

Impact of Composts Maturity on Growth and Agronomic Parameters of Maize (*Zea mays*)

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Abstract

Several methods have been developed in the literature which allow the maturity of composts to be assessed before it is used in agriculture. The objective of this study is to assess the maturity of the composts produced at the platform of the NGO ENPRO in Lomé on the growth and agronomic parameters of maize (*Zea mays* L., var. IKENE). To do so, three types of compost (gargabe, fruit waste, animal litter) were made for at least 3 months. The chemical analysis, phytotoxicity and agronomic tests carried out made it possible to assess the maturity of these composts. Indeed, the evolution of the C/N ratio, of the electrical conductivity, the phytotoxicity tests and the growth parameters of the composts show that the composts N°1 and N°2 are mature at the end of the 3rd month of composting while the compost N°3 can only be considered mature at the end of the 5th month of composting. But, with a yield of 2.39 ± 0.28 t/ha and a mass of 1000 grains of 346 ± 4 g, the treatment at 5 t/ha of compost N°3, has the best agronomic parameters compared to other types of compost and treatment without organic amendment. These results also show that compost with a high electrical conductivity has an inhibitory effect on the growth of corn plants (*Zea mays* L., var. IKENE). Basic chemical analysis, phytotoxicity tests and height growth of maize (*Zea mays* L., var. IKENE) are relatively efficient methods for evaluating the maturity of composts.

Keywords

Compost, Phytotoxicity, Agronomic Parameters, Growth, Maize (*Zea mays* L., var. IKENE)

1. Introduction

The accelerated growth of the population in developing countries generates an increase of the food demand [1]. To satisfy this demand, agricultural intensification appears as an unavoidable option which is putting pressure on the ecosystem and in turn leading to reduced soil fertility. Togo, like the other countries of sub-Saharan Africa, is faced with a decline in soil fertility which leads to increasingly low yields and therefore very far from potential crop yields. Agricultural production is still largely cereals on soils that are not very productive and naturally poor in mineral elements essential for germination and growth and good crop yields. Akanza and Yao-Kouamé (2011) find that the nutrients exported from the already poor soil by crop harvests are not sufficiently well replaced and the use of mineral or organic fertilizers in food crops remains insignificant [2]. The use of chemical fertilizers by Togolese farmers has also shown its limits. To reverse the trend, the rational supply of organic fertilizers, composts, is now necessary to support the soils and improve the yields of all crops, in particular that of maize, which is Togo's main food crop. Despite a high potential yield, maize cultivation is characterized by low productivity. This low crop productivity is believed to be due to several constraints, mainly inappropriate soil fertilization practices [3]. Compost clearly appears as an organic amendment that can allow maize to achieve its genetic potential in a sustainable way. Indeed, compared to the original substrates, composts, among other advantages, have a beneficial effect on the growth of plants, improve the structure of soils by increasing aggregates and also improve the physical and chemical qualities of soils by providing nutrients that are progressively assimilable for plants [4]. Rational use of composts involves controlling the substrates used, managing the composting process and especially the degree of maturation. Indeed, it is generally accepted that compost produced with substrates rich in nitrogen will have a better fertilizing effect, compared to other compost whose substrates are mainly woody. Likewise, immature compost will have a repressive effect on seed germination and plant growth [5]. Compost with high salinity and containing toxic elements also has a repressive effect on plant growth. To assess the maturity of compost, several parameters are used by different authors. Some authors associate maturity with the C/N ratio, between 15 and 20 (AFNOR standard, reported by [6]). Others believe that this C/N ratio is far from sufficient. It should be combined with pH, organic matter content and phytotoxicity tests [7]. The main objective of this study is to assess the maturity of three types of composts, at different composting times through the study of chemical characteristics, nutrients, phytotoxicity tests and agronomic tests on corn (*Zea mays* L., var. IKENE).

2. Materials and Methods

2.1. Nature of Waste and Waste Composting Process

After a pre-collection by voluntary contribution from the populations and a door-to-door pre-collection mainly provided by neighborhood associations us-

ing human-drawn carts and motorized carts [8], the waste from the Djidjolé neighborhoods, Agbalepedogan and Adidogomé are transported directly to the composting platform of the NGO ENPRO in Lomé. Three types of compost (**Table 1**) have been developed from waste: compost N°1 made up of household waste, compost N°2 made up of 50% pineapple waste and 50% household garbage, compost N°3 made up of animal litter and straw. Each type of compost is duplicated.

The windrow composting method is the one chosen for this study because it is the method used on the platform. 600 kg of waste are used for each type of compost and placed in piles (windrows) alternately in three series of layers. According to Puyuelo *et al.* (2010) [9], the minimum oxygen level in the gaps in a fermentation windrow should be 5%. Conditions favorable to anaerobiosis occur if the oxygen content is too low or the mass to be composted too compact. To guarantee a grade above this value, reversals were made on the 3rd, 10th, 22nd, 36th and 71st days after the launch. This is to aerate the piles and allow better degradation of the organic matter. The piles are watered regularly to maintain a humidity level of 50% [8]. The humidity level is obtained after drying in an oven at 105°C for about 24 hours. During the composting process, the temperature was measured every day (from the 1st to the 107th day) using JEULIN TYPE K electronic thermometers, precision 10⁻¹, equipped with a thermometric probe. The temperature value is an average of 6 measurements taken along the length of the windrow, on each side [10]; and at varying depths (0.5; 1.0; 1, 5 and 2.0 m). The selected site is the platform of the NGO ENPRO located in the Adidogomé district in Lomé in Togo (6°10'12.0"N; 1°10'53.9"E).

2.2. Sampling and Characterization of the Compost and Soil of the Experimental Site

After 3, 4, 5 and 6 months from the start of composting, 2 heaps of each type of compost (at a rate of 10 kg per heap) were taken for screening. On average, 15 kg of compost is obtained after screening 20 kg of raw compost using a 5 mm mesh. The soil of the experimental site was also collected in different places and at depths of 0 - 20 cm (to constitute a single sample for analysis).

The methods for determining some chemical parameters of the different samples (soil and composts) are grouped below (**Table 2**). All measurements have been duplicated.

2.3. Assessment of the Phytotoxicity of Composts

Germination tests were carried out in triplicate on maize (*Zea mays* L.), in Lomé between September and October 2019, in order to assess the phytotoxicity of the composts [13]. The tests are carried out in plastic jars 10 cm in diameter and 8 cm in height, in the laboratory and at room temperature (**Table 3**) with regular daily watering with 50 mL of running water in order to maintain the rate of humidity between 60% and 80% of the field capacity.

Table 1. Composition of windrows.

	Household garbage (kg)	Pineapple waste (kg)	Animal litter + straw (kg)
Compost substrates N°1	600	0	0
Compost substrates N°2	300	300	0
Compost substrates N°3	0	0	600

Table 2. Methods for determining the chemical parameters of composts.

Parameters	Materials and methods	References or standard
Hydrogen potential	Ratio 1/5 (Compost/distilled water) JEULIN 701 296 pH meter INITIO. Accuracy: 10 ⁻²	AFNOR NF ISO 10-390, 2005
Electrical conductivity (EC)	Ratio 1/5 (Compost/distilled water). CTA JEULIN 701 328 conductivity meter INITIO. Accuracy: 10 ⁻²	AFNOR NF ISO 10-390, 2005
Total Organic Carbon (TOC)	Oxidation of organic matter (1 M potassium dichromate in acidic H ₂ SO ₄ medium). -Reduction of the excess of potassium dichromate by an excess of double ferrous iron and ammonium sulphate solution at 0.5 N dosed in return with dichromate (1 M)	[11]
Organic matter (OM)	Baking at 550°C for 2 hours. Weight difference between the mass of dry waste and the mass of calcined waste	[10]
Total nitrogen Kjeldahl, (TNK)	-Mineralization in an acidic medium and in the presence of a catalyst (K ₂ SO ₄ and Se) -Distillation after neutralization of the excess acid with 30% sodium hydroxide solution -Titration of the distillate with a sodium hydroxide solution (0.1 M) in the presence of methyl red	AFNOR NF T 90-110
Phosphorus (P)	Extraction of compost with sulfuric acid at 15% by volume -Spectroscopic assay at 660 nm	[12]
Potassium (P), calcium (Ca), magnesium (Mg), sodium (Na)	Mineralization of hot compost samples and aqua regia (HNO ₃ + HCl) -Determination by flame atomic absorption spectrophotometry	AFNOR NF ISO 11 460 of June 1995.

Table 3. Weather data for the period of phytotoxicity tests (source: historique-Météo.net).

	Mean temperature (°C)	Maximum temperature (°C)	Minimum temperature (°C)	Temperature variation (°C)	Cloud cover (%)	Duration of the day	Duration of the night
September 2019	27	29	24	5	69	12:14:0	11:46:0
October 2019	28	30	26	4	61	12:04:0	11:56:0

Phytotoxicity is a peculiarity of composts which makes it possible to evaluate their maturity [13]. Ten (10) maize seeds (*Zea mays* L., var. IKENE) considered as a staple crop in Togo, are germinated, at a depth of 2 to 3 mm, with the treatments in **Table 4** [14]. These treatments are made for the three types of compost and at 3, 4, 5 and 6 months of composting.

The number of germinated seeds is counted after 6 days [13]. The germination rate, evaluated as a percentage, is calculated according to formula (1).

$$\text{Germination rate (\%)} = 100 \times \frac{\text{number of germinated seeds}}{\text{Number of seeds sown}} \quad (1)$$

The results of the control treatment were taken as a reference and considered as 100%.

Table 4. Different treatment for the phytotoxicity tests.

	To treatment (sand only)	T ₁ treatment (3/4 sand + 1/4 compost)	T ₂ treatment (1/2 sand + 1/2 compost)	T ₃ treatment (1/4 sand + 3/4 compost)	T ₄ treatment (compost only)
Volume of sand (cm ³)	400	300	200	100	400
compost volume (cm ³)	0	100	200	300	0

2.4. Evaluation of the Effects of Composts on the Agronomic Parameters of Maize

2.4.1. The Experimental Site: Location and Climatic Situation

The experimental tests are carried out on a site preserved from any agricultural activity, for more than ten years, in the region of the plateaux in Kpalimé (6°54'00" North latitude, 0°37'59" East longitude and altitude of 225 m above sea level). The site is a land of 600 m² (6°55'36.3" latitude North and 0°37'52.3" longitude East), fenced and therefore protected from parasitic intrusions by animals. The site enjoys a tropical climate with heavy rainfall. The average temperature in Kpalimé is 26.0°C and the average annual precipitation is 1446 mm (Figure 1).

2.4.2. Chemical Characteristics of the Soil

Table 5 summarizes the chemical characteristics of the soil used for the agronomic trials.

2.4.3. The Experimental Protocol

The device used has 24 elementary plots corresponding to 8 treatments (Table 4) distributed randomly (Fischer block). Each treatment is repeated 3 times (Figure 2). The basic plots are separated from each other by an alley 0.7 meters wide, which serves as a passage during regular watering. Each elementary corn plot (with the walkways) occupies an area of approximately 6 m² (3.5 m long by 1.7 m wide). This device is repeated 4 times (M₃, M₄, M₅ and M₆ respectively 3, 4, 5 and 6 months after composting). In total, the agronomic trials took place on 96 plots bordered by four walls that protect the crops throughout the trials.

The experiment was carried out for 6 months, according to the standard plan shown in Figure 2.

The first 4 months were devoted to M₃ and M₄. Two months later, the sowing of M₅ and M₆ takes place. The composts are applied at two doses (10 t/ha and 5 t/ha) and the chemical fertilizer at a dose of 200 kg/ha in accordance with the recommendations of the Togolese Institute for Agronomic Research (ITRA) and the Institute of Advice and Technical Support (ICAT) to farmers (Table 6).

The plots are prepared one week before sowing and benefit from an irrigation of 30 L/plot three days before sowing depending on the retention capacity of the soil. The sowing is carried out with spacings of 60 cm × 40 cm at the rate of 4 seeds per pocket. The stripping 2 weeks after sowing made it possible to maintain two plants per pocket. During the trial period, each plot benefited from three manual weeding 14 days, 35 days and 56 days after sowing. Two insecticide

treatments, suitable for growing corn, are applied to the plots 6 and 10 weeks after sowing to rid the crops of pests.

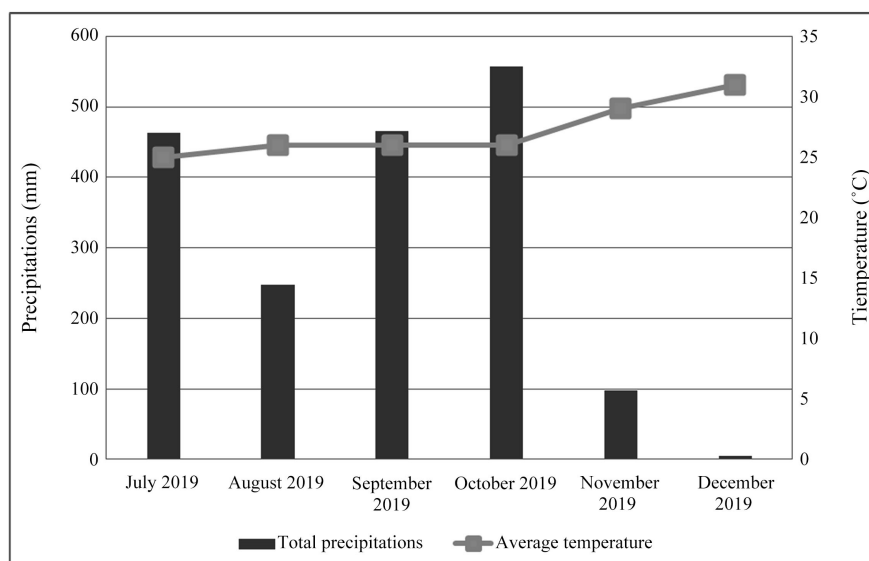


Figure 1. Monthly evolution of temperature and rainfall during the period of agronomic trials (source: historique-Météo.net).

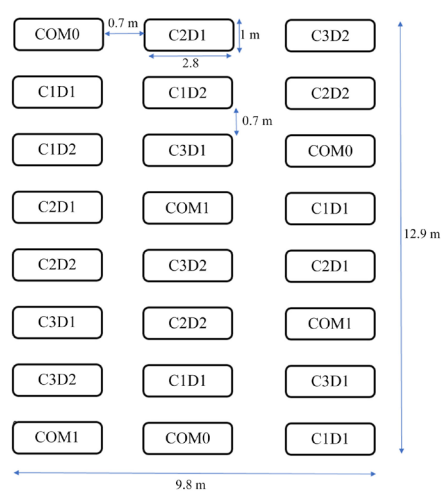


Figure 2. Standard sowing plan.

Table 5. Chemical characteristics of the soil.

	TOM (% _{ms})	TNK (% _{ms})	TOC (% _{ms})	C/N	pH	EC ($\mu\text{S}\cdot\text{cm}^{-1}$)	P ($\text{mg}\cdot\text{g}^{-1}\cdot\text{m.s}$)	K ($\text{mg}\cdot\text{g}^{-1}\cdot\text{m.s}$)
Content	2.02 ± 0.20	0.07 ± 0.03	1.2 ± 0.30	16.7 ± 0.3	8.5 ± 0.4	80.0 ± 6.0	1.83 ± 0.06	0.07 ± 0.01

Table 6. Characteristics of the treatments studied in the field trials.

Type of amendment	Compost N°1		Compost N°2		Compost N°3			
	C ₀ M ₀	C ₀ M ₁	C ₁ D ₁	C ₁ D ₂	C ₂ D ₁	C ₂ D ₂	C ₃ D ₁	C ₃ D ₂
Amount of amendments	No amendment (Control)	200 kg/ha of chemical fertilizer	10 t/ha	5 t/ha	10 t/ha	5 t/ha	10 t/ha	5 t/ha

Daily watering at the rate of 30 L/plot or natural rains (a total of 1733 mm of water for M₃ and M₄ and 1125 mm of water for M₅ and M₆), from sowing until 90 days after seedlings, allowed the plants to benefit from a good water regime. The average temperature during the period of the first test is 26°C ± 1°C and that of the second test is 28°C ± 2°C. The rainfall data for the test period are shown (Figure 1).

2.4.4. Measurement of Physiological and Agronomic Parameters

The height of the plants and the physiological parameter of growth are evaluated at 3, 6 and 9 weeks after sowing. 120 days after sowing, the harvest is carried out. The grain yields and the 1000 grain weight of the different treatments are evaluated. Equation (2) is used to calculate the grain yield.

$$\text{Yield} = M \times \frac{100 - G_f}{100 - S_h} \quad (2)$$

Yield (in tonnes/hectare);

M = Mass of grains (ton) harvested per hectare;

G_f = Grain moisture in the field (%);

S_h = Standard humidity (the humidity recommended for good grain preservation, 14%).

The 1000 grain weight is estimated by counting the grains of each replicate and weighing 1000 grains. The results are expressed in g.

2.5. Statistical Treatment of Results

The data collected was analyzed using XLSTAT software. These data were subjected to a two-tailed equality of expectations test. The means were compared using the Student-Newman-Keuls test at the 5% threshold. Values followed by the same letter are not significantly different (Duncan, $p \leq 0.05$).

3. Results and Discussion

The maturity assessment of the three types of compost from M₃ to M₆ is based on the analysis of their physicochemical characteristics, their phytotoxic properties through the germination test and their physiological and agronomic parameters.

3.1. Evolution of the Chemical Characteristics and Nutrients of Composts

The pH and the C/N ratio are the parameters most often used to assess the maturity of compost. The pH of the different types of compost from the end of the 3rd month of composting varies from 7.4 ± 0.1 to 8.1 ± 0.1, corresponding to the pH of ripe composts. This is consistent with the results of the work of [15] and [6] whose pH values of mature composts are respectively between 7 and 8.1. However, taken in isolation, pH is not a relevant parameter to assess the maturity of a growing medium [11]. In this case, the C/N ratio should be added. The values of the C/N ratios for the three types of composts studied are between 6.2

± 0.3 and 13.9 ± 0.4 . These values are all below 15, the threshold below which [12] consider compost to be ripe. The composts studied are therefore ripe.

But it is also believed by many authors that the C/N ratio of mature compost decreases over time. The C/N ratio of composts N°1 and N°2 gradually decreases from M₃ to M₆ (13.1 ± 0.1 to 6.2 ± 0.3 for compost N°1 and 13.9 ± 0.4 at 7.5 ± 0.5 for compost N°2). This corroborates the work of [16] who showed that the C/N ratios of two household waste composts decrease regularly during the 246 days of composting (15.4 to 6.3 for the first and $13, 1$ to 6.0 for the second compost) (Table 7).

Table 7. Evolution of the chemical characteristics and nutrients of composts.

	M ₃	M ₄	M ₅	M ₆	(Toundou, 2017)	ENPRO
pH						
Compost N°1	8.3 ± 0.1^a	8.0 ± 0.1^a	7.5 ± 0.1^a	7.7 ± 0.1^a		
Compost N°2	8.2 ± 0.1^a	8.1 ± 0.0^a	7.4 ± 0.1^a	7.6 ± 0.0^a	7.80 - 8.14	-
Compost N°3	8.1 ± 0.1^a	8.1 ± 0.1^a	7.4 ± 0.0^a	7.7 ± 0.1^a		
Electrical conductivity (mS·cm⁻¹)						
Compost N°1	3.43 ± 0.06^a	3.13 ± 0.06^a	3.37 ± 0.06^a	4.03 ± 0.06^a		
Compost N°2	4.13 ± 0.06^b	4.03 ± 0.06^b	4.50 ± 0.00^b	4.10 ± 0.00^a	1.297 - 3.080	-
Compost N°3	8.03 ± 0.06^c	7.93 ± 0.06^c	4.60 ± 0.10^b	4.03 ± 0.06^a		
Total organic matter (% m.s)						
Compost N°1	19.3 ± 0.0^a	18.7 ± 0.1^a	16.6 ± 0.1^a	14.9 ± 0.4^a		
Compost N°2	22.1 ± 0.1^b	21.3 ± 0.4^b	19.3 ± 0.2^b	18.5 ± 0.5^b	11.0 - 15.2	26.1 ± 0.7
Compost N°3	35.1 ± 0.1^c	40.6 ± 0.1^c	35.8 ± 0.4^c	40.4 ± 0.9^c		
Total Organic Carbon (% m.s)						
Compost N°1	11.2 ± 0.0^a	10.9 ± 0.1^a	9.7 ± 0.1^a	8.7 ± 0.2^a		
Compost N°2	12.8 ± 0.1^b	12.4 ± 0.2^b	11.2 ± 0.1^b	10.7 ± 0.3^b	6.39 - 8.83	12 ± 2
Compost N°3	20.4 ± 0.1^c	23.6 ± 0.1^c	20.8 ± 0.2^c	23.5 ± 0.5^c		
Total nitrogen Kjeldahl (% m.s)						
Compost N°1	0.86 ± 0.01^a	0.88 ± 0.04^a	1.05 ± 0.01^a	1.40 ± 0.04^a		
Compost N°2	0.92 ± 0.02^a	0.93 ± 0.03^a	1.09 ± 0.03^a	1.44 ± 0.05^a	0.41 - 1.20	0.50 ± 0.02
Compost N°3	2.07 ± 0.03^b	2.11 ± 0.01^b	2.04 ± 0.05^b	2.44 ± 0.45^b		
C/N ratio						
Compost N°1	13.10 ± 0.11^a	12.33 ± 0.51^a	9.23 ± 0.01^a	6.20 ± 0.31^a		
Compost N°2	13.93 ± 0.40^a	13.28 ± 0.63^b	10.28 ± 0.14^b	7.46 ± 0.45^b	7.35 - 15.87	24.7
Compost N°3	9.83 ± 0.17^b	11.16 ± 0.04^c	10.20 ± 0.14^b	9.63 ± 0.50^c		
Total phosphorus (mg·g⁻¹)						
Compost N°1	1.54 ± 0.08^a	1.85 ± 0.07^a	2.53 ± 0.04^a	2.65 ± 0.21^a		
Compost N°2	1.93 ± 0.10^b	3.58 ± 0.06^b	3.80 ± 0.14^b	4.55 ± 0.21^b	2.6 - 4.5	0.3 ± 0.0
Compost N°3	3.18 ± 0.04^c	3.55 ± 0.07^b	4.23 ± 0.10^c	5.40 ± 0.14^c		

Continued

		Potassium (mg·g ⁻¹)						
Compost N°1	8.8 ± 0.1 ^a	11.2 ± 0.1 ^a	12.7 ± 0.1 ^a	19.9 ± 0.1 ^a				
Compost N°2	9.6 ± 0.2 ^b	10.0 ± 0.1 ^b	13.3 ± 0.2 ^a	20.5 ± 0.2 ^a	4.2 - 6.0		4.0 ± 0.0	
Compost N°3	10.4 ± 0.1 ^c	10.9 ± 0.1 ^a	18.5 ± 0.1 ^b	19.8 ± 0.1 ^a				
		Calcium (mg·g ⁻¹)						
Compost N°1	26.8 ± 0.3 ^a	30.9 ± 0.1 ^a	31.4 ± 0.1 ^a	31.4 ± 0.2 ^a				
Compost N°2	23.3 ± 0.1 ^b	28.8 ± 0.1 ^a	30.1 ± 0.4 ^a	30.7 ± 0.1 ^a	9.2 - 16.3		29.1 ± 0.7	
Compost N°3	22.1 ± 0.4 ^b	30.5 ± 0.1 ^a	30.9 ± 0.2 ^a	30.9 ± 0.1 ^a				
		Magnesium (mg·g ⁻¹)						
Compost N°1	2.50 ± 0.42 ^a	2.95 ± 0.21 ^a	2.95 ± 0.21 ^a	3.25 ± 0.21 ^a				
Compost N°2	2.60 ± 0.14 ^a	3.05 ± 0.21 ^a	3.15 ± 0.21 ^a	3.25 ± 0.35 ^a	-		2.1 ± 0.2	
Compost N°3	6.40 ± 0.14 ^b	6.65 ± 0.21 ^b	6.95 ± 0.21 ^b	6.85 ± 0.07 ^b				
		Sodium (mg·g ⁻¹)						
Compost N°1	2.10 ± 0.14 ^a	2.35 ± 0.07 ^a	2.45 ± 0.07 ^a	2.70 ± 0.28 ^a				
Compost N°2	1.60 ± 0.14 ^b	2.35 ± 0.35 ^a	2.50 ± 0.14 ^a	2.75 ± 0.07 ^a	-		-	
Compost N°3	6.15 ± 0.21 ^c	7.10 ± 0.00 ^b	7.45 ± 0.21 ^b	7.65 ± 0.21 ^b				

Vertically, the values followed by the same letter are not significantly different (Duncan, $p \leq 0.05$).

According to the same authors, the evolution of the C/N ratio is strongly linked to the biodegradation of organic matter which results in the elimination of carbon in the form of CO₂ and an increase in the concentrations of mineral elements essential for the development of plants (N, P, K).

The C/N ratio of compost N°3 after an increase of 14% between M₃ and M₄, has experienced a gradual decrease from M₅. This development suggests that compost N°3 continued its fermentation process between M₃ and M₄ before entering the maturation phase from M₅. This development would be due to the nature of the substrates used (animal litter).

3.2. Phytotoxicity Test

Maturity is an essential criterion for evaluating the agronomic quality of compost and the toxicity linked to the incorporation of composts into the soil. Immature compost causes a phenomenon of phytotoxicity which has a negative effect on seed germination and plant growth [5]. Germination tests help to establish a relationship between the amount of compost and the rate of germination. Overall, the germination rate of the three types of compost decreases when the dose of compost in the different treatments increases (Table 8). This result shows that germination is suppressed with an increase in the dose of compost. This is corroborated by the work of [12] who showed that the repressive effect of compost is not only linked to its characteristics, but also depends on the dose applied.

Table 8. Evolution of the germination rate of the different compost treatments.

	M ₃	M ₄	M ₅	M ₆	[14]	[7]
Treatment T₁ (3/4 sand + 1/4 compost)						
Compost N°1	100%	100%	100%	100%		
Compost N°2	90%	90%	90%	100%	84% - 95%	90%
Compost N°3	70%	70%	80%	100%		
Treatment T₂ (1/2 sand + 1/2 compost)						
Compost N°1	80%	70%	100%	100%		
Compost N°2	90%	90%	90%	100%	-	80%
Compost N°3	10%	60%	70%	100%		
Treatment T₃ (1/4 sand + 3/4 compost)						
Compost N°1	70%	70%	100%	90%		
Compost N°2	90%	90%	90%	90%	31% - 55%	-
Compost N°3	20%	0%	60%	50%		
Treatment T₄ (only compost)						
Compost N°1	70%	60%	90%	90%		
Compost N°2	40%	30%	90%	100%	27% - 45%	80%
Compost N°3	0%	0%	90%	50%		
Control treatment (only sand)						
					100%	98%
						80%

The results of the germination rate of composts N°1 and N°2 clearly show that the T₁ and T₂ treatments give germination rates of the two types of compost which are significantly high and higher or close to the 80% recommended by the AFNOR standard (2005). It can therefore be concluded that at a dose of 25% or less, a 3-month composting would suffice to avoid a reduction in the germination rate in the case of household and similar waste. In addition, the evolution of the two types of composts from M₃ to M₆ for the two types of treatment shows a certain stability in the germination rates (Table 6). In addition, these values are close to the results of the phytotoxicity tests carried out on maize by [14] and [7]. For these authors, the results of their work testify to the maturity of composts and their low concentration of phytotoxic substances. All these data show that composts N°1 and N°2 would be ripe at the end of the 3rd month of composting as shown by the work of [13] who admitted that mature compost has no phytotoxic effects on seed germination and plant growth. These results also show that the germination rates of composts N°1 and N°2 are all equal to 100% after 6 months of composting. This shows that after 6 months of composting, household refuse and similar composts are really ripe and do not exhibit phytotoxic effects on the germination of corn seeds (*Zea mays* L., var. IKENE).

The germination rate of compost N°3, between M₃ and M₆ for the T₁ treatment, reaches at least 80% from M₅ (Table 8). This threshold is only reached

from M_6 for T_2 treatment. It can therefore be concluded that at a dose of 25% or less, composting of at least 5 months is necessary to avoid a reduction in the germination rate in the case of household and similar waste. In addition, whatever the treatment, the germination rate of compost N°3 is less than 80% between M_3 and M_4 . This could be explained by the relatively high value of the electrical conductivity of this compost ($8.1 \pm 0.1 \text{ mS}\cdot\text{cm}^{-1}$ in M_3 and $7.9 \pm 0.1 \text{ mS}\cdot\text{cm}^{-1}$ in M_4), likely to create a repressive effect on seed germination and plant growth, as some authors have shown. According to [10] an electrical conductivity between 2 and 3 $\text{mS}\cdot\text{cm}^{-1}$ is an acceptable level for the application of mature compost. Although [12] showed that compost with an electrical conductivity close to 5 $\text{mS}\cdot\text{cm}^{-1}$ has no remarkable phytotoxic effects on garlic seeds, the germination rate of which (74%) remains correct, the fact remains that the relatively high value of the electrical conductivity of compost N°3 between M_3 and M_4 could have a phytotoxic effect on seed germination. In addition, the significant drop in conductivity from M_5 (67% between M_4 and M_5) coincides with a significant increase in the germination rate. These results show that compost N°3 has phytotoxic effects on the germination of corn seeds (*Zea mays* L., var. IKENE) between M_3 and M_4 . These effects are strongly attenuated in M_5 to practically disappear in M_6 . The results of the germination rate of compost N°3 also show that for the T_1 and T_2 treatments, the germination rate after 6 months of composting is equal to 100%. Like composts N°1 and N°2, animal litter composts are effectively ripe after 6 months of composting and therefore do not exhibit phytotoxic effects on the germination of corn seeds (*Zea mays* L., var. IKENE).

3.3. Effects of Composts Maturity on Corn Growth and Agronomic Parameters

3.3.1. Plant Height

The use of composts generally improves plant growth [10]. At the end of the 3rd week after sowing, the 3- and 4-month-old composts, apart from the C_1D_2 compost (household waste compost at a dose of 5 t/ha), have plant heights less than or equal to the Control test, C_0M_0 , having received no organic amendment while the 5- and 6-month composts show plant heights greater than or equal to the Control test, C_0M_0 . The heights of the plants at the 6th and 9th weeks of growth under the different composts at the two doses of 5 and 10 t/ha are greater compared to the Control test, C_0M_0 (Table 9).

Table 9. Evolution of the height of the plants for the different treatments.

	M_3	M_4	M_5	M_6
	Week 3 (cm)			
C_1D_1	28 (-9.7%)	29 (-6.5%)	33 (6.5%)	31 (0%)
C_1D_2	32 (3.2%)	32 (3.2%)	37 (19.4%)	38 (22.6%)
C_2D_1	34 (9.7%)	28 (-9.7%)	36 (16.1%)	31 (0%)

Continued

C₂D₂	29 (-6.5%)	31 (0%)	36 (16.1%)	34 (9.7%)
C₃D₁	28 (-9.7%)	31 (0%)	34 (9.7%)	31 (0%)
C₃D₂	28 (-9.7%)	31 (0%)	34 (9.7%)	31 (0%)
C₀M₀	31 (0%)	31 (0%)	31 (0%)	31 (0%)
C₀M₁	33 (6.5%)	33 (6.5%)	33 (6.5%)	33 (6.5%)
Week 6 (cm)				
C₁D₁	107 (0%)	108 (0.9%)	133 (24.3%)	118 (10.3%)
C₁D₂	123 (15.0%)	126 (17.8%)	125 (16.8%)	132 (23.4%)
C₂D₁	117 (9.3%)	117 (9.3%)	125 (16.8%)	125 (16.8%)
C₂D₂	119 (11.2%)	117 (9.3%)	126 (17.8%)	131 (22.4%)
C₃D₁	129 (20.6%)	125 (16.8%)	141 (31.8%)	126 (17.8%)
C₃D₂	123 (15.0%)	116 (8.4%)	126 (17.8%)	127 (18.7%)
C₀M₀	107 (0%)	107 (0%)	107 (0%)	107 (0%)
C₀M₁	129 (21.2%)	129 (21.2%)	129 (21.2%)	129 (21.2%)
Week 9 (cm)				
C₁D₁	139 (7.4%)	142 (8.3%)	150 (14.5%)	143 (9.2%)
C₁D₂	130 (-0.8%)	131 (0%)	129 (-1.5%)	155 (18.3%)
C₂D₁	136 (3.8%)	134 (2.3%)	138 (5.3%)	143 (9.2%)
C₂D₂	139 (7.4%)	131 (0%)	137 (4.6%)	141 (7.6%)
C₃D₁	131 (0%)	148 (13.0%)	151 (15.3%)	152 (16.0%)
C₃D₂	144 (9.9%)	133 (1.5%)	136 (3.8%)	146 (11.5%)
C₀M₀	131 (0%)	131 (0%)	131 (0%)	131 (0%)
C₀M₁	152 (16.0%)	152 (16.0%)	152 (16.0%)	152 (16.0%)

C₁D₁: Compost N¹ to 10 t/ha; C₁D₂: Compost N¹ to 5 t/ha; C₂D₁: Compost N² to 10 t/ha; C₂D₂: Compost N² to 5 t/ha; C₃D₁: Compost N³ to 10 t/ha; C₃D₂: Compost N³ to 5 t/ha; C₀M₀: No organic growth; C₀M₁: 200 kg/ha of chemical fertilizer.

Regardless of the number of weeks, waste that has undergone composting time of at least 5 months has greater plant heights. More mature compost therefore appears to promote better height growth than less mature compost. This is corroborated by the work of [10] which showed that immature compost can induce negative effects on the germination, growth and development of plants.

Generally, the macronutrient contents of composts are much higher than those of the soil. The contribution of composts promotes good plant nutrition, inducing a high growth of plants cultivated under organic amendment compared to plants cultivated on control soil without organic amendment. The poor growth noted for certain plants under compost amendment at the start of growth, particularly at week 3, could be attributed to salinity or to any toxic elements in the composts [11]. The heights of plants under N°3 compost amendment experienced a growth retardation at the start of the agronomic trials in M₃ and M₄. This could be explained by the high ion content of the applied compost (Table 5). Indeed, a high cation content can inhibit the absorption of potassium and ammonium [10] which can slow down the growth of the plant. This growth retardation reversed from M₅ from which plants subjected to the N°3 compost amendment experienced strong growth compared to that without organic amendment and even those subjected to chemical fertilizer.

These results show, like the germination test, that composts N°1 and N°2 can be considered as ripe at the end of the 3rd month of composting, whereas compost N°3 can only be considered ripe. These results also show that compost with high electrical conductivity has an inhibitory effect on the growth of maize plants (*Zea mays* L., var. IKENE).

3.3.2. Grain Yield

Compost treatments improved corn grain yields compared to the control treatment (32.9% to 41.2% for compost N°1, 29.4 to 31.8% for compost N°2, 28, 8 to 40.6% for compost N°3) (Table 8). This is corroborated by the work of [10] who showed that corn plants under compost treatment have yields of 2.29 ± 0.29 t/ha on average against 0.97 t/ha for the treatment without organic amendment. These results can be explained by the contribution of high levels of organic matter, especially nitrogen and phosphorus, to the soil (Table 10). The work of [17] has shown that a high organic matter content in the soil strongly contributes to the absorption of phosphorus, a very important nutrient, which plays an important role in the photosynthesis of plants.

In M₆ (Table 10), the grain yields of the different compost treatments are not significantly different (Duncan, $p \leq 0.05$). The strong disparities observed in M₃ gradually disappeared throughout the tests to give way to a relative homogenization of the M₆ yields.

Throughout the agronomic trials, chemical fertilizer treatment had the highest yield (Table 10). This could be explained by an optimal concentration of essential plant nutrients (N, P, K).

Table 10. Evolution of the grain yield of maize under different treatments from M₃ to M₆ (from the third to the sixth month).

	M ₃	M ₄	M ₅	M ₆
C ₁ D ₁	1.79 ± 0.20 ^a (5.9%)	1.84 ± 0.05 ^a (8.9%)	2.19 ± 0.20 ^a (28.8%)	2.26 ± 0.15 ^a (32.9%)
C ₁ D ₂	1.65 ± 0.50 ^b (-2.4%)	1.68 ± 0.20 ^b (-0.06%)	2.34 ± 0.35 ^a (37.6%)	2.40 ± 0.30 ^a (41.2%)
C ₂ D ₁	1.70 ± 0.20 ^{ab} (0.06%)	1.88 ± 0.23 ^a (11.2%)	1.60 ± 0.05 ^b (-5.9%)	2.24 ± 0.35 ^a (31.8%)
C ₂ D ₂	2.04 ± 0.05 ^c (20.7%)	1.96 ± 0.35 ^a (16.0%)	2.20 ± 0.17 ^a (29.4%)	2.20 ± 0.28 ^{ab} (29.4%)
C ₃ D ₁	1.97 ± 0.17 ^{cd} (16.6%)	2.19 ± 0.10 ^c (28.8%)	1.54 ± 0.06 ^b (-9.4%)	2.19 ± 0.23 ^{ab} (28.8%)
C ₃ D ₂	1.95 ± 0.15 ^d (15.4%)	2.29 ± 0.23 ^c (35.5%)	2.02 ± 0.04 ^c (18.8%)	2.39 ± 0.28 ^a (40.6%)
C ₀ M ₀	1.69 ± 0.13 ^{ab} (0%)	1.69 ± 0.13 ^b (0%)	1.70 ± 0.17 ^b (0%)	1.70 ± 0.17 ^c (0%)
C ₀ M ₁	2.59 ± 0.10 ^e (53.3%)	2.59 ± 0.10 ^d (53.3%)	2.61 ± 0.08 ^d (53.5%)	2.61 ± 0.08 ^d (53.5%)

C₁D₁: Compost N°1 to 10 t/ha; C₁D₂: Compost N°1 to 5 t/ha; C₂D₁: Compost N°2 to 10 t/ha; C₂D₂: Compost N°2 to 5 t/ha; C₃D₁: Compost N°3 to 10 t/ha; C₃D₂: Compost N°3 to 5 t/ha; C₀M₀: No organic growth; C₀M₁: 200 kg/ha of chemical fertilizer; Vertically, the values followed by the same letter are not significantly different (Duncan, $p \leq 0.05$).

It is concluded that after 6 months of composting, the three types of compost applied at 5 and 10 t/ha improve the grain yield of maize (*Zea mays* L., var. IKENE) compared to treatment without organic amendment. Regardless of the type of compost and the dose used, plants treated with composts obtained after six months of composting show a uniform yield.

However, the results of the grain yield do not allow a conclusion to be drawn about the maturity period of the different types of compost used.

3.3.3. Mass of 1000 Grains

The mass of 1000 grains is a very relevant parameter for the quality of a yield. The more the plant accumulates organic matter in its grains, the higher the mass of 1000 grains is and vice versa (Toundou, 2017). This is shown by the relatively low mass of 1000 grains of plants under chemical fertilizer treatment, C₀M₁ (276 ± 6 g) compared to other treatments (Table 11), while this treatment has the highest grain yield.

The plants subjected to the composts obtained after six months of composting have masses of 1000 grains which are significantly little different from each other. These masses are, however, greater than those of plants grown without organic amendment.

These values are higher than those obtained during the work of [18] who noted a maximum mass of 1000 grains between 302 ± 20 g and 322 ± 13 g.

Table 11. Evolution of the mass of 1000 grains of the plots subjected to the different treatments.

	M₃	M₄	M₅	M₆
C₁D₁	285 ± 3^a (-6.6%)	290 ± 4^a (-4.9%)	298 ± 6^a (-2.3%)	328 ± 8^a (7.5%)
C₁D₂	285 ± 5^a (-6.6%)	288 ± 4^a (-5.6%)	295 ± 1^{ab} (-3.3%)	338 ± 2^a (10.8%)
C₂D₁	252 ± 2^b (-17.4%)	266 ± 6^b (-12.8%)	334 ± 10^d (9.5%)	327 ± 6^a (7.2%)
C₂D₂	261 ± 1^{bc} (-14.4%)	298 ± 3^a (-2.3%)	309 ± 2^a (1.3%)	338 ± 3^a (10.8%)
C₃D₁	311 ± 0^d (2.0%)	275 ± 4^{ab} (-9.8%)	279 ± 9^a (-8.5%)	311 ± 1^{ab} (2.0%)
C₃D₂	301 ± 1^{ad} (-1.3%)	344 ± 6^c (12.8%)	304 ± 0^{ac} (-0.3%)	346 ± 4^a (13.4%)
C₀M₀	305 ± 2^a (0%)	305 ± 6^a (0%)	305 ± 5^a (0%)	305 ± 2^{ab} (0%)
C₀M₁	276 ± 6^{ac} (-9.5%)	276 ± 6^{abc} (-9.5%)	276 ± 6^{bc} (-9.5%)	276 ± 6^c (-9.5%)

C₁D₁: Compost N°1 to 10 t/ha; C₁D₂: Compost N°1 to 5 t/ha; C₂D₁: Compost N°2 to 10 t/ha; C₂D₂: Compost N°2 to 5 t/ha; C₃D₁: Compost N°3 to 10 t/ha; C₃D₂: Compost N°3 to 5 t/ha; C₀M₀: No organic growth; C₀M₁: 200 kg/ha of chemical fertilizer; Vertically, the values followed by the same letter are not significantly different (Duncan, $p \leq 0.05$).

Whatever the type of compost and the dose used, the plants treated with composts obtained after six months of composting have, like the grain yield, a uniform mass of 1000 grains and much greater than that of the plants under treatment of chemical fertilizer.

Here too, it is difficult to draw a conclusion relating to the maturity period of the different types of compost used.

4. Conclusion

The results obtained in this work allow to conclude that the treatment at 5 t/ha of compost N°3 has the best agronomic parameters compared to other types of compost and to treatment without organic amendment. It is therefore more efficient in improving soil fertility. The evolution of the C/N ratio, of the electrical conductivity, the phytotoxicity tests and the growth parameters of the composts also allow to conclude that the composts N°1 and N°2 are ripe from the end of the 3rd month of composting. That compost N°3 can only be considered ripe at the end of the 5th month of composting. To improve soil fertility and thus ensure better agronomic performance of maize (*Zea mays* L., var. IKENE), composts produced from refuse and fruit waste could be used from the end of the 3rd month of composting then that composts from animal litter could only be used after at least 5 months of composting. The results of this work also show that compost with high electrical conductivity has an inhibitory effect on the growth of corn plants (*Zea mays* L., var. IKENE).

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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