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ORIGINAL PAPER

Effect of peanut shells amendment on soil properties and growth of seedlings of *Senegalia senegal* (L.) Britton, *Vachellia seyal* (Delile) P. Hurter, and *Prosopis juliflora* (Swartz) DC in salt-affected soils

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Abstract

• ***Key message*** **The soil amendment with peanut shells (4, 6 or 8 t ha^{-1}) improves soil properties and growth of *Senegalia senegal* (L.) Britton, *Vachellia seyal (*Delile) P. Hurter and *Prosopis juliflora* (Swartz) DC seedlings on salty soils (86, 171, 257 mM NaCl).**

• ***Context*** Salinization causes the degradation of biological, chemical, and physical properties of soils. Salty soils reclamation can be achieved with organic amendments and afforestation with salt tolerant species.

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Contribution of the co-authors Dioumacor FALL coordinated the research project and greenhouse work, performed the data analysis, and wrote the paper.
Niokhor BAKHOUM, Fatoumata FALL and Fatou DIOUF contributed to data analysis.
Mathieu N FAYE and Cheikh NDIAYE participated to the greenhouse and laboratory experimentations.
Valérie HOCHER participated to the research project and the writing of the paper.
Diégane DIOUF co-coordinated the research project, designed the study, supervised the work, and edited the paper.

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• ***Aims*** The aim of the study was to assess in greenhouse conditions the effect of peanut shells on soil chemical characteristics and growth of multipurpose leguminous trees *Senegalia senegal*, *Vachellia seyal*, and *Prosopis juliflora* under salt-affected soils.
• ***Methods*** Seedlings were individually cultivated in plastic bags containing a mixture of non-saline and non-sterile soil and crushed peanut shells. Four doses of peanut shells (0, 4, 6, and 8 t ha^{-1}) of 73-33 variety were tested. Salt stress was gradually applied after 1 month of cultivation at a rate of 43 mM NaCl per day until concentrations of 0, 86, 171, and 257 mM were reached. Seedlings growth, physiological responses, and soil characteristics were evaluated after 3 months of stress.
• ***Results*** Peanut shells application improved soil chemical properties (carbon, nitrogen, phosphorus contents, pH, total microbial activity, and cation-exchange capacity) and reduced soil salinity. They also increased height, collar diameter, shoots and root biomass, chlorophyll, and proline contents of seedlings.
• ***Conclusion*** The organic amendment with peanut shells improves soil fertility and tree growth under saline conditions.

Keywords Organic amendment · Salinization · Saline soil reclamation · *Senegalia Senegal* · *Vachellia seyal* · *Prosopis juliflora*

1 Introduction

Soil salinization is one of the major factors that contribute to land degradation and decrease in plant growth and productivity in semi-arid regions (Al Yassin, 2005; Anjum et al. 2005). Around 20% of the total cultivated and 33% of irrigated agricultural lands are affected by salinity in the world (Shrivastava and Kumar 2015). In Senegal, 45% of the agricultural lands are salt-affected (FAO-LADA 2009). Salt-affected soils are characterized by high concentration of soluble salts and low organic matter and nitrogen content (Asma et al. 2009). The negative effects of salinization are intensified by the low levels of soil organic matter (Muhammad et al. 2005) and decrease in stability of soil structure, i.e., the tendency to slake, disperse, and swell under specific conditions (Qadir and Schubert 2002). Salinity also affects soil chemical properties such as pH, cation-exchange capacity (CEC), exchangeable sodium percentage (ESP), soil organic carbon, and available nutrients (Aderoju and Festus 2013).

NaCl, a major salt component in saline soil, is a small molecule, which dissociates in water to produce sodium (Na^+) and chloride (Cl^-). At high concentration, these toxic ions cause ionic and osmotic stress at the cellular level in higher plants, especially in glycophyte species (Mansour and Salama 2000; Chinnusamy et al. 2005). High NaCl concentrations in the growth medium of plants, generate primary and secondary effects that negatively affect plant growth and several physiological parameters, i.e., photosynthesis, water status, respiration, nitrogen fixation, and carbohydrate metabolism (Chen et al. 2008). Plant adaptations to salinity include sequestration of salt ions in vacuoles and accumulation of several compatible compounds, particularly proline (Ashraf and Harris 2004).

There are many ways for improving salt-affected land, such as water leaching, chemical remediation, and phytoremediation (Ahmad and Chang 2002; Sharma and Minhas 2005; Qadir et al. 2007). The remediation of salt-affected soil using chemical agents, as gypsum, calcite, calcium chloride, and organic matter (farmyard manure, household waste, etc.) is a successful approach that is able to enhance plant growth and productivity (Choudhary et al. 2004; Wong et al. 2009). Many studies reported that this approach is effective, low cost, and simple (Mitchell et al. 2000; Hanay et al. 2004; Sharma and Minhas 2005; Tejada et al. 2006). The physical, chemical, and biological properties of soil in salt-affected areas are improved by the application of organic matter (OM), leading to enhance plant growth and development. The replacement of ions responsible for the salinity as sodium by adding organic matter with high calcium content will be a viable strategy in ameliorating of salt-affected soils (Shaimaa et al. 2012).

Peanut shells are traditionally used as organic matter by farmers to restore their paddy fields affected by salinity. In addition, positive effects of peanut shells on yield of millet and corn on salty soils were observed in Senegal (PROGERT 2008). Unfortunately, their effects have been never scientifically reported for the recycling and sustainable use. Their effects on soil physical, chemical, and biological characteristics remained up to now less prioritized. The addition of peanut shells as organic amendment increases nutrient levels such as carbon, nitrogen, phosphorus, and calcium structure and reduces soil salinity (Mojiri et al. 2011).

Soil microorganisms such as nitrogen-fixing bacteria (rhizobia) and arbuscular mycorrhizal fungi establish triple association, capable of supplying N and P contents to the plants, particularly in poor soils (Silveira and Cardoso 2004). So the addition of peanut shells leading to improve soil fertility could affect microbial symbiosis (nodulation and mycorrhization). Thus, the study of the effect of this amendment on these symbioses is necessary for the combination of peanut shells and microbial inoculation.

Senegalia senegal (Syn. *Acacia senegal*), *Vachellia seyal* (Syn. *Acacia seyal*), and *Prosopis juliflora* are multipurpose legume trees used in many reforestation programs in arid and semi-arid areas. These species have considerable potential in agroforestry systems, fuelwood production, forage, and medicinal products. They contribute to soil conservation and enhancement of soil fertility in agroforestry systems by their capacity to fix atmospheric nitrogen and phosphorus (Dommergues et al. 1999). *S. senegal* and *V. seyal* are also used by farmers in the arid and semi-arid zones of Africa for gum arabic production. However, despite their importance, salinity decreased their growth (Fall et al. 2016). Thus, improving salty soil characteristics by adding peanut shells could also enhance their growth under saline conditions. So, the aim of this study was to evaluate the effects of peanut shells on soil chemical and microbial characteristics. The growth, physiological responses, and microbial symbiosis of *S. senegal*, *V. seyal*, and *P. juliflora* seedlings on salty soils were also studied in greenhouse conditions.

2 Material and methods

2.1 Growth substrate

Growth substrate was a mixture of non-saline and non-sterile soil (Table 1) collected from Sadioga (Centre of Senegal Peanut Basin, 16° 23′ 18″ W; 14° 03′ 53″ N) mixed with powdered peanut shells. They were crushed with an electric grinder. Four doses (0, 4, 6, and 8 t ha^{-1}) of peanut shells of the variety 77-33 were tested. This variety is the most cultivated in the Peanut Basin of Senegal, which is the most affected area by soil salinization. The doses 0, 4, 6, and 8 t ha^{-1} correspond respectively to 0, 113.04, 169.56, and 226.08 g of peanut shells per bag (25 cm × 12 cm × 1 cm; volume 2826 cm^3). Chemical characteristics of peanut shells are N = 1.00 ± 0.02%; C = 46.24 ± 4.7%; C/N = 46; P = 0.61 ± 0.01 g kg^{-1}; Ca = 6.9 ± 1.3 g kg^{-1}; K = 4.73 ± 0.9 g kg^{-1}; Na = 1.4 ± 0.02 g kg^{-1}; Cl = 1.7 ± 0.03 g kg^{-1}.

Table 1 Physical and chemical characteristics of soil used in the study. Soil was collected at Sadioga (Central part of Senegal) at 0–25 cm layer in non-saline zone

	Values
Physical characteristics	
Clay	05.5%
Silt	11.5%
Sand	83.0%
Chemical characteristics	
pH $_{H2O}$	5.5
Electrical conductivity (at 25 °C)	0.027 mS cm^{-1}
Salinity	0.00‰
Total nitrogen	0.05%
Total carbon	0.56%
Total phosphorus	52.00 mg kg^{-1}
Calcium (Ca^{2+})	0.78 meq%
Magnesium (Mg^{2+})	0.25 meq%
Sodium (Na^{+})	0.09 meq%
Potassium (K^{+})	0.15 meq%
Cation-exchange capacity (CEC)	2.99 meq%

2.2 Seedlings growth, experimental design, and salt stress treatment

Seeds of *Senegalia senegal*, *Vachellia seyal*, and *Prosopis juliflora* were provided by the National Centre for Forestry Research (CNRF) of the Senegalese Institute of Agricultural Research (ISRA). Seeds scarification and pre-germination were done as described by Fall et al. (2009). Seedlings were individually cultivated in plastic bags containing the growth substrate.

Seedlings were arranged in a randomized completed block design including two factors: peanut shells (0, 4, 6, 8 t ha^{-1}) and salinity (0, 85, 171, 257 mM NaCl), 16 treatments (4 × 4) with ten replications per treatment. Salt stress treatment was applied 1 month after transplantation. Seedlings were gradually exposed to NaCl in order to minimize any salinity shock. NaCl concentrations were increased by 43 mM per day until reaching the required final concentration. The electrical conductivity of the leachate from representative pots was monitored regularly with a salinometer (Digit 100 ATC Salinity pocket refractometer, CETI, Optical Instruments, Belgium) to ascertain actual NaCl concentrations within the rooting medium (Fall et al. 2016). The experiment was carried out in greenhouse conditions at the LCM-Laboratoire Commun de Microbiologie IRD/ISRA/UCAD of Dakar-Senegal (certified ISO 9001: 2015).

2.3 Plants' growth measurement

Four months after salt stress application, the plants height and collar were measured. The plants were harvested and the shoot (leaves + stems) and root dry biomass were evaluated. Shoot and root were dried for 4 days in stove (70 °C).

2.4 Physiological traits measurement

2.4.1 Leaf water relations

Relative water content (RWC) and leaf water potential (LWP) were measured to evaluate the water state in seedlings. RWC was evaluated from the upper fully expanded young leaves as described by Fall et al. (2016). Stem fragment (5 cm) was incubated in 15 ml distilled water for 24 h and dried in a stove during 96 h at 80 °C. RWC was calculated according to Yamasaki and Dillenburg (1999) using the following formula:

$$\mathrm{RWC}\ (\%) = [(\mathrm{FW}-\mathrm{DW})/(\mathrm{TW}-\mathrm{DW})] \times 100; \text{where FW} = \text{Fresh Weight, DW} = \text{Dry weight, and TW} = \text{Turgid Weight}$$

LWP was measured before the sunset (06:00–07:00 a.m.) using a Scholander pressure chamber (Scholander et al. 1965).

2.4.2 Leaf chemical characteristics

Total chlorophyll and proline contents were evaluated. The total chlorophyll content was evaluated from 100 mg of fresh leaves according to Arnon (1949) method. The total chlorophyll content was calculated using the following formula: $C = [20.2\ (A645) + 8.02\ (A663)] \times V/M$; where V and M are the extraction volume (L) and weight (mg) of crushed leaves, respectively. Free proline content was determined according to Monnevaux and Nemmar method (1986). One hunded milligrams of leaf samples were grinded in 2 ml 40% methanol, and the whole was heated at 85 °C in water bath for 60 min. After cooling, 1 ml of supernatant was added to 1 ml of 2.5% ninhydrin and 1 ml of mixture reaction. The resulting solution was boiled for 30 min at 100 °C, then 5 ml of toluen were added to tubes, and two separate phases were formed after shaking tubes. The optical density of the upper phase was determined using a spectrophotometer at a wavelength of 528 nm. The proline concentration was obtained from a calibration graph prepared with a series of standard proline solutions.

2.5 Assessment of seedlings natural symbiosis

For rhizobial symbiosis, the number of nodules per plant was counted. For evaluating mycorrhizal root colonization (MRC) for mycorrhizal symbiosis, subsamples of total root mass were cleared at 90 °C for 30 min in 10% KOH and stained with 0.05% Trypan blue (Phillips and Hayman, 1970). Mycorrhizal root colonization (corresponding to the proportion of cortex colonized by AMF) was evaluated microscopically using the notation scale described by Trouvelot et al. (1986).

2.6 Assessment of soil chemical and microbial characteristics

Since *S. senegal* uptakes less Na^+ than the two other species (Fall et al. 2016), the soil used for its cultivation was used to assess chemical and microbial characteristics. After the seedlings were harvested, the soil was collected for analysis. Soil chemical analysis (total carbon, total nitrogen, total phosphorus, pH, electrical conductivity, exchangeable cations, and cation-exchange capacity) was carried out by the *LAMA-Laboratoire des Moyens Analytiques* (Certified ISO 9001: 2015) of the *Institut de Recherche pour le Développement* (IRD) at Dakar (Senegal). AMF spores density and total microbial activity were assessed for soil microbial characteristic under saline conditions.Spores were extracted from 100 g of soil of each sample by wet sieving followed by floatation centrifugation in 50% sucrose (Gerdemann and Nicolson 1963). Hydrolysis of fluorescein diacetate (FDA) has been widely used as accurate, sensitive, and simple method for determining total microbial activity in soil (Schnürer and Rosswall 1982; Adam and Duncan 2001; Nannipieri et al. 2003). FDA hydrolysis was performed according to Adam and Duncan (2001). Briefly, 2 g soil was placed in a conical flask and 15 ml of 60 mM potassium phosphate buffer pH 7.6 were added. Stock solution (0.2 ml 1000 mg FDA ml^{-1}) was added to start the reaction. Controls were prepared without the addition of the FDA substrate along with a suitable number of sample replicates. The fluorescein released during the assay was extracted with chloroform/methanol (2:1 *v*/*v*) and measured at 490 nm using a spectrophotometer (Spectronic 401, Spectronic Instruments, France).

2.7 Statistical analysis

Three replicates (three seedlings) per treatment were used for statistical analyses. Generalized linear models (GLM) were used to assess the effect of salinity and peanut shells on measured variables. Akaike information criterion (AIC) was used to selected best model while considering with and without interaction between salinity and peanut shells. Student-Newman-Keuls's post-hoc test was used to determine significant differences ($P \leq 0.05$) among peanut shells' doses for various traits. All simulations were carried out with R software (R Core Team 2015).

Data availability The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

3 Results

3.1 Effect of salinity and peanut shells on soil chemical and microbiological characteristics

Results showed that salinity had a significant ($p < 0.05$) positive effect on electrical conductivity (EC) and the sum of exchangeable cations (SEC) and a significant negative effect on AMF spores density (Table S1). The peanut shells treatment had a significant positive effect on pH, capacity of exchange cations (CEC), carbon (C), nitrogen (N), phosphorus (P), total microbial activity (FDA), and a significant negative effect on AMF spores density of soils (Table S1). The interaction between salinity and peanut shells had a significant effect on EC, FDA, and AMF spores density (Table S1). The results of all GLM were presented in supplementary Table 1.

The independent effects of salinity and peanut shells on soil chemical and microbiological characteristics are presented in Tables 2 and 3. EC and SEC of soil were significantly increased by 591 and 228%, respectively, with 257 mM of NaCl whereas FDA and AMF spores density were significantly decreased by 47 and 51%, respectively (Table 2). Chemical characteristics of soil were improved by the application of peanut shells. Soil total carbon, nitrogen, and phosphorus contents were significantly increased by 272, 81, and 65% with 8 t ha^{-1}, respectively (Table 3). The same trend was observed in pH and CEC that were significantly increased by 8 t ha^{-1} with 8 and 22%, respectively. Electrical conductivity was significantly decreased only by high dose of peanut shells (8 t ha^{-1}) with a decreasing rate of 60%. FDA was significantly increased by peanut shells application while spores density decreased. An increase of 606% of total microbial activity was observed with 8 t ha^{-1} of peanut shells while AMF spores density was decreased by 91% with the same dose of peanut shells (Table 3).

3.2 Effect of peanut shells on *S. senegal*, *V. seyal*, and *P. juliflora* seedlings growth under saline conditions

Results showed that salinity had a significant ($p < 0.05$) negative effect on the growth parameters of *S. senegal* and *V. seyal* seedlings and on the shoot dry weight (SDW) and root dry weight (RDW) of *P. juliflora* (Table S2). However, irrespective of the species, the peanut shells treatment had a significant positive effect on all the growth parameters. In contrast, the interaction between salinity and peanut shells had no significant ($p > 0.05$) effect on their growth parameters except the collar diameter ($p = 0.008$) of *S. senegal* seedlings (Table S2). The results of all GLM on seedlings growth were presented in supplementary Table 2.

Figure 1 presented the independent effect of peanut shells on seedlings growth. Results showed that peanut shells application improved significantly height, collar diameter, and shoot and root dry biomass of seedlings of all tree species. In general, no significant differences were noted among peanut shells' doses on height and collar diameter of seedlings (Fig. 1a). The same result was observed between 6 and 8 t ha^{-1} peanut shells' doses on SDW of seedlings (Fig. 1b). Whatever the species, the highest growth was obtained with 6 t ha^{-1} of peanut shells with an increase of 199, 314, and 1029% in terms of SDW, respectively, in *V. seyal*, *S. senegal*, and *P. juliflora* compared to control seedlings. High dose of peanut

Table 2 Values of pH_{H2O}, electrical conductivity (EC), sum of exchangeable cations (SEC), cation-exchange capacity (CEC), total carbon (C), total nitrogen (N), total phosphorus (P), total microbial activity (FDA), and AMF spores density of non-sterile sandy soils exposed to four NaCl concentrations (0, 86, 171, and 257 mM)

Salinity (mM NaCl)	pH_{H2O}	EC (mS cm^{-1})	SEC (meq%)	CEC (meq%)	C (mg kg^{-1})	N (mg kg^{-1})	P (mg kg^{-1})	FDA (µg fluorescein g soil^{-1} h^{-1})	AMF spores density (spores 100 g soil^{-1})
0	6.5 ± 0.3b	0.65 ± 0.14a	3.32 ± 0.84a	3.10 ± 0.33a	100.5 ± 15.6b	7.3 ± 2.1a	73.6 ± 10.8a	5.26 ± 1.82b	74 ± 10b
86	6.1 ± 0.1a	1.19 ± 0.44a	5.33 ± 0.8b	3.04 ± 0.33a	97.4 ± 14.9b	7.0 ± 2.5a	72.8 ± 17.8a	4.18 ± 1.25b	60 ± 7b
171	6.1 ± 0.2a	3.20 ± 1.00b	9.21 ± 1.09c	3.06 ± 0.20a	93.6 ± 13.4b	7.0 ± 2.0a	71.6 ± 11.8a	3.59 ± 1.12ab	61 ± 9b
257	6.0 ± 0.2a	4.49 ± 1.38b	10.88 ± 1.62c	3.02 ± 0.38a	76.3 ± 8.2a	6.2 ± 2.1a	60.8 ± 16.1a	2.79 ± 1.05a	36 ± 4a

Values in column sharing the same letter comparing NaCl concentrations are not significantly different at $p < 0.05$ (Student-Newman-Keuls test)

SEC = $K^+ + Ca^{2+} + Mg^{2+} + Na^+$

Table 3 Values of pH_{H2O}, electrical conductivity (EC), sum of exchangeable cations (SEC), cation-exchange capacity (CEC), total carbon (C), total nitrogen (N), total phosphorus (P), total microbial activity (FDA), and AMF spores density of non-sterile sandy soils amended with different doses of peanut shells (0, 4, 6, and 8 t ha^{-1})

Peanut shells (t ha^{-1})	pH_{H2O}	EC (mS cm^{-1})	SEC (meq%)	CEC (meq%)	C (mg kg^{-1})	N (mg kg^{-1})	P (mg kg^{-1})	FDA (µg fluorescein g soil^{-1} h^{-1})	AMF spores density (spores 100 g soil^{-1})
0	6.1 ± 0.2a	3.08 ± 1.01b	5.9 ± 1.9a	2.67 ± 0.25a	49.8 ± 11.0a	4.8 ± 1.3a	51.0 ± 12.3a	0.89 ± 0.33a	169 ± 22b
4	6.1 ± 0.2a	2.80 ± 1.07b	6.9 ± 1.7ab	3.15 ± 0.20b	85.0 ± 13.9b	6.6 ± 2.1b	67.4 ± 18.8b	4.31 ± 1.10b	29 ± 12a
6	6.2 ± 0.3a	2.41 ± 0.42b	7.8 ± 1.9ab	3.23 ± 0.24b	106.2 ± 18.4bc	7.5 ± 1.7bc	76.0 ± 15.3bc	4.89 ± 1.21bc	19 ± 9a
8	6.6 ± 0.4b	1.24 ± 0.21a	8.1 ± 1.7b	3.27 ± 0.27b	126.8 ± 19.0c	8.7 ± 1.5c	84.3 ± 14.1c	5.74 ± 0.71c	15 ± 8a

Values in column sharing the same letter comparing peanut shells doses are not significantly different at $p < 0.05$ (Student-Newman-Keuls test)

SEC = $K^+ + Ca^{2+} + Mg^{2+} + Na^+$

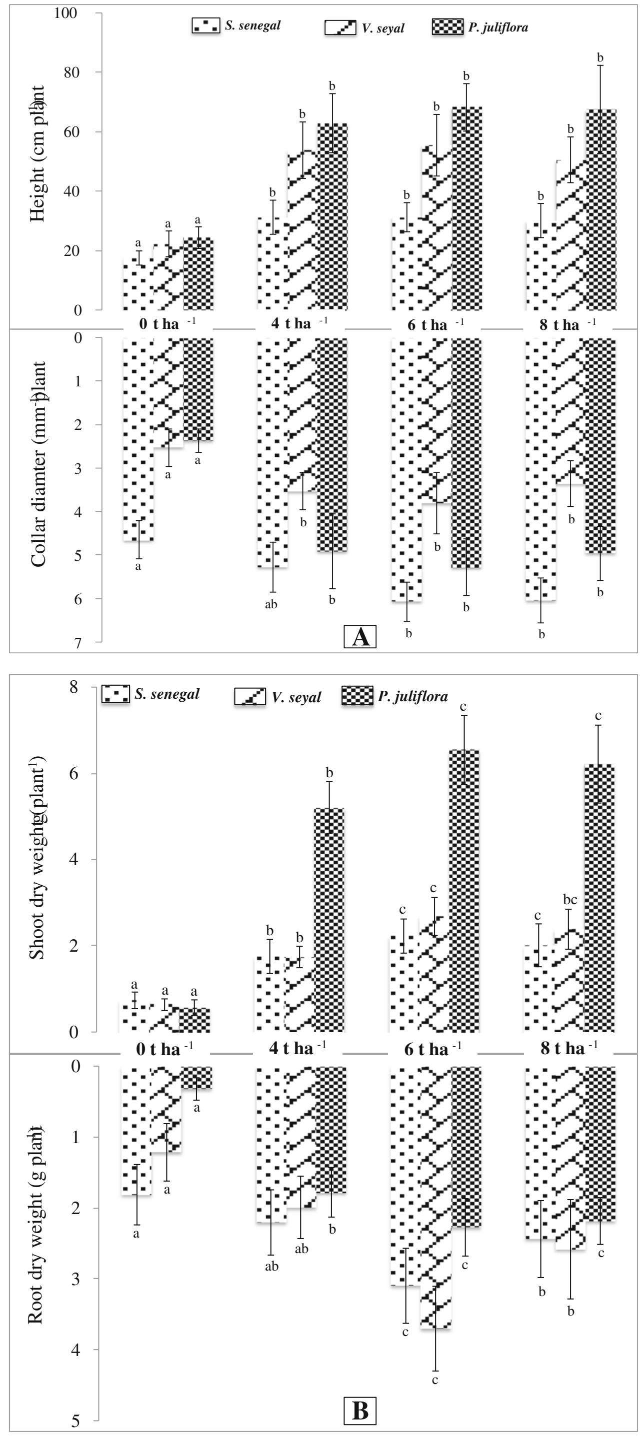


Fig. 1 Height and collar diameter (**A**). shoot dry weight, and root dry weight (**B**) of *Senegalia senegal*, *Vachellia seyal*, and *Prosopis juliflora* seedlings grown on non-sterile sandy soil amended with four doses of peanut shells (0, 4, 6, and 8 t ha^{-1}) during for 4 months under greenhouse. For each species, bars sharing the same letter comparing peanut shells doses are not significantly different at $p < 0.05$ (Student-Newman-Keuls test)

shells (8 t ha^{-1}) seemed to decrease SDW with a reduction of 10, 10, and 5%, respectively, for *S. senegal*, *V. seyal*, and *P. juliflora*, compared to seedlings amended with 6 t ha^{-1}. The same trend was observed for RDW for all species (Fig. 1b).

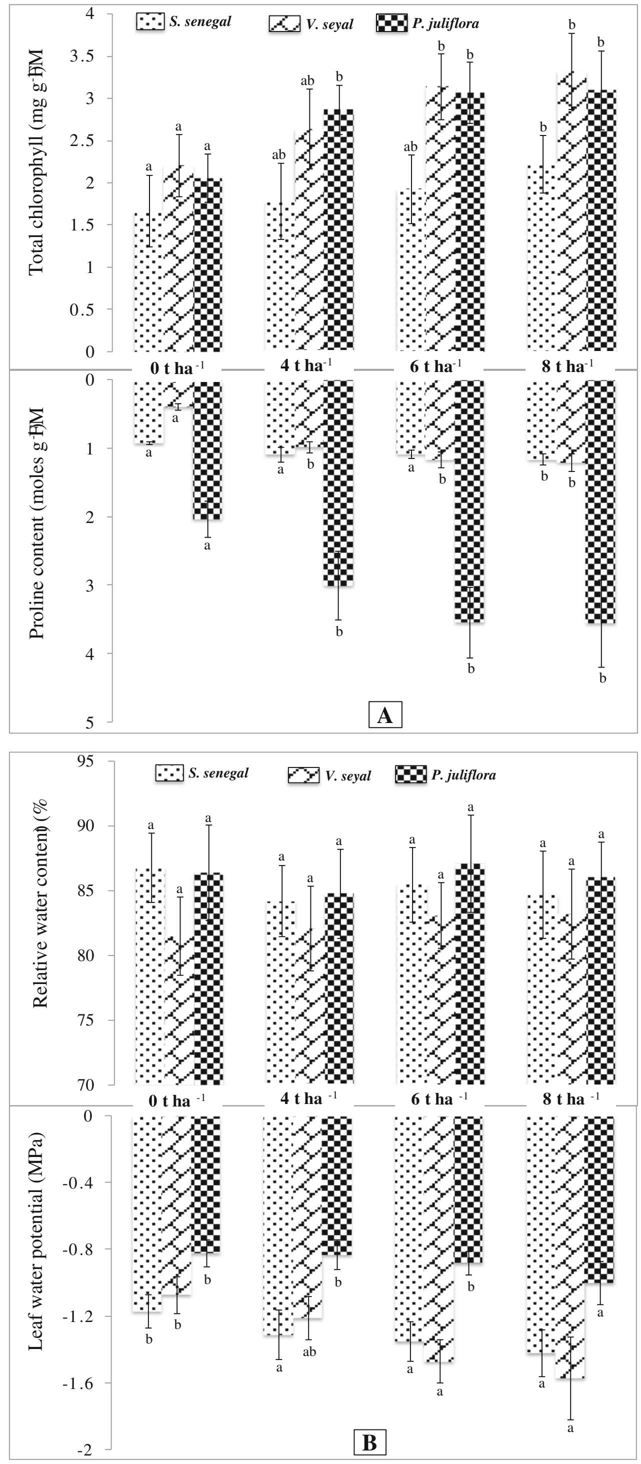
3.3 Effect of peanut shells on *S. senegal*, *V. seyal*, and *P. juliflora* seedlings physiological traits

Results showed that salinity had a significant ($p < 0.05$) negative effect on chlorophyll content in *S. senegal* and *V. seyal*, on leaf water potential (LWP) in *S. senegal*, and on relative water content (RWC) in *P. juliflora* seedlings (Table S3). Results also showed a significant positive effect of salinity on proline content in *V. seyal* and *P. juliflora*. Peanut shells had a positive effect on proline content in all species, on chlorophyll content in *V. seyal*, and *P. juliflora* and a negative effect on LWP in *S. senegal* and *V. seyal.* The interaction between salinity and peanut shells' treatments had no significant ($p > 0.05$) effect on physiological traits of species except in proline content of *V. seyal* seedlings where a significant (($p = 0.014$) positive effect was observed. The results of all GLM on seedlings physiological traits were presented in supplementary Table 3.

The effect of peanut shells on seedlings' physiological traits was presented in Fig. 2. Chlorophyll content was significantly increased by all peanut shells' doses in *V. seyal* and *P. juliflora* while only 8 t ha^{-1} increased it in *S. senegal* seedlings (Fig. 2a). The highest chlorophyll content was obtained with the highest peanut shells dose (8 t ha^{-1}) for all species with an increase of 33, 50, and 50%, respectively, in *S. senegal*, *P. juliflora*, and *V. seyal*. The same trend was observed on proline content (Fig. 2a). The highest proline content was obtained with 8 t ha^{-1} of peanut shells for all species. Proline content was increased by 26, 48, and 208%, respectively, in *S. senegal*, *P. juliflora*, and *V. seyal* compared to control seedlings (not amended). No significant effect of peanut shells was observed on RWC of seedling for all species (Fig. 2a). The effect of peanut shells on LWP depended on species and peanut shells dose. Nevertheless, LWP became more negative with increasing of peanut shells dose for all species with a significant effect from 4 t ha^{-1} for *S. senegal*, 6 t ha^{-1} for *V. seyal*, and 8 t ha^{-1} for *P. juliflora* seedlings (Fig. 2b).

3.4 Effect of peanut shells on root nodulation and mycorrhization of *S. senegal*, *V. seyal*, and *P. juliflora* seedlings under salt stress conditions

The number of nodules per plant and mycorrhizal root colonization (MRC) decreased with increasing NaCl concentration (Table 4). However, peanut shells increased the



FM= fresh matter

Fig. 2 Total chlorophyll and proline contents (**A**), relative water content, and leaf water potential (**B**) of *Senegalia senegal*, *Vachellia seyal*, and *Prosopis juliflora* seedlings grown on non-sterile sandy soil amended with four doses of peanut shells (0, 4, 6, and 8 t ha$_{-1}$) during for 4 months under greenhouse. For each species, bars sharing the same letter comparing peanut shells doses are not significantly different at $p <$ 0.05 (Student-Newman-Keuls test)

Table 4 Nodules number per plant and mycorrhizal root colonization (%) of *Senegalia senegal*, *Vachellia seyal*, and *Prosopis juliflora* seedlings grown on non-sterile sandy soil amended with four doses of peanut shells (0, 4, 6, and 8 t ha^{-1}) and exposed for 4 months to four salinity levels (0, 86, 171, and 257 mM NaCl) under greenhouse conditions

Salinity (mM NaCl)	Peanut shells (t ha^{-1})	*S. senegal*		*V. seyal*		*P. juliflora*	
		NN	MRC	NN	MRC	NN	MRC
0	0	4 ± 1.2b	6.1 ± 2.3a	2±0.10b	1.4 ± 0.72a	4 ± 1.4a	21.2 ± 3.9b
	4	0a	18.5 ± 5.4b	16±2.3c	2.6 ± 0.80a	10 ± 2.1b	23.0 ± 3.1b
	6	0a	1.1 ± 0.01a	14±4.1c	10.9 ± 3.4b	14 ± 3.2b	32.8 ± 5.3c
	8	0a	0.1 ± 0.0a	0±0.0a	2.6 ± 0.9a	11 ± 2.5b	14.6 ± 2.4a
86	0	0	2.3 ± 1.7a	0	1.1 ± 0.02a	1 ± 0.0a	16.4 ± 2.2b
	4	0	19.3 ± 4.9b	0	2.0 ± 0.24b	18 ± 3.0c	37.7 ± 5.2c
	6	0	16.6 ± 3.3b	0	2.5 ± 0.26b	15 ± 2.4bc	19.7 ± 2.6b
	8	0	9.1 ± 4.7a	0	2.4 ± 0.23b	13 ± 1.9b	0.5 ± 0.01a
171	0	0	1.1 ± 0.92a	0	0.3 ± 0.21a	0	13.2 ± 2.8b
	4	0	11.2 ± 3.2b	0	1.7 ± 0.38b	0	16.6 ± 3.5b
	6	0	8.3 ± 1.3b	0	1.2 ± 0.29ab	0	10.9 ± 2.8b
	8	0	4.8 ± 2.1a	0	0.7 ± 0.3a	0	0.8 ± 0.02a
257	0	0	1.1 ± 0.86a	0	0.2 ± 0.12a	0	5.6 ± 1.02b
	4	0	8.7 ± 2.6b	0	2.5 ± 0.25c	0	7.7 ± 1.9b
	6	0	3.6 ± 2.7a	0	2.1 ± 0.21c	0	7.6 ± 1.4b
	8	0	2.4 ± 1.4a	0	1.4 ± 0.3b	0	1.8 ± 0.03a

For each NaCl concentration, values in column sharing the same letter comparing peanut shells doses are not significantly different at $p < 0.05$ (Student-Newman-Keuls test)

NN nodules number, *MRC* mycorrhizal root colonization

number of nodules in *V. seyal* and *P. juliflora* seedlings. No nodule was obtained for NaCl concentrations above 86 mM in *S. senegal* and *V. seyal*, and 171 mM in *P. juliflora*. Peanut shells increased significantly MRC in all species. However, high dose of peanut shells (8 t ha^{-1}) decreased MRC for all species compared to other doses (4 and 6 t ha^{-1}). The highest positive effect of peanut shells on MRC was obtained with 4 t ha^{-1} of peanut shells (Table 4).

4 Discussion

The increase of soils EC and SEC by the addition of sodium chloride, observed in our results, is due to the dissociation of NaCl. Indeed, when NaCl is dissolved in water, it dissociates into sodium ions (Na^{+}) and chloride ions (Cl^{-}). These ions increase the SEC and also can circulate in solution and make the solution more conductor of electricity. The negative effect of NaCl on soils AFM spores density and microbial activities is widely documented (Rietz and Haynes 2003; Evelin et al. 2009). However, it is important to note that salinization can increase AFM spores density by the stimulation of sporulation and the inhibition of spores germination under severe conditions (Aliasgharzadeh et al. 2001).

The low productivity of saline soils is usually attributed to salt toxicity or damage caused by excessive amounts of soluble salts, but also to their low soil fertility (Liang et al. 2003). Our results showed that peanut shells application improved chemical properties of soil. The use of peanut shells as organic amendment increased the soil total carbon, total nitrogen, total phosphorus, and total microbial activity (FDA) independently of salinity. The addition of peanut shells increases substrate availability for microbial activities. The mineralization of this organic matter increases nutrient availability for plants. Our findings are in accordance with those reported with several types of organic matter (Madejon et al. 2001; Marschner et al. 2003; Lakhdar et al. 2010). The decrease AMF in spores density with peanut shells addition could be due probably to soil dilution but also to P availability. Indeed, increase of soil P results in a reduction in spore production (Khakpour and Khara 2012).

Cation-exchange capacity (CEC) is an intrinsic property of soil defining the concentration of negatively charged sites on soil colloids that can adsorb exchangeable cations and can be a good indicator of soil productivity. Soils with high CEC are more fertile because they retain more cations (McKenzie et al. 2004) and many plant nutrients are cations (Klute et al. 1994). Our results demonstrated that application of peanut shells increased the CEC, which could result on a high rate of organic matter mineralization. Similar results were obtained by Walker and Bernal (2008) with olive mill waste compost and poultry manure.

Electrical conductivity (EC) is a soil parameter that indicates a direct measurement of salinity. Soil EC showed a decreasing trend with the application of peanut shells and had a significant effect at high dose (8 t ha^{-1}). As reported by Qadir and Oster (2004), an increase in the Ca^{2+} concentration in the soil solution causes the replacement of Na^{+} by Ca^{2+} at the cation-exchange sites on the soil particles, which will subsequently be leached, reducing of soil sodicity (Tejada et al. 2006). It is important to note that the weak effect of peanut shells on soil EC noted in our experimental conditions could be due to the low leaching. Indeed, seedlings were watered to field capacity which causes a lack of runoff to drain Na^{+}. A significant decrease of soil EC was obtained by Wang et al. (2014) in natural condition after a 2-year application of green waste compost at 0.45 t ha^{-1}.

Results showed that peanut shells application increased the exchangeable cations such as Ca^{2+} K^{+} and Mg^{2+}, which are competitors of Na^{+} under sodicity conditions, thus, limiting the entry of Na^{+} into the exchange complex (Bao 2005). The application of high dose of peanut shells (8 t ha^{-1}) increased soil pH. This positive effect of peanut shells could be due to the high content of basic cations (Ca^{2+}, K^{+}…). Basic cations act in a similar manner as mineral lime, increase is most likely due to the high soil pH (Pocknee and Sumner 1997). Similar results were obtained by Wang et al. (2014) with green waste compost. Our findings contrasted with those obtained by Pattanayak et al. (2001), Yaduvanshi (2001), and Smiciklas et al. (2002), which showed a decrease in soil pH after the use of organic materials.

The negative effect of salinity on growth and physiological traits of *S. senegal*, *V. seyal*, and *P. juliflora* seedlings, observed in our results, had been presented and discussed in our previous work (Fall et al. 2016). Furthermore, this negative effect of salinity had been well documented (Abari et al. 2011; Fall et al. 2016; Sharma and Vimala 2016). So in this present study, we focused on the effect of peanut shells on their growth under salinity and not saline conditions. Results showed that peanut shells increased the growth and physiology of *S. Senegal*, *V. seyal*, and *P. juliflora* seedlings. The increased tree height, basal diameter, and shoot biomass might be due to better physiological behavior of plants. Peanut shells application improved physical, chemical, and microbiological properties of saline soil and also of non-saline ones probably resulting in an increased of the availability of macronutrients as well as micronutrients for plants. Similar results were obtained with different organic amendments on *Sophora japonica* (Wang et al. 2014) and on rice (Shaaban et al. 2013; Hossain and Sarker 2015). The decrease in plant growth observed in the presence of high dose of peanut shells (8 t ha^{-1}) could be explained by the modification of soil's physical characteristics. Indeed, the addition of organic matter rich in calcium enhances soil *aggregation* and flocculation (Bigham 2013), limiting root development and consequently the absorption of mineral elements by plant. Rengasamy (2002) reported that Ca^{2+} ion has a high relative flocculating power (45) compared to others cations.

Our results showed that the low dose of peanut shells (4 t ha^{-1}) stimulated rhizobial and endo-mycorrhizal symbiosis except in *V. seyal* and *P. juliflora* at 0 mM NaCl, whereas the higher dose (8 t ha^{-1}) inhibited these parameters. The establishment of microbial symbiosis requires a minimum of nutrient content because these symbioses are biological processes quite expensive in energy for the plant. In our experiment, the dose of 4 t ha^{-1} of peanut shells allows a nutrient availability especially P and N for a good symbiosis, while the high concentrations of these elements with 8 t ha^{-1} will inhibit these symbioses. It is known that the low or high soil nutrient levels such as nitrogen and phosphorus reduce nodulation (Gentili and Huss-Danell 2002 2003) and endo-mycorrhization of plants (Asimi et al., 1980; Koide 1991).

5 Conclusion

Our results showed that the application of peanut shells as organic amendment improved the fertility imparted through both chemical characteristics and microbial activity and also reduced electrical conductivity of salty soils. Peanut shells application improved the growth of *S. senegal*, *V. seyal*, and *P. juliflora* seedlings. However, the doses of 6 and 8 t ha^{-1} reduced nodulation and mycorrhization of seedlings. This inhibition would be due to a high concentration of nutrients in the soil. At high concentrations of NaCl (257 mM), the amendment with 8 t ha^{-1} of peanut shells inhibited seedlings growth. So, 6 t ha^{-1} of peanut shells seemed to be the best dose for seedlings growth in saline conditions and also in non-saline soils. However, long-term field trials are needed to confirm our findings.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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