Original Research Article

Effects of phosphogypsum and organic amendments on rice growth in a saline environment

ABSTRACT

Aims: The aim of this study was to investigate the effects of organo-mineral amendments on rice growth under saline stress conditions.
Study design: A 3x8 factorial block design was adopted, with 3 concentration levels: 0, 1.94 and 3.88 g/l NaCl and 8 different amendments: control, phosphogypsum (Phos), compost (C), biochar (B), Phoc+C, Phos+B, B+C and Phos+B+C. This system was repeated 3 times in 3 blocks. Organics amendments were applied at a rate of 5 kg/m² and 0,2 kg/m² for phosphogypsum.
Place and Duration of Study: The trial was conducted from April to June 2021 on the farm of the Agroforestry Department of the Assane SECK University of Ziguinchor, located at 12°32 - 88' N, 16°17 - 23' W, in the Ziguinchor region.
Methodology: After two months of cultivation under semi-controlled conditions, growth parameters were measured. In fact, the survival rate is obtained by counting the number of plants that have survived, and the height of the plants is determined using a graduated ruler. The number of tillers was obtained by counting the number of branches and the diameter using a caliper at the base of the crown. Root and above-ground biomass were determined by weighing the plants after 72 hours of oven-drying at 70°C.
Results: For the amended treatments, plant survival rate was 100% compared with unamended controls, where plant survival decreased with increasing salinity, with rate of 96, 80 and 70% corresponding to 0; 1,94 and 3,88 g/l NaCl respectively. The number of tillers, crown diameter and above-ground and root biomass of the plants were significantly higher (pr < 0,001) for compost amendments alone (C) and those combined with compost: B+C, Phoc+C, Phos+B+C, regardless of the salinity level.
Conclusion: The combined use of organic and chemical amendments could enable farmers to restore salinity-affected soils and improve rice growth.

Keywords:Phosphogypsum, organic amendments, Rice, Salinity stress.

1. INTRODUCTION

Soil salinization is one of the most severe constraints on agricultural production systems (Imane, 2012). Of the 1.5 billion hectares of cultivated land in the world, around 77 million hectares (5%) are affected by soil salinization (Sheng et al., 2008). In Senegal, more than a million hectares are affected, with salinization affecting virtually all regional soils, particularly those in the Casamance river basins (Tamba et Faye, 2011). In this area, salinization is the result, on the one hand, of the invasion of soils by salt water from the hydrographic network during high tides and, on the other, of the capillary rise of the salt water table during the dry season. This leads to a considerable increase in saline surfaces, with harmful consequences for mangrove swamps and a progression of the salinity front towards the plateaus, resulting in increasing crop degradation (Aidara et al., 2020). Several strategies have been put forward to improve crop development in the face of salinity, including: desalination of irrigation water or saline soils; selection of rice species and/or varieties adapted to salinity (Allen et al., 2010); and adoption of appropriate cropping practices, including organo-mineral amendments (Fahima, 2009). In fact, organic matter promotes salt leaching thanks to organic acids that bind sodium ions and carry them away with rainwater (Ngom, 1999). Organic amendments help to maintain fertility and enrich the soil by adding nitrogen, carbon, phosphorus, magnesium and calcium; they increase available nutrients, improve aggregate formation and the soil's water retention capacity (Diop1 et al., 2019). Mulaji (2011) has also shown that organic amendments can improve the physico-chemical properties of soils affected by salinity and enhance plant growth. Also, the use of phosphogypsum as an input resulted in an increase in rice yields of over 50% (INP et Assolucer, 2009). It would therefore be interesting to study the effect of the combined application of organic-mineral amendments on the resilience of rice to salinity. The aim of this study was to determine the effects of phosphate inputs combined with organic amendments on the agro-morphological parameters of rice under salinity stress.

2. MATERIAL AND METHODS

2.1 Presentation of the study area

The trial was conducted on the farm of the Agroforestry Department of the Assane SECK University of Ziguinchor, located at 12°32 - 88' N, 16°17 - 23' W, in the Ziguinchor region. The mean annual temperature of the area is 27°C, with a maximum (35°C) in April and a minimum (15°C) in December (Sagna, 2005).

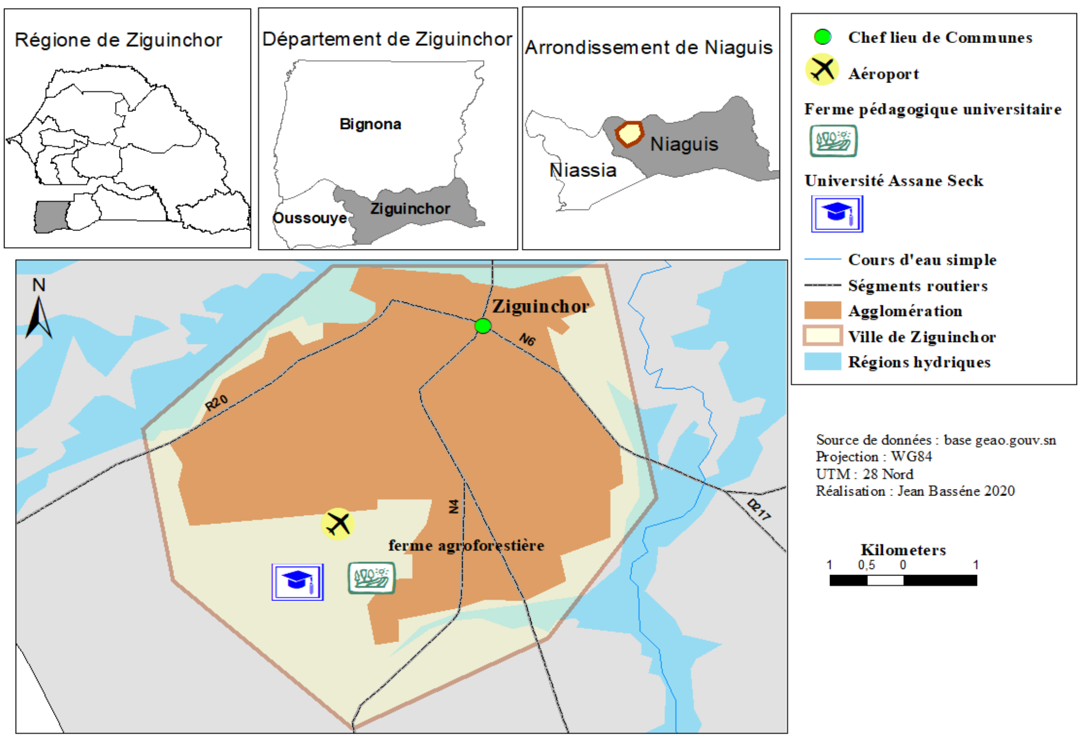

Fig. 1.Situation map of the Study Area

2.2 Chemical and organic Material

The material consists of organo-mineral amendments (Phosphogypsum, Biochar and Cashew Compost) and the rice variety Sahel 108.

<u>2.2.1 Phosphogypsum</u>

Phosphogypsum is a by-product of the synthesis of fluorinated calcium phosphate and sulfuric acid. The phosphogypsum used consists mainly of calcium (CaO) and sulfur (S), but also of heavy metals in low concentrations: lead (Pb), cadmium (Cd), chromium (Cr) (Table 1)**.**

Table 1. Composition of phosphogypsum produced in Senegal

Elements	CaO%	SO_3%	P_2O_5%	F%	Fe_2O_3	Al_2O_3
Composition	32.0	18.0	1.7	1.20	Trace	Trace

Source : (Diop, 2017)

2.2.2 Organic amendments

The organic amendments used are biochar and cashew compost. Compost is obtained from pressed and decomposed cashew apples. Biochar was collected from charcoal sellers. Organic amendments were applied at a rate of 5 kg/m², corresponding to 90 g per sheath, and phosphogypsum at a rate of 0.2 kg/m², corresponding to 36 g per sheath.

Table 2.Physico-chemical composition of Biochar and Cashew compost.

	Biochar	Compost d'anacarde
pH eau 1/ 2,5	7,5	6
CE 1/ 10 µs.cm^{-1}	173	148
%C	5,56	8,98
MO %	9,58	15,48
N %	0,56	0,84
C/N	10	11
Ca^{2+} meq.$100g^{-1}$	13,5	1,425
Mg^{2+} meq.$100g^{-1}$	3,75	1,2
Na^{+} meq.$100g^{-1}$	0,073	0,050
K^{+} meq.$100g^{-1}$	3,32	0,74
P ppm	14,17	15,71
S meq.$100g^{-1}$	20,64	3,42
CEC meq.$100g^{-1}$	9	11
T %	229	31
PSE %	0,8	0,5

2.2.3 Rice variety

The SAHEL 108 rice variety of the Sativa species and the salinity-sensitive Indica varietal group was used. It has a semi-early cycle of 76 days in winter and 86 days in the hot counter-season. It has a maturity of 105 days in winter and 117 days in the warm counter-season. Potential yield is around 10 t/ha, with little ginning. Seeds were supplied by the Djibélor research center (CRA/ISRA) in Ziguinchor.

2.3 Experimental Design

A 3x8 factorial block design was adopted with the two factors: type of amendment and salinity level. There were 8 modalities for the amendment factor: unamended control (T), phosphogypsum (Phos), cashew compost (C), biochar (B), phosphogypsum + cashew compost (Phos + C), phosphogypsum + biochar (Phos + B), biochar + cashew compost (B + C) and phosphogypsum + biochar + cashew compost (Phos + B + C) (figure 2). The salinity factor has 3 levels (0 dS/m, 3 dS/m and 6 dS/m) corresponding respectively to salt quantities of 0, 1.94 and 3.88 g/l NaCl. Treatments were repeated 3 times to form blocks for a total of 72 experimental units (3 x 8 x 3 = 72). Each treatment, representing an experimental measurement unit, consisted of 6 sheaths measuring 20*30 cm. These sheaths were 3/4 filled with a substrate consisting of a mixture of rice field soil and the corresponding dose of organo-mineral amendments. The distance between blocks is 100 cm, while a distance of 30 cm is maintained between salinity levels and between experimental units.

2.4 Conduction of the experimentation

Sowing was carried out in April 2021 at a rate of four seeds per sheath, and after emergence, a gradual removal is carried out to keep just one plant per sheath. The plants were irrigated at a rate of 200 ml per plant per day using a beaker. Salt stress was applied on day 21 after sowing (JAS) with the following different salinity levels: N1 (control), N2, and N3 corresponding respectively to an NaCl concentration of 0 g/l; 1.94 g/l and 3.88 g/l. Salt doses were applied progressively every two days to avoid osmotic shock. Initially, a concentration of 25 mM corresponding to 1.46 g/l was used [9]. This concentration was readjusted and, if necessary,

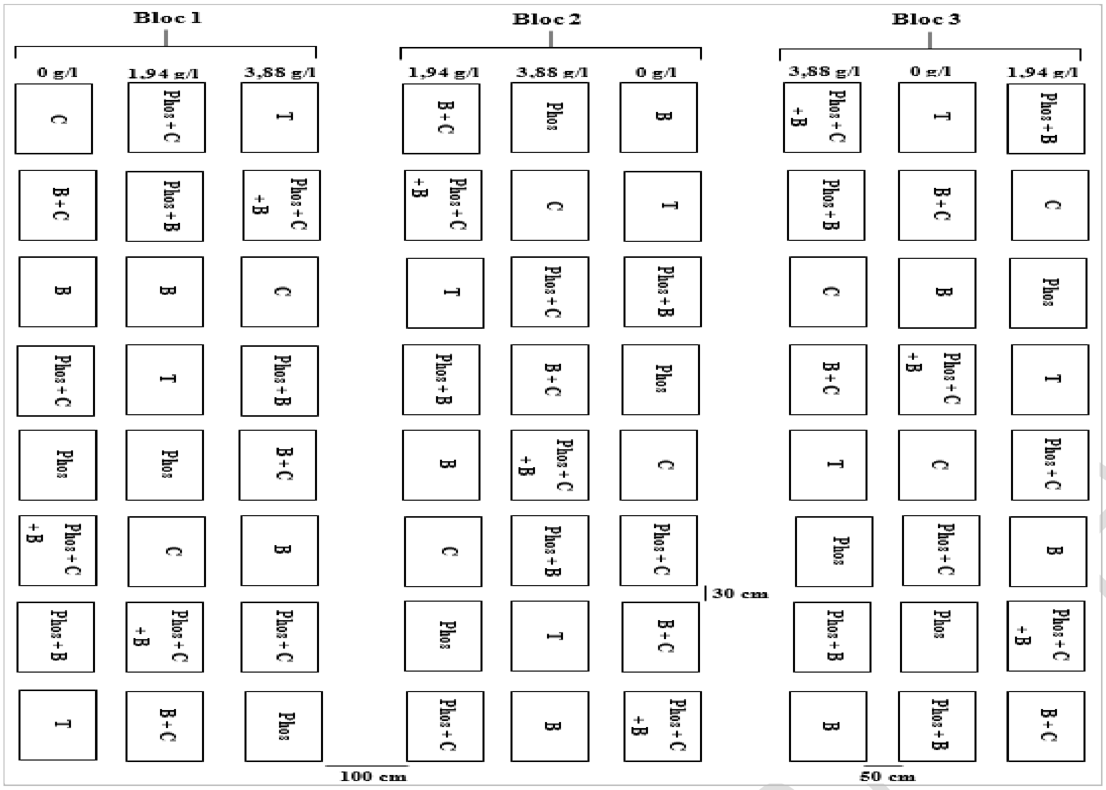

Fig. 2. Experimental Design

multiplied by 2 every 2 days until the various desired concentrations were reached. The assay was monitored for 2 months. After 2 months of cultivation, the plants were collected and the growth parameters: number of tillers, plant height, above-ground and root biomass were measured.

2.5 Parametersstudied

Survival rate, plant height, number of tillers and crown diameter were determined 60 days before harvest. Survival rate was determined by counting the number of plants that survived after the addition of NaCl in each experimental unit and then deducing the percentage. Plant height was obtained using a graduated ruler by measuring the plant from the base of the crown to the axil of the tallest leaf. The number of tillers was obtained by counting the number of plant branches in each experimental unit. Diameter at the crown was measured at the 60th DAS using a caliper at the base of the crown of each plant in the experimental unit, before deducing the average. For root and aerial biomass, after 2 months of experimentation, all plants were sacrificed and the root biomass was separated from the aerial biomass. These biomasses were oven-dried for 72 hours at a temperature of 70°C and then weighed.

2.6 Data processing and analysis

R software version 4.2.2 was used for data analysis. The means of each rice variety according to the parameters studied were then subjected to a Principal Component Analysis (PCA). The student-Newman-Keuls (SNK) test was used to compare means at the 5% probability threshold.

3. RESULTS

3.1 Plant survival rate

Analysis of Table 3 shows that there was no significant variation in seedling survival rate as a function of salinity levels ($pr > 0.5$). On the other hand, there was a significant variation in the survival rate of seedlings as a function of amendments, whatever the salinity level ($pr < 0.001$). In fact, the highest survival rates (100%) were obtained with all treatments receiving organic and mineral amendments, compared with the control treatments. This suggests that organic and mineral amendments had a positive effect on rice plant survival rates.

Table 3.Variation in survival rate at 60 days as a function of amendments and salinity levels.

NaCl	Amendments	Survival rate (%)
N1	B	100 a*
	B+C	100 a
	C	100 a
	Phos	100 a
	Phos+B	100 a
	Phos+B+C	100 a
	Phos+C	100 a
	T	96 b
N2	B	100 a
	B+C	100 a
	C	100 a
	Phos	100 a
	Phos+B	100 a
	Phos+B+C	100 a
	Phos+C	100 a
	T	80 c
N3	B	100 a
	B+C	100 a
	C	100 a
	Phos	100 a
	Phos+B	100 a
	Phos+B+C	100 a
	Phos+C	100 a
	T	70 **d**

***Values in the same column with identical letters are not statistically different at the Student-Newman-Keuls (SNK) 5% LSD threshold*.

3.2 Diameter at crown, number of tillers and plant height

Neck diameter, number of tillers and average plant height as a function of salinity levels and amendments are shown in Table 4. There was a significant difference between treatments as a function of amendment input (pr < 3.19e-08) for crown diameter and number of tillers, and no difference between salinity levels. Generally speaking, the largest collar diameters and number of tillers were obtained with treatments C, B+C, Phoc+C and Phos+B+C compared with the other treatments, whatever the salinity level (table 4).

This shows that the amendments or combination of amendments had a positive influence on the diameter at the crown of the rice plants and the number of tillers compared with the control, whatever the salinity level. However, there were no significant differences in collar diameter or number of tillers according to the different salinity levels.

Height was significantly different according to salinity levels (pr < 9.29e-08), as well as according to organic amendments (pr < 8.19e-14). In fact, plant height decreased with increasing salinity levels. Salinity therefore had a negative effect on the height growth of rice plants. Nevertheless, in terms of absolute values, certain amendments such as B+C, C, Phos+B+C, Phoc+C and Phos+B stood out for their greater heights than the others, particularly (T).

Table 4. Variation in crown diameter (D), number of tillers (NT) and plant height (H) as a function of salinity levels and amendments.

NaCl	Amendments	D (cm)	NT	H (cm)
N1	B*	2,5 c-g	9 efg	47,5 d-h
	B+C	3 abc	12 c	57,7 a
	C	3,1 ab	13 b	54,9 adc
	Phos	2,4 d-g	9 efg	44,4 hij

	Phos+B	2,5 c-g	10 def	50,8 d-f
	Phos+B+C	2,8 a-d	14 b	55,6 ab
	Phos+C	2,8 a-d	12 c	52,1 dcb
	T	2,2 efg	8 gh	39,2 lm
N2	B	2,5 c-g	11 cd	43,9 h-l
	B+C	3,2 a	17 a	50,9 b-f
	C	3,1 ab	14 b	51 b-f
	Phos	2,1 fg	9 efg	44,9 hij
	Phos+B	2,4 d-g	10 def	45,8 g-j
	Phos+B+C	3 abc	14 b	51,3 b-e
	Phos+C	2,6 b-f	14 b	50,8 b-f
	T	2 g	8 gh	39,4 klm
N3	B	2,2 efg	10 cde	41,2 j-m
	B+C	2,9 a-d	14 b	50,1 c-g
	C	2,9 a-d	12 c	48,5 d-h
	Phos	2,1 fg	7 hi	42,1 i-l
	Phos+B	2,2 efg	9 efg	44,2 h-k
	Phos+B+C	2,7 b-e	10 def	46,1 f-i
	Phos+C	2,8 a-d	10 def	46,4 e-i
	T	2 g	6 i	36,3 m

**Values in the same column with identical letters are not statistically different at the Student-Newman-Keuls (SNK) 5% LSD threshold.*

Legend: *a-d = abcd; b-e = bcde ; b-f = bcdef ; c-g = cdefg ; d-g = defg ; d-h = defgh ; e-i = efghi ; f-i = fghi ; g-j = ghij ; h-k = hijk ; h-l = hijkl ; i-l = ijkl ; j-m = jklm.*

3.3 Variation in average root and above-ground biomass

Root biomass did not vary significantly with salinity level (pr = 0.808) between treatments. However, there was a significant difference as a function of soil amendment (pr = 1e-08).
As for above-ground biomass, there was a significant difference depending on the salinity level (pr = 0.0062) but also depending on the amendments (pr = 1.34e-14).
Above-ground and root biomass were highest with amendments B+C, C, Phos+B+C, Phoc+C and Phos+B, irrespective of salinity level (Table 5).

Table 5.Variation in average (AR) root and above-ground biomass (AB) as a function of salinity levels and amendments.

NaCl	Amendments	AR (g)	AB (g)
N1	B*	17 f-k	57 f-i
	B+C	30 a	125 a
	C	32 a-d	114 ab
	Phos	21 h-k	46 g-k
	Phos+B	21 h-k	58 e-i
	Phos+B+C	29 ab	89 b-e
	Phos+C	25 d-h	77 c-f
	T	16 ijk	30 ijk
N2	B	22 e-i	50 f-k
	B+C	33 bc	131 a
	C	33 bc	101 a-d
	Phos	22 e-i	44 h-k

	Phos+B	30 b-e	53 f-j
	Phos+B+C	36 ab	110 ab
	Phos+C	26 c-g	70 d-h
	T	18 f-i	31 ijk
N3	B	23 d-i	25 jk
	B+C	34 abc	102 abc
	C	34 abc	91 bcd
	Phos	22 e-i	39 h-k
	Phos+B	27 b-f	34 ijk
	Phos+B+C	26 c-g	76 c-g
	Phos+C	32 bc	77 c-f
	T	14 i	21 k

**Values in the same column with identical letters are not statistically different at the Student-Newman-Keuls (SNK) 5% LSD threshold.*
Legend: *a-d = abcd ; b-e = bcde ; b-f = bcdef ; c-f = cdef ; c-g = cdefg ; d-i = defghi ; e-i = efghi ; f-i = fghi ; f-j = fghij ; f-k = fghijk ; g-k = ghijk ; h-k = hijk.*

3.4 Correlation between agro-morphological parameters, salinity levels and organo-mineral amendments.

The factorial planes F1 (Dim 1) and F2 (Dim 2) explain 96.4% of the variations observed in the distribution (figure 3). Survival rate is strongly correlated with Phos+B; B and Phos amendments at salinity level N1 along the positive side of the y-axis.
On the negative abscissa side, parameters such as height, above-ground and root biomass, number of tillers and crown diameter are correlated with amendments B+C; C; Phos+B+C and Phoc+C associated with salinity level N2.
However, the Control treatment (no amendment) is correlated with salinity level N3 on the positive abscissa side. So, following the axes, the correlations between agro-morphological parameters and amendments, PCA enables us to highlight the classification of three more or less homogeneous groups:

- The first group is made up of amendments B+C; C; Phos+B+C and Phoc+C.
- The intermediate group with Phos+B; B and Phos amendments
- At the end of the (T).

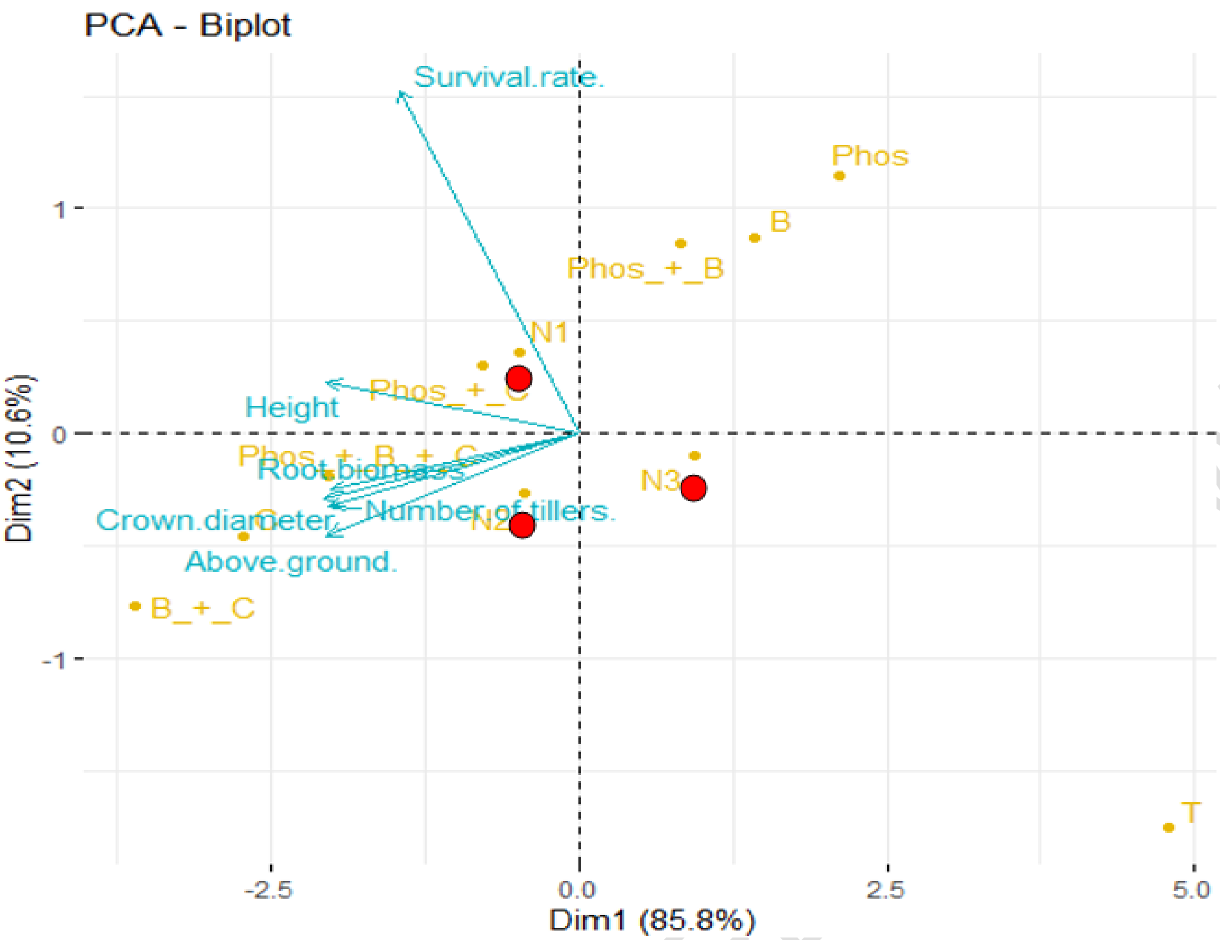

Fig. 3. **Correlation between agro-morphological parameters, salinity levels and organo-mineral amendments**.

4. DISCUSSION

The analysis showed that all the plants that received amendments survived to the end of the experiment, compared with the controls, whose survival rate fell with increasing salinity levels. This suggests that the amendments had a positive influence on the survival rate of salt-stressed rice plants. In fact, excess salt in the soil reduces the availability of nutrients to plants, leading to their mortality (Kémassi, 2011). However, the addition of soil improvers not only increases nutrient availability, but also raises the pH of the environment. This increase in pH has a direct impact on the availability of soil nutrients. These nutrients will then boost plant growth and increase their tolerance to salinity. Bonaventure (2016) has reported an increase in pH following the burial of compost and biochar in acid soils. In our study, there were a positive influence of amendments on all parameters, with the exception of plant height. The work of Prendergast-Miller et al., (2014) showed that compost and biochar are direct sources of nutrients, and their application to horticultural substrates improves the physical properties of the soil and generates higher mineral concentrations. It should be noted that organic soil improvers have a buffering effect on soil pH, which they chemically stabilize (Kwey et al., 2015).
In our study, the addition of soil improvers had a stimulating effect on the number of tillers, crown diameter and root and aerial biomass. The favorable effects of these amendments on plant growth are due to their improving action on structure, porosity and water retention capacity, as well as on the supply of mineral elements (nitrogen, phosphorus, potassium, calcium and other trace elements). Several studies have demonstrated the effectiveness of organic soil improvers in combination with gypsum under saline stress conditions. According to PROPAGAR (2012), gypsum combined with organic soil improvers lowers electrical conductivity (EC). In fact, phosphogypsum, thanks to its calcium content, combats the harmful effects of sodium on soil structure. The calcium (Ca^{2+}) supplied binds to soil colloids in exchange for the release of two Na^+ ions, which are gradually flushed away by water. The presence of large quantities of calcium will continue the evacuation of sodium ions over time, thus lowering salinity and restructuring the soil (Diop, 2017). Calcium, in association with organic soil improvers, acts on soil structure and stability by promoting humification and stabilization of the clay-humus complex, and consequently the availability of nutrients to ensure good plant growth. The beneficial effects

of the combined use of chemical and organic fertilizers for the sustainable management of soil fertility and agricultural production have been widely documented (Soltner, 2003).
The lack of effect of soil improvers on plant height can be explained by the fact that salinity reduces photosynthesis, which in turn limits the supply of carbohydrates needed for growth. Salinity can also cause a disturbance in the supply of mineral elements, either an excess or a deficit, inducing changes in the concentrations of specific ions in the growing medium, directly affecting plant growth. Thus, to adapt to salt stress, the plant can avoid damage by reducing growth (Zhu, 2002).

5. CONCLUSION

Through this work, we have highlighted the beneficial effects of the combined application of organo-mineral amendments on the agro-morphological parameters of rice under saline stress conditions. Amendments had a positive effect on the survival of rice plants, recording no mortality regardless of the salinity level. Amendments with C, B+C, Phos+B+C and Phoc+C significantly increased the number of tillers, crown diameter, root biomass and above-ground biomass, demonstrating their beneficial effects on rice, with the exception of height.
For a better understanding of the effects of these amendments, it would be important to carry out this experiment in a real environment.

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