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Effects of inoculation and organic amendments (biochar and compost) on rice growth and production in saline environments

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Abstract: The objective of this semi-controlled study was to evaluate the combined effect of Glomus mosseae and organic amendments on the development of rice plants under two levels of salinity. To do this, a three-factor Fisher block design was set up (salinity doses, organic amendments and mycorrhizal fungi). The parameters studied were seedling survival rate, rice agro-morphological parameters, and the frequency and intensity of mycorrhization of rice plants. The results revealed that plant survival was negatively affected by the highest salt dose (5.4 dS.m-1). However, regardless of the salt dose applied, the compost, C+G1 (fungus+compost), B+C+G1 (Biochar+compost+fungus) and B+C (Biochar+compost) treatments resulted in better survival rates of 98.42%; 100%; 100% and 97.11%, respectively. The compost treatment also increased heights, number of tillers and above-ground and root biomass regardless of salt dose. As for mycorrhization, plants receiving the fungus alone had a higher frequency (80%) and intensity (50%) for the highest salt dose (5.4 dS.m-1). Given the similar effect of fungus+C+B and organic amendments alone (B+C) on production parameters, so for better sustainability of rice cultivation, the use of organic amendments alone is more effective and requires use in salt-affected rice fields. These amendments would contribute to agricultural development by combating food insecurity and poverty.

1. Introduction

Rice occupies a prominent place in the consumption habits of the Senegalese population. In addition, population growth and increasing urbanization have significantly increased the consumption needs for this commodity. Although rice is grown locally in Senegal, rice imports are massive, reaching a net value of 189.27 billion CFA francs in 2016, or 966,498 tons imported (Fall, 2016). Two rice cultivation systems are used in Senegal: irrigated farming, which accounts for up to 60% of production, and rain-fed farming, which is widely practiced in the central, southern, and southeastern parts of the country (ANSD, 2013). In Casamance, rain-fed rice cultivation is the main activity carried out by producers during the rainy season. However, this type of rice cultivation faces several constraints, including climatic constraints that cause a decrease in crop yields and also the abandonment of plots by producers. Among these constraints, the salinization of rice fields is a major issue. According to (Barnawal *et al*., 2014), salinization leads to a deterioration in the biological, chemical, and physical properties of soils, causing a decline in soil fertility, yields, and vegetation cover. In Senegal, saline soils cover an area of 1,700,000 ha out of 3,800,000 ha of arable land (LADA, 2009). Several strategies have been developed to address this problem. These strategies include the construction of anti-salt dikes and levees, the addition of organic amendments (peanut shells, manure, household waste), chemical amendments (phosphogypsum), and reforestation with forest species adapted to salinity. Despite all the efforts made by the population, the salinization of these lands continues to increase. Thus, other approaches such as inoculating crops with mycorrhizal fungi could be considered to improve rice production in saline lowlands (Djatta *et al.*, 2013, Diallo *et al.*, 2016). These fungi form a symbiotic association with nearly 80% of plant species (Garbaye, 2013). This association results in improved absorption of minerals, particularly phosphorus and nitrogen (Djatta *et al.*, 2013; Haro *et al.*, 2015; Manga *et al.*, 2017), increased resistance and tolerance to numerous abiotic and biotic stresses and pathogens, while promoting better water absorption in dry weather and, ultimately, better plant growth (Diouf *et al.*, 2010, Hamza, 2014; Laita *et al.*, 2024a and 2024b). The inoculation of crops with mycorrhizal fungi could be combined with organic amendments. The latter enable the sustainable restoration of the fertility of saline soils, thus leading to good plant productivity (Choudhary et *al.*, 2004; Diatta et *al.*, 2019; Wong et *al.*, 2009). Integrated management combining organic amendments with the use of mycorrhizal fungi in rice fields affected by salinity could be very beneficial. It is in this context that this work aims to characterize the effect of mycorrhizal inoculation in combination with the addition of organic amendments on the growth and production of rice in saline environments.

2. Materials and Methods

2.1. Experimental site

This study was carried out at the application farm of the University of Ziguinchor in Senegal (see **Figure 1**). climate is a tropical sudano-coastal type with a rainy season that last 3 months followed by a 9-month dry season. The average annual rainfall is between 1300 and 1500 mm per year (Sagna *et al.*, 2016).

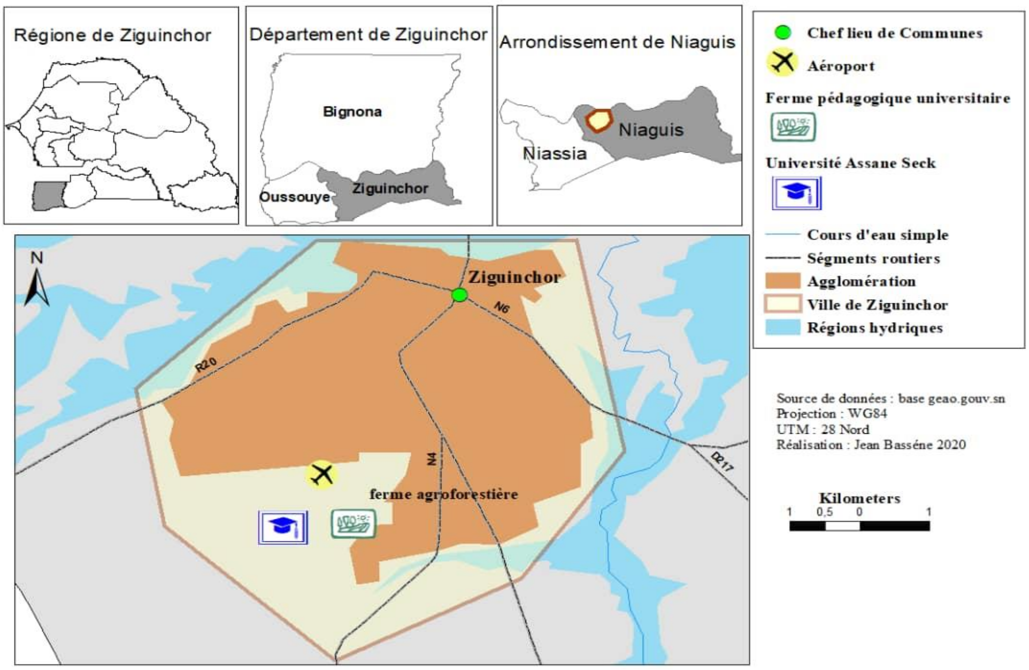

Figure 1. Map showing the location of the experimental site.

2.2 *Plant material, organic amendments, and fungi*

The WAR77 variety of the Oryza genus was used as plant material; the rice variety group is indica. This variety is adapted to lowlands and resistant to salinity. Biochar (B) and cashew compost (C) were used as organic amendments. The biochar was collected from charcoal sellers and has a pH of 7.5. The compost is made from pressed cashew apples that have been left to decompose in piles for at least 12 months; the pH is 6. The chemical compositions of these two amendments are shown in **Table 1**. For the fungus, we used Glomus mosseae (G1, 1000-2000 propagules per 100g of soil). This fungus was supplied by the joint soil microbiology laboratory in Senegal.

Table 1: Chemical composition of the biochar and compost

	Biochar	**Compost**
pH eau 1/ 2,5	7,5	6
CE 1/ 10 µs/Cm	173	148
%C	5,56	8,98
MO %	9,58	15,48
N %	0,56	0,84
C/N	10	11
Ca^{2+} meq/100g	13,5	1,425
Mg^{2+} meq/100g	3,75	1,2
Na^{+} meq/100g	0,073	0,050
K^{+} meq/100g	3,32	0,74
P ppm	14,17	15,71
S meq/100g	20,64	3,42
CEC meq/100g	9	11
T %	229	31
PSE %	0,8	0,5

Legend: CE (Electric Conducty) ; pH (potential hydrogen) ; MO% (Pourcentage of organic matter) ; %C (Pourcentage of Carbon) ; N % (Pourcentage od Nitrigen) ; P (Phosphorus) ; K+ (Potassium) ; S (Sulfur) ; CEC (Cation-Exchange Capacity) ; C/N (Carbone/Nitrogen ratio) ; Na+ (Sodium) ; T% (bases saturation rate) ; Mg (Magnésium) ; Ca (Calcium)

2.3 *Experimental setup and test procedure*

A three-factor Fisher block was used for this experiment. The factors studied were the fungus with two treatments (*Glomus mosseae* and no *Glomus mosseae*), organic amendments with four treatments (compost, biochar, compost + biochar, and control), and salt concentration with three modalities (0 dS.m-1, 2.7 dS.m-1, and 5.4 dS.m-1), corresponding to salt quantities of 0, 1.6875, and 3.375 g/l of NaCl, respectively. For each salinity level, we have 2x4 = 8 treatments, giving a total of 24 treatments for the 3 salt levels, repeated 3 times. For each treatment, 6 bags measuring 20x25 cm were used, containing a mixture of sieved sand and/or organic amendment in proportions of 2/3 amendment and 1/3 sand, depending on the treatment **(Figure 2).** For mycorrhization, the rice seeds were inoculated during sowing with the Glomus mosseae fungus strain at a rate of 10 g of inoculum per seed. Four seeds were sown and gradual thinning was carried out after emergence;

only one plant was kept. Watering was carried out daily at a rate of 200 ml of water per sleeve. In order to facilitate the mycorrhization of the plants, the different doses of NaCl were applied 21 days after sowing (DAS).

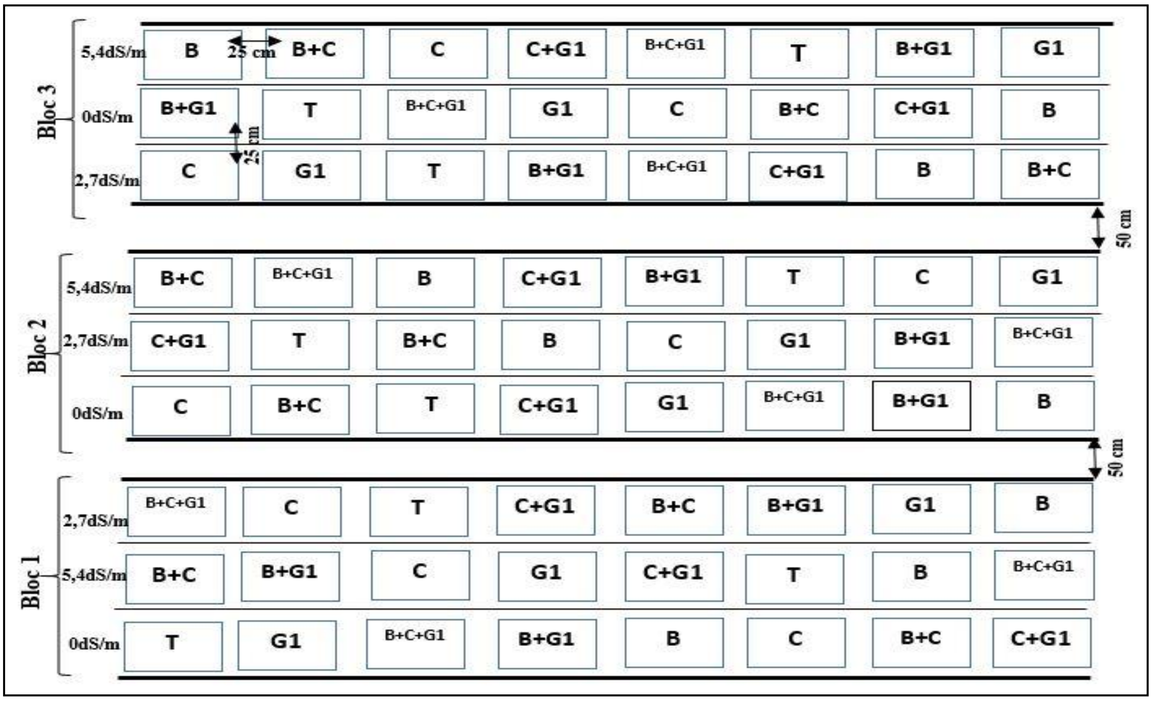

Figure 2: Experimental setup

Legends: B = biochar; C = compost; T = control; B+C = biochar and compost; G1 = Glomus mosseae

2.4. Data collection

Data on agromorphological parameters were collected after NaCl application at 21 DPA, and subsequently every 15 days. Measurements were taken on six plants per treatment for all three blocks. Plant biomass was determined by calculating the average mass of plants per treatment after two months of salt stress application. The collected biomass was weighed after drying in an oven at 70°C for 72 hours using a precision balance with a sensitivity of 10^{-4}.

2.4.1. Frequency and intensity of mycorrhization

These parameters were determined using the method developed by (Phillips, & Hayman, 1970). This method consists of first extracting the roots, then washing them, and finally staining them using a solution (Trypan blue). The frequency and intensity of mycorrhization were assessed under an optical microscope at 400x magnification using the (Trouvelot, 1986). Six rice plants were selected after harvest for each treatment. For the mounting, we chose three slides and mounted 20 fragments on each slide between the slide and cover slip, giving a total of 60 fragments per treatment. The following formulas were used to determine the two parameters:

$$\text{Fréquence } \% = \frac{\text{Nombre de fragments mycorhizés}}{\text{nombre total de fragments}} \times 100$$

$$\text{Intensité } \% = \frac{\text{Longeur des racines infectées}}{\text{longeur tolale des racines}} \times 100$$

2.4.2. Indice de sensibilité relative au stress salin (ISRS)

L'indice de tolérance (IT) sera calculé selon la formule de (Cano et *al*., 1998) :

$$\text{IT } \% = \frac{\text{BAS plant stréssé}}{\text{BAS plant témoin}} \times 100$$

BAS = Biomasse Aérienne Sèc

2.5. Statistical analysis

The data were analyzed using XLSTAT 2014 version 5.03 software. A three-factor ANOVA was used to analyze the data. The means were then compared using Fisher's LSD test at a 5% probability threshold.

3. Results

3.1. Survival rate of plants at different salt concentrations depending on amendments, measurement dates, and years

The survival rate was not significantly influenced by NaCl doses at 15 DAP and 30 DAP, regardless of the type of amendment (p=0.31) **(Table 2).** However, a decrease in the number of plants for both years of the study was observed at 45 DAP and 60 DAP. This decrease varied with the NaCl dose but also with the type of amendment used. Plants that received the 5.4 dS.m-1 salt dose had the lowest survival rates (87.77%) compared to the controls (98.01%). With regard to amendments, regardless of the NaCl dose applied, their effect was highly significant (P=0.001). Thus, the best survival rates for all treatments with NaCl and over the two years of experimentation were obtained with treatments B+C (97.11%), C (98.42%), C+G1 (100%), and B+C+G1 (100%) (Table 8). In contrast, the lowest survival rates were obtained with the biochar (77.76%), B+G1 (87.03%) and G1 (95.22%) treatments for the same dose of NaCl compared to the controls.

3.2. Variation in plant height at different salt doses depending on treatment

Overall, we note that plant heights increased significantly (p=0.0001) over time for all salt doses (control, 2.7 dS.m-1, and 5.4 dS.m-1) applied **(Figures 3a, 3b, and 3c)** for the first and second years of the experiment. For the same date, the heights recorded in the first year are significantly greater (p<0.05) than those recorded in the second year of the experiment **(Table 3).** Some organic amendments had a positive effect on plant growth (p<0.0001). In fact, the highest heights for both years and for all dates compared to the controls, regardless of the salt dose applied, were obtained with the Compost (50.94 cm), Compost+G1 (51.56 cm), B+C+G1 (49.92 cm), and B+C (48.89 cm) treatments **(Table 3).** The lowest heights were obtained with the biochar (28.71 cm), biochar+G1 (25.75 cm), and G1 (35.73 cm) amendments for both years.

Table 2: Survival rate of plants at different salt doses according to treatments and measurement dates

*Values in the same column for the same date with the same letters are not statistically different (Fisher LSD test, 5% threshold). G1=Mushroom, B=biochar, and C=compost

	Biochar		**Compost**		**B+C**		**control**		**Biochar + G1**		**Compost + G1**		**B+C+G1**		**G1**	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
(0 dS.m^{-1}) control																
Initiale	100^{a*}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}
15JAS	100^{a}	$94,44^{a}$	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}
30JAS	$88,86^{b}$	$94,44^{a}$	100^{a}	100^{a}	$93,35^{a}$	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}
45JAS	$77,76^{b}$	$83,33^{ab}$	100^{a}	100^{a}	$93,35^{a}$	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}
60JAS	$77,76^{b}$	$77,77^{b}$	100^{a}	100^{a}	$93,35^{a}$	100^{a}	100^{a}	$83,33^{ab}$	100^{a}	$83,33^{ab}$	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}
Average	**88,87**	**89,99**	**100**	**100**	**96,01**	**100**	**100**	**96,66**	**100**	**96,66**	**100**	**100**	**100**	**100**	**100**	**100**
2,7 dS.m^{-1}																
Initiale	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}
15JAS	$94,43^{a}$	$77,77^{bc}$	100^{a}	100^{a}	100^{a}	$94,44^{a}$	100^{a}	$94,44^{a}$	$94,43^{a}$	$94,44^{a}$	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}
30JAS	$94,43^{a}$	$66,66^{b}$	100^{a}	100^{a}	100^{a}	$94,44^{a}$	100^{a}	$88,88^{ab}$	$94,43^{a}$	$77,77^{b}$	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}
45JAS	$94,43^{a}$	$38,88^{cd}$	100^{a}	100^{a}	100^{a}	$88,88^{ab}$	$86,73^{ab}$	$83,33^{b}$	$72,23^{bc}$	$77,77^{b}$	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}
60JAS	$77,76^{bc}$	$33,33^{cd}$	100^{a}	100^{a}	100^{a}	$88,88^{ab}$	$86,73^{ab}$	$72,22^{bc}$	$72,23^{bc}$	$72,22^{bc}$	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	$88,88^{ab}$
Average	**92,21**	**63,32**	**100**	**100**	**100**	**93,32**	**94,69**	**87,77**	**86,66**	**84,44**	**100**	**100**	**100**	**100**	**100**	**97,77**
5,4 dS.m^{-1}																
Initiale	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}
15JAS	$81,16^{abcd}$	$83,33^{b}$	$91,65^{ab}$	100^{a}	100^{a}	100^{a}	$86,67^{b}$	$88,88^{ab}$	$88,66^{ab}$	$88,88^{ab}$	100^{a}	100^{a}	100^{a}	100^{a}	$85,01^{ab}$	$94,44^{a}$
30JAS	$81,16^{abcd}$	$44,44^{c}$	$91,65^{ab}$	100^{a}	100^{a}	$94,44^{a}$	$86,67^{b}$	$77,77^{bc}$	$88,66^{ab}$	$77,77^{b}$	100^{a}	100^{a}	100^{a}	100^{a}	$85,01^{ab}$	$83,33^{ab}$
45JAS	$57,75^{c}$	$33,33^{cd}$	$91,65^{ab}$	100^{a}	100^{a}	$88,88^{ab}$	$81,1^{ab}$	$66,66^{b}$	$61,1^{c}$	$72,22^{bc}$	100^{a}	100^{a}	100^{a}	100^{a}	$85,01^{ab}$	$83,33^{ab}$
60JAS	$57,75^{c}$	$22,22^{d}$	$77,76^{b}$	100^{a}	100^{a}	$83,33^{ab}$	$81,1^{ab}$	$33,33^{cd}$	$61,1^{c}$	$33,33^{cd}$	100^{a}	100^{a}	100^{a}	100^{a}	$85,01^{ab}$	$66,66^{b}$
Average	**75,56**	**56,66**	**90,54**	**100**	**100**	**93,33**	**87,1**	**73,32**	**79,9**	**74,44**	**100**	**100**	**100**	**100**	**88**	**85,55**

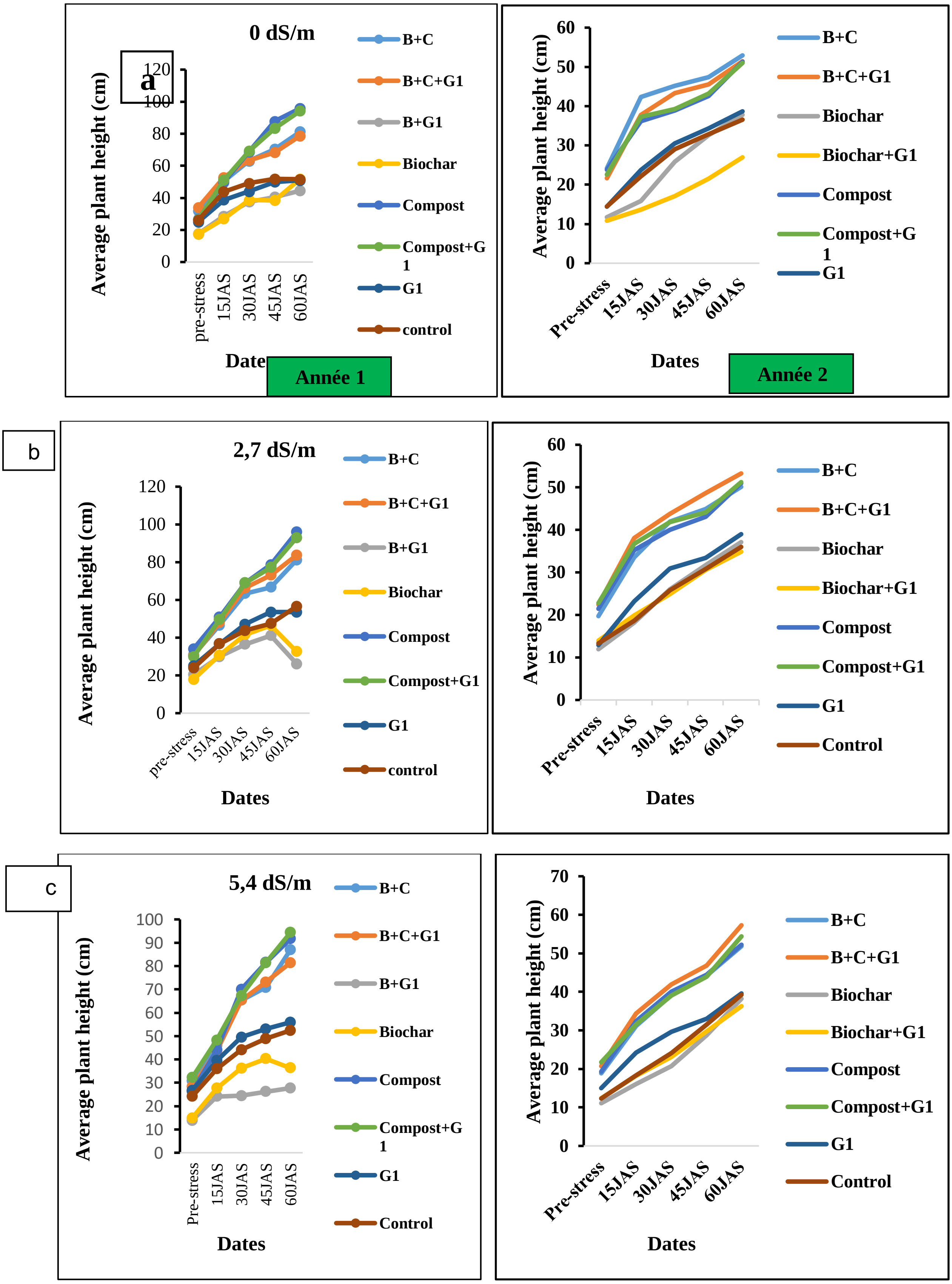

Figure 3: Effect of organic amendments associated with CMA on average plant height growth under saline stress conditions: a (0 $dS.m^{-1}$), b (2.7 $dS.m^{-1}$), and c (5.4 $dS.m^{-1}$)

Table 3: Average plant height according to treatments and measurement dates following different doses of NaCl

	Biochar		**Compost**		**B+C**		**Control**		**Biochar + G1**		**Compost + G1**		**B+C+G1**		**G1**	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
(0 dS.m^{-1}) Control																
Pre-stress	17,38^{e*}	11,71^{e}	26,77^{e}	23,8^{e}	31,8^{de}	24,16^{e}	26,19^{e}	14,45^{e}	17,6^{e}	10,81^{e}	26,41^{e}	22,57^{e}	34,11^{de}	21,63^{e}	25,1^{e}	14,4^{e}
15JAS	27^{e}	15,81^{e}	49,78^{bc}	36,15^{de}	50,49^{bc}	42,31^{bcd}	43,88^{bcd}	22,12^{e}	28,72^{e}	13,57^{e}	51,18^{bc}	37,3^{de}	52,77^{bc}	37,78^{de}	38,8^{de}	23,74^{de}
30JAS	38,46^{de}	25,88^{e}	68,76^{ab}	38,92^{de}	63^{ab}	45,12^{bcd}	49,22^{bc}	28,98^{e}	37,49^{cd}	17,12^{e}	69,19^{ab}	39,27^{cd}	63,44^{ab}	43,30^{bcd}	44,12^{bcd}	30,45^{de}
45JAS	38,66^{de}	32,59^{de}	87,82^{a}	42,53^{bcd}	70,38^{ab}	47,41^{bcd}	51,66^{bc}	32,88^{de}	40,55^{cd}	21,26^{e}	83,44^{a}	43,13^{bcd}	68,38^{ab}	45,53^{bcd}	49,93^{bc}	34,34^{de}
60JAS	51,86^{bc}	37,79^{de}	95,85a	51,31^{bc}	81,23^{a}	52,92bc	51,86^{bc}	36,5^{de}	44,49^{bcd}	26,96^{e}	94,2^{a}	51^{bc}	78,72^{a}	51,42^{bc}	51,03^{bc}	38,67^{cde}
Average	**34,67**	**24,75**	**65,79**	**38,54**	**59,38**	**42,38**	**44,56**	**26,98**	**33,77**	**17,94**	**64,88**	**38,65**	**59,48**	**39,93**	**41,79**	**28,32**
2,7 dS.m^{-1}																
Pre-stress	17,92^{e}	11,93^{e}	34,07^{de}	21,44^{e}	30,80^{de}	19,72^{e}	23,87^{e}	13,31^{e}	20,38^{e}	13,96^{e}	29,93^{de}	22,77^{e}	30,33^{de}	22,42^{e}	25,06^{e}	12,91^{e}
15JAS	30,77^{de}	18,22^{e}	50,79^{bc}	35,20^{de}	46,55^{bcd}	33,53^{de}	36,8^{de}	18,63^{e}	30,01^{e}	19,86^{e}	49,51^{bc}	36,67^{de}	48,05^{bcd}	38,1^{cde}	36,74^{cde}	23,15^{e}
30JAS	32,66^{de}	26,05^{e}	68,98^{ab}	39,97^{de}	63,33^{ab}	41,92^{bcd}	43,77^{bcd}	25,77^{e}	36,43^{cd}	24,87^{e}	68,98^{ab}	41,86^{bcd}	66,39^{ab}	43,70^{bcd}	47,1^{bcd}	30,93^{de}
45JAS	41,62^{bcd}	31,67^{de}	78,64^{a}	43,05^{bcd}	66,66^{ab}	44,92^{bcd}	47,5^{bc}	30,74^{de}	41,1^{bcd}	30,56^{de}	77,25^{a}	44,08^{bcd}	73,14^{a}	48,62^{bc}	53,49^{bc}	33,42^{de}
60JAS	46,46^{bc}	37,11^{de}	95,92^{a}	50,94^{bc}	81,21^{a}	50,11^{bc}	56,61^{b}	35,98^{de}	26,13^{e}	34,85^{de}	93^{a}	51,21^{bc}	83,77^{a}	53,25^{bc}	53,56^{bc}	38,98^{cd}
Average	**33,88**	**24,99**	**65,68**	**35,31**	**57,71**	**38,04**	**41,71**	**24,88**	**30,81**	**24,82**	**63,73**	**39,31**	**60,33**	**41,21**	**43,19**	**27,87**
5,4 dS.m^{-1}																
Pre-stress	14,9^{e}	11,08^{e}	26,13^{e}	19,28^{e}	30,7^{de}	18,85^{e}	24,15^{e}	12,3^{e}	13,88^{e}	12,37^{e}	32,19^{de}	21,72^{e}	28,27^{e}	20,71^{e}	26,65^{e}	15^{e}
15JAS	27,66^{e}	16,03^{e}	43,98^{bcd}	32,42^{de}	45,83^{bcd}	31,17^{de}	35,92^{de}	18,38^{e}	24,1^{e}	18,20^{e}	48,27^{bc}	31,53^{de}	43,55^{bcd}	34,41^{de}	39,47^{cd}	24,2^{e}
30JAS	36,23^{de}	20,73^{e}	70,03^{ab}	40,03^{bcd}	65,38^{ab}	39,22^{cd}	44,08^{bcd}	24,07^{e}	24,46^{e}	23,14^{e}	67,3^{ab}	39,02^{cd}	65,38^{ab}	41,93^{bcd}	49,52^{bcd}	29,62^{e}
45JAS	36,32^{de}	28,73^{e}	81,55^{a}	44,45^{bcd}	70,83^{ab}	44,15^{bcd}	48,9^{bc}	31,46^{de}	26,2^{e}	29,73^{e}	81,44^{a}	43,88^{bcd}	73,16^{ab}	46,83^{bcd}	53,05^{bc}	33,06^{de}
60JAS	40,25^{bcd}	38,22^{cd}	91,7^{a}	52,22^{bc}	81,44^{a}	51,85^{bc}	52,42^{bc}	39,25^{cd}	27,7^{e}	36,28^{cd}	94,33^{a}	54,4^{bc}	81,44^{a}	57,28^{b}	55,91^{b}	39,58^{cd}
Average	**31,07**	**22,95**	**62,67**	**37,68**	**58,83**	**37,04**	**41,09**	**25,09**	**23,26**	**23,94**	**64,71**	**38,11**	**58,36**	**40,23**	**44,92**	**28,29**

Values in the same column for the same date with the same letters are not statistically different (Fisher LSD test, 5% threshold). G1=Mushroom, B=biochar, and C=compost.

3.3.Variation in the number of shoots at different NaCl doses depending on treatment

Data analysis revealed a similar variation in plants depending on the different doses of salt applied **(Figures 4a, 4b, and 4c)**.

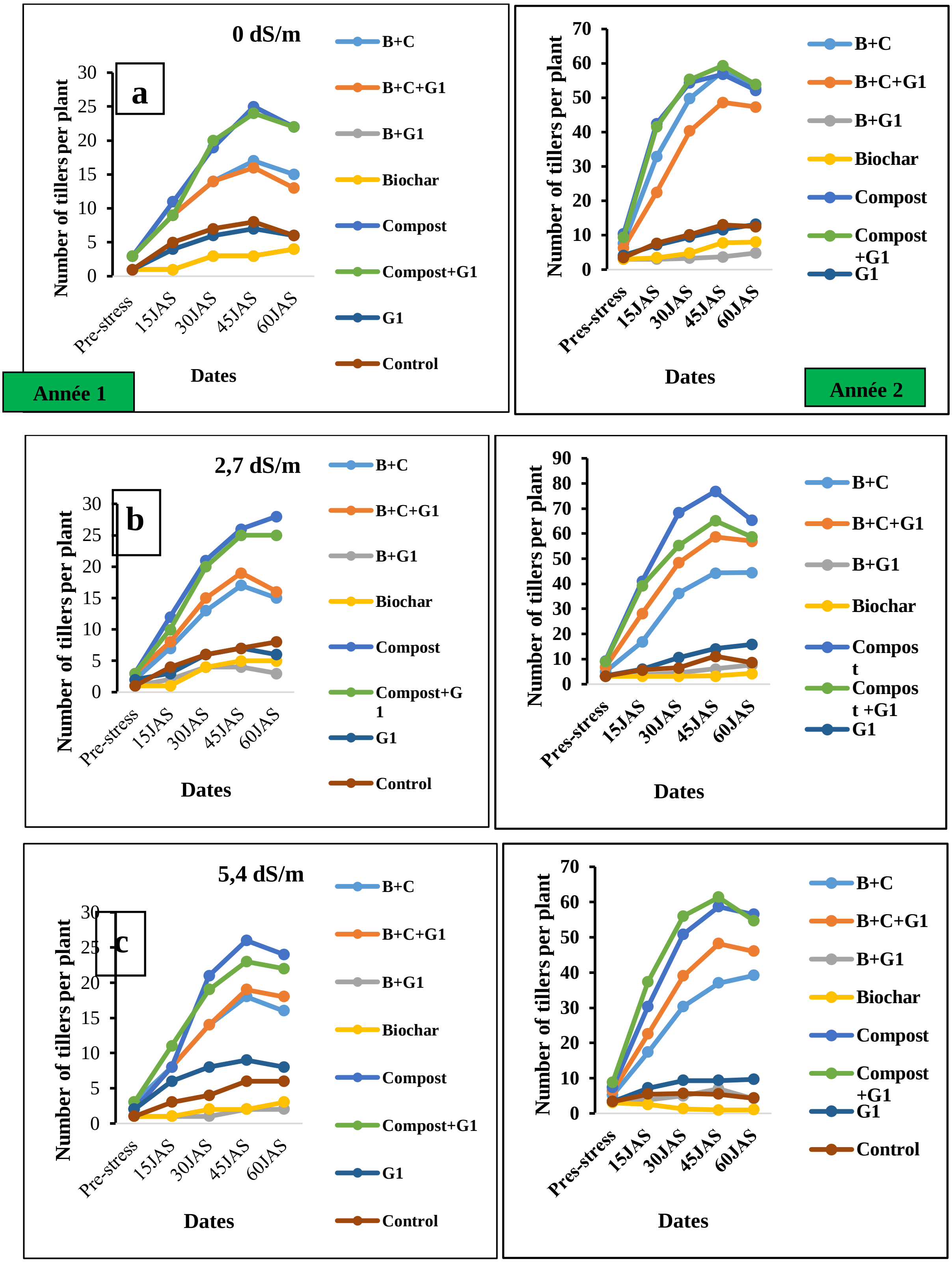

Figure 4: Effect of organic amendments associated with CMA on the number of tillers per plant under saline stress conditions: a (0 dS.m^{-1}), b (2.7 dS.m^{-1}), and c (5.4 dS.m^{-1})

We observed an increase in the number of tillers in rice plants before the application of salt stress up to 45 days after the application of salt stress for all doses of NaCl and treatments used. From 45 days after the application of salt stress, we observed a decrease in the number of tillers for all treatments and salt doses applied. This same trend was observed in the first and second years of the experiment. Analysis of **Table 4** showed us that there is a highly significant difference between the organic amendments used, regardless of the NaCl dose, the dates considered, and the years of experimentation ($p<0.0001$). In fact, the highest number of shoots was obtained with the organic amendments compost (16 shoots), compost+G1 (15 shoots), B+C+G1 (12 shoots) and B+C (12 shoots), regardless of the NaCl dose applied. On the other hand, the lowest number of tillers was obtained with organic amendments such as biochar (2 tillers), biochar+G1 (2 tillers) and G1 (4 tillers) in both the first and second years of the experiment **(Table 4).**

3.4. Variation in dry plant biomass (above-ground and root) of rice plants according to treatment

The highest dry root and total biomasses were obtained with NaCl doses of 0 $dS.m^{-1}$ and 2.7 $dS.m^{-1}$ during the first year **(Table 5).** Biomass was significantly higher for the treatments: compost, compost+G1, B+C, and B+C+G1 in both the first and second years of the experiment ($p=0.0001$). The combination of the Glomus fungus with organic amendments had similar effects to those of organic amendments alone on growth parameters.

3.5. Variation in tolerance index according to different treatments

The NaCl tolerance index (TI) decreased with increasing NaCl concentration **(Table 6).**

At harvest, a significant difference was noted between the ITs for the two NaCl levels (2.7 and 5.4 dS.m-1). This index was higher (100%) with the treatments (compost, compost+G1) for both NaCl doses applied (2.7 and 5.4 $dS.m^{-1}$) and B+C+G1 for the NaCl dose of 2.7 $dS.m^{-1}$. The lowest indices were obtained with biochar and B+G1. It became zero (0%) with the NaCl dose (5.4 dS.m-1) for the biochar treatment **(Table 6).**

3.6. Influence of NaCl and organic amendments on mycorrhization

The intensity and frequency of mycorrhization depending on the different organic amendments were significantly different ($p=0.02$) regardless of the NaCl doses and the years of experimentation **(Table 7).** Plants that received the highest dose of NaCl (5.4 dS.m-1) had a lower frequency (56.31%) compared to the controls (0 dS.m-1) (63.02%) regardless of the year. For the same NaCl concentration, the intensity of mycorrhization varied depending on the different types of organic amendments. At 0 dS.m-1, a significant difference was noted between the different treatments ($p<0.001$).

Table 4: Number of shoots according to organic amendments and depending on measurement dates and NaCl doses

	Biochar		**Compost**		**B+C**		**Control**		**Biochar + G1**		**Compost + G1**		**B+C+G1**		**G1**	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
(0 dS.m^{-1}) Control																
Pre-stress	1^{i*}	1^{i}	3^{hi}	3^{hi}	3^{hi}	3^{hi}	1i	1^{i}	1i	1^{i}	3^{hi}	3^{hi}	3^{hi}	2^{i}	1^{i}	1^{i}
15JAS	1^{i}	1^{i}	11^{ef}	14^{de}	9^{fg}	11^{ef}	5^{ghi}	3^{hi}	1^{i}	1^{i}	9^{fg}	14^{de}	9^{fg}	8^{fg}	4^{ghi}	2^{i}
30JAS	3^{hi}	2^{i}	19^{cd}	18^{cd}	14^{de}	17^{cd}	7^{gh}	3^{hi}	3^{hi}	1^{i}	20^{bc}	18^{cd}	14^{de}	13^{de}	6^{ghi}	3^{hi}
45JAS	3^{hi}	3^{hi}	25^{ab}	19^{cd}	17^{cd}	20^{bc}	8^{fg}	4^{ghi}	3^{hi}	1^{i}	24^{ab}	20^{bc}	16^{de}	16^{de}	7^{gh}	4^{ghi}
60JAS	4^{ghi}	3^{hi}	22^{bc}	17^{cd}	15^{de}	18^{cd}	6^{ghi}	4^{ghi}	4^{ghi}	2^{i}	22^{bc}	18^{cd}	13^{de}	16^{de}	6^{ghi}	3^{hi}
Average	**2**	**2**	**16**	**14**	**12**	**14**	**5**	**3**	**2**	**1**	**16**	**15**	**11**	**11**	**5**	**3**
2,7 dS.m^{-1}																
Pre-stress	1^{i}	1^{i}	3^{hi}	3^{hi}	2^{i}	2^{i}	1^{i}	1^{i}	1^{i}	1^{i}	3^{hi}	3^{hi}	3^{hi}	2^{i}	2^{i}	1^{i}
15JAS	1^{i}	1^{i}	12^{ef}	14^{de}	7^{gh}	6^{ghi}	4^{ghi}	2^{i}	2^{i}	1^{i}	10^{ef}	13^{de}	8^{fg}	9^{fg}	3^{hi}	2^{i}
30JAS	4^{ghi}	1^{i}	21^{bc}	23^{ab}	13^{de}	12^{ef}	6^{ghi}	2^{i}	4^{ghi}	1^{i}	20^{bc}	18^{cd}	15^{de}	16^{de}	6^{ghi}	4^{ghi}
45JAS	5^{ghi}	1^{i}	26^{ab}	29^{a}	17^{cd}	30^{a}	7^{gh}	4^{ghi}	4^{ghi}	2^{i}	25^{ab}	22^{bc}	19^{cd}	20^{bc}	7^{gh}	5^{ghi}
60JAS	5^{ghi}	1^{i}	28^{a}	22^{bc}	15^{de}	15^{de}	8^{fg}	3^{hi}	3^{hi}	3^{hi}	25^{ab}	20^{bc}	16^{de}	19^{cd}	6^{ghi}	5^{ghi}
Average	**3**	**1**	**18**	**18**	**11**	**13**	**5**	**2**	**3**	**2**	**17**	**15**	**12**	**13**	**5**	**3**
5,4 dS.m^{-1}																
Pre-stress	1^{i}	1^{i}	2^{i}	2^{i}	3^{hi}	2^{i}	1^{i}	1^{i}	1^{i}	1^{i}	3^{hi}	3^{hi}	2^{i}	2^{i}	2^{i}	1^{i}
15JAS	1^{i}	1^{i}	8^{fg}	10^{ef}	8^{fg}	6^{ghi}	3^{hi}	2^{i}	1^{i}	1^{i}	11^{ef}	12^{ef}	8^{fg}	8^{fg}	6^{ghi}	2^{i}
30JAS	2^{i}	1^{i}	21^{bc}	17^{cd}	14^{de}	10^{ef}	4^{ghi}	2^{i}	1^{i}	2^{i}	19^{cd}	19^{cd}	14^{de}	13^{de}	8^{fg}	3^{hi}
45JAS	2^{i}	1^{i}	26^{ab}	18^{cd}	18^{cd}	12^{ef}	6^{ghi}	2^{i}	2^{i}	2^{i}	23^{ab}	20^{cd}	19^{cd}	16^{de}	9^{fg}	3^{hi}
60JAS	3^{hi}	1^{i}	24^{ab}	19^{cd}	16^{de}	13^{de}	6^{ghi}	1^{i}	2^{i}	1^{i}	22^{bc}	18^{cd}	18^{cd}	15^{de}	8^{fg}	3^{hi}
Average	**2**	**2**	**16**	**13**	**12**	**9**	**4**	**2**	**1**	**1**	**16**	**14**	**12**	**11**	**7**	**2**

**Values in the same column for the same date with the same letters are not statistically different (Fisher LSD test, 5% threshold). G1=Mushroom, B=biochar, and C=compost*

Table 5: Plant biomass, above-ground biomass, and root biomass of plants according to treatment.

Treatments	Total biomass (g)		Above-ground biomass (g)		Root biomass (g)	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
			(0 dS.m^{-1}) control			
Biochar	2,66^{d*}	3,31^{b}	1,917^{de}	2,34^{b}	1,08^{de}	0,97^{efg}
Compost	27,23^{a}	23,5^{a}	17,15^{a}	17,35^{a}	10,08^{abcde}	6,15^{a}
B+C	27,68^{a}	24,11^{a}	13,97^{ab}	19,77^{a}	13,70^{a}	4,34^{ab}
control	7,44^{cd}	5,01^{b}	3,85^{cde}	3,62^{b}	3,58^{abcde}	1,39^{efg}
Biochar + G1	3,053^{d}	1,06^{b}	1,77^{de}	0,73^{b}	1,27^{de}	0,33^{g}
Compost + G1	25,3^{a}	21,26^{a}	14,49^{ab}	17,23^{a}	10,8^{abcd}	4,02^{bc}
B+C+G1	30,16^{a}	20,69^{a}	19,75^{a}	16,92^{a}	10,41^{abcde}	3,77^{bc}
G1	7,41^{cd}	4,86^{b}	3,80^{cde}	3,48^{b}	3,61^{abcde}	1,38^{efg}
Average	**17,35**	**12,97**	**9,71**	**10,18**	**7,68**	**2,79**
			2,7 dS.m^{-1}			
Biochar	5^{d}	2,48^{b}	2de	1,98^{b}	3^{bcde}	0,5^{g}
Compost	23,91^{a}	23,89^{a}	11,33^{abcd}	20,51^{a}	12,58^{ab}	3,37^{bcd}
B+C	19,16^{abc}	19,83^{a}	11,04^{abcd}	18,1^{a}	7,98^{abcde}	1,73^{defg}
control	5,52^{d}	4,58^{b}	3,47^{de}	3,63^{b}	2,04^{cde}	0,94^{fg}
Biochar + G1	1,66^{d}	5,21^{b}	0,27^{e}	3,79^{b}	1,38^{de}	1,41^{efg}
Compost + G1	26^{a}	21,95^{a}	13,81^{ab}	19,2^{a}	12,18^{abc}	2,75^{bcde}
B+C+G1	23,95^{a}	24,24^{a}	15,22^{a}	20,26^{a}	8,73^{abcde}	3,98^{bc}
G1	7,77^{cd}	5,64^{b}	5,06^{bcde}	4,66^{b}	2,7^{bcde}	0,97^{efg}
Average	**16,51**	**13,47**	**8,86**	**11,51**	**7,62**	**1,95**
			5,4 dS.m^{-1}			
Biochar	0^{d}	0,77^{b}	0^{d}	0,62^{b}	0^{d}	0,15^{g}
Compost	21,04^{ab}	19,4^{a}	10,96^{abcd}	16,96^{a}	10,06^{abcde}	2,43^{cdef}
B+C	22,91^{a}	21,23^{a}	14,99^{a}	18,62^{a}	7,91^{abcde}	2,6^{bcde}
control	7,29^{cd}	3,94^{b}	3,68^{cde}	3,5^{b}	3,61^{abcde}	0,44^{g}
Biochar + G1	0,443^{d}	1,76^{b}	0,33^{e}	1,27^{b}	0,11^{e}	0,48^{g}
Compost + G1	26,88^{a}	22,41^{a}	13,23^{abc}	19,62^{a}	13,65^{a}	2,79^{bcde}
B+C+G1	20,27^{ab}	17,97^{a}	11,24^{abcd}	16,21^{a}	9,02^{abcde}	1,76^{defg}
G1	9,16^{bcd}	5,48^{b}	5,34^{bcde}	5,07^{b}	3,82^{abcde}	0,41^{g}
Average	**14,95**	**11,62**	**8**	**10,23**	**6,95**	**1,38**

**Values in the same column for the same date with the same letters are not statistically different (Fisher LSD test, 5% threshold). G1=Mushroom, B=biochar, and C=compost*

Table 6: Salinity tolerance indices (%) of dry above-ground biomass after 2 months of cultivation according to treatment

Treatments	NaCl doses: 0 $dS.m^{-1}$ (Control)		2,7 $dS.m^{-1}$		5,4 $dS.m^{-1}$	
	Year 1	Yera 2	Yera 1	Yera 2	Yera 1	Yera 2
Compost	100^{a*}	100^{a}	100^{a}	100^{a}	100^{a}	$97,75^{a}$
Compost +G1	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}
Biochar	100^{a}	100^{a}	$76,66^{a}$	$84,61^{a}$	0^{b}	$26,49^{b}$
Biochar +G1	100^{a}	100^{a}	$33,33^{b}$	100^{b}	$10,01^{b}$	100^{a}
B+C+G1	100^{a}	100^{a}	100^{a}	100^{a}	$93,333^{a}$	$95,80^{a}$
B+C	100^{a}	100^{a}	$99,27^{a}$	$91,55^{a}$	$89,460^{a}$	$94,18^{a}$
control	100^{a}	100^{a}	$93,67^{a}$	100^{a}	$81,834^{a}$	$96,68^{a}$
G1	100^{a}	100^{a}	$93,182^{a}$	100^{a}	$91,909^{a}$	100^{a}
Average	**100**	**100**	**87,01**	**97,02**	**70,81**	**88,86**

**For each column, values followed by the same letters are not significantly different at the 5% threshold according to Fisher's LSD test (5% threshold). G1=Mushroom, B=biochar, and C=compost*

Table 7: Variation in the frequency and intensity of mycorrhization of rice plants according to treatment

Treatments	Mycorrhiza: Frequency (%)		Intensity (%)	
	Year 1	Year 2	Year 1	Year 2
(0 $dS.m^{-1}$) control				
Biochar	$64,44^{abc*}$	$53,88^{bcdef}$	$5,983^{d}$	$21,317^{b}$
Compost	$48,88^{cdefg}$	35^{fg}	$11,75^{bcd}$	$11,75^{bcd}$
B+C	$69,44^{abc}$	$74,44^{ab}$	$41,65^{a}$	$41,65^{a}$
Control	$57,7^{bcdef}$	30^{fg}	24^{b}	24^{b}
Biochar + G1	$81,66^{a}$	$64,44^{abc}$	$21,317^{b}$	$5,983^{d}$
Compost + G1	$53,33^{bcdef}$	$57,22^{bcdef}$	$8,594^{cd}$	$8,594^{cd}$
B+C+G1	$74,44^{ab}$	$69,44^{abc}$	$43,922^{a}$	$43,922^{a}$
G1	$54,1^{bcdef}$	$66,66^{abc}$	$17,083^{bcd}$	$17,083^{bcd}$
Average	**62,99**	**56,38**	**21,78**	**21,78**
2,7 $dS.m^{-1}$				
Biochar	$36,66^{fg}$	$38,88^{fg}$	$4,95^{d}$	$4,95^{d}$
Compost	$48,88^{cdefg}$	35^{fg}	$2,783^{d}$	$2,783^{d}$
B+C	$39,16^{defg}$	$62,08^{abcd}$	$10,217^{bcd}$	$10,217^{bcd}$
Témoin	$37,77^{fg}$	$67,77^{abc}$	$22,606^{b}$	$22,606^{b}$
Biochar + G1	$72,77^{abc}$	$62,22^{abcd}$	$23,733^{b}$	$23,733^{b}$
Compost + G1	$78,88^{a}$	$59,44^{bcdef}$	$24,067^{b}$	$24,067^{b}$
B+C+G1	$62,08^{abcd}$	$77,5^{a}$	$24,633^{b}$	$24,633^{b}$
G1	$63,88^{abcd}$	$67,77^{abc}$	$24,756^{b}$	$24,756^{b}$
Average	**55,01**	**58,83**	**17,21**	**17,21**
5,4 $dS.m^{-1}$				
Biochar	$51,6^{bcdef}$	$78,88^{a}$	$9,45^{cd}$	$23,233^{b}$

Compost	63,33^{abcd}	43,33^{cdefg}	18,661^{bc}	18,661^{bc}
B+C	33,33^{fg}	63,33^{abc}	0,017^{d}	0,017^{d}
Témoin	25,55^{g}	35^{fg}	7,333^{cd}	7,333^{cd}
Biochar + G1	66,66^{abc}	75^{ab}	23,233^{b}	9,45^{bcd}
Compost + G1	60,55^{abcd}	75^{ab}	21,392^{b}	21,392^{b}
B+C+G1	67,77^{abc}	41,25^{cdefg}	21,217^{b}	21,217^{b}
G1	81,66^{a}	80^{a}	50,033^{a}	50,033^{a}
Average	**56,3**	**61,47**	**18,91**	**18,91**

For each column, values followed by the same letters are not significantly different at the 5% threshold according to Fisher's LSD test (5% threshold). G1=Mushroom, B=biochar, and C=compost

Biochar combined with the fungus had a higher mycorrhization frequency (81.66%), followed by treatment B+C+G1 (74.44%). At a salinity of 2.7 dS.m-1, only plants inoculated with Glomus in combination with organic amendments showed significantly higher mycorrhization intensities and frequencies. At a concentration of 5.4 dS.m-1, the intensities and frequencies were significantly higher in plants inoculated with G. mosseae alone compared to other plants that were mycorrhized but in combination with organic amendments. For control plants and those treated with organic amendments, mycorrhization was observed with organic amendment treatments, with significantly increased mycorrhization intensity and frequency ($p<0.05$).

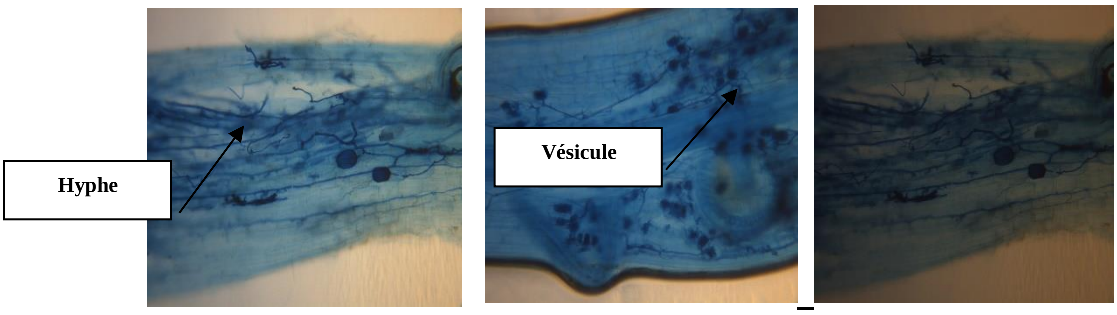

Figure 5: Photos showing the different vesicles and hyphae in rice roots (photo credit: Yaya DIATTA)

4. *Discussion*

4.1. Effect of NaCl, mycorrhizal fungus (*Glomus mosseae*), and organic amendments on rice growth and dry matter production

The survival rate of rice plants varied depending on the NaCl doses, the dates of measurement, and the organic amendments applied. The low survival rate recorded with the NaCl dose of 5.4 dS.m-1 is thought to be due to the unavailability of nutrients resulting from the salinity level. According to Munns *et al*., (2006) and KEMASSI, (2011), excess salt in the soil reduces the availability of nutrients for plants, leading to their death. Similar results were found by Labo *et al*., (2016), who noted higher plant mortality depending on the duration of salt stress application. Plant responses to salinity could therefore vary with the degree and duration of the stress imposed, as well as the stage of plant development (Munns, 1993; Chetouani *et al*., 2023) . Diatta *et al*., (2019) highlighted the sensitivity of rice to salt stress during the seedling stage and also at the time of maximum tillering. These results are consistent with the work of Diatta *et al*., (2019), who noted significant mortality of rice plants in saline areas during the seedling stage and during tillering.

Rice growth was strongly stimulated by the addition of organic amendments regardless of the NaCl dose applied. The highest plant biomass yields were obtained with the Compost, C+G1, B+C, and B+C+G1 treatments. This stimulation of growth can be explained by the availability of nutrients in the organic amendments used (Mukendi *et al*., 2017). These results are consistent with the work of Mrabet *et al*., (2011), who obtained significant biomass with compost. Zamil *et al*., (2004) and Zro *et al*. (2018) showed that organic amendments improved the availability of nitrogen, phosphorus, and potassium, leading to better plant growth. In our study, the combination of biochar and compost stimulated plant growth more effectively than compost alone. Similar results were found by Ognalaga *et al*., (2015), who noted greater heights when combining biochar with compost. According to these authors, plant height growth and production parameters are largely related to the availability of nitrogen and phosphorus in the soil.

The combined use of fungi and organic amendments did not significantly stimulate rice growth compared to organic amendments alone. These results could be explained by the nutrient content of the organic amendments applied, which would limit the effect of fungi on improving plant growth. A previous study (Hérinasandratra, 2019) showed that mycorrhizae stimulated the growth of host plants, particularly in soils with low mineral availability; fungi appear to be more effective when the environment is poor in minerals. These results corroborate those of (Haro *et al*., 2015), who showed that plants do not need to establish mycorrhizal symbiosis if nutrients are available and directly accessible. Thus, fertilization applied to plants during their growth has a major influence on the establishment of mycorrhization (Boukcim & Mousain, 2001).

4.2.Effect of NaCl and organic amendments on mycorrhization

The highest frequency and intensity of mycorrhization were obtained with the Glomus treatment alone, regardless of the NaCl dose. These results are consistent with the work of Ndonda *et al*., (2019), who noted high frequency and intensity of mycorrhization in cassava plants without organic amendments. They concluded that organic amendments reduced the effectiveness of fungi. The same observation was made by Diouf *et al*., (2010), who noted that high levels of nitrogen and assimilable phosphorus in the soil inhibited microbial symbiosis. In our study, the intensity of mycorrhization did not reach 50% regardless of the treatment used. Quilambo, (2003) argues that low rates of root colonization are linked to the secretion of antifungal substances or the quality of root exudates, which inhibit the establishment of mycorrhizal infection. The mutualistic relationship between the Glomus fungus and its host was not beneficial for rice development despite its high mycorrhization frequency of 80%. The growth of rice plants is therefore not necessarily linked to the intensity and frequency of mycorrhization. These results are consistent with those of Hetrick *et al*., (1992), who showed that plant growth was not necessarily linked to the degree of colonization of their roots by fungi.

Conclusion

The objective of this study was to evaluate the response of rice to mycorrhizal inoculation and organic amendments (cashew compost and biochar) as a function of NaCl concentration. The results show similar effects between the application of organic amendments alone and mycorrhizal inoculation combined with organic amendments on the growth parameters (height and number of tillers) and production parameters (above-ground and root biomass) of rice, regardless of the NaCl dose applied.

It appears that NaCl doses of 5.4 dS.m-1 negatively affect the survival rate of rice plants at 45 and 60 days after sowing. The frequency and intensity of mycorrhization of rice plants were higher when the fungus was used alone. Thus, their combination with organic amendments reduced the establishment of mycorrhization. It would be interesting to conduct a further study on double mycorrhizal and rhizobial inoculation to evaluate their effects on rice growth and biomass production.

It would also be interesting to monitor the effect of these factors on rice growth and soil characteristics in natural environments, in the field, in order to establish an effective resilience strategy in the face of increased salinization of agricultural land. .

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Disclosure statement: *Conflict of Interest:* The authors declare that there are no conflicts of interest.
Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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