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Characteristics of two compost formulas to valorize organic matter in Casamance (Senegal)

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Abstract
Two different composting formulations F1 and F2 were studied at the station using different organic matter sources. F1 is made from rice straw and ground shells. F2 is composed of *Andropogon gayanus* K, phosphogypsum and urea. Temperature, humidity and pH were monitored during the composting process. Phytotoxicity tests were performed on rice using different doses of F1 and F2 composts to evaluate their maturity at 40 days and 50 days after incubation (DAI). The results showed that mean temperatures at the beginning of incubation were 49° C for (F1) and 41° C for (F2) and 31°C (F1) and 33°C (F2) at the 50th day after incubation (DAI). From the 28th DAI the average temperatures were similar for F1 (35.8° C) and F2 (35.7° C). The average values of the humidity varied between 50% and 60%. Variation of the pH showed that the compost went from a slightly acidic phase at the 18th and 21th after incubation to a neutral phase towards the 50th DAI and tended finally stabilized at maturity with pH values of 6.4-6.5. Moreover, GI at T40 days after incubation was significantly higher ($p = 0.001$, F = 117, 38) for F1 compared with F2, regardless of the associated compost dose. Thus, in (F1) 40 days are enough for GI ≥ 50% whatever the associated compost dose against 50 days for F2. F2 would have more stable organic fractions and would result in longer composting time.

1. Introduction

The organic status of cultivated soils is a major determinant of soil vulnerability and its functions with respect to climate change. By way of adaptation, [1] have suggested to improve soil amendment techniques. However, in the Middle and Lower Casamance (Senegal), organic matter is under exploited and the technology is weakly used despite the potential that exist in the region. Composting [2-4-5] can be summarized as a controlled process of degradation of constituents and residue of plant and animal origin. It is done by microbial (bacteria, fungi, etc.) activities in aerobic conditions, causing a rise in temperature, and leading to the development of stabilised organic matter called compost. In the Lower and Middle Casamance, the cultural practices adopted by farmers promote the use of mineral fertilizers compared to the organic matter. This has the effect of depleting the soils of organic matter (OM) and accentuate the pollution of the layers by chemical fertilizers. This phenomenon physically translates into a decrease in the structural stability of the soil and an increase in the risk of erosion and biodiversity. The valorization of organic carbon in stable composts represents a way to prevent these situations. The application of composted organic matter in the soil helps to reduce crop export losses after harvest, and improves fertility. Compost affects the physical properties of the soil, particularly by promoting good permeability and structural stability by its beneficial effects on porosity and aggregation [6-7]. In addition, organic matter humidification and soil carbon immobilization mechanisms have a role to play in the global carbon cycle. As a result, any change in soil carbon stock influences atmospheric carbon concentration, and climatic variability [8]. Agriculture in Lower and Middle Casamance faces a double challenge. First food security must be provided to a population with strong growth and second to preserve the social and environmental systems in a context of climatic variations. Thus, the optimization of OM composting techniques to reconcile agronomic and environmental purposes is a key issue to address low producer incomes and food insecurity. In this study, we tried to valorise the existing and accessible organic resources in the region. These are mainly ricepaddyresidues (Oryzasativa L.), herbaceous biomass consisting of dominant species with high C potential such as Andropo gongayanus K, leguminous biomass Crotalaria retusa L. Further there are industrial waste from SONACOS SA made up of peanut powder, slaughter house waste from SOGAS, etc. Thus, several organic matter composting formulas can be established or defined according to the diversity of organics matters. Despite this potential in terms of diverse organic resource, no composting formula has so far, been clearly defined and proposed by research in this region. The challenge is to promote composting technology as an effective strategy of soil management in agro-farming systems and to allow the fixation of C in soils. This will involve the study and development of composting formulas for better agronomic valorisation but with a shortening of the composting time. Indeed, the variety of composting process (time of turning and the differences in the nature of the substrates modify the rate and the time of degradation of the organic matter, the final quality of the compost produced as well as the duration of the maturation) can have a notable impact on the feasibility and the adoption of technology. The objective of this study is to contribute to the development of a composting technology of organic matter. The hypothesis is that the composition of the organic matter influences the duration of the maturation and/or stabilization of the compost.

2. Material and Methods

2.1. Material

2.1.1. Presentation of the experimental site

The study was conducted at Agricultural Research Center of Djibélor (12°33′39″N; 16°18′25″O) located in the district of Niaguis in the region of Ziguinchor (Senegal).

The technique adopted is that of aerobic composting. The composting area was built with concrete pavement. Each concrete block was filled with the amounts of biodegradable materials (table 1) which represent the fermentable organic matter.

Table 1 : Composition of the different composts formulas F1 and F2

Formulas	Ashes of dead wood	Manure crumb	**Rice straw (*Orizea sativa* L.)**	Poultry droppings	**Crushed oyster shells**	Fresh green residues of *Crotalaria retusa* L.	peanut powder	**straw (stems + leaves) of *Andropogongayanus* K.**	**Urea**	**phosphogypsum**	**Total (Kg)**
Formula F1	25	93	190	37	04	02	85	00	00	00	436
Formula F2	25	93	00	29	00	02	85	190	08	02	434

***We have in bold the discriminating source material between the two formulas F1 and F2**

The composting unit or block (figure 1) consists of two container of equal size with a volume capacity of 2.6 m^3. These two container were filled with different organic materials described according to the formulas F1 and F2.

Figure 1: composting units with shelters

2.2. Composting process

This is an aerobic composting method. After the incubations, the turning frequency was constant (every 8 days) during the composting process. In the case of our study, to ensure better aeration, a mixing of organic matter and a good microbial activity, the process of turning was carried out weekly for the two blocks. During this process, watering was performed to moisten the contents of the block. On the 40th and 50th day starting the composting process, the decomposed organic matter was sieved at 2 mm for ripening and/or stability tests.

2.2.1. Measurement of the physical and chemical parameters

2.2.1.1. Tempeture

Temperature were recorded in 48 hours interval using a thermometer. Three measurements were taken at different point of the block. Results are given in degree Celsius (°C).

2.2.1.2. Humidity

Humidity H (%) of the composts was determined every 48 h in the laboratory after oven drying at 105° C for 72h. The calculation was performed according to the following formula.

$$\text{H (\%)} = 100\ \text{X}\left[\left(\frac{\text{Fresh compost weight} - \text{dry compost weight}}{\text{dry compost weight}}\right)\right]$$

2.2.1.3. pH

The pH was determined using a pH meter (HANNA HI98127). The pH was measured in a suspension compost/water solution ratio of 1: 2.5.

2. 2. 2. Phytotoxicity test, germination rate, shoot and root biomass of compost F1 and F2

2.2.2.1. Germination test

Germination tests were performed on the 40th and 50th day after incubation compost to determine their maturity and/or stability on rice. The tests were performed on five (5) treatments with three (3) repetitions for each formula. This included a control treatment with 100% sand representing the treatment (1:0); 70% sand and 30% compost representing the treatment (3:1); 50% sand and 50% compost for treatment (1:1); 30% sand and 70% compost for treatment (1:3) and the 100% compost for treatment (0:1).The equivalent dry weight of 100g of sand or compost were measured and packaged in Petri dishes corresponding to 100% sand or 100% compost treatment. The other intermediate treatments received the dry weight equivalent of the compost and sands mixes on the proportions 70%sable + 30% compost; 50% + 50% sandy compost; 30% + 70% sandy compost. Germination and rootlet growth (roots length) with a millimeter rule were measured and the germination index (GI) calculated after 14 days of incubation.

2.2.2.1.1. Germination rate (GR)

This is the ratio of the number of seeds sprouted for the total number of seeds sown during a 14-day incubation period. For the plant test material, we used certified rice seeds with the variety Nerica 6 (cycle 120 days). The ratio has been defined by the following formula [9].

$$\text{GI} = 100\text{x}\left[\left(\frac{Ni}{Nt}\right)\right]\text{x}\left[\left(\frac{Nc}{Nt}\right)\right]$$

Ni= Number of rice seeds sprouted in a treatment
Nc= Number of rice seeds sprouted in control
Nt= total number of rice seeds sown

2.2.2.1.2. Germination mean index (GI)

The germination mean index was determined according to the formula defined by [10-11]. This index considers both germination rate and leachate effect (compost water) on root length which provides information on the maturity of the compost.

$$GI=\left[\left(\frac{Gl}{Gt}\right)\right]x\left[\left(\frac{Ll}{Lt}\right)\right]$$

Gl= Average number of germinated seeds in the leachate of a treatment
Gt= Average number of germinated seeds in control
Ll= root length of germinated seeds in the leachate of a treatment
Lt= root length of germinated seeds in the control treatment

2.2.2.3. Aboveground and root biomass production

Aboveground and root biomass production {A. B} root {R. B} and total dry matter (TDM) were determined 14 days after sowing. The roots were first separated from the soil and compost after wiping with water and then separated by hand. Aerial and total root dry weight was measured in each treatment after oven drying at 65 ° C for 72 h.

2.3. Data analysis

XLSTAT (version 2016) was used for data analysis. We fitted an ANOVA and Fischer (5% threshold) and Newman and Kheuls (5% threshold) tests for multiple comparisons. The model tested took into account the interaction between the two factors.

3. Results and discussion

3.1. Effect of F1 and F2 formulas on the variation of the physical and chemical parameters

One of the main characteristics of composting is the production of heat due to exothermic oxidation reactions. Heat production is an indirect measure of microbial respiratory activity. The results on the evolution of temperature and humidity in the two blocks are indicated in Figure 2.

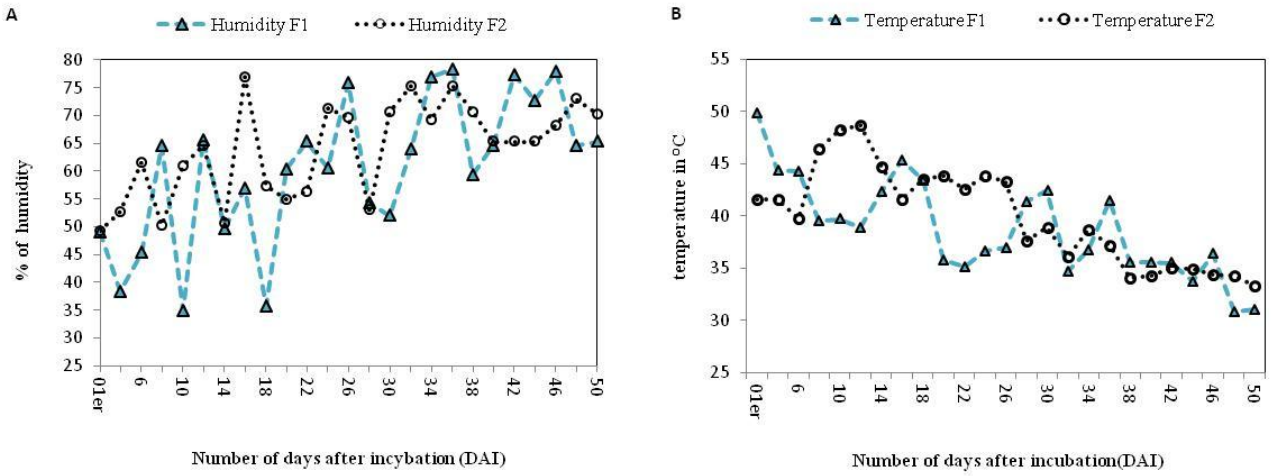

Figure 2: the average value dynamics of the moisture and the temperature of the compost for the formulas F1 (A) and F2 (B) during the time in number of days after the incubation (DAI)

The analysis shows general tendency of lower temperature from the beginning of incubation to the end of the composting process whatever the formula adopted. First, there was a latent time before the temperature rise up for F2 from the beginning of the incubation to the 8th DAI. The mean temperatures passed at the beginning of the incubation (1st DAI), respectively, from 49° C for F1 and 41° C for F2 to 31° C (F1) and 33° C (F2) at the 50th DAI. There were time ranges where temperatures are significantly ($p < 0.007$) different between F1 and F2. These were between the 8th DAI and the 14th DAI and then a second from the 18th to the 26th DAI. Then, a significant variation of temperature between F2 and F1 with average amplitudes of 6.9° C between 8th and 14th DAI and 5.8° C between 18 and 26° C DAI. According to [12], the variations of the temperature of the compost depend not only on the heat produced, but also on other factors such as aeration, humidity, heat exchange, composition and the particle size of the substrate. Finally, from the 28th DAI mean temperatures are equivalent in both blocks with average values of 35.8° C (F1) and 35.7° C (F2) respectively. This period of stabilization of the temperature from the 28th DAI could correspond to the initiation of the maturation stage of the composts. Regarding to the humidity of the composts, F1 reaches its maximum at the 26th day with a value of 76% and its minimum at the 10th day with

35% before stabilizing at the 50th day at 65%. However, F2 has reached its optimum peak at the 16th day with a value of 77% and its minimum at the 08th day with 50.3% before following an average variation of 66.6% until the end of the process. The analysis of the mean humidity for F1 and F2 shows that the values were between 50 and 60%. These agree with previous work of [13-14], which showed that the ideal humidity is generally between 50 and 60%. The results on the pH (table 2) showed that the compost gone from an acid phase to a neutral phase towards the 52th DAI and finally stabilizes at maturity with pH value around 6.4 to 6.5. There is a significant (F=7,333; p<0, 0001)

Table 2 : Variation of the pH during the period after incubation (DAI) for the (F1) and (F2) formula

Dates (in DAI)	pH (F1)	pH (F2)
18th	4,467 d	5,467 b
21th	4,967 cd	4,400 d
28th	5,767 b	5,200 bc
35th	5,100 c	5,500 b
42th	5,433 bc	4,933 c
49th	5,667 b	6,467 a
52th	6,467 a	6,400 a

interaction between the dates of pH measurements and the different compost formulas. The composts formulas did not have a significant (p=0,449) effects on pH. On the other hand there are significant differences between the pH measurement and dates. For F1 at 18th and 21th DAI, the pH values are more acidic at 49th and 52th days after incubation. On the other hand, on the 52nd day, pH values tend toward neutrality, regardless of the compost formula. For F1 at 18th and 21th DAI, the pH values are more acidic at 49th and 52th days after incubation. On the other hand, on the 52th day, pH values tend toward neutrality, regardless of the compost formula. pH stability is due to slow maturation reactions and buffering effects of humus [15].

3.2. Effect of compost formulas on germination and growth parameter of rice (*Oryza sativa* L.)

The inhibitory effects of compost were studied with different doses of 0 to 100% compost. Increasing doses of compost result in decreased germination of seeds, root growth, aerial growth and total dry matter yield. The results from some of the studies showed that, leachate from immature compost causes damage to the roots and their growth [3-10].

In addition, the results of these studies (table 3) also showed that compost formulations had significant effects (F 4554, p 0.048 *) on {A. B} at T40th DAI, and very significant (F 126,692; 0, 0001 ***) on the {R. B} T50th DAI. There are significant effects (F 9.543, p 0.006) of T40th DAI composts formulas. Its effects cancel out at T50th DAI with germination rate significantly (F=2.364, p=0.140) equivalent for the two formulas of compost (F1=84,904%, F2=81.785%). In the other hand, at T50th DAI, root growth was significantly greater with the formula F2 (0.067g) than with formula F1 (0.035g) (table 4).

Table 3 :ANOVA of Treatments Factors vs. Compost Formulas and Newmans & Keuls Mean Comparison Test on above ground Biomass Parameters {A. B}root biomass {B. R}, total dry matter (TDM) and germination rate (GR) at T40 day and T50 day after incubation.

Synthesis for all Y:

	{A. B } T40thDAI	{A. B } T50thDAI	{R. B} T40thDAI	{R. B} T50thDAI	{TDM} T40thDAI	{TDM} T50thDAI	(GR) T40thDAI	(GR) T50thDAI
R^2	0,760	0,893	0,753	0,953	0,839	0,925	0,830	0,525
F	7,032	18,535	6,790	45,384	11,563	27,323	10,819	2,455
Pr> F	0,000	< 0,0001	0,000	< 0,0001	< 0,0001	< 0,0001	< 0,0001	0,045
treatments	14,051	40,027	14,040	66,689	24,593	59,542	20,707	4,728
	< 0,0001	< 0,0001	< 0,0001	< 0,0001	< 0,0001	< 0,0001	< 0,0001	0,008
Formulas (F1* F2)	4,454	3,553	2,255	126,692	1,601	2,697	9,543	2,364
	0,048	0,074	0,149	< 0,0001	0,220	0,116	0,006	0,140
Treatments* Formulas	0,657	0,789	0,674	3,753	1,024	1,260	1,250	0,204
	0,629	0,546	0,618	0,020	0,419	0,318	0,322	0,933

At T40th days after incubation, the same trends are observed for aboveground biomass with average values of 0.131 g for F1 and 0.160 g for F2. Some authors [11] have also used as indicators the germination rate to assess the maturity of compost and define the composting time. Results from this study indicated a germination rate (%G) significantly higher for F1 (74.4%) than for F2 (64.2%) after 40 days of incubation whereas it was equivalent for F1 (84.9%) and F2 (81.7%) at T50th DAI. Further, it was observed that the germination rate decreases with the increased doses of composts whatever the formula used. The immature compost contains substances that could inhibit seed germination. According to [15], mature compost is low in ammonium (inhibiting substance) and rich in nitrate (favouring germination).

Table 4 : Effects of Compost Formula and Treatment on aboveground biomass {A. B}, root {B. R}, total dry matter (TDM) and germination rate (GR) at T40 day and T50 day after incubation. The same letters on the same column indicate groups for which averages are not significantly different.

Summary (Estimated Averages) Formulas -Treatments:

Formulas	{A.B} T40thDAI	{A.B} T50thDAI	{R. B} T40thDAI	{R. B} T50thDAI	{TDM} T40thDAI	{TDM} T50thDAI	(GR) T40thDAI	(GR) T50thDAI
F1	0,131 b	0,214 a	0,051 a	0,035 b	0,183 a	0,249 a	74,444 a	84,904 a
F2	0,160 a	0,199 a	0,042 a	0,067 a	0,202 a	0,265 a	64,222 b	81,785 a
Pr> F	0,000	< 0,0001	0,000	< 0,0001	< 0,0001	< 0,0001	< 0,0001	0,045
Significant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(1:0=100% S+0% C)	0,237 a	0,291 a	0,091 a	0,090 a	0,328 a	0,381 a	94,61 a	89,25 a
(3:1=70% S+ 30% C)	0,162 b	0,235 b	0,052 b	0,060 b	0,215 b	0,294 b	76,66 b	86,07 a
(1:1=50% S+ 50% C)	0,117 bc	0,194 c	0,035 b	0,047 c	0,152 c	0,241 c	65,81 bc	81,85 ab
(1:3+30% S+ 70% C)	0,091 c	0,178 c	0,029 b	0,034 d	0,120 c	0,212 c	56,42 c	83,44 ab
(0:1=0% S+ 100% C)	0,122 bc	0,135 d	0,025 b	0,023 e	0,147 c	0,157 d	53,14 c	76,09 b
Pr> F	0,000	< 0,0001	0,000	< 0,0001	< 0,0001	< 0,0001	< 0,0001	0,045
Significant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

3.3. Phytotoxicity test, germination rate, shoot and root biomass of compost F1 and F2

Results of the phytotoxicity test through the measurement of root length and the computed average index of germination are shown in Figs. 3 (A, B, C, D) which also indicate the average root length in response of the increasing doses formulas F1 and F2 at T40th DAI and T50th DAI.

There was an overall trend in root length (LR) higher for F2 than for F1. At T40th DAI (Figure 3A), the mean values are equivalent for treatments associated with compost (0:1); (1:1); (1:3) and (3:1) whatever the formula and the dose. Root growth was reduced for all compost treatments for F1 and F2 formulas comparing controls and different doses. In particular for the 50th DAI treatment, we noted better root growth for F1 compared to F2. The average germination index value (Figs. 3C and 3D) is 1 for 100% sand treatments (1:0) at T40th DAI and T50thDAI. This index is statistically equivalent to F1 and F2 at T50thDAI whatever treatment associated with the compost (Figure 3D). However, at T40thDAI, it was observed with the treatments associated with the compost, that the GI was significantly higher for F1 compared to F2 ($p = 0.011$). It was respectively 0.74 for F1 vs 0.50 for F2 for the treatment (3-1 = 70% S + 30% C); 0.56 for F1 vs 0.37 for F2 for treatment (1:1); 0.54 for F1 vs 0.24 for F2 for (1:3); 0.50 for F1 vs 0.32 for F2 for treatment (0:1). It was thus observed that the stability index or average germination index (GI) was greater than or equal to 50% in all treatments associated with the formula F1 to T40thDHA. This was not observed for the treatments associated with the different doses of the F2 formula.

This suggests a higher phytotoxicity in F2 than in F1 at 40 days. Indeed, [11] have established that the age of the compost affects the percentage and the germination index. According to these authors [11], compost is considered as stabilized and matured when the GI exceeds 60%. In our study, this value was reached after 40 days of incubation for the F1 compost formula.While similar values were observed for F2 only at the 50th day after incubation. This difference in the maturation time of compost F1 with respect to F2 could be explained by the differentiated biochemical composition of the organic matter used as substrate. The biochemical composition of organic fractions in F1 would be less stable than that in F2. We can assume the hypothesis of a stabilized organic fraction contained in the stems of *Andropogongayanus* K. in F2 through a more complex composition than that in the rice straw residues in F1. Indeed, results from [16] showed a high content of cellulose and hemicellulose in the *Andropogongayanus* K. tissues but also a C and N content of 457.1 C mg/g of dry mater and 9.0 N mg/g with a C/N ratio of 50.8. The results of this work suggest that in our composting technique associated with F2, the hypothesis of the presence of relatively recalcitrant compounds slowed the rate of mineralization of the OM.

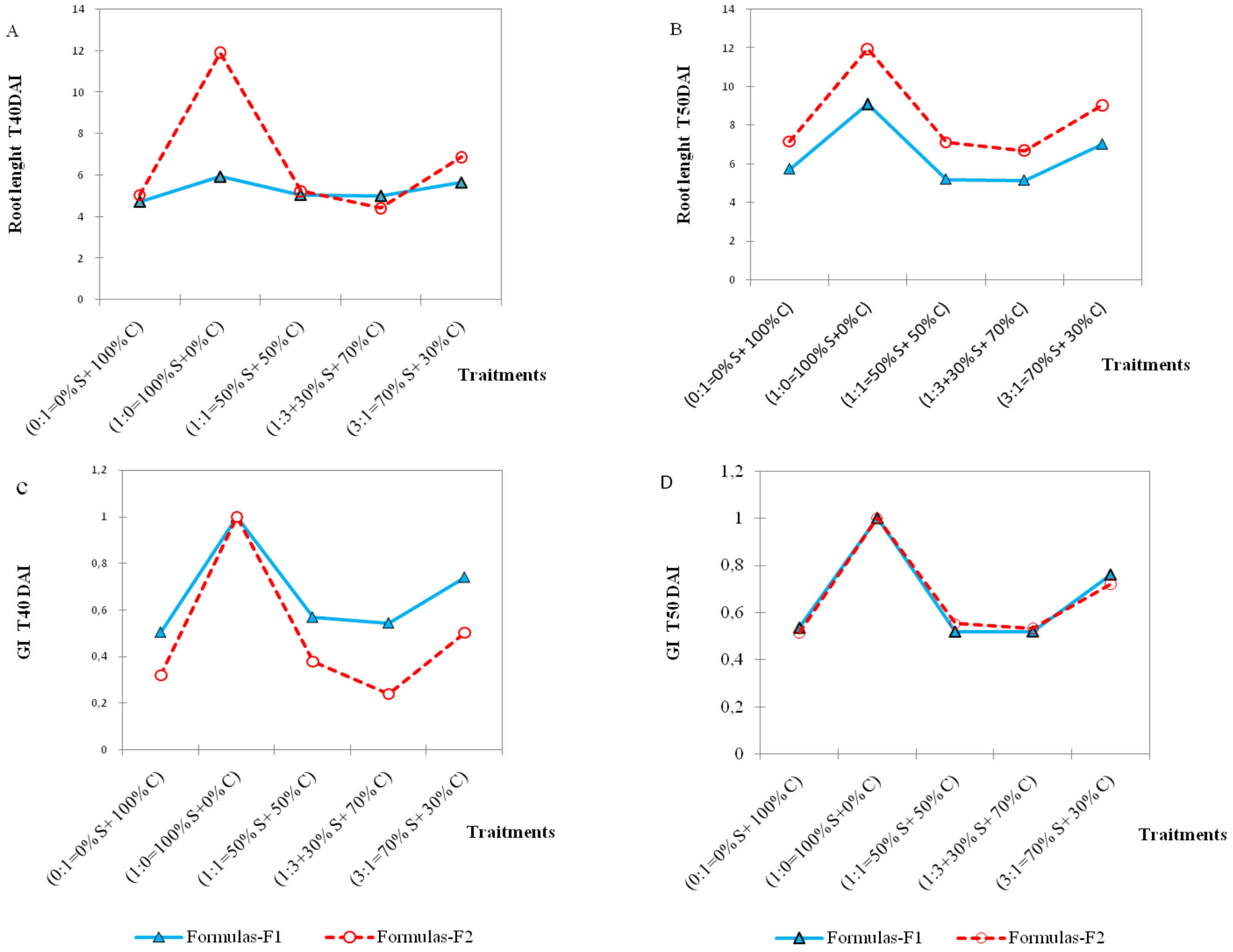

Figure 3: Mean root length (LR) for F1 and F2 at T40thDAI (A) and T50thDAI (B) after incubation and germination mean index (GI) for F1 and F2 at T40thDAI (C) and T50thDAI (D) after incubation based on the treatments (0:1 = 0% S + 100% C); (1:0 = 100% S + 0% C); (1:1 = 50% S + 50% C); (1:3 = 30% S + 70% C); (3:1 = 70% S + 30% C)

Conclusion

In this study, the aeration conditions (turning of the compost every eight (8) days) and the choice in the constitution of the mixtures of organic matter (differentiated organic matter) allowed the development of the F1 and F2 compost formulas and to appreciate the evolution of their stabilization through a phytotoxicity test. Results from the stability test allowed us to define a 40th-day matured compost formula; especially the F1 composed of rice straw and crushed shell. However, for F2, this period corresponded to 50 th days of composting time. With the availability of rice straw in Casamance, it would be interesting to test these composting technologies in farmers' field in order to promote its adoption to better alleviate soil carbon losses and increase farmer's yields.

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