Addition of organic fertilizer affects soil nitrogen availability in a salinized fluvo-aquic soil

Xiao-Wen Wang, Hui Cai, Yan-Li Liu, Cheng-Liang Li, Yong-Shan Wan, Fu-Peng Song and Wei-Feng Chen

*National Engineering Laboratory for Efficient Utilization of Soil and Fertilizer Resources, College of Resources and Environment, Shandong Agricultural University, Ta’ian, Shandong, China; †Soil and Water Science Department, Tropical Research & Education Center, University of Florida, Homestead, FL, USA

ABSTRACT

Organic matter application was one of the suitable ways to improve soil nitrogen availability in saline soils. In this study, two soils of different levels of total soluble salts, 2.45 g kg⁻¹ (LS) and 4.03 g kg⁻¹ (HS), were used in a pot experiment with eight treatments: bio-organic fertilizer (prepared with cow dung) and farmyard manure (fowl manure) each at three dosages (3350, 6700, and 13,400 kg ha⁻¹), chemical fertilizer control (DAP: 1675 kg ha⁻¹), no fertilizer blank. At the same time, an indoor nitrogen mineralization incubation experiment with the same treatments without alfalfa planting was carried out. We aimed to explore the effects of the types and application amounts of organic fertilizers on soil nitrogen mineralization in saline soils and to improve its quality and finally realize its sustainable utilization. The main conclusions are as follows: the biomass of alfalfa treated with medium dose of organic fertilizer was higher than that of alfalfa treated with low or high dose of organic fertilizer. Compared with farmyard manure, bio-organic manure was more effective in increasing the biomass of alfalfa. The nitrogen uptake of alfalfa in high-dose treatment was significantly higher than that in low-dose treatment. The effects of the fertilizer treatments on soil nitrogen availability were in the increasing order of: medium dose, high or low dose of fertilizer treatment, single chemical fertilizer, and fertilizer free treatments by principal component analysis. For possible potential application, medium dosage of bio-organic fertilizer was recommended to apply in the region with saline fluvo-aquic soil.

1 Introduction

Saline soils are an important land resource distributed widely in China [1, 2], which can relieve the pressure for arable land resources under rational exploitation [3]. No doubt that rational exploitation extent is really depended on the level of salt in soil since the salt content in soil will affect biological and chemical processes and consequently influence plant growth [4, 5]. The availability of nitrogen in soil was hindered for wide reclaimed land due to excessive amounts of salts in saline soil [6]. Ammonification was inhibited at higher salt amounts in soils; likewise, nitrification was very sensitive to salinity [7]. Net nitrogen mineralization decreased with the increase of soil salinity [8, 9]. Amendment practices proved that organic matter application was a feasible method to improve nitrogen availability in saline soils [3, 10–12].

Livestock husbandry has been developing rapidly in Shandong Province, China, producing huge amounts of livestock excrements and posing a threat to the environment. One good way to utilize these excrements such as cow dung and fowl manure is using them for organic fertilizer production. The produced organic fertilizers contain not only nutrient elements essential for plant growth, including nitrogen (N), phosphorus (P), potassium (K), sulfur (S), and calcium (Ca) [13], but also free humic acids, fulvic acids and residues of different biopolymers. When the organic fertilizers are applied to soil, nutrients are released during mineralization and available for crop growth [14, 15]. In addition, N loss decreases due to reduced nitrification-denitrification [16] and ammonia volatilization from soil [10]. Application of organic fertilizers, which contain rich elements essential for plant growth including nitrogen fractions [17], stimulates soil microbial activity and improves soil nitrogen mineralization [9, 18]. Therefore, a pot study was conducted to investigate the effects of two types of organic fertilizers produced with cow dung and fowl manure, respectively, on changes in nitrogen status in two saline soils of different salt levels.

Alfalfa is a good fodder for livestock due to its excellent quality, high yield as well as high-stress tolerance, and it is widely cultivated to meet the huge requirement by the animal husbandry [19, 20]. Some field trials showed that the amount of available nutrients was significantly increased with the increased duration of alfalfa cultivation [21]. At present, there

CONTACT Yan-li Liu yanliliu2013@163.com

© 2019 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.
are few researches on the effects of organic fertilizers on alfalfa growth and soil nitrogen availability in different saline alkali lands. Organic fertilizers should be used to improve saline soil utilization in China due to shortage of tillage land area. In the present research, a bio-organic fertilizer (produced with cow dung) and a fowl manure were used at three dosages in two saline soils of different salt levels planted with alfalfa. The present study aimed to investigate: (i) the response of alfalfa to organic fertilizer application in two salinized fluvo-aquic soil; (ii) the effects the two organic fertilizers at three application dosages on soil nitrogen availability. It was hypothesized that organic fertilizers applied at high dosages improve alfalfa growth and soil nitrogen availability better in both soils.

2 Materials and methods

2.1 Soil and fertilizers used

The two soils used in the pot experiment were collected from two saline fields in Bohai farm in Dongying City (37.79° N, 118.63° E), Shandong Province, China. The fields had been used for maize (Zea mays L.) and wheat (Triticum aestivum) cultivation for several years. At each field, soil samples were randomly taken from the surface 0–15 cm layer at 9 different locations and mixed into one composite soil sample. The soil sample was air-dried. A portion was ground to pass a 2-mm sieve and a portion was ground to pass a 0.15-mm sieve for soil basic characteristics measuring. The left was used in the pot experiment and incubation experiment. The basic physical and chemical properties of the soils are shown in Table 1. The soil with total soluble salt content of 2.45 g kg\(^{-1}\) is hereafter referred to as LS, and the soil with total soluble salt content of 4.03 g kg\(^{-1}\) HS [22].

The bio-organic fertilizer used in the study was produced with cow dung, which was kindly provided by Shandong Agricultural University Fertilizer Technology Co., Ltd. Another organic fertilizer used in this study, fowl manure, had been composted with rice husk, which was purchased from local market. Fowl manure is a popular fertilizer for vegetable production in Shandong, and referred to as farm manure in this study. The basic properties of the bio-organic fertilizer and farm manure are listed in Table 2.

2.2 The pot experiment

In this experiment, eight fertilization treatments were set up with three replicates. In the six treatments with the bio-organic fertilizer or farm manure applied, both the organic fertilizers were applied at three dosages of 3350, 6700, and 13,400 kg ha\(^{-1}\) (referred to as H1, H2, and H3, respectively, for the bio-organic fertilizer; M1, M2, and M3, respectively, for the farm manure). Only diammonium phosphate (1675 kg ha\(^{-1}\)) was applied in the control treatment, and no fertilizer was applied in the blank. After corresponding soil and organic fertilizer were mixed thoroughly, 2 kg of the soil-fertilizer mixture was transferred into a pottery pot (15 cm in diameter and 14 cm in height). A total of 48 pots were prepared for both LS and HS. The pot experiment was conducted in a greenhouse of the National Engineering Laboratory for Efficient Utilization of Soil and Fertilizer Resources, Shandong Agricultural University, China from April to June, 2018. Twenty seeds of alfalfa (Medicago sativa L) were sown in each pot to achieve a planting density of 2 g m\(^{-2}\) (a local typical planting density) and thinned to 10 plants per pot after complete germination.

The upper parts of the plants were harvested 45 days after germination, washed with tap water and then distilled water. The plants were oven-dried first at 105°C for 1 h and then at 75°C to constant weight. The oven-dried plants were milled and sieved through 2-mm sieve for later analyses. For the soil in each pot, a portion was air-dried, ground, and sieved to 2 mm for later measurement while the rest was kept at 4°C.

2.3 The incubation experiment

The same treatments were used in the incubation experiment as in the pot experiment. Plastic bottles of 100 ml in volume were filled with 100 g soil with or without fertilizers. After soil water holding capacity (WHC) was adjusted to 60%, the bottles were put in an incubator and incubated at 28°C in the dark. The

| Table 1. Basic physical and chemical properties of the two saline soils used in this study. |
|-----------------------------------------------|
| Saline soils | Total nitrogen content (g kg\(^{-1}\)) | Nitrate content (mg kg\(^{-1}\)) | Ammonium content (mg kg\(^{-1}\)) | Organic carbon content (g kg\(^{-1}\)) | pH | Total soluble salt content (g kg\(^{-1}\)) | C/N |
| LS | 1.55 | 12.57 | 8.96 | 12.29 | 8.8 | 2.45 | 14.97 |
| HS | 0.76 | 5.46 | 5.83 | 10.21 | 9.2 | 4.03 | 26.48 |

Note: LS refers to the soil with low total soluble salt content; HS refers to the soil with high total soluble salt content.

| Table 2. Basic properties of the bio-organic fertilizer and farm manure used in this study. |
|-----------------------------------------------|
| Organic fertilizer | Total N (g kg\(^{-1}\)) | Nitrate (mg kg\(^{-1}\)) | Total P (g kg\(^{-1}\)) | Total K (g kg\(^{-1}\)) | Organic matter (g kg\(^{-1}\)) | pH (1:2.5 H\(_2\)O) | Free humic acids (g kg\(^{-1}\)) |
| Bio-organic fertilizer | 35.95 | 11.93 | 13.30 | 17.86 | 289.10 | 4.8 | 102.50 |
| Farm manure | 25.18 | 8.25 | 22.40 | 9.24 | 283.10 | 7.8 | 145.50 |
bottles were not capped for aeration [23] and WHC in each bottle was maintained by water replenishing every 3 days. Three bottles of each treatment were taken on days 1, 3, 7, 14, and 21 during the incubation. The soil samples were extracted with 2 M KCl solution and the contents of nitrate and ammonium nitrogen were determined using a double wavelength UV and indophenol blue spectrophotometer. Soil mineralized nitrogen was quantified as the difference in the amount of mineral nitrogen (the sum of NO₃⁻N and NH₄⁺-N) between that at the beginning and that at the sampled time of the incubation experiment and the mineralization rate of soil nitrogen was calculated based on the amount of mineral nitrogen.

### 2.4 Chemical analyses

Soil pH was measured with soil: water ratio of 1:2.5 (w/w) using a pH meter with a combination reference glass electrode. Total N content was determined by the Kjeldahl method [24]. Nitrate content and ammonium content of soil were determined with a double wavelength UV spectrophotometer and using the indophenol blue spectrophotometric method, respectively. Soil organic carbon content was measured by the potassium dichromate volumetric method, respectively. Soil organic carbon content was measured by the Kjeldahl method [24]. Total soluble salt content of soil was determined by the residue drying mass method. The organic fertilizers were digested with nitric acid and sulphuric acid, and total P and total K contents were determined by the ammonium vanadomolybdate process and with a flame photometer, respectively. The content of free humic acids in the organic fertilizers was measured by the potassium dichromate volumetric method. Organic matter concentration of the organic fertilizers was measured following the method for soil organic carbon content determination.

Plant samples were digested with a mixture of acids and total N content was determined by the Kjeldahl method [24]. Nitrogen accumulation by alfalfa was calculated as the product of the biomass of alfalfa and the nitrogen content of plant.

### 2.5 Statistical analysis

Statistics were conducted with the IBM SPSS 22 Statistics software for Windows. Two-way analysis of variance (ANOVA) was performed to determine the effect of fertilization treatments on soil inorganic nitrogen content, soil organic nitrogen mineralization, nitrification and the biomass of alfalfa. Differences between treatments were separated by least significant difference (LSD) at \( P < 0.05 \), unless otherwise noted. The paired-samples t-test method was used to analyze the effects of salt level on the biomass of alfalfa at \( P < 0.05 \), unless otherwise noted. Principal component analysis was then used to cluster all variables connected with soil nitrogen availability and to discern common factors affecting groups of variables. Scores of varimax rotated principal components were compared using one-way ANOVA to test the effects of fertilization treatments.

### 3 Results and discussion

#### 3.1 Alfalfa biomass and nitrogen accumulation in different fertilization treatments

Bio-organic fertilizer and farm manure increased alfalfa growth in both soils (Table 3). In both soils, medium dosage of bio-organic fertilizer brought out the highest alfalfa biomass, followed by the low dosage and then the high dosage. The same trend was observed for farm manure. Alfalfa biomass was improved by 23.24% and 17.23% in H2 and M2, respectively compared with the control treatment in LS. Similarly, alfalfa biomass was improved by 19.55% and 20.44% in H2 and M2, respectively in HS. Paired-samples t-test showed that alfalfa biomass in LS was higher than in HS under the same fertilization treatment.

Application of fertilizer, chemical fertilizer or organic fertilizer, increased nitrogen content of alfalfa in comparison with Blank treatment (Table 4). No matter which kind of organic fertilizer was applied, compared with the control treatment, the high-dose treatment significantly increased the nitrogen content of alfalfa. Nitrogen content of alfalfa in LS was markedly higher

---

**Table 3.** Biomass of alfalfa in the two soils of different salt contents (low salt content soil, LS; high salt content soil, HS) with different fertilization treatments (Means ± standard errors).

| Fertilizer treatment | Alfalfa biomass (g m⁻², dry weight) | Increase vs control treatment (%) |
|----------------------|------------------------------------|----------------------------------|
|                      | LS                                 | HS                               |
| Blank                | 205.07 ± 9.46f                      | 185.65 ± 2.14c                    |
| Control              | 225.79 ± 4.42e                      | 210.84 ± 5.28bc                   |
| H1                   | 254.21 ± 7.35bcd                    | 241.25 ± 4.36ab                   |
| H2                   | 278.27 ± 1.73a                      | 252.06 ± 9.91ab                   |
| H3                   | 297.58 ± 7.72abc                    | 237.40 ± 22.52ab                  |
| M1                   | 240.68 ± 5.11de                     | 232.81 ± 12.16ab                  |
| M2                   | 264.69 ± 5.47abc                    | 253.93 ± 15.86a                   |
| M3                   | 235.87 ± 8.27de                     | 222.68 ± 13.67abc                 |
| F-Test Sig.          | p = 0.01                           | p < 0.01                          |

Same letters in one column indicate no significant differences between the fertilizer treatments (\( n = 3, P < 0.05 \)). F-Test Sig. means differences in alfalfa biomass between LS and HS by paired-samples t-test analysis.
than that in HS. The tendency of nitrogen accumulation in alfalfa was similar to that of nitrogen content (Table 4). In both soils, only the H3 treatment significantly increased nitrogen accumulation of alfalfa among three levels of bio-organic fertilizer application. Nevertheless, there were no significant differences in nitrogen accumulation of alfalfa between three levels of farm manure application.

Both biomass and nitrogen accumulation of alfalfa were significantly higher \((P < 0.01)\) in LS than in HS based on paired-samples t-test analysis. This is due to the high soil fertility of LS and the continuous supply of bio-organic fertilizer. Previous studies have shown that manure produced with cow dung can decompose in soil to produce a large number of nutrient elements needed by plant growth and improve soil fertility in saline-alkali soil in the Yellow River Delta [26]. Similar results were obtained in the present research. It was reported that cotton plants in organic fertilization treatments had higher chlorophyll contents than those in CK [3]. High chlorophyll content might have boosted alfalfa growth. Application of humic acid (HA) extracted from lignite significantly increased wheat growth and nitrogen uptake in both calcareous and non-calcareous soils, while the medium dose of HA (60 mg kg\(^{-1}\) soil) was either more efficient in promoting plant growth or at par with high doses [27].

### 3.2 The content of inorganic nitrogen in soils at the harvest of alfalfa

Nitrate and ammonium contents in soil are pivotal for plant growth. Soil inorganic nitrogen content was expressed as the sum of NH\(_4^+\)-N and NO\(_3^-\) N contents in the sampled soils. At harvest, NO\(_3^-\) N content in both soils was significantly increased by either chemical fertilizer or organic fertilizer application compared with Blank treatment. Surely, both organic fertilization markedly improved NO\(_3^-\) N content in soil. NO\(_3^-\) N content in both soils was pronouncedly increased with increasing application dosage of the bio-organic fertilizer (Figure 1).

Similarly, NH\(_4^+\)-N content in soil was significantly increased by organic fertilizer application in both soils compared with that in Control treatment (Figure 1). Medium dosage of bio-organic fertilizer (H2) or farm manure (M2) observably raised NH\(_4^+\)-N content in both soils in comparison with the other two dosages. There was no significant difference in soil NH\(_4^+\)-N content between low and high dosages of the two organic fertilizers.

Soil inorganic nitrogen and NO\(_3^-\) N content changed in a similar trend in the treatments with the application of bio-organic fertilizer and farmyard manure. Inorganic nitrogen content in the two soils was pronouncedly increased with increasing application dosage of bio-organic fertilizer. There was no marked difference in inorganic nitrogen content between M1 and M2 in LS (Figure 1). It was reported that humic acid application led to increased N mineralization and in turn significantly increased NO\(_3^-\) N content in a calcareous soil with wheat cultivation [27]. It was also documented that application of farm manure produced with cow dung led to an increase in total N content in the soil profile (0–5, 5–20 and 20–40 cm) in the saline-alkaline soils in northern Jiangsu Province, China [28]. Based on regression analysis, Sastre-Conde et al. (2015) demonstrated that organic amendments improved several chemical characteristics of saline soils, most notably the levels of nutrients such as C, N and P. Additionally, amendment dose had a significant positive effect on soil N and P contents with both nutrients showing high levels in high dosage treatments [29]. Similar results were found in the present research.

### 3.3 Mineralization dynamic of soil nitrogen with different fertilization treatments

Soil nitrogen mineralization is a crucial process of nitrogen transformation and consequently affects soil nitrogen availability and nitrogen balance in the terrestrial environment. The rate of soil nitrogen mineralization followed the trend of increasing, then gradually
decreasing, and finally being stable in the incubation process, showing a peak on the third day of incubation (Figure 2(a)). For any same treatment, soil nitrogen mineralization rate was higher in LS than in HS. The fertilization treatments significantly induced soil nitrogen mineralization, and organic fertilization had a stronger inducing effect than chemical fertilization.

Cumulative mineralized nitrogen increased with incubation time and increase gradually slowed down (Figure 2(b)). In addition, it increased more rapidly in the treatments with organic fertilizer application compared with that in the control and blank treatments. Difference in soil nitrogen mineralization amount between the fertilization treatments was marginal at the early stage of incubation but became remarkable with time.

At the end of incubation, the accumulated mineralization amount of nitrogen in the treatments with application of the bio-organic fertilizer was in the order of: H3 (90.55 mg kg$^{-1}$) > H2 (84.03 mg kg$^{-1}$) > H1 (62.43 mg kg$^{-1}$). Similar order was found for the treatments with farm manure application at the end of the

![Figure 1. Inorganic nitrogen content in soils under different fertilization treatments at the harvest of alfalfa. Same letters above the bars indicate no significant differences between treatments at p < 0.05 (means and standard errors, n = 3).](image)

![Figure 2. Mineralization rates (a) and accumulative quantities (b) of soil nitrogen under different fertilization treatments.](image)
incubation experiment. Statistic result showed that smaller amount of accumulated mineralized nitrogen was obtained in the high saline soil than in the low saline soil. Pathak and Rao presented a similar finding that total inorganic N decreased with an increase in salinity during incubation [9]. Humic acid application stimulated nitrogen mineralization in calcareous soils with wheat cultivation.

3.4 Interrelationships of soil nitrogen availability and correlative chemical parameters

Soil nitrogen availability was indicated by alfalfa nitrogen accumulation, which was influenced by soil inorganic nitrogen content and soil nitrogen mineralization. The accumulation of nitrogen by alfalfa was fitted well by a quadratic polynomial model of soil inorganic nitrogen content ($R^2 = 0.8620$, $P < 0.01$) (Figure 3(a)). Linear regression was used to interpret the relationship between nitrogen accumulation by alfalfa and accumulative quantity of mineralized nitrogen. There was a positive correlation between accumulative quantity of mineralized nitrogen in soil and accumulation of nitrogen by alfalfa ($R^2 = 0.9254$, $P < 0.01$) (Figure 3(b)), which confirmed that the mineralization of soil nitrogen was stimulated by alfalfa uptake of nitrogen.

The application of organic fertilizer increased soil N availability because the nutrients added by the organic fertilizers increased the activity and growth of soil microbial communities, which induced the mineralization of N in soil [11]. The medium dosage treatments of organic fertilizers produced higher alfalfa biomass than low or high dosage, while the bio-organic fertilizer produced more alfalfa biomass than the farm manure. The reason for the result above was probable related to the lower pH of the bio-organic fertilizer than that of the farm manure, which buffered the alkalinity of the saline soil and increased soil nitrogen availability [10], leading to the improvement of plant growth. Alfalfa biomass was not constantly increased and had a quadratic polynomial correlation with soil inorganic nitrogen content (Figure 3(b)). This finding was similar to the published result that medium dose of humic acid application was either more efficient in promoting wheat plants growth or at par with high doses [27]. Significantly higher ($P < 0.01$) alfalfa biomass was found in LS than in HS based on paired-samples t-test analysis, which indicated that salinity inhibited the formation of alfalfa biomass.

Principal components analysis (PCA) was usually adopted to describe overall patterns of interrelationships among all tested factors to extract common factors responsible for total variation. In this case, alfalfa biomass, nitrogen content in alfalfa, nitrogen accumulation by alfalfa, soil inorganic nitrogen content, NO$_3^-$–N and NH$_4^+$–N content, soil nitrogen mineralization rate and soil nitrogen mineralization quantity was selected for PCA. The factors had significant correlations between each other with correlation coefficients $>0.60$. PCA explained 93.56% of the total variation of the properties correlative soil nitrogen availability examined with two principal components (Table 5). The first principal component (PC 1) explained 53.79% of the total variance and had strong loadings for plant nitrogen content, soil NO$_3^-$ N content, soil inorganic N content, and soil nitrogen mineralization rate and quantity. The second principal component (PC 2) explained 39.77% of the total variation and was primarily associated with variances in biomass of alfalfa and soil NH$_4^+$–N content. This demonstrated a strong interrelationship between plant growth and soil NH$_4^+$–N content. The first two principal components were affected by fertilization treatments (Figure 4). The availability of soil nitrogen was significantly differentiated by fertilization treatments in the first, second, third and fourth quadrants for both saline soils. According to the component score coefficient matrix in principal component analysis, the score of each fertilization treatment was calculated to show the rank of fertilization treatment. With the same dosage of organic fertilizer, the score in light salinity soil was higher than that in heavy salinity soil, which further explained the differences in soil nitrogen availability between the treatments. Higher dosage of organic fertilization treatment achieved higher soil nitrogen availability.

In the present research, N mineralization was more induced by bio-organic fertilizer than by farm manure (Figure 2). Soil inorganic nitrogen content was increased more by higher dose of organic fertilizer.
application, especially so with the bio-organic fertilizer due to the higher contents of total N and NO$_3^-$ when compared with the farm manure (Table 2). It was reported that total N content had a positive correlation with the mineralization of organic fertilizer [30, 31]. In this study, soil inorganic nitrogen content presented a positive correlation with the mineralized accumulative quantities of soil nitrogen ($P < 0.01$) (Figure 3(a)).

### 4 Conclusion

Organic fertilizer application increased soil inorganic nitrogen content, soil nitrogen mineralization and alfalfa biomass compared with the blank treatment and control treatment. Soil inorganic nitrogen content was positively correlated with soil nitrogen mineralization quantity and was fitted well with a quadratic polynomial model with the accumulation by alfalfa. The medium level (2.68 g kg$^{-1}$ soil) of organic fertilizer treatment had a higher effect on soil inorganic nitrogen content and alfalfa biomass than low or high levels. Alfalfa biomass was improved by 23.24% and 17.23% by H2 and M2, respectively, compared with the control treatment in the low saline soil. Similarly, alfalfa biomass was improved by 19.55% and 20.44% by H2 and M2, respectively, in the high saline soil. Soil NO$_3^-$ N content, soil inorganic N content, and soil nitrogen mineralization rate and quantity were indices for soil nitrogen availability, which was higher in the soil with low total soluble salt content than in the soil with high total soluble salt content under the same fertilization rate. Consequently, Bio-organic fertilizer was more suitable to improve soil nitrogen availability and alfalfa growth than farm manure in salinity fluvo-aquic soils.

### Author Contribution

Yanli Liu conceived and designed the research. Xiaowen Wang carried out the experiment and wrote the first draft. All authors contributed to read and approved the manuscript.

### Disclosure statement

No potential conflict of interest was reported by the authors.

### Funding

Funding for this research was supported by the Key Research and Development Program of Shandong Province in China (Nos. 2017CXGC0301, 2016CYJ505A02 and 2017GSK17113).

### ORCID

Xiao-Wen Wang http://orcid.org/0000-0002-9823-7879
Yan-Li Liu http://orcid.org/0000-0002-6570-1735
References

[1] Farifteh J, Farshad A, George RJ. Assessing salt-affected soil using remote sensing, solute modeling, and geophysics. Geoderma. 2006;130:191–206.

[2] Li N, Shao TY, Zhu TS, et al. Vegetation succession influences soil carbon sequestration in coastal alkali-saline soils in southeast China. Sci Rep. 2018;8:9728–9739.

[3] Wu Y, Li Y, Zhang Y, et al. Responses of saline soil properties and cotton growth to different organic amendments. Pedosphere. 2018;28:521–529.

[4] Tejada M, Garcia C, Gonzalez JL, et al. Use of organic amendment as a strategy for saline soil remediation: influence on the physical, chemical and biological properties of soil. Soil Biol Biochem. 2006;38:1413–1421.

[5] Islam F, Yasseen T, Arif MS, et al. Plant growth promoting bacteria confer salt tolerance in Vigna radiata by up-regulating antioxidant defense and biological soil fertility. Plant Growth Regul. 2016;80:23–36.

[6] Zeng WZ, Xu C, Huang J, et al. Emergence rate, yield, and nitrogen-use efficiency of sunflowers (helianthus annuus) vary with soil salinity and amount of nitrogen applied. Commun Soil Sci Plant Anal. 2015;46:1006–1023.

[7] McCormick RW, Wolf DC. Effect of sodium chloride on CO2 evolution, ammonification and nitrification in a Sassafras sandy loam. Soil Biol Biochem. 1980;12:153–157.

[8] McClung G, Frankenberger WT Jr. Nitrogen mineralization rates in saline vs salt amended soils. Plant Soil. 1987;104:13–21.

[9] Pathak H, Rao DLN. Carbon and nitrogen mineralization from added organic matter in saline and alkali soils. Soil Biol Biochem. 1998;30:695–702.

[10] Iqbal T. Rice straw amendment ameliorates harmful effect of salinity and increases nitrogen availability in a saline paddy soil. J Saudi Soc Agri Sci. 2018;17:445–453.

[11] Zhang T, Wang T, Liu K, et al. Effects of different amendments for the reclamation of coastal saline soil on soil nutrient dynamics and electrical conductivity responses. Agric Water Manage. 2015;159:115–122.

[12] Wang W, Lai DYG, Wang C, et al. Effects of rice straw incorporation on active soil organic carbon pools in a subtropical paddy field. Soil Tillage Res. 2015;152:8–16.

[13] Gaihre YK, Wassmann R, Villegas-Pangga G. Impact of elevated temperatures on greenhouse gas emissions in rice systems: interaction with straw incorporation studied in a growth chamber experiment. Plant Soil. 2013;373:857–875.

[14] Byous EW, Williams JE, Jonesa GE, et al. Nutrient requirements of rice with alternative straw management. Better Crops. 2004;36:6–11.

[15] Ahmad W, Khan F, Shah Z, et al. Quality and crop yield potential of moderately degraded Alfisols under different nutrient inputs and cropping patterns. Pedosphere. 2019;29(2):235–247.

[16] Asten PJA, Bodegom PM, Mulder LM, et al. Effect of straw application on rice yields and nutrient availability on an alkaline and a pH-neutral soil in a Sahelian irrigation scheme. Nutr Cycling Agroecosyst. 2005;72:25–266.

[17] Zhang B, Pang C, Qin J, et al. Rice straw incorporation in winter with fertilizer-N application improves soil fertility and reduces global warming potential from a double rice paddy field. Bio Fer Soils. 2013;49:1039–1052.

[18] Liang YC, Si J, Nikolic M, et al. Organic manure stimulates biological activity and barley growth in soil subject to secondary salinization. Soil Biol Biochem. 2005;37:1185–1195.

[19] Cao J, Li X, Kong X, et al. Using alfalfa (Medicago sativa) to ameliorate salt-affected soils in Yingda irrigation district in Northwest China. Acta Ecologica Sinica. 2012;32:68–73.

[20] Xiong J, Sun Y, Yang Q, et al. Proteomic analysis of early salt stress responsive proteins in alfalfa roots and shoots. Proteome Sci. 2017;15:19.

[21] Fan ZL, Ma JY, Ma YJ. Assessment and prediction of developing trend of soil salinization of the cultivated land in west China. Arid Land Geogr. 2002;2:97–101. in Chinese.

[22] Soil Survey Staff. Keys to soil taxonomy. 8th ed. Washington, DC: NRCS; 1998.

[23] Menyailo OV, Lehmann J, Cravo MDS, et al. Soil microbial activities in tree-based cropping systems and natural forests of the Central Amazon, Brazil. Biol Fertil Soils. 2003;38:1–9.

[24] Bremner JM, Mulvaney CS. Nitrogen – total. Methods Soil Anal Chem Methods Part. 1982;72:532–535.

[25] Nelson DW, Sommers LE. Total carbon, organic carbon, and organic matter. In: Sparks DL, editor. Methods of soil analysis. Part 3. Chemical methods. No. S. Wi American Society of Agronomy Inc and Soil Science Society of America Inc; 1996. p. 961–1010.

[26] Wang RT, Lu ZH, Sun JK. Effect of soil ameliorants on coastal saline-alkali soil in the Yellow River Delta. J Soil Water Conserv. in Chinese. 2012;26(4):239–244.

[27] Tahir MM, Kurshid M, Khan MZ, et al. Lignite-derived humic acid effect on growth of wheat plants in different soils. Pedosphere. 2011;21:124–131.

[28] Liu L, Long X, Shao H, et al. Ameliorants improve saline–alkaline soils on a large scale in northern Jiangsu Province, China. Ecol Eng. 2015;81:328–334.

[29] Sastre-Conde I, Lobo MC, Beltr´an-Hern´andez RI, et al. Remediation of saline soils by a two-step process: washing and amendment with sludge. Geoderma. 2015;247–248:140–150.

[30] Ma L, Yang LZ, Ci E, et al. Effects of long-term fertilization distribution and mineralization of organic carbon in paddy soil. Acta Pedologica Sinica. 2009;46:1050–1058. in Chinese.

[31] Tian QX, Yang XL, Wang XG, et al. Microbial community mediated response of organic carbon mineralization to labile carbon and nitrogen addition in topsoil and subsoil. Biogeochemistry. 2016;128:125–139.