International Journal of Applied Research 2018; 4(12): 187-196

ISSN Print: 2394-7500
ISSN Online: 2394-5869
Impact Factor: 5.2
IJAR 2018; 4(12): 187-196
www.allresearchjournal.com
Received: 15-10-2018
Accepted: 20-11-2018

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Agronomic valorization of farm waste by composting for sustainable production of plant material of rubber tree (*Hevea brasiliensis* Müll ARG.) in Cote D'ivoire

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Abstract
A composting study of farm wastes was carried out on the site of the CNRA Research Station (Bimbresso, in the South of Côte d'Ivoire) in order to evaluate the agronomic characteristics of the compost obtained for a sustainable production of plant material of rubber tree (*Hevea brasiliensis* Müll Arg.) in nursery. During the composting process, temperature, humidity rate, pH and C/N ratio were followed. It appears that all these parameters evolved according to two major characteristics phases. Firstly, a phase of active fermentation characterized by high temperatures (≥ 45 °C), resulting from intense microbial activity. Secondly, a phase of maturation and stabilization characterized by a slow process of mineralization and humification at low temperature (≈ 27 ° C). The compost obtained, after 18 weeks, show an important proportion of fine elements (φ ≤ 2 mm), about 60% and has an almost homogeneous structure. The chemical characteristics of this compost indicate that the mineral element content (N, P, K, Ca and Mg), expressed in percentage of dry matter, is acceptable according to the AFNOR standard. This could allow it to play the double role of amender and fertilizer. The vegetative growth test used to evaluate the effect of this compost on the development of plant of rubber tree in nursery showed that the compost obtained did not present any toxicity. Moreover, the compost-based substrates made, permit to achieve a significant growth gain ranging from 17 to 24% in height and from 24 to 27% in diameter compared to control substrate. This composting technique, which valorize farm waste in a fast and efficient way, could reduce the flow of organic waste presented as a source of pollution for the environment and also contribute to sustainable production of quality plant material of rubber tree.

Keywords: Pit composting, farm waste, vegetative growth test, rubber tree nursery, Côte d'Ivoire

Introduction

Following the example countries of space UEMOA (West African Economic and Monetary Union), Côte d'Ivoire has the advantage of having a multitude source of organic matter easily exploitable in agriculture (FAO, 2014) [14]. The majority of these are crop residues, the nature and availability of which vary according to the agro-ecological zones and the types of crops. Except, these agricultural residues, the livestock sector offers a wide variety of organic resources that are available in large quantities and almost all the year. The development of this sector, especially in urban and peri-urban areas, inevitably leads to the massive production of by-products. These by-products, stored or abandoned in piles with a difficulty of evacuation enter spontaneously into anaerobic digestion. This generates fatty acids and nitrogen derivatives (ammonia, pyridine) responsible for unpleasant odors, nitrogen pollution of water resources and also, various toxins, reduced organic compounds (such as methane), much more active than carbon dioxide in the greenhouse effect. This waste, presented as a source of pollution for the environment, could be an important source of organic matter essential for sustainable agricultural production. The valorization of organic waste, in particular, by the composting technique can be a solution to their elimination and allow some of their constituents to be recycled for agricultural purposes. Composting is currently considered as an ecologically sustainable component in an integrated waste management system (Compaoré et Nanéma, 2010) [14]. Compost, and generally, organic matter, plays a very important role in improving the physicochemical and biological properties of soils.

These benefits are manifested by reductions in plant health risk and the cost of mineral fertilizer (Misra *et al*., 2005) [30]. However, the generalization of the use of compost requires firstly the answer to some concerns about the availability and accessibility of the material envisaged, the cost of production, the agronomic characteristics, the behavior in culture, and the existence of possible economic and ecological prejudice related to its large-scale use (Benamirouche et Chouial, 2018) [8]. Also, some studies have shown that composts are not exempt from problems of phytotoxicity and soil pollution. Moreover, the immature compost may have negative effects on germination, growth and plant development (Tiquia *et al.*, 1997) [39].
In order to contribute to a sustainable management of agricultural residues, taking into account all these concerns, this paper presents the results of a study on composting in a pit of chicken droppings and dry straw of Panicum sp, enriched by adding ash of firewood and urea, as activators. This study aims to evaluate the possibilities of introduction of compost in the process of sustainable production of plant material of the rubber tree in nursery.

Materials and Methods
The study was conducted on the experimental site of the Research Station of CNRA – Bimbresso, in the south of Côte d'Ivoire (N 05° 18' 45.2" and W 004° 9' 18.9"). The climate is humid subtropical, characterized by four seasons, clearly differentiated by their bimodal rainfall regime. The average annual rainfall is around 1 800 mm. The soil has a clayic sand texture, is deep like a ferralsol (Kéli *et al*., 1992) [26].

Plant material
The choice of the rootstock being an important element of the success of the grafting of the plants (Penot, 2004) [35], the plant material of rubber tree used was the clone GT 1, which is considered as the reference clone in Côte d’Ivoire. He is currently the best rootstock. It has been selected in Indonesia in Gondang Tapen region from where it takes its name. This clone is a vascular plant whose radial vegetative growth is moderate (Obouayeba *et al*., 2000) [34]. It is the only clone currently planted in all of the 18 rubber growing sectors in Côte d'Ivoire.

Experimental material
The compost used was obtained by recycling into a pit the chicken waste, the dry straw of *Panicum sp*, firewood ash and urea (46% N). The Chicken waste, collected in the surrounding farms, was packaged in the plastic bags of 50 kg content and transported to the composting site. The straw of *Panicum sp.* cuted in the surrounding natural vegetation, was dried in the sun and the ashes of firewood was collected in the households. Adding of urea contribute to reduce the C/N value that is high at the start of the composting process. Ash is thought to weaken the woody structure of plants and increase the microbial population, as well, as the potassium content (K) in compost (Misra *et al*., 2005) [30]. Thus, wood ash and urea are present as activators of the metabolic activity of the micro fauna in the composting process.

Production of the compost
The adopted technique was that of aerobic composting in the pit. This technique appears best adapted to farms in humid tropical zones, as demonstrated by its high adoption rate in Burkina Faso (Berger, 1996; Karambiri, 2007; Zongo 2013) [9, 25, 41]. The pit dimensions was 2 m for the length, 2 m for the width and 1 m for the deep (4 m^3 of volume). It was opened in the rainy season, under tree whose the foliage served as protection against insolation and the direct impact of rainwater. The process of assembly of pit composting was carried out in successive layer units according to the following sequence (Figure 1):
- 10 kg of *Panicum sp* dry straw per layer;
- 60 kg of chicken waste per layer;
- 6 kg of firewood ash per layer;
- 1 kg of urea (46% N) per layer.

The pit composting consisted of 5 units of identical layers. The first layer unit was installed on a ventilation system made of fresh twigs of *Chromolaena odorata*. The quantities of materials supplied for the assembly of the pit composting are shown in Table 1. To humidify the organic substrate to be composted, a moderate water intake of 20 liters was made, so as not to cause the leaching of the ash and urea, After the installation of each unit. So, a total of 100 liters of water was needed for the composting starting process. The method of overturning of the substrate has been adopted to accelerate the process of decomposition of organic matter (Tiquia *et al.*, 1997) [39]. At each overturning, the pit contents were moistened and covered by palm leaves. The overturning frequency was as follows:
- 1st overturning of the substrate, 4 weeks, after starting the composting process;
- 2nd overturning of the substrate, 8 weeks;
- 3rd overturning of the substrate, 12 weeks;
- Fourth overturning of the substrate, 16 weeks, after.

Table 1: Quantity of materials brought for the assembly of the pit composting

Organic material	Quantity used (kg)
Chicken waste	300 (60 kg per layer)
dry straw of *Panicum sp.*	50 (10 kg per layer)
Urea	5 (1 kg per layer)
firewood ash	30 (6 kg per layer)
Total quantity (kg)	385 (77 kg per layer)

Experimental plot preparation, making trenches and cultivation substrates
The experimental plot, with an area of 300 m^2 (20 m × 15 m), was cleared manually. It was then materialized by eight (8) trenches on the ground using stakes. These trenches were opened, according to the following dimensions: width 0.2 m; length: 4 m, depth: 0.2 m and distance between two trenches: 1 m. The soil, placed on the same side during the digging of the trenches, served as a cultivation substrate, in mixture or not with the compost obtained. These substrate was used to fill bags of whose length is 40 cm and 10 cm of width. The bags were buried 2/3 of the height and arranged in the trenches in discontinuous tetrahedrons. A trench constitutes a micro-plot.

Making the seedbed and transplanting seedlings of rubber
The establishment of a rubber tree nursery necessarily passes by a seedbed. It consisted of a band of one (1) square meter being able to contain to 1000 seeds. This band

consisted to an environment of about 5 to 10 centimeters thick of sand and was covered by a shade made of oil palm stalks. The seeds used were those of clone GT 1. The transplanting into the bags was done at the seedling stage of the seed, 30 days after sowing.

Valorization of compost for a sustainable production of plant material of the rubber tree

Experimental design and treatments

The experimental design was a complete randomized block with three treatments (Table 2). Each treatment had three repetetions and each repetition consisted of 40 plants. The number of useful plants was 360 out of a total of 720. Compost applications were carried out in only once (when filling bags).

Step 1: Laying a ventillation layer made of fresh twigs of *Chromolaena Odorata*

Step 2: Laying a dry straw layer of *Panicum sp* (10 kg)

Step 3: Laying a layer of chicken waste (60 kg)

Step 4: Spreading of firewood ash (5 kg)

Step 5: Spreading of Urea (1 kg) on the wood ash layer

Step 6: Adding of 20 liters of water to the chicken dung layer

Step 7: Laying of a dry gauge wood in the center of the pit

Step 8: Pit composting filled and covered with palm leaves

Fig 1: Process of assembly of the pit composting realized in station

Table 2: Doses of compost constituting the cultivation substrates or treatments

cultivation substrates or treatments	Signification	Quantity of compost (g/plant)
S0	Soil without adding compost (Control)	0
S1	Compost mixed with soil per bags	300
S2	Compost mixed with soil per bags	600

Nursery maintenance: water supply and weeding

The water requirements of plants of rubber tree in nurseries are estimated at 120 mm of water per month without rain. The watering was, therefore, done twice a week at the rate of 15 mm of water at each passage in addition to the rainfall, in the warmest hours of the day (early morning or afternoon). After transplanting, nursery weeding was done manually with cutlass each weed regrowth.

Collection of composting data

Temperature (°C) during composting

During the organic matter decomposition process, the temperature of substrate was recorded every week, at 04:00 pm in the day, at each corner and at the center of the composting pit, at a depth of 50 cm, with an electronic thermometer (MERCK pH 85 T type) equipped with a penetration probe. The temperature of the substrate is the average value of the temperature collected in the different measurement points (Ben Ayed *et al.*, 2005) [7].

pH and C/N ratio during composting

Determination of the pH and C/N ratio of the compost was made on the substrate samples during the organic matter decomposition process, at the following weeks: 4, 8, 12 and 16. These samples were sent to the laboratory for these different analyzes.

Humidity rate or water content (% H)

In the laboratory, the water content or humidity rate of the decomposing substrate was measured by drying a mass of 50 g of fresh compost (Fm) for 48 ho urs at 70 ° C in the oven. After steaming, the dry mass (Dm) was weighed. The water content was expressed according to the following formula (Soudi, 2001) [38]:

$$\text{Water content } (\%) = \frac{Fm - Dm}{Dm} \times 100$$

Fm: Fresh mass of compost and Dm: Dry mass of compost after steaming

Physical and chemical characterization of the obtained compost

Compost yield

At maturity, the compost previously filled in bags was weighed using a load cell. The parameters of yield and weight loss (% of initial weight) were determined according to the following formula:

$$\text{Yield compost } (\%) = (Pf / Pi) \times 100$$

Pf: represents the final weight of the compost obtained
Pi: the initial weight of the organic substrate before placing in the pit.

Granulometric composition (%) of compost

Particle size is a relevant parameter for the physical characterization of composts. It allows to appreciate the degree of physical decomposition of the organic matter. At the end of the composting process, three composite samples of 300 g of compost were taken, dried and then fractionated using sieves of 10, 5 and 2 mm.

Mineral composition and agronomic quality of the compost

To determine the chemical characteristics of the compost obtained at maturity, 300 g of composite sample was collected, dried, and then sent to the plant analysis laboratory. The parameters taken into account for laboratory analysis are related to pH, total nitrogen (Nt), carbon (C), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg). Moreover, the quality or the agronomic value of the compost obtained was appreciated from the qualification standard AFNOR (French Association of NO Rmalisation).

Collection of agronomic data

In order to evaluate the performance of the cultivation substrates elaborated, measurements of the vegetative growth parameters of the plants of the rubber trees were carried out monthly during the nursery cycle, from the 15th to the 165th day after transplanting (DAT), that is 6 months of cycle. These measurements are based on the height (mm), the collar diameter (mm) and the number of leaf stages or growth unit (GU). The total height (mm) of the plant measured from the ground level to the apical end of the plant using a graduated ruler. The diameter (mm) of the plant, at 5 cm from the ground level using a digital caliper "Stainless Hardened".

The monthly average increases in height (ΔH) and in diameter (ΔD) were obtained according to the following formula

$$\Delta\,(H, D) = M_i - M_{i-1}$$

M_i and M_{i-1} are two measurements made at successive observation stages.

The determination of the monthly average increase made permit to determine the growth gain expressed as in a percentage compared to the control treatment.

Statistical analysis

Data on composting and vegetative growth parameters of plants of rubber tree in nursery were entered and processed using the Excel spreadsheet. One-way analysis of variance (substrate) was used to evaluate the performance of the cultivation substrates on plant development. Mean values were ranked using the Fisher's Least Significant Difference (Lsd) method. Probabilities were evaluated at the 5% threshold. Statistica 7.1 software was used to perform these analyzes

Results

Evolution of some physico-chemical parameters during a composting

The results obtained in this study indicate that all physicochemical parameters (temperature, water content, pH and carbon-nitrogen ratio) of the substrate have, generally, evolved during the decomposition process of organic matter.

Temperature evolution

The evolution of temperature, which expresses the activity of the succession of microbial populations linked to the modifications of the environment, has been quite perceptible during the decomposition process of the organic matter (Figure 2). The temperature in the substrate (30.3 ° C) at the start of the composting process quickly reached the maximum of 50 ° C during the first week, then gradually decreases to at the ambient temperature value (≈ 27 ° C). In the detailed analysis of the temperature evolution curve, sinusoids have been observed, whose "hollows" correspond to temperature drops, and "rises" reflect a rise in temperature following the substrate overturn. In general, the evolution of the temperature shows that the temperature within the substrate gradually decreases to ambient temperature. The beginning of the maturation phase was identified when the substrate overturn did not cause any increase in temperature, which stabilizes around 27 °C.

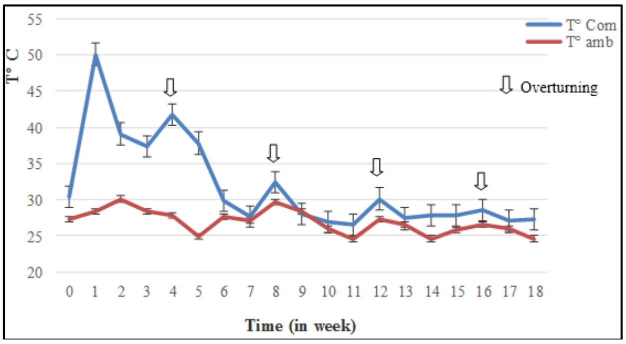

Fig 2: Evolution of temperature during the composting process

Humidity rate evolution

The evolution curve of the humidity rate of the substrate has known two characteristic phases (Figure 3). A first phase, relatively short, characterized by an increase in the humidity rate which went from 40.3 to 55.51% of the 1st to the 5th week of the composting process. This phase, maintained by rainwater, was followed by a phase of gradual decrease of this rate until the end of the decomposition process of the organic matter. Humidity is around 30.16% at the maturity of the compost.

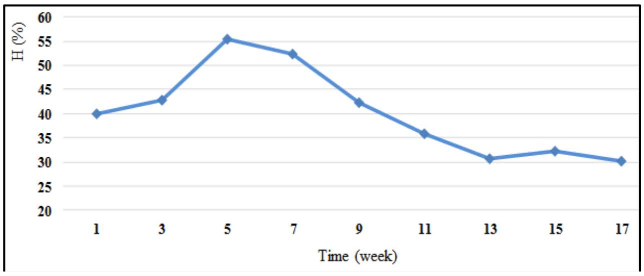

Fig 3: Evolution of water content (% H) during the composting process

PH evolution

In this study, the composting process was characterized by a slightly acidic initial pH value of 6.2 at the 4th week (Figure 4). The evolution of pH shows three different phases. An acidogenic phase of about 5 weeks, where the pH tends to 6.5. Around the 7th week, there is a rapid transition from the acidogen phase to the neutral phase (pH = 7). And finally, from the 8th to the 12th week, the decomposition process goes to the phase of alkalization, where the pH reaches 7.6 before stabilizing at the value of 7.2 around the 16th week.

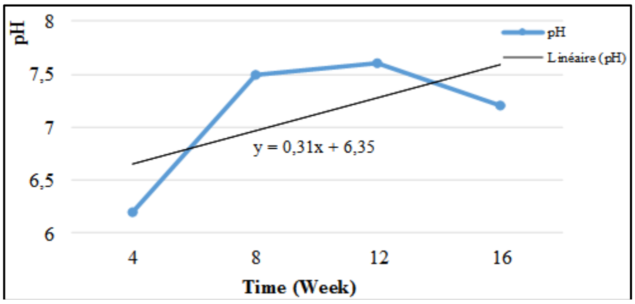

Fig 4: Evolution of pH during the composting process

C/N ratio evolution

The C/N ratio is in the order of 33 at the start of the composting process (Figure 5). This ratio, then experienced three phases of decline during the composting process, which are:

- A phase of rapid decrease from 4th week to 8th week (from 33.97 to 18.54);
- A relatively moderate decrease phase between 8th and 12th weeks (from 18.54 to 13.18);
- And finally, a phase of slow decrease from the 12th week (from 13.18 to 12.06).

The C/N ratio reached, at the end of the decomposition process of the organic matter, the value of 12.06

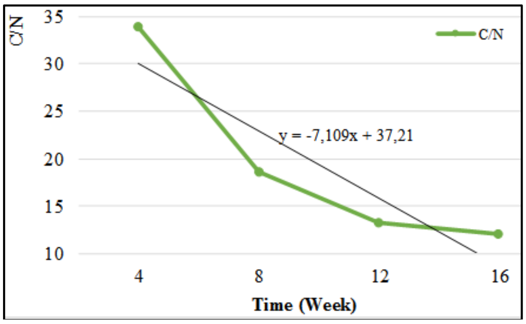

Fig 5: Evolution of C/N ratio during the composting process

Physical and chemical characteristics of the compost at maturity

Yield of compost and weight loss of the substrate

The compost yield and weight loss parameters of the substrate are reported in Table 3. The analysis in the table shows that the initial compost volume decreased significantly. The volume reduction was in the order of 21.40%, with a yield of 78.60%.

Table 3: The parameters of compost yield and weight loss of the substrate

Organic materials	Quantity used (kg)	Quantity of compost obtained (kg)
Chicken dung	300	-
dry straw of *Panicum sp.*	50	-
Urea	5	-
firewood ash	30	-
Total quantity (kg)	385	
Total quantity (kg) of compost obtained	-	302.60
Yield (%)	-	78.60
Weight loss of substrate (%)	-	21.40

Physical characteristics of compost

Figure 6 shows the appearance of the compost obtained after 18 weeks of composting. This compost has the appearance of a dark brown soil and moist. It does not emit a particular odor and has a temperature (27.51 °C) like the ambient temperature. Its structure is almost homogeneous and granular.

Fig 6: Appearance of compost made from chicken dung and *Panicum sp* obtained

Granulometric composition (%) of compost

The average values of the various particle size fractions (Figure 7) of the compost are as follows:

- 4.46% for particles larger than 10 mm;
- 24.86% for those whose size is between 5 and 10 mm;
- 13.39% for those of size between 2 and 5 mm;
- 57.29% for particles smaller than or equal to 2 mm.

The compost, thus, obtained has a proportion of fine elements (φ ≤ 10 mm) the largest, a rate of the order of 95.54%. Also, it has a structure whose particles are smaller and fairly homogeneous whose texture is similar to that of a soil.

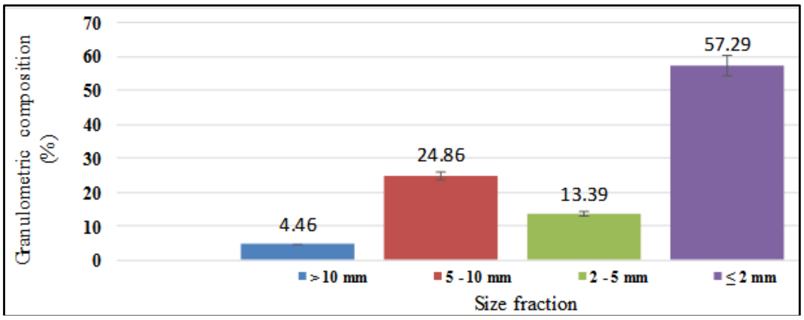

Fig 7: Granulometric composition of compost

Maturity and nutrient content of the compost

The maturity of the compost obtained was assessed according to various methods, among others, based on the determination of the organic matter content, the temperature, the pH, the C/N ratio, the mineral content. The C/N ratio obtained at the end of the composting process is in the order of 12.06 (Table 4). This ratio is between 10 and 15. The pH value at the end of composting which is 7.2 is in the range of pH values (7 to 9). The contents of organic matter, carbon, nitrogen, phosphorus and exchangeable cations (Ca and Mg) expressed as a percentage of dry matter is an acceptable level compared to the AFNOR on composting. However, the potassium content (0.39% ms) in the compost is lower than that recommended by the AFNOR standard, despite, significant amounts of firewood ash (50 kg) brought to the assembly of the compost pit.

Table 4: Mineral composition of the compost obtained, relative to the total dry matter (% ms)

Chemical caracteristics	Moisture	pH	Fertilizer value (% ms)							
			C	MO	N	C/N	P	K	Ca	Mg
	30.16	7.2	7.72	13.28	0.64	12.06	0.68	0.39	2.0	0.87
Norme AFNOR*				> 5	> 0.25	< 20	> 0.3	> 1		

AFNOR: French Association of NO Rmalisation

Vegetative Behavior of plants of rubber tree in nursery

The figure 8 shows the evolution of vegetative growth parameters of plants of rubber trees in nursery over an observation period of 165 day after transplanting (DAT). It brings out the following observations:

- The first two measures (15th and 45th DAT) do not show any significant difference (p > 0.05) between the 3 cultivations substrates tested for all growth parameters (Height, Diameter, and Growth Unit). Mean values, all treatments combined, from the 1st to the 2nd stage of observations vary from 255.78 to 480.00 mm for the height, from 3.72 to 5.42 mm for the diameter and from 1.27 to 2.58 for the growth unit.
- 3rd to 6th stage of observation (75th to 165th DAT), highly significant differences (p <0.001) between the treatments were observed, in particular, at the level of the height (H) and the diameter (D).

In general, the used of compost (S1: 300 g and S2: 600 g; of compost mixed with soil) performed better than the control substrate S0 (without compost) with statistically significant differences in vegetative growth parameters studied over the entire duration of the experiment. Thus, the mean values of the height at the end of the experiment were 1344.36 mm and 1281.10 mm respectively for the substrates S1 and S2 against 1126.81 for the control S0. In addition, these same trends have also been observed on the neck diameter (Dc) of the plants. The highest average values obtained were 13.84 mm and 13.41 mm respectively for substrates S1 and S2 against 11.54 mm for control S0.

Monthly average increase in height (ΔH) and diameter (ΔD) and growth gain (%) compared with control treatment

The results of the monthly mean increments of height (ΔH) and diameter (ΔD) growth gain for the different stages of plant development are presented in Tables 5 and 6, respectively. These results show, overall that the monthly average increments between different substrates have varied very little. However, at the end of the experiment, significant differences (p ≥ 0.05) in the mean monthly increases in height (ΔHmoy) and in diameter (ΔDmoy) were observed between the culture substrates. The highest mean values of the increases (ΔH; ΔD) were obtained with the compost-based substrate plants (S1 and S2). Mean values for diameter increase, the most important parameter in nursery management of rubber tree, were significantly greater in compost-based substrate plants (S1: 2.00 mm per month and S2: 1.95 mm per month) than those of the control substrate (S0: 1.57 mm per month). In addition, compost-based substrates yielded significant growth gains ranging from 17 to 24% in height and from 24 to 27% in diameter compared to the control substrate. However, the intake of compost based on chicken waste induces, certainly, a better vegetative growth of the plants, but, at a high dose (S2: 600

g of compost per plant), a depressive state and growth delays in height and in diameter are observed compared to the plants of the substrate S1 (300 g of compost).

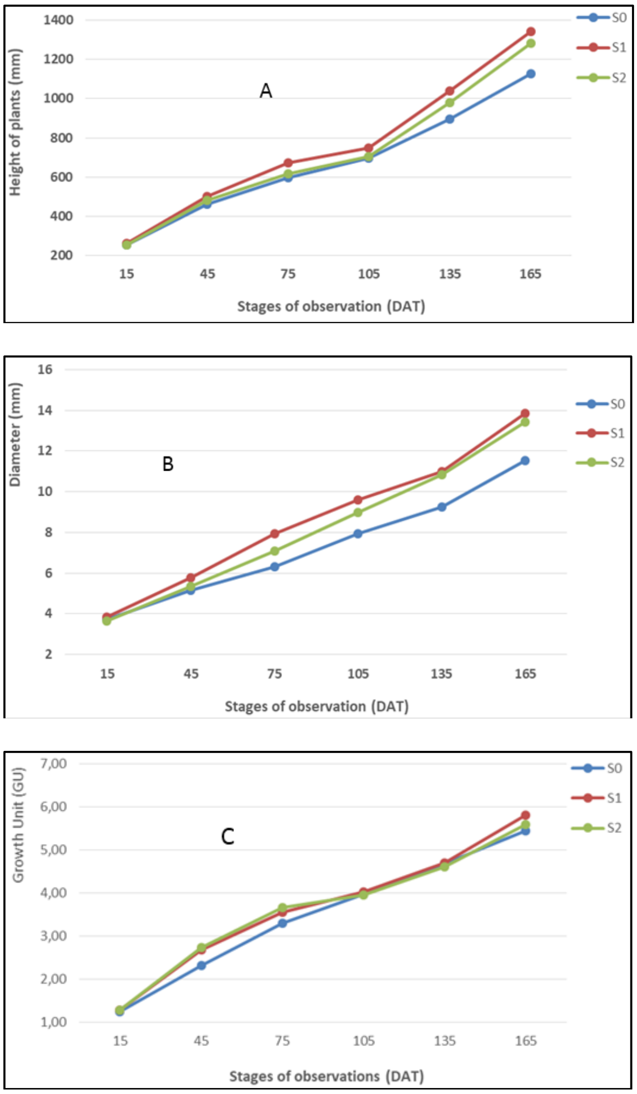

Fig 8: Evolution of vegetative growth parameters of plants of rubber tree in nursery. (A: Height; B: Diameter and C: Growth Unit; DAT: Day After Transplanting S0: Control without compost; S1: 300 g of compost mixed with soil and S2: 600 g of compost mixed with soil

Table 5: Monthly Mean Height Increases (mm) and Growth Gain Compared to Control Treatment

5	ΔH1	ΔH2	ΔH3	ΔH4	ΔH5	Δ Hmoy	gain (%)
0 D	208,29 a	136,25b	98,47 a	201,14 b	231,03 b	175,04 c	0,00
1 D	239,45 a	172,00 a	75,05 b	291,04 a	306,12 a	216,73 a	23,82
2 D	224,92 a	135,53 b	90,81 a	274,57 a	300,40 a	205,24 b	17,26
MG	*224,22*	*147,93*	*88,11*	*255,58*	*279,18*	*199*	
P	*0,16*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	

ΔH: Monthly mean Height increase (mm) for two stages of observations
ΔHmoy: Average monthly increase in height (mm) during the test
Gain (%): Height growth gain compared with the control treatment

Table 6: Monthly Mean Diameter Increases (mm) and Growth Gain Compared to Control Treatment

Treatments	ΔD1	ΔD2	ΔD3	ΔD4	ΔD5	ΔDmoy	gain (%)
0 D	1,46 c	1,17 b	1,60 a	1,33 b	2,27 a	1,57 b	0,00
1 D	1,96 a	2,17 a	1,65 a	1,38 b	2,86 a	2,00 a	27,38
2 D	1,69 b	1,76 b	1,88 a	1,88 a	2,55 a	1,95 a	24,20
MG	*1,70*	*1,7*	*1,71*	*1,53*	*2,56*	*1,84*	
p	*0,00*	*0,00*	*0,84*	*0,01*	*0,16*	*0,03*	

ΔH: Monthly mean Diameter increase (mm) for two stages of observationsn
ΔHmoy: Average monthly increase in Diameter (mm) during the test
Gain (%): Diameter growth gain compared with the control treatment

Discussion

Physico-chemical parameters during composting and quality of compost obtained

Temperature evolution

The first phase of composting begins with a mesophilic phase where the temperature progresses rapidly within a few days after the process is set up. It is then followed by a thermophilic phase characterized by high temperatures (Mustin, 1987) [32]. At this level, the temperature within the substrate reached 50.16 °C after one week of composting. This rise in temperature, indicative of a significant microbial activity, is the direct consequence of the oxidation of the organic matter of the substrates (Hassen *et al.,* 2001). Indeed, during composting, organic compounds are degraded by microorganisms following the fermentation process. This biochemical mechanism is accompanied by a strong production of heat and carbon dioxide. The heat generated accelerates the decomposition of proteins, fats and complex sugars such as cellulose and hemicellulose and reduces the duration of the process (Misra *et al.*, 2005, Compaoré and Nanema, 2010) [30, 13]. In addition, the evolution of temperature during the composting process was marked by sinusoids, whose "hollows" corresponding to falls in temperature are due to a slowdown in microbial activity, and the "increases" in temperature, due to the reactivation of these microbial activities, following a sufficient aeration caused by the substrate overturn. These results corroborate the conclusions of Seck (1987) [36] and Segda *et al.* (2001) [37]. The beginning of this phase is identifiable when the flipping does not cause any more increase of the temperature of the mixture from the 12th week, which stabilizes around 27 °C at the 16th week. This temperature kink can be explained by a slowdown in the activity of microorganisms due to a depletion of easily degradable materials (Soudi, 2000) [38]. This lack of temperature rise is a good criterion for the stabilization of compost.

Humidity rate evolution

The evolution of the humidity rate in the substrate has been characterized by two phases; a relatively short rise phase followed by a phase of gradual decrease. The fluctuations of the humidity rate of the substrate observed during the composting process could be due, on the one hand, to the presence of aerobic microorganisms and, on the other hand, to the heterogeneity and quality of the substrates to be composted, in particular chicken dung and dry straw from *Panicum sp*. Indeed, the work of Mazet, (1985) and Compaoré and Nanéma, ((2010) [14] showed that microorganisms, by their breathing, exhaust the oxygen of the composting mass and produce energy released in the form of during the oxidation of the organic matter, which leads to a rise in temperature, composting is itself a producer of moisture by the simple fact that the oxidation of the organic matter gives, in addition to the CO_2. The humidity rate would then tend to decrease under the combined action of rising temperature and aeration due to the overturning of compost heaps, which leads to water losses underwater. (Mustin 1987, Aoun et Bouaoun 2008) [32, 4] Moreover, the higher humidity rate observed between the 4th and the 8th week of composting is due to the high rainfall observed during the composting period (may to september) with a maximum of 555 mm in June 2017 (Abidjan Town, Côte d'Ivoire).

pH evolution

The pH monitoring during the composting process is characterized by a succession of phases (acidogen, neutrality, alkalization). The initially acidic pH (pH = 6.2) in the first four weeks of composting would result from the formation of organic acids in the pile (Diaz *et al*., 1993). These acids, also, serve as food for microbial populations. The passage of the pH of the acidogenic phase (pH = 6.2) to the alkalization phase (pH = 7.2) is the result, on the one hand, of the production of ammonia from the degradation of the amines, and on the other hand, the liberation of bases previously incorporated into organic matter (Juspin *et al.*, 2002; Ben Ayed *et al*., 2005) [7]. The pH stabilization (at 7.2) at the end of the process is thought to be due to ammonium oxidation by bacteria and precipitation of calcium carbonate (Juste, 1980, Morel *et al.*, 1984, Beck-Friis *et al*., 2003) [23, 31, 6]. The final pH, slightly alkaline, makes this compost a product without risks for the soil and for the plants.

C/N ratio

The C/N ratio, which expresses the proportion of the bio-available amounts of carbon and nitrogen respectively, decreased during the composting process. Evolution has experienced three phases of decline (fast, moderate and slow). The initially high C/N value (C/N = 33.97) is thought to be due to the large amount of woody tissue present in the poultry feed manufacturing and especially in the dry straw of *Panicum sp*, thus leading to a high value of C/N greater than optimal (25-30) (Cooperband 2002, Misra *et al*., 2005) [15, 30]. The drop in the C/N ratio over time could be explained by the active transformation of carbon into carbon dioxide by the microorganisms, which consume 5 to 20 times more carbon than nitrogen during the aerobic fermentations phenomena (Culot et Lebeau, 1999) [16]. This transformation is also accompanied by a decrease in the levels of organic acids in the mass of waste to be composted (Chefetz *et al*., 1998) [11]. Moreover, Jedidi *et al.* (1991) [21] and Guene (2002) [20] point out that the decrease in the C/N ratio corresponds to a change in organic matter towards more stable and humified forms.

Physical and chemical characteristics of the compost at maturity

The resulting compost has the appearance of a dark brown potting soil. It is moist and has the characteristics of a stabilized compost. It does not give off a particular smell. The compost obtained has a structure whose particles are smaller, homogeneous and whose texture is similar to those of a soil. This result corroborates those obtained by several authors including Soudi (2001) [38]; Charnay (2005) [10]; Compaoré and Nanema (2010) [14]. The value of the weight loss obtained is similar to that obtained by Berger (1996) [9], which is around 25%. Moreover, the high rate of fines from the resulting compost could be explained by the decomposition-degradation process initiated during composting. The high proportions of the fine elements testify to a good physical quality of the compost with a refusal approaching the 5%. Because, the international standards (AFNOR) of appreciation of organic substances qualify as very rich, composts whose fine particles ($\varphi \leq 10$ mm) are greater than 60% and having less than 5% of undesirable elements. According to Anid (1982) [3], the physical structure of organic waste evolves during treatment. In particular, the particle size decreases, both because of the mechanical manipulations (reversals) and biodegradation reactions of the organic matter. The maturity of the compost is an important characteristic to consider when assessing its quality. It is an organo-chemical condition that indicates the presence or absence of ammonia and phytotoxic organic acids, inhibiting the vegetative growth of plants. The maturity of the compost obtained was assessed according to various methods, among others, chemical based on the determination of the organic matter content according to Mustin (1987) [32] and Larbi (2006) [24], the temperature, the pH, the C/N ratio, the mineral content and a vegetative growth test. The C/N ratio obtained at the end of the composting process is of the order of 12.06 (Table 4). This ratio between 10 and 15 attests that the compost produced is mature (Mustin, 1987) [32]. The pH value at the end of composting, which is 7.2, is in the range of pH values (7 to 9) of mature compost according to Avnimelech *et al*. (1996) [5]. The contents of organic matter, carbon, nitrogen, phosphorus and exchangeable cations (Ca and Mg) expressed as a percentage of dry matter are at a acceptable level to AFNOR standard for composting. The supply of *Panicum sp* straw has favored a good supply of carbon, hence the high rate of organic matter. Compaoré et Nanéma (2010) [13] reported that the fertilizing value of compost at maturity depends on the initial content of major elements of the waste. However, potassium (K) content (0.39% ms) in the compost is lower than that recommended by AFNOR standard, despite, significant quantities of firewood ash (50 kg) brought to the start of the pit composting. This low potassium content observed during compost maturation is attributed to the leaching of this element due to climatic events (Nielsen *et al*., 1998), including the amounts of rainfall recorded during the composting process (with a maximum of 555 mm in June).

Vegetative behavior of plants of rubber tree in nursery according to culture substrates

In terms of nursery growth, compost-based substrates performed better than the control substrate. The difference in growth of plants of rubber tree in nursery observed with compost-based cultivation substrates is related to maturity on the one hand and the richness of nutrients in this compost. This confirms the observations made by Amadji *et al*., (2009) [2] after using compost enriched with chicken manure for the production of cabbages on sandy soil. The same results were obtained by Essehi *et al*., (2016) [18] on the impact of organic fertilization on some characteristics and rubber tree (*Hevea brasiliensis* Müll Arg) parameters growth during the installation phase in Bonoua, in the south of the Côte d'Ivoire. Chemical elements from the mineralization of chicken waste and *Panicum sp* dry straw had to enrich the soil and contributed positively to the development of the plant of the rubber tree in nursery. This suggests that the transfer of soil nutrients to rubber plants was less important with the 600 g of compost per plant. The opposite would have been logical, because Dorn *et al.* (1985) [17] reported that higher doses provide more nutrients for plants. But, Kouadio (2007) [27] also found that higher doses produced a negative impact on the plant growth. This depressive effect of the compost is not related to the immaturity of the compost, but, to the high dose of compost (Abad Berjon *et al.*, 1997, Compaoré *et al.*, 2010) [1, 13]. There is, therefore, a threshold beyond which any additional input could hinder the development of plants. A reasonable application of compost of chicken waste at a dose of 300 g per plant would be appropriate for sustainable production of plant material of rubber tree on sandy loam soil

Conclusion

This study of pit composting of chicken waste and dry straw of *Panicum sp* enriched by adding urea and firewood ash, as activators, show several key points:

- a similarity in the evolution of composting parameters during the decomposition process of organic matter is observed;
- the first phase of the process has been more active and is the result of the presence of a large variability of substrates to be composted and a large non-specific microbial diversity;
- the contribution of dry straw of *Panicum sp* to the composting process has favored a good supply of carbon, hence an activation of the microbial population which is summed up by an acceleration of the decomposition of the organic matter;
- the addition of compost activators, in particular, urea stimulated this process;
- driving in terms of overturning and watering was effective;
- however, composting in the pit, especially during the rainy period, does not allow reaching a sufficiently high temperature (≥ 65 °C) to favor the evaporation of water and the elimination of pathogens and weed seeds.

The compost obtained after 18 weeks contains acceptable nutrient levels that could allow it to play the dual role of amender and fertilizer. The growth test, carried out to evaluate the effect of this compost on the development of plants of rubber tree in bag, showed that the compost obtained did not show any toxicity. This composting technique, which valorize farm waste in a fast and efficient way, could reduce the flow of organic waste presented as a source of pollution for the environment and also contribute to sustainable production of quality plant material of rubber tree. The compost obtained favored a marked improvement in the growth of plants of rubber tree in bags. This would indicate that the compost obtained had reached maturity and was of good quality. It would, however, be interesting to evaluate, in the future, the economic profitability of this technique of pit composting, their influence on the physicochemical parameters of the soil as well as their effects in combination with mineral fertilizers.

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