutrition, resulting in increased crop yields. Organic inputs such as compost improve the physical and chemical properties of the soil, enrich the soil with various nutrients useful for the proper development of plants and their vegetative constituents.

In this sense, organic manure has a very beneficial effect on the physicochemical and biological properties of soil. This results in a significant increase in plant height, number of pods per plant, seed weight and seed yields per hectare of soybean compared to inorganic fertilization [38]. Organic fertilizers enriched with *Trichoderma* significantly improve the growth of tomato plants. Organic matter would be an additional source of nutrients that would improve the efficiency of mineral fertilizers. It would make nutrients more available for plant growth. Trichoderma-enriched compost is richer in nutrients and contributes to better plant growth [30]. Moya et al. [39], who tested several strains of *Trichoderma* on the growth of tomato, showed that almost all strains of *Trichoderma* succeeded in stimulating plant growth parameters to varying degrees. Alla et al. [40] also reported that combined organic manure applications are more effective on solanaceous plant growth than organic fertilizer applications alone.

4. CONCLUSION

The study involved assessing the effect of organic compost with or without *Trichoderma harzainum* spores on the agronomic performance of soybean and soil fertility. The study showed that inputs of 3 t ha^{-1} with or without 1 m^{-3} of *Trichoderma* spores improved the organic status and chemical fertility of the soil. 3 t ha^{-1} of compost combined with *Trichoderma harzainum* improved the morphological performance of the soybean. 3 t ha^{-1} of compost with or without *Trichoderma harzainum* improved soybean biomass production on a lixisol. Nodule production of soybean was significantly higher under fertilization regimes with no inputs and *Trichoderma harzainum* inputs, although the *Trichoderma harzainum* fertilization regime was better. In order to disseminate these results, it is necessary to evaluate the effects of these fertilization regimes on the biological fertility of the soil to assess the technical and economic performance of the experiment, and to conduct the experiment in the farming environment and on other types of soil.

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