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Effects of mycorrhization and organic amendments on sweet potato (*Ipomoea batatas* L.) growth in a saline environment

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Abstract: Sweet potato (*Ipomoea batatas* L.) production is hindered by an increase salinization of agricultural soils in the south of Senegal. Combined use of organic amendments and mycorrhizal fungi could be a mean to improve agricultural productivity in soils affected by salinity. The aim of this study was to determine the effect of organic amendments: biochar (B) and compost (C), combined with mycorrhization on the growth of sweet potato under saline conditions. Sweet potato cuttings were transplanted into plastic buckets of 18 l capacity in a split-plot experimental design with two factors: salt concentrations (0 $dS.m^{-1}$, 2 $dS.m^{-1}$ and 4 $dS.m^{-1}$) and organic treatments (compost biochar and mycorrhizae). A total of 24 treatments with 3 replicates consisting of different combinations of salt concentrations and/or mixture with mycorrhizal fungi species *Glomus fasciculatum*, (*G*) and/or organic amendments were used. Data on pH, agro-morphological parameters, and mycorrhization were collected at different periods: 30 days after transplanting (30DAT), 45DAT, 60DAT, 75DAT, 90DAT. Results showed that the pH was not significantly influenced by different treatments ($P>0.05$). Plants that received 4 $dS.m^{-1}$ of salt had the lowest survival and mycorrhization rates compared to the control (0 $dS.m^{-1}$) ($P<0.05$). However, these rates increased significantly with the addition of organic amendments ($P<0.05$). Overall, organic treatments such as B+C, B+G resulted in an increase in height, number of leaves and root biomass regardless of salt concentrations. Aerial and root biomasses was not significantly impacted by salt ($P>0.05$). This study suggests that compost and biochar combined with mycorrhizal fungi with *G. fasciculatum* could improve sweet potato growth in salinity-affected environments.

1. Introduction

Land salinization is a major issue on a global scale (Diallo et *al.*, 2015), with highly depressive effects on agricultural production (Snoussi and Abbad, 2012). In arid and semi-arid zones, saline stress limits the production of plant species (Khaled et *al.*, 2003; Abouatallah et *al.*, 2012; Alaoui et *al.*, 2013; Laita *et al.*, 2024). Sweet Potato (*Ipomoea batatas* L.) is one of the most widely consumed tuberous plants in the world, due to its high nutritional value (Bovell-Benjamin, 2007; Garane et *al.*, 2017). In sub-Saharan Africa, it ranks 3rd among tuber crops after cassava and yam (Dibi et *al.*, 2020), and is one of the most important carbohydrate staples (Mbanaso et *al.*, 2012; Djinet et *al.*, 2015). However,

production of sweet potato has been declining in the Senegalese River Valley due to a decline in soil fertility and the impact of salinity (Diallo et *al.*, 2015; N'guessan et *al.*, 2021). The use of chemical fertilizers could be a solution to offset the drop in production (Haro et *al.*, 2015). However, in addition to their high cost, these chemical fertilizers are likely to lead to pollution, loss of biodiversity and thus the degradation of the most fragile agricultural systems (Plenchette et *al.*, 2005; Djinet and Ngaryam, 2021). As a result, there is a need to develop methods for boosting sweet potato production in Africa, and more specifically in Senegal, in a context of sustainable agriculture. The use of arbuscular mycorrhizal fungi (AMF) could be an alternative for boosting sweet potato production under saline stress conditions. These symbiotic microorganisms are used to increase plant productivity (Diop et *al.*, 2013). AMF are known for their ability to improve plant hydromineral nutrition and for helping plant to withstand environmental stresses such as salinity (Smith and Read, 2008; Haro et *al.*, 2015). Plant resilience to salinity could also be overcome by the use of organic amendments (compost and biochar). Indeed, in addition to stimulating biological activity by increasing soil humus, they contribute to improving the physical, chemical and biological properties of the soil by improving its structure, increasing its water retention capacity and increasing soil nutrient availability (Donia et *al.*, 2013).

A combination of organic amendments and AMF could be very promising to improve crop production and in particular sweet potato in saline environment. It is with this perspective that this study has been carried out to determine how sweet potato growth could be improved in saline environment by using organic amendments (biochar and compost) and AMF *Glomus fasciculatum*.

2. Materiel 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 (Descroix et *al.*, 2015; Sagna et *al.*, 2016).

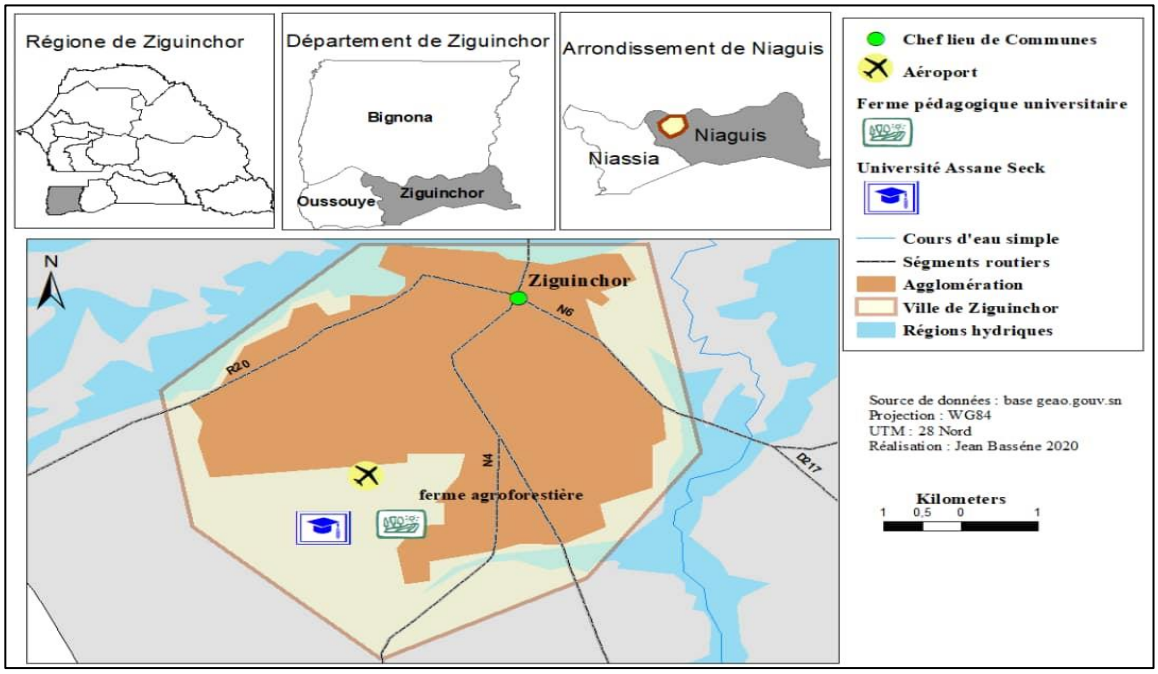

Figure 1. Map showing the location of the experimental site.

2.2. Plant material

Sweet potato cuttings of the "*Walo"* variety were used as plant material. The variety have a cycle of production ranging from 100 to 120 days. Cutting of sweet potato having 3 nodes was used for the experiment.

2.3. Organics amendments and soil properties

Two types of organic amendments were used in this study: biochar and cashew compost. Biochar was collected from charcoal sellers, while compost was collected from cashew apples that were pressed and left to decompose in piles for at least 12 months. The chemical compositions of these two amendments are shown in **Table 1**. Organic amendments were mixed at a rate of (1v/20v) for x volume of a sandy-limon soil collected at the experimental station. The mixture was then distributed at 2/3 of 18 L buckets.

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

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)

2.4. Fungal material

A strain of AMF *Glomus fasciculatum* from the joint microbiology laboratory LCM in Dakar, Senegal, was used in this study. *Glomus fasciculatum* has a spore density ranging from 10 to 20 spores per g of soil. The inoculum consisted of spores and was supplied at a rate of 20 g per experimental unit.

2.5. Experimental design and trial conduct

A two-factor split-plot design was used in this experimental. The 2 factors were: salt concentration (1st factor) with 3 modalities (0 dS.m^{-1}, 2 dS.m^{-1} and 4 dS.m^{-1}) corresponding to the respective concentrations of NaCl of 0 g.l^{-1}, 1.25 g.l^{-1} and 2.5 g.l^{-1} and organic amendments (2nd factor) with 8 modalities: biochar (B), compost (C), *Glomus* (G), biochar + compost, biochar + *Glomus*, compost + *Glomus*, biochar + compost + *Glomus* and control). The total number of treatments was 8 x 3 = 24 with 3 replicates distributed in 3 blocks. This gives a total of 24 x 3 = 72 experimental units for all three blocks (see **Figure 2**). For each experimental unit, a bucket of 18 l where one sweet potato cutting was planted was used. Spacing was 1 m between blocks. Potato cuttings were inoculated during

transplant with the *Glomus fasciculatum* strain at a rate of 20 g fungal inoculum per cutting. To facilitate mycorrhization of the seedlings, salt stress was applied at 30 days after transplanting (DAT). Watering was carried out daily.

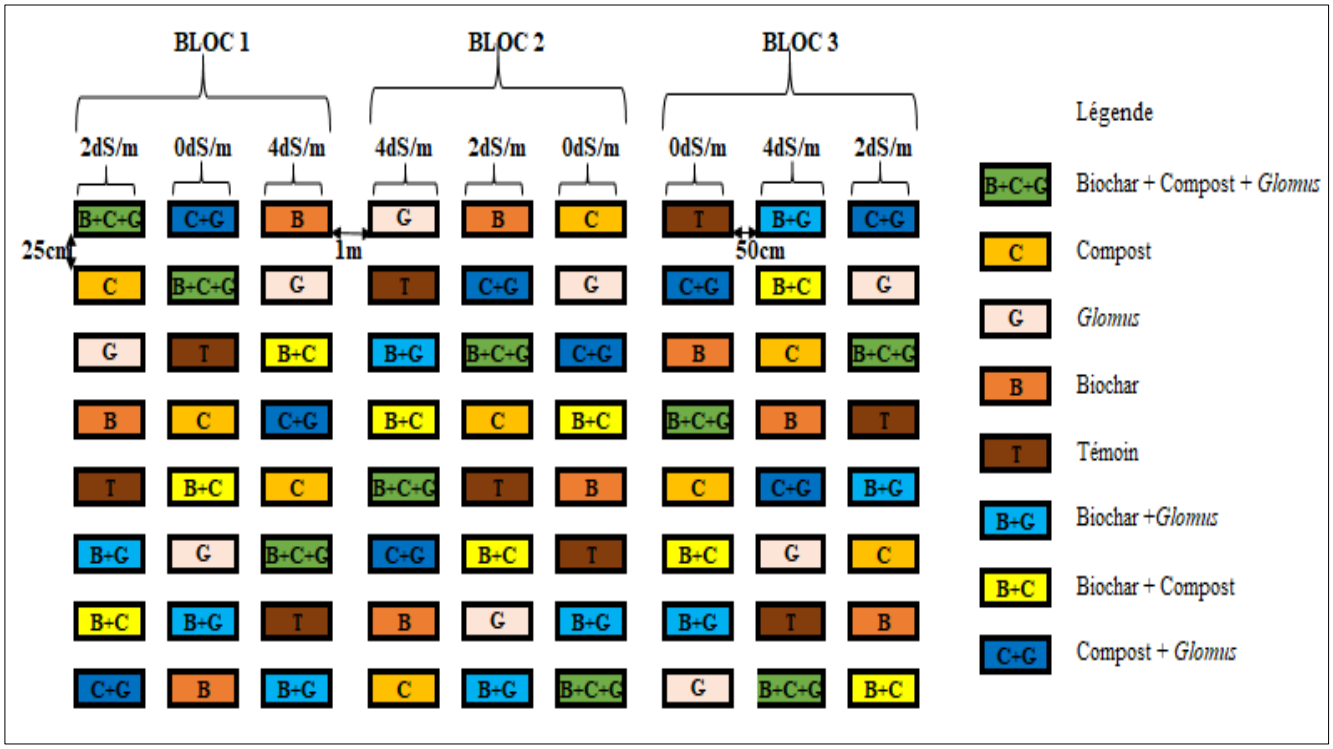

Figure 2. Diagram of the experimental design

2.6 Data Collection

Data pertain to soil parameters, mycorrhization intensity and frequency, and agro-morphological parameters of sweet potato under salt stress were collected.

2.6.1 Soil parameters

Soil samples were collected and air-dried for 72 hours to reduce moisture content. For each sample, the pH was measured from a 20 g of soil mixed with 50 ml of distilled water at 15DAT, 30DAT, 45DAT and 60DAT.

2.6.2. Agromorphological parameters and Plant biomass

Survival rates were determined for each treatment at 15DAT, 30DAT, 45DAT and 60DAT. The number of leaves, branches and the height of the plants were evaluated at the same dates. Plant height was measured using a metric tape. The date at which 50% of the plants had flowered was recorded. Above-ground and root biomasses were collected at each sampling date, oven-dried at 70°C for 72 h, and weighed using a 10^{-4} precision balance.

2.6.4. Mycorrhization parameters

Mycorrhization frequency and intensity were determined using the method of Phillips and Hayman (1970). For each treatment, 3 cuttings of sweet potato were selected after harvest and the roots were collected. After thorough rinsing with distilled water, root fragments were incubated in 10%

KOH at 90°C before being stain with a blue methyl. Mycorrhization frequency and intensity were assessed using the method of Trouvelot et *al.*, (1986). The following formulas were used to compute the frequency and intensity of the mycorrhization:

$$F\,\% = \frac{\text{Number of mycorrhizal fragments}}{\text{total number of fragments observed}} \times 100$$

$$I\,\% = \frac{(95n5 + 70n4 + 30n3 + 5n2 + n1)}{\text{total number of fragments observed}}$$

2.7. Statistical Analyses

Data were processed with R-studio software version 4.1.0 and the Shapiro Wilk normality test was performed. A two-factor ANOVA was used to analyze the data. Treatment means were compared using the Fisher LSD test at the 5% probability threshold.

3. RESULTS

3.1. Soil parameters

3.1.1. pH variation

pH data across all treatments showed no difference (P>0.05) among the date, amendment or applied salt concentrations (*see* **Table 2**).

Table 2. Variation of pH according to dates, amendments and salt concentrations

	pH							
	Biochar	Compost	B+C	Control	B+G	C+G	B+C+G	G
	Salt concentration: 0 dS.m^{-1}							
Initial	5.6±0.3^{ab*}	5.9±0.7^{ab}	6.4±0.6^{a}	5.8±0.3^{ab}	5.8^{ab}	5.6±0.2^{ab}	5.4±0.2^{ab}	5.7±0.2^{ab}
15DAT	5.7±0.6^{a}	5.7±0.4^{a}	5.7±0.4^{a}	5.8±0.5^{a}	5.9±0.5^{a}	5.8±0.5^{a}	5.8±0.6^{a}	5.8±0.4^{a}
30DAT	5.7±0.1^{a}	5.9±0.3^{a}	5.7±0.3^{a}	5.8±0.1^{a}	5.7±0.2^{a}	5.9±0.1^{a}	5.7±0.2^{a}	5.7±0.1^{a}
45DAT	6.4±0.4^{a}	6.3±0.1^{a}	6.4±0^{a}	6.3±0^{a}	6.3±0^{a}	6.4±0.1^{a}	6.4±0.2^{a}	6.4±0.1^{a}
60DAT	7.2±0.4^{a}	7.2±0.3^{a}	7.1±0.3^{a}	7.2±0.3^{a}	7±0.3^{a}	7.1±0.2^{a}	6.9±0.2^{a}	7±0.2^{a}
Average	6.12	6.2	6.26	6.18	6.14	6.16	6.04	6.12
	Salt concentration: 2 dS.m^{-1}							
Initial	5.8±0.1^{a}	5.7±0.1^{a}	5.7±0.3^{a}	5.6±0.5^{a}	5.8±0.1^{a}	5.7±0.1^{a}	5.8±0.1^{a}	5.6±0.3^{a}
15DAT	5.7±0.2^{a}	5.7±0.3^{a}	5.5±0.1^{a}	5.8±0.2^{a}	5.8±0.2^{a}	5.6±0.1^{a}	5.6±0.2^{a}	5.7±0.2^{a}
30DAT	6±0.4^{a}	5.6±0.4^{a}	5.8±0.1^{a}	5.7±0.2^{a}	5.9±0.2^{a}	5.4±0.3^{a}	5.5±0.1^{a}	5.7±0.3^{a}
45DAT	6.3±0.1^{a}	6.5±0.2^{a}	6.3±0.1^{a}	6.4±0.1^{a}	6.4±0.1^{a}	6.4±0.1^{a}	6.3±0.2^{a}	6.4±0.1^{a}
60DAT	6.5±0.3^{ab}	6.6±0.3^{a}	6.4±0.1^{a} b	6.3±0.1^{ab}	6.4±0.1^{a} b	6.4±0.1^{ab}	6.3±0.2^{ab}	6.3±0.1^{ab}
Average	6.06	6.02	5.94	5.96	6.06	5.9	5.9	5.94
	Salt concentration: 4 dS.m^{-1}							
Initial	5.8±0.6^{a}	5.7±0.2^{a}	5.9±0.4^{a}	5.9±0.1^{a}	5.7±0.2^{a}	5.9±0.1^{a}	6.2±0.5^{a}	6.2±0.3^{a}
15DAT	6±0.4^{a}	5.6±0.4^{a}	5.8±0.1^{a}	5.7±0.2^{a}	5.9±0.3^{a}	5.4±0.3^{a}	5.5±0.1^{a}	5.7±0.3^{a}
30DAT	5.8±0.3^{a}	6.1±0.5^{a}	5.9±0.2^{a}	5.9±0.1^{a}	6.1±0.3^{a}	5.8±0.3^{a}	5.9±0.2^{a}	5.8±0.4^{a}
45DAT	6.5±0.3^{a}	6.6±0.3^{a}	6.4±0.1^{a}	6.3±0.1^{a}	6.4±0.1^{a}	6.4±0.1^{a}	6.3±0.2^{a}	6.3±0.1^{a}
60DAT	6.6±0.1^{a}	6.7±0.3^{a}	6.6±0.1^{a}	6.8±0.3^{a}	6.8±0.2^{a}	6.8±0.6^{a}	6.5±0.51^{a}	6.7±0.3^{a}
Average	6.14	6.08	6.12	6.12	6.18	6.06	6.08	6.14

*Values in the same column followed by the same letters are not statistically different (Fisher's test, 5% LSD).

3.2. Agromorphological parameters

3.2.1. The effect of organic amendments on agro-morphological parameters of Ipomoea batatas (L.), grown under salt stress conditions

Agro-morphological parameters were significantly different among sampling dates, organic treatments and salt concentrations ($p<0.05$). The effect of the amendment on the number of leaves, the number of branches and the survival rate with the exception of the number of branches were significantly dependent of the salt concentration ($p<0.001$).

3.2.1.1. Survival rate

The results of the interaction test between the factors (see **Table 3**) reveal very highly significant effects ($P<0.001$) of all the factors on plant survival. In fact, survival rates varied according to the amendments applied, salt concentrations and sampling dates. Overall, plants receiving the highest concentration (4 $dS.m^{-1}$) showed the lowest survival rates (87.72%) compared with the control (96.66%). However, a non-significant decrease in survival rate was noted for all amendments, with the exception of B+C and B+G for the intermediate concentration (2 $dS.m^{-1}$) at 60DAT. The best rates (100% and 100%) were obtained with B+G and biochar respectively.

Table 3. Variation in survival rate according to dates, amendments and salt concentrations

	Survival rate (%)							
	Biochar	Compost	B+C	Control	B+G	C+G	B+C+G	G
				Salt concentration: 0 $dS.m^{-1}$				
Initial	100±0^{a*}	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}
15DAT	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}
30DAT	100±0^{a}	100±0^{a}	100±0^{a}	66.67±0^{b}	100 ±0^{a}	100 ±0^{a}	100 ±0^{a}	100 ±0^{a}
45DAT	100±0^{a}	100±0^{a}	100±0^{a}	66.67±0^{b}	100 ±0^{a}	100 ±0^{a}	100 ±0^{a}	100 ±0^{a}
60DAT	100±0^{a}	100±0^{a}	66.67±0^{b}	66.67±0^{b}	100 ±0^{a}	100 ±0^{a}	100 ±0^{a}	100 ±0^{a}
Average	100	100	93.33	80	100	100	100	100
				Salt concentration: 2 $dS.m^{-1}$				
Initial	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}
15DAT	100±0^{a}	100±0^{a}	100±0^{a}	66.67±0^{b}	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}
30DAT	100±0^{a}	100±0^{a}	100±0^{a}	66.67±0^{b}	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}
45DAT	100±0^{a}	100±0^{a}	100±0^{a}	66.67±0^{b}	100±0^{a}	100±0^{a}	66.67±0^{b}	66.67±0^{b}
60DAT	66.67±0^{b}	33.33±0^{c}	100±0^{a}	NA±0^{a}	100±0^{a}	66.67±0^{b}	66.67±0^{b}	66.67±0^{b}
Average	93.33	86.66	100	75	100	93.33	86.66	86.66
				Salt concentration: 4 $dS.m^{-1}$				
Initial	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}
15DAT	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}	100±0^{a}
30DAT	100±0^{a}	100±0^{a}	100±0^{a}	66.67±0^{b}	100±0^{a}	66.67±0^{b}	100±0^{a}	66.67±0^{b}
45DAT	100±0^{a}	100±0^{a}	100±0^{a}	66.67±0^{b}	100±0^{a}	33.33±0^{c}	100±0^{a}	66.67±0^{b}
60DAT	66.67±0^{b}	66.67±0^{b}	66.67±0^{b}	NA±0^{a}	66.67±0^{b}	33.33±0^{c}	66.67±0^{b}	NA±0^{a}
Average	93.33	93.33	93.33	83.33	93.33	66.66	93.33	83.33

*Values in the same column followed by the same letters are not statistically different (Fisher's test, 5% LSD).

3.2.1.2. Variation in number of leaves

The variation in the number of plant leaves as a function of the amendments and salt concentrations is represented in **Table 4**. The number of leaves increased with each samplig date, irrespective of salt concentration and organic amendment. Analysis of variance showed a highly

significant difference (P<0.001) between treatments (organic amendments, salt concentration and sampling dates). The lowest number of leaves was obtained with the salt concentration of 4 $dS.m^{-1}$. Regardless of sampling date, amendments B+C, C+G and B+C+G gave the highest number of leaves for all salt concentrations.

Table 4. Variation in number of leaves according to dates, amendments and different salt concentrations

	Number of leaves							
	Biochar	Compost	B+C	Témoin	B+G	C+G	B+C+G	G
Salt concentration: 0 $dS.m^{-1}$								
Initial	6.3 ±4^{a*}	4±0^{a}	8±6^{a}	6.3±1.5^{a}	6.3±1.5^{a}	5.3±0.5^{a}	5.6±1.5^{a}	4.6±0.5^{a}
15DAT	8.6±4.6^{a}	4.6±1.1^{a}	11±7.2^{a}	5.3±1.1^{a}	7.6±1.5^{a}	7.6 ±4.5^{a}	8.6±4.9^{a}	6.6 ±3^{a}
30DAT	16±11.2^{a}	9±3.0^{a}	19±13.5^{a}	9.6±4.1^{a}	10±5.0^{a}	15±12.5^{a}	20.6±11^{a}	11.3±7^{a}
45DAT	22.3±9.4^{a}	13.6±3^{a}	17±19.9^{a}	11.6±7.3^{a}	14.6±9.0^{a}	20.3±15^{a}	26±10.7^{a}	15±8.5^{a}
60DAT	27.6±7^{ab}	19.3±7^{ab}	40±12.7^{a}	18.6±7.5^{a} b	20±12.1^{ab}	24.3±14^{ab}	33.6±7.5^{a} b	17.3±7.5^{a} b
Average	16.16	10.1	19	10.28	11.6	14.5	18.94	10.96
Salt concentration: 2 $dS.m^{-1}$								
Initial	9.6±7^{a}	5.3±1.1^{a}	7.3±4.1^{a}	3.6±0.57^{a}	7.33±0.6^{a}	7.6±6.3^{a}	6.6±2^{a}	7.3±3.2^{a}
15DAT	14.0±7^{a}	6.6±1.5^{a}	9 ±4.3^{a}	3.5±0.7^{a}	15.0±1^{a}	10.0±11^{a}	9±2.6^{a}	8.6±1.1^{a}
30DAT	19±11.5^{ab}	7±3.6^{ab}	11.3±3.7^{ab}	6±2.8^{ab}	26.6±6.3^{a}	12±13.8^{ab}	7±2.6^{ab}	9.6±2.8^{ab}
45DAT	20±16.5^{a}	5.5±3^{a}	14.3±9.4^{a}	5± 5.65^{a}	31.6±7.0^{a}	11±13.0^{a}	8±2.8^{a}	10±2.6^{a}
60DAT	20.6±17^{a}	9±NA^{a}	21.6±4.0^{a}	9±NA^{a}	31.3±5.0^{a}	18.0±8.3^{a}	18.5±0.7^{a}	13.5±2.1^{a}
Average	16.64	6.68	12.7	5.42	22.33	11.72	9.82	9.8
Salt concentration: 4 $dS.m^{-1}$								
Initial	6±2.6^{ab}	4.6±2.5^{ab}	5±1^{ab}	6±2^{ab}	6.3±1.5^{ab}	3.3±0.5^{b}	7.6±3.2^{a}	5.6±0.5^{ab}
15DAT	10.6±5^{a}	5.6±1.5^{bc}	7.3±1.1^{ab}	7.3±5.6^{ab}	11.6±3.7^{a}	4.0±1.7^{b}	10.3±3.5^{a}	6±2.6^{ab}
30DAT	11.6±4.7^{b}	5±1^{bc}	12.3±3.7^{b}	12±8.4^{b}	20.3±5.5^{a}	3.3±2.3^{c}	10±3.6^{bc}	10.5±3^{bc}
45DAT	13.6±6^{ab}	3.5±2.1^{c}	17.6±5.1^{ab}	16^{abc}	23.6±6.5^{a}	2.0^{c}	7.6±5.1^{c}	11±1.4^{bc}
60DAT	16.6±8^{ab}	4±NA^{b}	19.0±4.5^{ab}	16.0^{ab}	25±6.5^{a}	0^{b}	11.5±2.1^{b}	12±^{ab}
Average	11.68	4.54	12.24	9.46	17.36	3.15	9.4	9.02

*Values in the same column within the same salt concentration followed by the same letters are not statistically different (Fisher's test, 5% LSD).

3.2.1.3. Variation in plant height

Overall, plant heights increased with sampling date for all salt concentration (see **Table 5**). There is a significant difference (P<0.05) for all amendments and all salt concentrations. The heights recorded with the control concentration (0 $dS.m^{-1}$) for the same sampling dates are significantly greater than those recorded with the 2 $dS.m^{-1}$ and 4 $dS.m^{-1}$ concentrations (Table 8). However, some organic amendments had a positive influence on plant height growth (P<0.05). Indeed, amendments such as G (46.13 cm), B+C (44.70 cm), biochar (44.02 cm) gave the greatest heights for all dates compared with the control regardless of the salt concentration (see **Table 5**). The lowest heights were obtained with the compost amendment and control for all salt concentrations.

3.2.1.4. Evolution of the number of branches

The number of branches by plant was not statistically different (P=0.0601) according to salt concentration and the type of organic amendments the same sampling date (see **Table 6)**. For all the salt concentration, the biggest numbers of branches were obtained with the amendments B+G and B+C.

Table 5. Variation in plant height according to dates, amendments and salt concentrations

*Values in the same column within the same salt concentration followed by the same letters are not statistically different (Fisher's test, 5% LSD).

	Height (cm)							
	Biochar	Compost	B+C	Control	B+G	C+G	B+C+G	G
Salt concentration: 0 dS.m^{-1}								
Initial	25.3±24^{ab}	25.6±6.4^{a}	21±6^{ab}	17.6±4^{ab}	16±4.3^{ab}	17.6±10^{ab}	28±10.5^{a}	12±1^{b}
15DAT	8.6±4.6^{a*}	4.6±1.15^{a}	41±18.1^{a}	27±6.1a	22±5.5^{a}	22.3±2.5^{a}	8.6±4.9^{a}	6.6 ±3^{a}
30DAT	46.6±13^{a}	39.6±14^{a}	55.6±21^{a}	27.5±12^{a}	38±9.5^{a}	50±16.6^{a}	44.3±6.6^{a}	39.6±21^{a}
45DAT	91±29.4^{a}	59.3±29^{a}	70±14^{a}	52.6±5.5^{a}	56±14.1^{a}	82.3±51^{a}	82.6±29^{a}	59.6±25^{a}
60DAT	92.3±29^{a}	82.6±35^{a}	80±1.4^{a}	74.3±23^{a}	66.3±4.7^{a}	108.6±37^{a}	114±49.5^{a}	85.6±24^{a}
Average	52.76	42.34	53.92	39.8	39.66	56.04	55.5	67.8
Salt concentration: 2 dS.m^{-1}								
Initial	31±9.8^{a}	25.6±16^{a}	22.3±13^{a}	13.3±2.1^{a}	29.6±9.1^{a}	20.3±13^{a}	24.6±11^{a}	25.3±5.6^{a}
15DAT	37±7^{a}	29±16.3^{a}	27±10.5^{a}	22±2.8^{a}	33±6.1^{a}	24.6±15^{a}	32±7.5^{a}	29.6±5.8^{a}
30DAT	51.6±16^{a}	34.3±16^{a}	42±9.1^{a}	32±14.1^{a}	47.3±5.1^{a}	25.6±15^{a}	39.6±3.5^{a}	38±6.2^{a}
45DAT	58.3±22^{a}	40^{a}	51.3±13^{a}	65^{a}	72±25^{a}	54±36.7^{a}	70±0^{a}	54±17.7^{a}
60DAT	31.5±12^{a}	0	58±7.1^{a}	0	52±14.7^{a}	49.5±27^{a}	64±30.2^{a}	76±NA^{a}
Average	41.88	25.78	40.12	26.46	46.72	34.7	46.04	44.58
Salt concentration: 4 dS.m^{-1}								
Initial	16.6±2.1^{a}	14.6±4^{a}	18.6±3^{a}	15±7.2^{a}	24±11.2^{a}	14.6±4^{a}	19.6±7.5^{a}	12.6±1.1^{a}
15DAT	23.6±10^{a}	28.3±11^{a}	29.6±7.6^{a}	21.3±1.5^{a}	27±2.6^{a}	22.6±7.1^{a}	26.6±0.5^{a}	21±2.6^{a}
30DAT	42±23.2^{a}	30±11^{a}	47.6±13^{a}	31.5±12^{a}	43.3±14^{a}	19.5±6.3^{a}	39.6±4.6^{a}	36.5±7.7^{a}
45DAT	59.6±45^{a}	32±NA^{a}	62.6±17^{a}	70±NA^{a}	59.3±5^{a}	NA	44.5±7^{a}	60±NA^{a}
60DAT	46^{a}	0^{b}	42±2.8^{a}	0^{b}	50^{a}	0^{b}	0^{b}	0^{b}
Average	37.44	20.98	40.08	27.56	40.72	11.34	17.16	26.02

Table 6. Variation in the number of branches according to dates, amendments and salt concentrations

*Values in the same column within the same salt concentration followed by the same letters are not statistically different (Fisher's test, 5% LSD).

	Nb of branches							
	Biochar	C	B+C	Control	B + G	C + G	B+C+G	G
Salt concentration: 0 dS.m^{-1}								
Initial	0±0^{a*}	3±NA^{ab}	2±0^{bc}	0±0^{a}	1±0^{a}	0±0^{a}	1±0^{a}	1±0^{a}
15DAT	1±NA^{a}	0±0^{a}	1±0^{a}	0±0^{a}	2±NA^{a}	1±NA^{a}	1.5±07^{a}	1±NA^{a}
30DAT	1±00^{a}	1±0^{a}	2±1^{a}	1±0^{a}	1±NA^{a}	1±NA^{a}	1±0^{a}	1±NA^{a}
45DAT	1±NA^{a}	1±0^{a}	1.6±0.5^{a}	1.5±0.7^{a}	1±0^{a}	1±0^{a}	3±1.41^{a}	1±0^{a}
60DAT	1.6±0.5^{b}	2±NA^{ab}	4±NA^{a}	4±2^{ab}	2.6±0.5^{ab}	2.6±1.1^{ab}	3.3±1.5^{ab}	2±NA^{ab}
average	0.93	1.40	2.13	1.30	1.53	1.13	1.86	1.20
Salt concentration: 2 dS.m^{-1}								
Initial	1±0^{a}	2.5±0^{a}	0±0^{a}	0±0^{a}	1±0^{a}	1±0^{a}	1±NA^{a}	1±0^{a}
15DAT	1±NA^{b}	5±NA^{a}	1±0^{b}	0±0^{b}	1.3±0.5^{b}	1±NA^{b}	1±0^{b}	1±0^{b}
30DAT	2±0^{a}	1±NA^{a}	1.6±0.5^{a}	1±0^{a}	1.6±0.5^{a}	2 ±NA^{a}	1.5±0.7^{a}	1±NA^{a}
45DAT	1±0^{a}	1.3±0.5^{a}	1.5±0.7^{a}	1.3±0.5^{a}	1±0^{a}	1±NA^{a}	1±NA^{a}	1.5±0.7^{a}
60DAT	2±1^{a}	1.5±0.7^{a}	3±2.6^{a}	1±NA^{a}	2±1^{a}	2±1.41^{a}	2.5±0.7^{a}	1.5±0.7^{a}
average	1.40	2.16	1.43	0.66	1.39	1.40	1.40	1.20
Salt concentration: 4 dS.m^{-1}								
Initial	0±0^{a}	0±0^{a}	0±0^{a}	0±0^{a}	0±0^{a}	0±0^{a}	0±0^{a}	0±0^{a}
15DAT	1.5±0.7^{ab}	1±0^{b}	1.3±0.5^{ab}	1±NA^{b}	2±NA^{ab}	1±NA^{b}	1±0^{ab}	2.5±0.7^{a}
30DAT	2±NA^{a}	1±0^{a}	1.6±0 .5^{a}	0±0^{a}	1.5±0.7^{a}	0±0^{a}	1±NA^{a}	1±NA^{a}
45DAT	1.5±0.7^{a}	1±NA^{a}	2.5±0.7^{a}	1.3±0.5^{a}	1.6±1.1^{a}	1.5±0.7^{a}	1.5±0.7^{a}	2.5±0.7^{a}
60DAT	2±1^{a}	1.5±0.7^{a}	3±0.6^{a}	1±NA^{a}	2±1^{a}	2±1.4^{a}	2.5±0.7^{a}	1.5±0.7^{a}
average	1.40	0.90	1.09	0.66	1.43	0.90	1.40	1.50

3.3. Production parameters

3.3.1. Flowering date

The flowering date of the plants depended on the amendments and salt concentration (**Figure 3**). The flowering date was statistically influenced by salt concentration according to ANONA. For the control, 0 $dS.m^{-1}$ of salt, there was no significant difference (P = 0.607) between flowering dates and the type of amendments. However, the plants receiving the biochar amendment (B) proved to be the flower the earliest, reaching 50% flowering at 90 DAT, compared with the others which reached this value 30 days later. For the 2 $dS.m^{-1}$ and 4 $dS.m^{-1}$ salt concentrations, the surviving plants all reached 50% flowering by 90DAT.

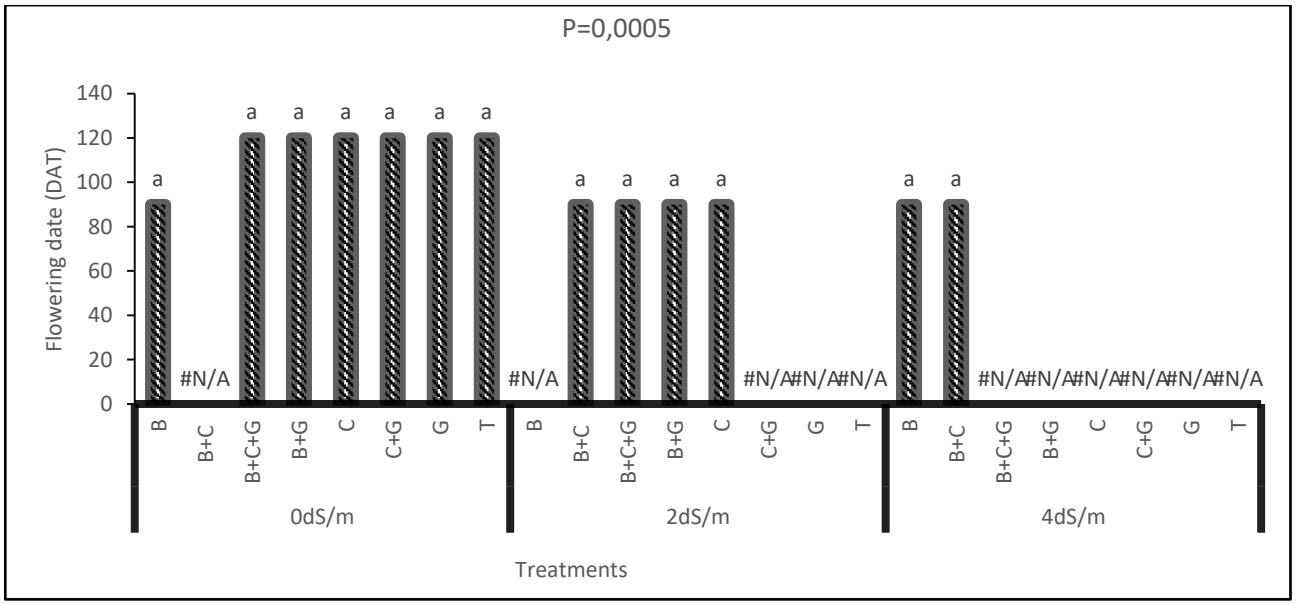

Figure 3. Variation in 50% flowering dates according to amendments and salt concentrations

3.3.2. Variation in aerial, root and total biomasses

Salt concentration had no significant effect (P>0.05) on above-ground, root and total biomasses (*see* **Table 7**). However, soil amendments did have a significant (P<0.0001) effect on root and total biomasses.

Table 7. Test for interaction between factors.

	Root biomass	Aerial biomass	Total biomass
NaCl	ns	ns	ns
Amendments	*	ns	**
NaClxAmendments	*	ns	ns

*Significatif (P<0.01)

Biomass variation is shown in **Table 8**. Overall, there was no difference in biomass between salt concentration (P>0.05). However, some organic amendments had a significant influence on root and total biomasses, regardless of the salt concentration. These were most significant with biochar for root biomass (21.8±15.9) and total biomass (42±21.3) at the highest concentration of 4 $dS.m^{-1}$. On the other hand, these parameters are weaker with compost. Similar results were obtained by studying the effect of composts addition on the development and growth of three type of trees which are peach, pear and orange (Atemni et *al.*, 2022).

Table 8. Variation in aerial, root and total biomasses as a function of treatments.

Treatments	Aerial biomass (g)	Root biomass (g)	Total biomass (g)
	Salt concentration : 0 dS.m^{-1}		
Biochar	13.4±5.7^{ab*}	24.1±5.7^{a}	37.6±28.1^{a}
Compost	9.5±0.7^{C}	7.5±1.5^{a}	15.1±2.7^{abc}
B+C	18.6±16.8^{a}	17.9±5.1^{a}	36.6±21.8^{ab}
Contol	13.0±6.1^{bc}	7.7±3.6^{a}	20.7±9.8^{abc}
B+G	17.1±7.7^{a}	10.6±4.8^{a}	27.7±4.3^{ab}
C+G	9.9±2.4^{bc}	15.2±2.9^{a}	25.1±4.9^{ab}
B+C+G	12.2±2.8^{bc}	17.2±3.2^{a}	29.4±6.1^{ab}
G	10.1±3.3^{bc}	12.3±2.9^{a}	22.5±6.7^{abc}
Average	13.1	13.2	26.8
Probabilité	0.0171	0.0988	0.05717
	Salt concentration : 2 dS.m^{-1}		
Biochar	9.1±6.5^{b}	13.5±2.8^{a}	22.6±3.6^{ab}
Compost	11.8±2.9^{ab}	13.1±4.9^{a}	20.9±7.3^{ab}
B+C	14.8±8.8^{a}	13.3±2.6^{a}	28.2±11.5^{ab}
Control	12.8±1.6^{ab}	23.8±3.5^{a}	36.6±3.7^{a}
B+G	10.7±0.4^{ab}	14.5±3.9^{a}	25.3±4.4^{ab}
C+G	10.4±2.1^{ab}	10.8±3.9^{a}	21.2±2.2^{ab}
B+C+G	12.5±0.4 ^{ab}	14.6±4.5^{a}	27.2±4^{ab}
G	11.3±4.7 ^{ab}	13.2±2.6^{a}	24.5±7.4^{ab}
Average	11.76	13.75	25.8
Probability	0.0171	0.213	0.145
	Salt concentration : 4 dS.m^{-1}		
Biochar	20.6±6.5^{a}	21.8±15.9^{a}	42±21.3^{a}
Compost	7.3±1.6^{c}	8.6±1.5^{a}	15.6±2.9^{abc}
B+C	10.5±6.1^{bc}	10.8±6.1^{a}	21.3±11.4^{abc}
Control	10.8±1.7^{bc}	7.9±1.5^{a}	18.8±2.9^{abc}
Biochar + G	20.2 ±9.2^{a}	11.9±0.3^{a}	32.5±9^{ab}
Compost + G	18.6±8.6^{ab}	15.7±6.8^{a}	34.3±12.1^{ab}
B+C+G	17.6±13.3^{ab}	12.7±1.4^{a}	32.4±14.7^{ab}
G	11.9±9^{bc}	15.5±4.1^{a}	27.4±8.2^{ab}
Average	14.69	12.75	28
Probability	0.023	0.202	0.0728

*Values in the same column within the same salt concentration followed by the same letters are not statistically different (Fisher's test, 5% LSD).

3.4. Mycorrhization parameters

3.4.1. Mycorrhization frequency and intensity

There was a highly significant P<0.001) influence of salt concentration, organic amendments and their interaction on mycorrhization frequency and intensity in sweet potato plants (see **Table 9, Figure 4**).

Table 9. Interaction test of factors on mycorrhization parameters**.**

	Frequency	Intensity
NaCl	***	***
Amendment	***	***
Amendment x NaCl	***	***

***Significatif (P<0.001)

Indeed, the highest mycorrhization frequency and intensity values were recorded with the control salt concentration of 0 $dS.m^{-1}$ compared with those obtained with the 4 $dS.m^{-1}$ concentration. There was also a highly significant difference ($P<0.001$) between the amendments for all salinity levels. Indeed, for the control (0 $dS.m^{-1}$), the biochar-*Glomus* (B+G) amendment recorded the highest mycorrhization frequency and intensity values, while the lowest were obtained with the control (T). For the 2 $dS.m^{-1}$ salt concentration, the B+G amendment recorded the highest mycorrhization frequencies and intensities, while the lowest were obtained with the compost (C). For the 4 $dS.m^{-1}$ salt concentration, the highest mycorrhization rates were obtained with the combination treatment of compost and *Glomus*(C+G).

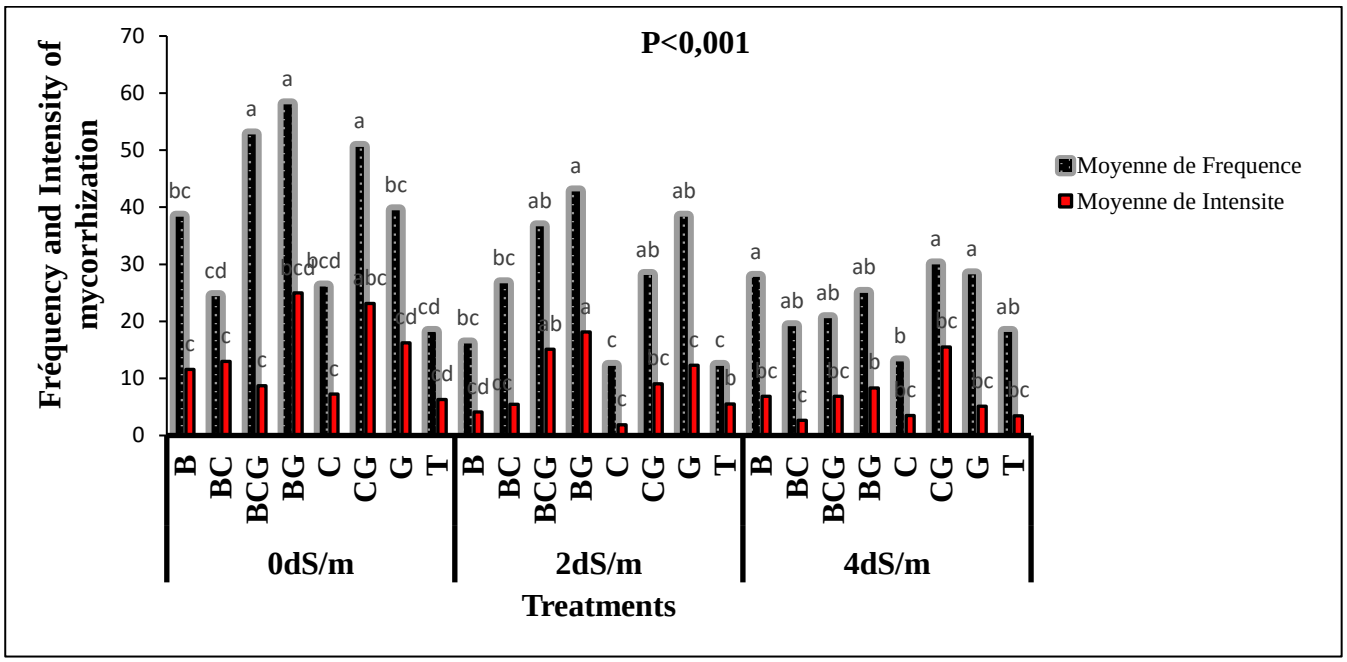

Figure 4. Variation in mycorrhization frequency and intensity as a function of amendments and salt concentrations

3.5. Correlation between variables studied

Analysis of the correlation circle allows us to distribute quantitative variables along the axes (see **Figure 5**). It can be seen that 46.13% of variability is expressed by the F1 axis, while 64.25% of total variability is expressed by the first two axes F1 and F2. Following the F1 axis (expressing 46.13% of variables), a strong correlation is noted between production parameters (above-ground, root and total biomasses) with the B+C+G amendment and the biochar amendment in the absence of stress. In contrast, agro-morphological parameters (number of leaves, plant height, number of branches, survival rate) and mycorrhization parameters (frequency and intensity) are correlated with the B+C and B+G amendments. There were negative correlations between the 4 $dS.m^{-1}$ salt concentration and all the parameters measured (see **Figure 5)**. Thus, this concentration appears strongly depressive on the growth, production and mycorrhization rate of sweet potato plants.

4. Discussion

4.1. Effect of salinity and organic amendments on Growth parameters of sweet potatoe

Salt application at a concentration of 4 $dS.m^{-1}$ has a strongly depressive effect on the survival rate of *Ipomoea batatas* (L.). This could be explained by a salinity-induced decrease in the osmotic

potential of the soil solution, and consequently a reduction in water uptake by the plant's roots. Our results are in line with those of Diatta et *al.*, (2019) and Djighaly (2019), who respectively noted high mortality of rice seedlings and *Casuarinaceae* species in areas affected by salinity. This survival rate varied according to the amendments applied and the duration of salt stress. In fact, amendments B+C and B+G gave the best results overall. This would appear to be linked to the availability of nutrients favored by the application of amendments. These results are in line with those obtained by Diatta et *al.*, (2019), who showed that the survival rate of rice plants in saline zones is positively affected by biochar and Cashew compost amendments.

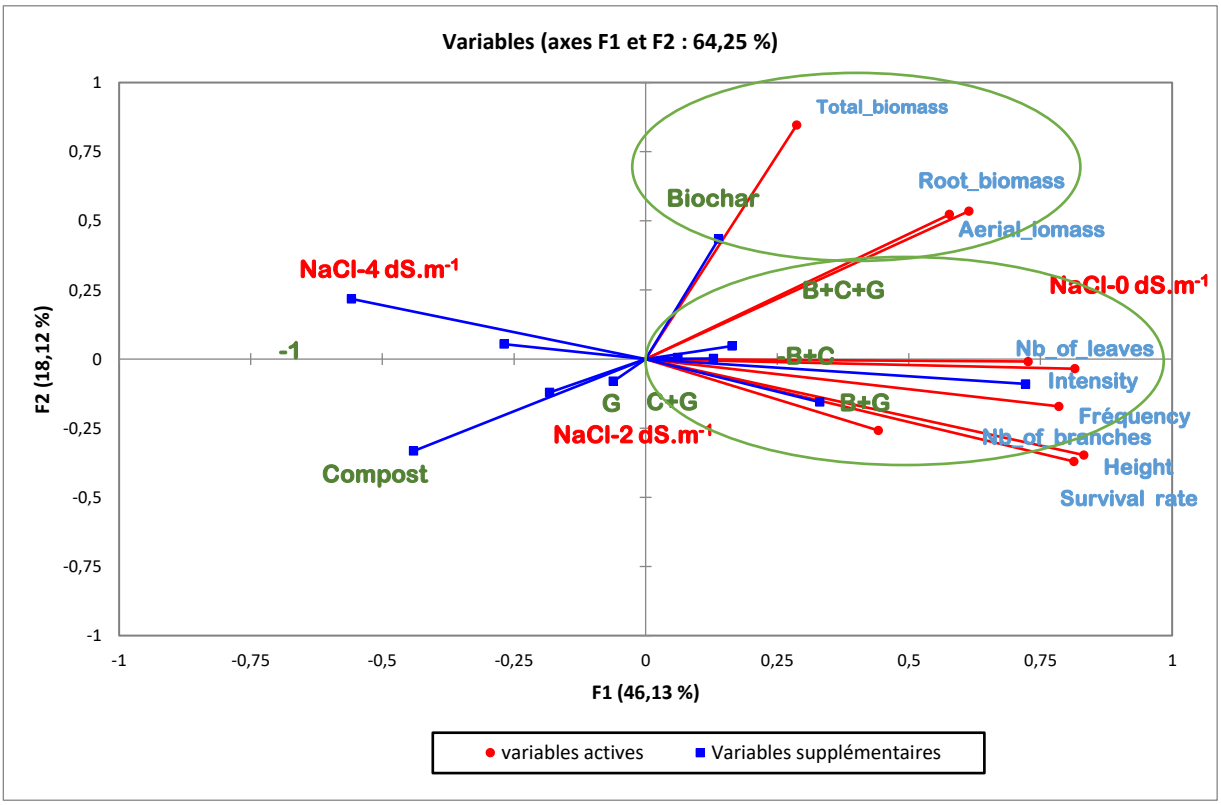

Figure 5. Correlation circle for agromorphological, production and mycorrhization parameters.

As for plant height, number of leaves and number of branches, salinity had negative effects on these parameters. In fact, the lowest values for these parameters were obtained with the maximum salt concentration of 4 $dS.m^{-1}$. This could be explained by a disruption in the plant's mineral nutrition under salt stress. Indeed, according to Zhu (2002), salinity disrupts plant mineral nutrition by interfering with the uptake of certain essential elements such as potassium and calcium. These results corroborate those obtained by Ly et *al.*, (2014) who report a reduction in the growth of *Jatropha curcas* (L.) seedlings under salt stress conditions. Plants that received the B+C and B+G amendments generally grew taller, with higher numbers of leaves. This can be explained by the increased availability of nutrients through biochar and compost, and improved hydro-mineral nutrition induced by AMF. Indeed, Sagna et *al.*, (2019) have shown that cashew compost and biochar positively influence growth parameters in salinity-affected zones. Furthermore, the results obtained by Ebrahim and Saleem (2017) showed that the addition of AMF improved the plant's mineral nutrition under salinity-stressed conditions and attenuates deficiencies in Mg^{2+}, P and N. Our results can be correlated with those of Diatta et *al.*, (2019) who showed the ability of biochar and compost-based amendments to improve growth parameters in rice.

With regard to flowering, early flowering was noted in sweet potato plants subjected to salt stress. This suggests that early flowering is a morpho-physiological response of the sweet potato to stress. According to Hassani et *al.*, (2008), under conditions of salt stress, the plant makes an osmotic adjustment to reduce and balance the concentration of ions in order to adjust the osmotic pressure in the cell cytoplasm. This maintains physiological functions and can occur at any stage of plant development. These results are not in agreement with those of Kinsou et *al.*, (2021), who found that the effect of salinity resulted in an extension of the flowering date of tomato plants (*lycopersicum esculentum* Mill.).

4.2. Effect of salinity and organic amendments on mycorrhization parameters (frequency and intensity)

The frequency and intensity of mycorrhization in sweet potato plants were negatively affected by salinity. This suggests an inhibition of root colonization by mycorrhizal fungi. Indeed, according to Hajiboland et *al.*, (2010), under stress conditions, reduced root colonization by mycorrhizal fungi is noted. Our results are in line with those of Djighaly (2019), who noted a negative effect of NaCl concentration on the mycorrhization rate of *Casuarinaceae* species. On the other hand, they are out of step with those of Zoulim (2017), who found no significant influence of salinity on mycorrhization frequency and intensity in wheat (*Triticum turgidum*). The results of this study also showed that plants treated with B+G generally have higher mycorrhization frequencies and intensities than those treated with non-mycorrhizae. For non-mycorhyzed plants, the biochar amendment alone showed the highest mycorrhization frequencies and intensities. This suggests the existence of natural mycorrhization, which can be explained by the fact that biochar is a biological activator that promotes natural mycorrhization. Indeed, according to Lehmann et *al.*, (2011), the high water-retention capacity of biochar gives it a good capacity to keep its pores moist, which favors the establishment of an environment conducive to the multiplication of soil microorganisms. These results are similar to those of Selmi (2016), who showed that the percentage of alfalfa root colonization by AMF was positively influenced by biochar supplementation.

Conclusion

This study revealed that salinity has negatively influenced the survival rate of sweet potato plants. Salinity effect was reflected by a sharp drop-in survival rate, leaf drop and reduced plant height for the 4 $dS.m^{-1}$ concentration. Mycorrhization frequency and intensity were also significantly hindered by salinity, indicating a negative correlation between these parameters and the increasing salt concentration gradient. Inoculation with symbiotic mychorrizae fungi *G. fasciculatum* and the application of organic amendments resulted in an increase in the number of leaves, number of branches, height and biomass of sweet potato plants regardless of salt stress. Sweet potato tolerance is thus improved by organic amendments combined with the inoculation of mychorrizae fungi. Looking ahead, it would be interesting to look into the mechanism of mycorrhized plant resilience to salt stress in a larger scale in farmer's field.

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