Journal of Agricultural Science and Technology B 8 (2018) 209-219
doi: 10.17265/2161-6264/2018.04.002

Improvement of Soil Fertility and Crop Yield through Biochar Amendment from Salt Affected Soil of Central China

Muhammad Siddique Lashari[1, 2], Bakht-un-Nisa Mangan[2], Inayatullah Rajpar[2], Haishi Ji[1], Genxing Pan[1], Ayaz Ahmed Lashari[2] and Jiangkuan Nan[1]

1. Institute of Resource, Ecosystem and Environment of Agriculture, Nanjing Agricultural University, Nanjing 210095, Jiangsu, China

2. Faculty of Crop Production, Department of Soil Science and Agronomy, Sindh Agriculture University, Tandojam 70060, Sindh, Pakistan

Abstract: Soil salinity has been considered a brutal environmental factor for decreasing crop yield due to the accumulation of excessive sodium salts in soil under arid and semi-arid region of the world. This study tries to address the potential use of biochar. An organic matter rich material, used to reclaim salt-stressed soil in order to enhance crop production in dry croplands as well as to increase soil organic carbon (SOC) and to improve soil fertility. In this regard, a field experiment for two years was conducted in a moderately salt-stressed soil of Central China with wheat-maize cropping system. The soil was amended with biochar composted with poultry manure (BPC) at 12 t/ha with diluted pyroligneous solution (PS) at 0.15 t/ha a week before sowing of crop. Results showed significant improvement in soil physical properties, soil nutrient content with reduction of sodium salts and soil pH by amendment of BPC-PS1 and BPC-PS2 over the experimental control salt-stressed cropland. Furthermore, wheat and maize grain yield, nitrogen, phosphorous potassium and K/Na ratio increased while sodium decreased with the application of BPC-PS amendment in wheat and maize grain. This study concluded that the biochar amendment in conjunction with PS greatly improved SOC storage, crop nutrient uptake and soil fertility. Thus, waste treatment of crop straw and poultry manure compost as biochar could be combined to alleviate salt stress and improve crop production in the vast area of arid and semi-arid regions of the world.

Key words: Plant nutrient, pyroligneous solution, salt stress, wheat and maize grain yield, poultry manure compost.

1. Introduction

Salt-stressed soils are most serious problems confronting sustainable agriculture production systems in arid and semi-arid region of the world due to low rainfall and increasing temperature [1]. Nearly 20% of the areas and over half of the world's productive land resources are affected by salt-stress [2]. Availability of excess sodium salts in soil is most versed abiotic stresses, responsible for substantive losses in agriculture production and crop quality. In the upcoming 25 years, due to climate change and degradation of soil environment, the soil salinity, it is expected to result in 30% land losses worldwide [3].

Being a dynamic medium, soil has different physical, chemical and biological characteristics depending on the nature of mineral matrix. The presence of sodium salts in excess amount have adversely impact on soil structure by, making plant growth deficient, decreasing soil organic carbon (SOC), reducing biological activity and chemical characteristics [4]. Along with it deflocculating clay particles and consequent increase in the tendency to slake disperses and swell under specific conditions. Saline soil become impermeable due to low infiltration rate, ceased percolation of water from

Corresponding authors: Genxing Pan and Muhammad Siddique Lashari, Ph.D., research field: soil science.

upper surface to downward in soil profile [5]. An excess of sodium salts not have only adverse effect on soil physical properties and chemical composition but also have specific negative impacts on soil microbes and availability of major nutrient for plant growth. Inferior effects of salt stress have been shown to decrease soil respiration rates and soil microbial biomass [6].

Biochar is a carbon-rich and biologically stable solid, produced by heating crop residues in an oxygen-limiting environment [7]. As an amendment, it means to achieve carbon sequestration and mitigate N_2O emission from cropland [8]. In addition, it yields beneficial effects for crop yield through moderating soil structure, bulk density, pore size distributions, and size declines in soil colloids of salt-affected soils [9]. Biochar promotes the systemic resistance of plant to several prominent foliar pathogens. The beneficial disease resistance [10] may be attributed to the biophysical effects of enhancing availability of air and water within root zone resulting in increase of seed germination and survival of plants [11]. Biochar can be used with organic and inorganic fertilizers to enhance crop productivity and improve availability of plant nutrients [12], along with it is used for attenuating toxic substances that are potentially harmful to soil biota and upland crops. Biochar amendment promote mycorrhizal fungi and alter soil microbial populations and functions, it restores secondary salinized lands and prevented desertification [13].

Pyroligneous solution (PS) is the condensates of volatilized substances captured during pyrolysis of straw residues in biochar production [14]. This liquor is composed of more than 200 chemicals, including organic acids, phenolic molecules, organic carbon compounds, acids substances, alcohol and neutral materials [15]. It has been shown that improved agronomic properties of crops can reduce pest and disease infection, enhance growth hormone levels in and inhibit weed infestations of soils [16]. PS also may influence the leaching of soluble salts and reduce soil pH thus increase crop production in salt-stressed soils [9].

The biochar technology is being rapidly developed and promoted around the world including China [17]. Does this product benefit the crop productions in salt-affected soils under both agro seasons? This study hypothesize that the biochar poultry-manure compost (BPC) in conjunction with PS amendments will alleviate the abiotic stresses and improve plant nutrition, physical properties of soil, grain quality and grain yield of wheat-maize crop growing on salt-affected soils. A long-term field experiment was conducted on wheat-maize crop, grown on salt-affected soils, which was amended with BPC in conjunction with PS tested against those grown on salt-stressed cropland v/s experimental control.

2. Materials and Methods

2.1 Experimental Site, Soil and Climate

The experimental field was located near Kangzhuang Village (34°32′ N, 115°30′ E) of Shangqiu municipality of Henan province, China (Fig. 1), which is influenced by an arid/semi-humid temperate monsoon climate with mean annual temperature 13.9 °C and accumulated temperature over 10 °C being 4,800 °C/year with 770 mm annual precipitation. The annual mean evaporation during 2008 to 2012 was 1,735 mm and the total sunshine time per year was 2,510 h with annual frost-free days. The soil was Aqui-Entisol, classified according to soil taxonomy [18], which is derived from the sedimentation of Yellow River known as paleo-alluvial soil. The basic soil properties are shown in Table 1. The conventional cropping system was followed with the cultivation of wheat in winter and maize in summer.

2.2 Treatment Methods and Source

Processed material (biochar) used for field experiment was produced through pyrolysis of wheat bio-wastes at 480 °C in a vertical kiln, by product of

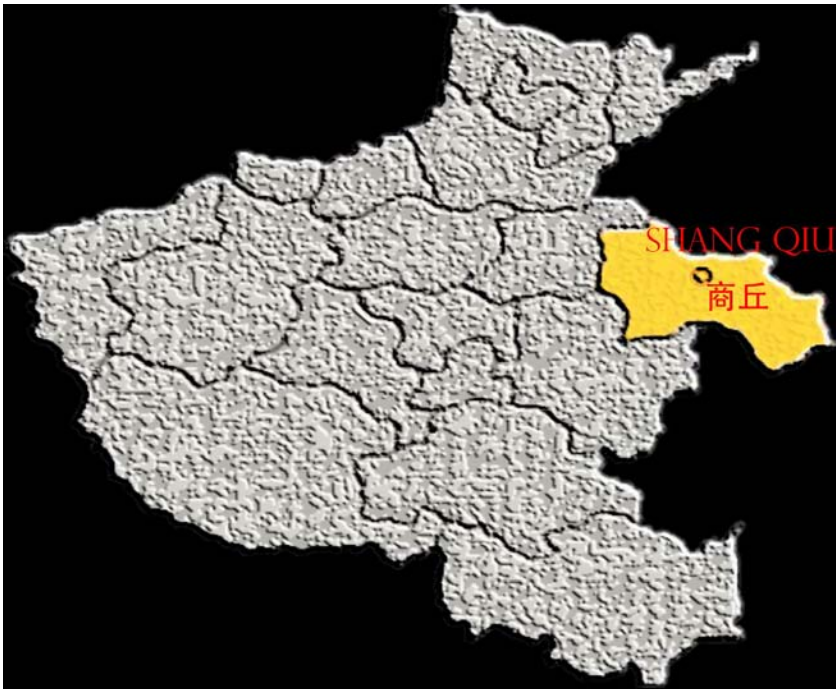


Fig. 1 Map of the location.

Table 1 Basic properties of the topsoil (0-20 cm), biochar and pyroligneous solution (PS) and biochar poultry-manure compost (BPC) before used for the experiment.

Sample	pH (H_2O)	TOC (g/kg)	Total N (g/kg)	Salt (g/kg)	CEC (cmol/kg)	Bulk density (g/cm^3)
Topsoil	8.25	5.13	0.70	12.68	21.26	1.33
Biochar	10.35	467.20	5.90	41.97	21.70	0.65
PS	9.37	3.87	0.55	ND	ND	ND
BPC	7.50	419.7	25.03	ND	ND	1.00

TOC: total organic carbon; CEC: cation exchange capacity; ND: indicates not detected.

Sanli New Energy Company in Shangqiu, China. The chemical composition of PS and basic properties of biochar were reported separately [15]. Before composting with manure, biochar was ground, homogenized and sieved from 2 mm sieve and the PS was diluted five folds by using distilled water.

2.3 Biochar Poultry Manure Compost (BPC)

For developing compost (biochar poultry-manure), manure was collected from a local poultry farm and dried for 15 d under ambient condition to lose extra amount of moisture. After that poultry manure (PM) was mixed with the wheat straw biochar (BC) in a ratio of 1:3 (PM:BC, v/v) and left for six weeks under composting process. The produced BPC was thoroughly mixed prior to soil amendment. Prepared compost of biochar poultry-manure was a dark loose neutral with pH 7.5 (in water), it was containing 419.7 g/kg organic material, with 25.0 g/kg of total N, and 0.82 g/kg of alkaline-releasable N and 12.2 mg/kg of Olsen-P with 0.83 mg/kg of NH_4NO_3 exchangeable K.

2.4 Soil Amendment Method

An abandoned salt-affected cropland of Central China Great Plain was treated with combined amendment of BPC-PS. Diluted PS at 0.15 t/ha was directly sprayed on soil surface while BPC was broadcasted on soil surface at 12 t/ha 7 d before sowing. The broadcasted BPC was thoroughly mixed with the topsoil by plowing at the depth of 20 cm and raked for leveling.

For comparison, a plot of un-reclaimed salt-affected soil was used as background control (CK), which was similarly fertilized and plowed expect BPC-PS application. The wheat/maize cultivar and rate of chemical fertilizers used under CK were the same as the BPC-PS treatment. The experiment was performed for a single year (BPC-PS1) and for two consecutive years (BPC-PS2) with two repeated crop of wheat and maize, respectively. The experiment was again repeated in 2011 for one-year duration to check the treatment effects. For this, a new plot (BPC-PS1, hereafter) was treated with the same procedure as was in 2010. The plots treated in 2010 were amended no more with BPC but with only PS in same dosage before maize sowing in 2011 (BPC-PS2). The same plot of control was used for comparison in 2011 (CK, here after). Through this design, the ongoing effect of BPC treatment can be addressed in terms of variation by years and two multiple crops. The experiment was repeated in triplicates in a complete randomized block design with 0.15 ha area of the individual plots. The crop growth management was consistent across the treated and untreated plots. No irrigation was performed during wheat/maize production, because the cropping system grown under rain feed conditions.

2.5 Crop Sowing and Fertilization

Crop of wheat and maize were cultivated during these experiments followed under crop rotational system. Basal dose of phosphorus, potassium and one third of nitrogen fertilizer were applied before sowing. Following the local conventional system of soil fertility and fertilization, basal fertilizers of urea, calcium super-phosphate and potassium sulphate were applied at 112.5 kg N/ha, 112.5 kg P_2O_5/ha and 112.5 kg K_2O/ha, respectively. Along with, additionally 120 kg N/ha (urea) was ditch-applied in the row as supplementary fertilizer at the initial development stage (after 40 d of sowing) at the depth of 10-15 cm and covered with soil by hand operating tools. All the crop production management practices including sowing, maintaining crop intensity, fertilization, weed and pest control was consistent across the treatment plots during the growing periods of wheat and maize crops.

2.6 Sampling of Soil and Analysis

For the assessment of the salt content and soil fertility, topsoil from experimental field was sampled after the harvesting of wheat and maize crops. A composite consisted of samples taken at the depth of 0-20 cm from six locations was arranged across each experimental field by using *S*-shaped pattern through an Eijkelkamp core sampler. Samples were stored in sealed plastic bags and shipped to the laboratory within 24 h. The whole visible plant detritus, gravels and visible tiny piece of biochar were removed from the samples before and after air-drying at room temperature. An aliquot of the dried sample was ground to pass a sieve with 2 mm openings and an aliquot of the < 2 mm soils was further ground to pass a sieve with 0.15 mm openings and saved for chemical analysis. Soil properties were determined according to the analytical protocols described [19].

2.7 Grain Sampling and Analysis

The grain samples from wheat and maize plants were randomly collected from each plot at the time of harvest. Further, these gain samples were dried to constant weight in an air-forced oven at 68 °C for 48 h. Aliquots of maize and wheat sample were crashed and ground in a stainless steel grinder to pass through 0.4 mm sieve. Furthermore, the digestion of plant samples were performed according to the procedure described [20]. Grain samples were digested with a semi-Kjeldahl digestion procedure in a mixed solution of H_2SO_4 + H_2O_2 with Se and $CuSO_4$ as catalysts. Digested N was determined with titration by dilute boric acid [21], phosphorus with spectrophotometer after reaction with ammonium molybdate and ammonium vanadium while as total K and Na were determined with flame photometer model (FP-6410).

2.8 Wheat and Maize Grain Yield

Grain yield of wheat and maize crop were recorded at the time of harvest. Wheat spikes and maize cobs were harvested from each experimental plot, dried for several days for loosing extra moisture content. After that, grains were threshed using an electric thresher and weighed to obtain a yield separately for each experiment plot.

2.9 Statistical Analysis

Recorded data was expressed as mean plus/minus one standard deviation. Statistical analysis was done using SPSS, version 16.0. The mean significant difference among treatments was explained by using one-way analysis of variance (ANOVA) at 0.05 probability level.

3. Results

3.1 Basic Chemical Properties of Soil and Major Nutrients

The experimental results showed great improvements in soil chemical properties and nutrient content with the amendment of BPC with conjunction of PS (Table 2). An amendments effect on soil alkalinity was observed with the slight reduction in soil pH (from 2.25% to 5.74%) with BPC-PS1 and BPC-PS2 application over the untreated salt-affected crop plot. BPC-PS amendment also decreases the quantity of total soluble salts, sodium and soil bulk density 36.85% to 42.18%, 34.96% to 39.86%, 7.58% to 11.36%, respectively, with the amendment of BPC-PS1 and BPC-PS2 as compared to control.

Meanwhile experimental finding indicates great improvement in major plant nutrient in soil medium with the amendment (BPC-PS). The significant increases were observed at $p < 0.05$ for SOC by 32.94% to 52.66%, available K 51.66% to 81.15%, total nitrogen 36.65% to 45%, available phosphorus 53.28% to 61.15% and cation exchange capacity (CEC) by 8.82% to 8.93% with the amendments of BPC-PS1 and BPC-PS2, respectively, over the untreated experimental control in salt-affected soil (Table 3).

3.2 Major Ion Content in Wheat and Maize Grain

Data of major ion content in wheat and maize grain with the amendments of BPC-PS over the experimental control salt-affected crop plot is presented in Table 4. According to findings high content of grain nutrients in wheat and maize like: total nitrogen, total K and total phosphorus were observed from 13% to 25% and 24% to 30%, 16% to 29% and 21% to 34%, 21% to 38% and 24% to 51%, with the amendments of BPC-PS1 and BPC-PS2 over the untreated salt-affected crop plot. Meanwhile the sodium (Na^+) content in wheat and maize grain was significantly decreased at $p < 0.05$ with BPC-PS amendment. The maximum decrease in sodium ion (Na^+) was recorded in wheat grain from 48% to 55%, in maize 38% to 44%, while as K/Na was increased from 57% to 65% in wheat grain and 56% to 63% in maize grain with the amendment of BPC-PS1 and BPC-PS2 over the untreated salt-affected crop plot (Figs. 2a and 2b).

Table 2 Average decreases in soil pH, total salts and sodium, bulk density with the BPC-PS amendment during wheat and maize crop.

Treatments	pH (H_2O)	Total soluble salt (g/kg)	Na^+ (g/kg)	Bulk density (g/cm^3)
CK (control)	8.02 ± 0.21a	8.63 ± 0.52a	5.52 ± 0.14a	1.32 ± 0.03a
BPC-PS1	7.84 ± 0.18ab	5.45 ± 0.28b	3.59 ± 0.15b	1.22 ± 0.01b
BPC-PS2	7.56 ± 0.13b	4.99 ± 0.15b	3.32 ± 0.06b	1.17 ± 0.01c

The different letters in the same column indicate significant differences ($p < 0.05$) between the treatments mean.

Table 3 Average improvement in soil organic carbon (SOC), major nutrient and exchange capacity of soil with the BPC-PS amendment during wheat and maize crop under salt-affected soil.

Treatments	SOC (g/kg)	Available K (g/kg)	Total N (g/kg)	Available P (mg/kg)	CEC (cmol/kg)
CK	6.23 ± 0.41c	0.131 ± 0.05c	0.534 ± 0.23b	26.69 ± 2.58c	23.06 ± 1.74b
BPC-PS1	9.29 ± 1.32b	0.271 ± 0.21b	0.843 ± 0.03ab	57.13 ± 2.92b	25.29 ± 0.68a
BPC-PS2	13.16 ± 1.15a	0.695 ± 0.02a	0.971 ± 0.03a	68.70 ± 1.10a	25.32 ± 0.05a

The different letters in the same column indicate significant differences ($p < 0.05$) between the treatments mean.

Table 4 Major nutrient content in wheat and maize grain (g/kg) with the BPC-PS amendment under salt-affected soil condition.

Treatments	Wheat grain			Maize grain		
	Total N	Total K	Total P	Total N	Total K	Total P
CK	21.01 ± 1.75b	3.42 ± 0.48b	2.25 ± 0.04b	11.82 ± 0.45c	3.27 ± 0.04b	2.65 ± 0.08b
BPC-PS1	24.17 ± 2.10ab	4.09 ± 0.07a	3.63 ± 0.03ab	15.72 ± 0.22b	4.60 ± 0.06ab	3.33 ± 0.05ab
BPC-PS2	27.57 ± 0.60a	4.33 ± 0.23a	4.67 ± 0.04a	16.82 ± 0.41a	4.95 ± 0.16a	3.52 ± 0.07a

The different letters in the same column indicate significant differences ($p < 0.05$) between the treatments mean (n = 15), three replicated plot of each treatment with 15 random samples of wheat and maize grain were collected at harvest stage of both crops.

3.3 Grain Yield of Wheat and Maize

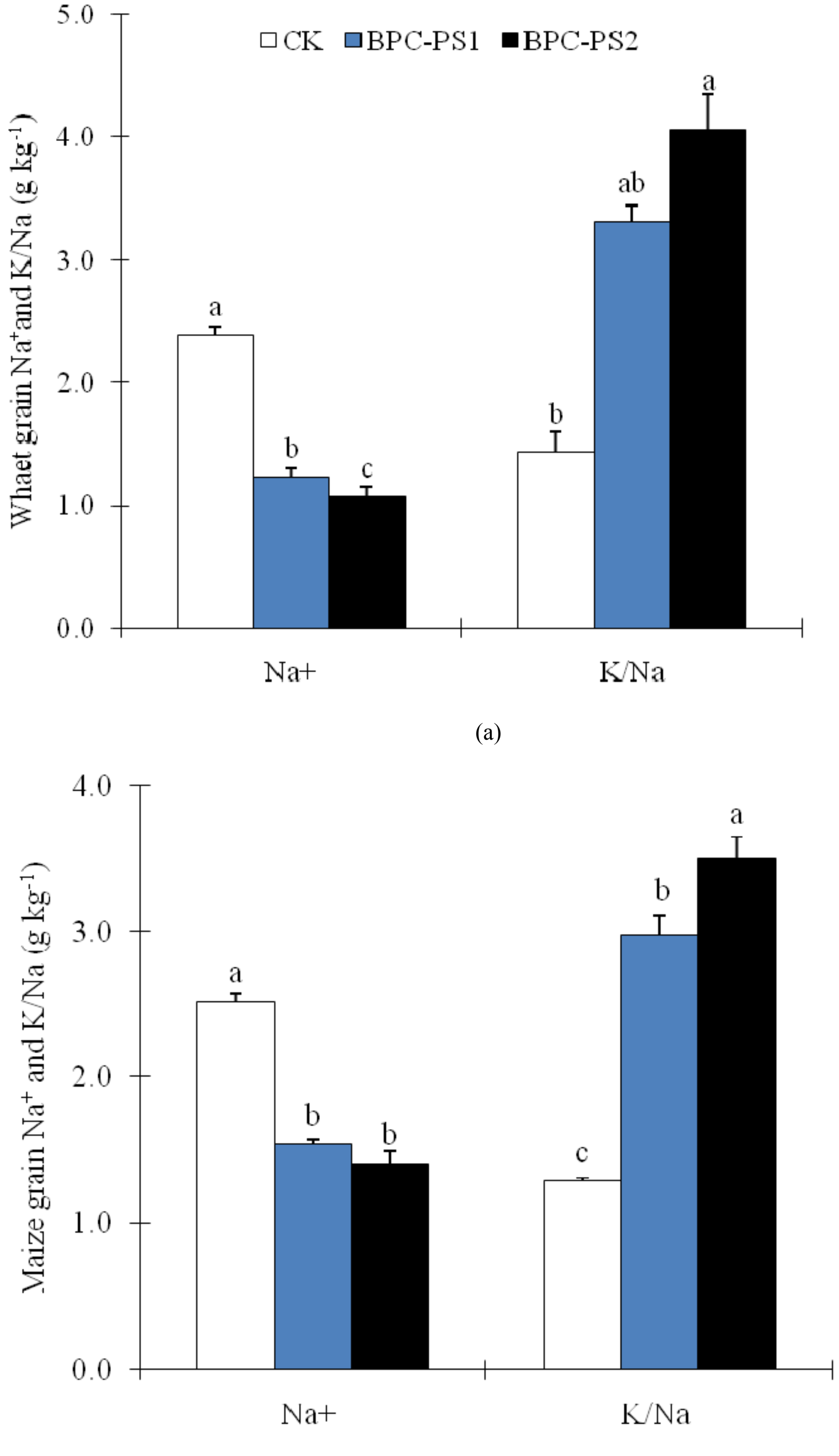
The greater increase in average yield of wheat and maize grain was recorded with the BPC-PS amendment shown in Fig. 3, was significantly high at $p < 0.05$ over the control experiment. The maximum increase in grain yield of wheat and maize were observed from 55% to 60% and from 59% to 65%, respectively, with the amendment of BPC-PS1 and BPC-PS2 over the experimental control plot in both crops.

4. Discussion

4.1 Impacts of BPC-PS Amendment on Soil Quality

Soil degradation via salinization and sodication is the scourge of intensive agriculture and major environmental threat, caused by increasing degree of temperature, low precipitation in the arid and semi-arid ecological regions of the world. Soil salinity, degrades soil properties by accumulation and adsorption of sodium (Na) salts on clay particles, it degrades and disturbs pore structure of surface soil along with it creates problem of soil permeability due to predominance of sodium salts [22, 23]. Due to all adverse impacts of salts on soil properties, soil become compact with high bulk density which have deteriorated pore size distribution [24]. Inferior effects of sodium salts caused insufficient aeration for plant roots and microbes and decreased infiltration rate of soil water. These all above unfavorable circumstances of salt-affected soils may cause ambitious problem for seed germination, plant growth and crop productivity due to specific ion toxicity, salt-induced osmotic stress, imbalanced hormonal activity and generation of certain reactive oxygen species [25, 26]. In such case, pyrolysis process of crop waste is a major source for the amendment of low productive salt affected cropland. Thus, stability of rich carbon source is not only important for improvement of physicochemical properties of soil but also equally important for soil productivity, increased stability and storage of SOC on a large scale [12]. The initial treatment with PS (which is stable organic rich molecule), with further dilution in pure water could have bettered resulted to enhance solubility and accelerate leaching of Na salts and to decrease soil alkalinity.

The other amendment, is composting of poultry manure, support nutritional component for plant growth as quick as possible for the dire need of plants and biochar contribute essential nutrients at the final composting stage and enhance soil microbial activity due to high surface area for microbe inhabitance with



(b)

Fig. 2 Wheat grain Na^+ and K/Na (a), maize grain Na^+ and K/Na (b) with the amendment of BPC-PS.
The white block shows untreated salt-affected soil (CK), blue block shows amended salt-affected soil year one (BPC-PS1) and black block shows amended salt-affected soil year two (BPC-PS2). The bar above the blocks with different letter indicates significant differences ($p < 0.05$) mean ± SD (n = 3) between the treatments.

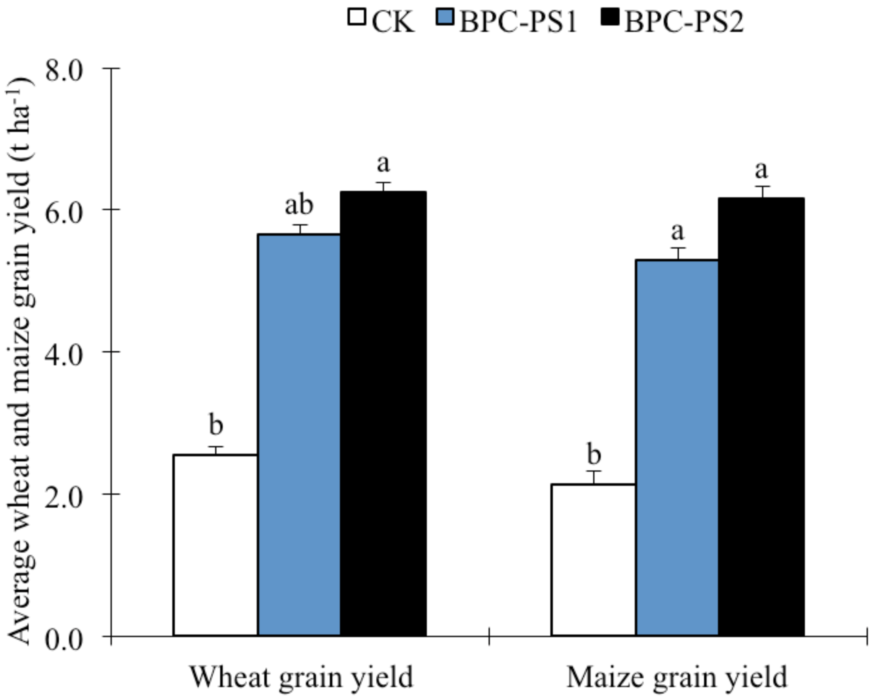


Fig. 3 Indicates average grain yield of wheat and maize crop at harvest with the amendment of BPC-PS.
The white block shows untreated salt-affected (CK), blue block shows amended salt-affected soil year one (BPC-PS1) and black block shows amended salt-affected soil year two (BPC-PS2). The bar above the blocks with different letter indicates significant differences ($p < 0.05$) mean ± SD (n = 3) between the treatments.

additional support of nutrient [27, 28]. Mega source of organic carbon biochar compost, have highly porous structure with greater surface area that increase the proportion of meso and macro pores of soil, improve soil structure, aggregate and stabilize of soil macro and microorganisms [29, 30] and increase water holding capacity of poor structural soil [31]. In this study, in which soil was amended with biochar manure compost in conjunction with PS, soil bulk density was decreased due to increased stability of soil aggregation while as the leaching of soluble salts and sodium content of soil increased; as well as BPC-PS amendment found, highly effective for increasing CEC, storage of SOC and major plant nutrient in soil medium which mostly suffered by salts due to low vegetation, crop cultivation and low microbial activity. These findings were highly agreed with the key findings [32]. The improvement of soil condition could further beneficial for leaching of soluble salts from the root zone of crop under dry land cropping system of wheat and maize crop for effective growth of crop.

4.2 Effect of BPC-PS Amendments on Plant Nutrient K/Na Ratio and Grain Yield

The amendment of BPC-PS is highly effective at seed germination stage due to favorable soil conditions while under saline soil salt stress suppress seed germination [33]. Salinity caused two types of plant stress: osmotic stress and ion stress left most harmful effects at initial stage of plant. Osmotic stress reduces the availability of soil water for plant and ion stress can make imbalance mineral nutrient and reduction of photosynthesis activity in plant [34]. For the active growth and metabolic functions of plant, plant needs some specific mineral nutrients at the time of root emergence and for the primary growth and development process. Therefore, the overall finding of scientific research on behalf of degraded soil have been shown in this study that salt-affected soils mostly suffer in nutrient content and availability due to low organic carbon, poor microbial growth, low CEC and dispersed soil physical condition. Most of the crop species may not survive under salt-affected soil environment due to high osmotic pressure, toxic effects of sodium salts and nutrient deficiency [35]. In the finding of this study, greater improvement of major nutrients (NPK) and K/Na ratio in wheat and maize grain were observed with significant low content of sodium ion (Na^+) by the amendment of BPC-PS over the control experiment untreated salt-stressed crop plants. On the behalf of untreated salt-stressed, amendment of BPC has been found to be a reliable source for the enhancement of soil nutrition due to high capability to retain soil nutrient through the application of chemical fertilizer [36]. Several findings showed that biochar stimulates soil fungi because biochar is a complex matrix degradable by soil fauna [37], reduce leaching of nutrient and nitrogen volatilization from soil, enhance water holding capacity, increase fertilizer use efficiency for crop growth and that helps plants better overcome under critical climatic conditions like drought [38]. The application of biochar with manure compost, promotes the propagation of beneficial soil microorganisms such as nitrogen fixing bacteria, increase yield by stimulation of mycorrhizal fungi [39]. Further it has been reported that amendment of soil with BPC-PS, improves availability of P and K while high availability of P improves plant root mechanism and nutritional component for active growth of plant and K enrichment improves plant enzymes activity for better quality and quantity of crop yield [40]. In this study, amendment showed effective mechanism for nutrient enrichment in wheat and maize grain, leads maximum average yield of wheat and maize crop over the non-amended salt-affected crop plot. Like this study, obtained 91% increased grain yield and 44% dry biomass from maize crop with biochar amendment [41]. Overall, it's concluded from the scientific evidences and experimental study of recent century that biochar manure amendment for soil is a functional key tool for improvement of nutritional components of soil and has been found effective application for nutrient uptake by maize crop under degraded salt-affected soil conditions.

5. Conclusions

The key finding from field experiments concludes that the amendment of biochar poultry manure can play an important role for the improvement of salt-affected soil as well as for crop nutrition and SOC storage. Thus, amendment shows greater improvement in K/Na ratio in wheat and maize grain, which is mostly affected by sat stress in both crops. Furthermore, result showed greater increase in wheat and maize grain yield with the amendment of BPC-PS over the control experiment. These all over finding show that BPC-PS amendment is highly effective source for the improvement of salt-affected soil under dry land cropping system and a key component for sustainable agriculture.

Acknowledgments

The authors would like to express their gratitude to the Ministry of Agriculture, P. R., China, for funding of the project. The authors are also highly thankful to Mr. Lin Zhenheng and Mr. Kang Quande from Sanli New Energy Company for providing biochar for composting, fieldwork and look after of the experimental plot.

References

[1] Ravindran, K., Venkatesan, K., Balakrishnan, V., Chellappan, K., and Balasubramanian, T. 2007. "Restoration of Saline Land by Halophytes for Indian Soils." *Soil Biol. Bioch*. 39: 2661-4.

[2] Turan, M. A., Elkarim, A. H. A., Taban, N., and Taban, S. 2009. "Effect of Salt Stress on Growth, Stomatal Resistance, Proline and Chlorophyll Concentrations on Maize Plant." *African J. Agric. Res*. 4: 893-7.

[3] Wang, W., Vinocur, B., and Altman, A. 2003. "Plant Responses to Drought, Salinity and Extreme

Temperatures: Towards Genetic Engineering for Stress Tolerance." *Planta*. 218: 1-14.

[4] Rietz, D. N., and Haynes, R. J. 2003. "Effects of Irrigation-Induced Salinity and Sodicity on Soil Microbial Activity." *Soil Biol*. *Bioch*. 35: 845-54.

[5] Qadir, M., and Schubert, S. 2002. "Degradation Processes and Nutrient Constraints in Sodic Soils." *Land Degradation & Development* 13: 275-94.

[6] Iiknur, A., Burhan, K., and Demet, A. 2011. "Effect of Salinity (NaCl) on Germination, Seedling Growth and Nutrient Uptake of Different Triticate Genotypes." *Turk*. *J*. *Field Crops* 16 (2): 225-32.

[7] Lehmann, J., and Joseph, S. 2009. "Biochar for Environmental Management: An Introduction." *Sci*. *& Tech*. 1-12.

[8] Liu, X., Qu, J., Li, L., Zhang, A., Jufeng, Z., Zheng, J., and Pan, G. 2012. "Can Biochar Amendment Be an Ecological Engineering Technology to Depress N_2O Emission in Rice Paddies? — A Cross Site Field Experiment from South China." *Ecol*. *Engin*. 42: 168-73.

[9] Lashari, M. S., Liu, Y., Li, L., Pan, W., Fu, J., Pan, G., Zheng, J., Zheng, J., Zhang, X., and Yu, X. 2013. "Effects of Amendment of Biochar-Manure Compost in Conjunction with Pyroligneous Solution on Soil Quality and Wheat Yield of a Salt-Stressed Cropland from Central China Great Plain." *Field Crops Res*. 144: 113-8.

[10] Kolton, M., Harel, Y. M., Pasternak, Z., Graber, E. R., Elad, Y., and Cytryn, E. 2011. "Impact of Biochar Application to Soil on the Root-Associated Bacterial Community Structure of Fully Developed Greenhouse Pepper Plants." *Applied & Environ*. *Microb*. 77: 4924-30.

[11] Zhang, A., Bian, R., Pan, G., Cui, L., Hussain, Q., Li, L., Zheng, J., Zheng, J., Zhang, X., and Han, X. 2012. "Effects of Biochar Amendment on Soil Quality, Crop Yield and Greenhouse Gas Emission in a Chinese Rice Paddy: A Field Study of Two Consecutive Rice Growing Cycles." *Field Crops Rese*. 127: 153-60.

[12] Lashari, M. S., Ye, Y., Ji, H., Li, L., Kibue, G. W., Lu, H., Zheng, J., and Pan, G. 2014. "Biochar-Manure Compost in Conjunction with Pyroligneous Solution Alleviated Salt Stress and Improved Leaf Bioactivity of Maize in a Saline Soil from Central China: A Two-Year Field Experiment." *J. Sci. Food Agric*. 95: 1321-7.

[13] Bai, Z., and Dent, D. 2009. "Recent Land Degradation and Improvement in China." *AMBIO* 38: 150-6.

[14] Pan, G., Zhang, A., and Zou, J. 2010. "Biochar from Agro-byproducts Used as Amendment to Croplands: An Option for Low Carbon Agriculture." *J*. *Ecol*. *Rural*. *Environ*. 26 (4): 394-400. (in Chinese)

[15] Yan, Y., Lu, X. D., and Li, L. 2011. "Components of Pyroligneous Solution from Straw Pyrolysis and Its Effect on Growth and Quality of Pepper Spice." *Journal of Nanjing Agriculture University* 34 (5): 58-62. (in Chinese)

[16] Apai, W., and Thongdeethae, S. 2001. "Wood Vinegar: New Organic for Thai Agriculture." In *Proceedings of the 4th Toxicity Division Conference,* Department of Agriculture, 166-9.

[17] Pan, G., Lin, Z., Li, L., Zhang, A., Zheng, J., and Zhang, X. 2011. "Perspective on Biomass Carbon Industrialization of Organic Waste from Agriculture and Rural Areas in China." *J*. *Agric*. *Sci*. *Techn*. 13: 75-82.

[18] Gong, Z. T. 1999. *Chinese Soil Taxonomy: Theory Approaches and Application.* Beijing: China Science Press, 109-92.

[19] Lu, R. 2000. *Methods of Soil and Agro-chemical Analysis.* Beijing: China Agric. Sci. Tech. Press. (in Chinese)

[20] Hofmeister, J., Mihaljevič, M., Hošek, J., and Sádlo., J. 2002. "Eutrophication of Deciduous Forests in the Bohemian Karst (Czech Republic): The Role of Nitrogen and Phosphorus." *Forest Ecol*. *& Manage*. 169: 213-30.

[21] Nelson, D. W., and Sommers, L. 1973. "Determination of Total Nitrogen in Plant Material." *Agron*. *J*. 65 (1): 109-12.

[22] Yao, F.,. Arbestain, M. C., Virgel, S., Blanco, F., Arostegui, J., Maciá-Agulló, J. A., and Macías, F. 2010. "Simulated Geochemical Weathering of a Mineral Ash-Rich Biochar in a Modified Soxhlet Reactor." *Chemos*. 80: 724-32.

[23] Delibacak, S., and Ongun, A. R. 2016. "Influence of Treated Swwage Sludge Application on Corn and Succeeding Wheat Yield and on Some Properties of Sandy Clay Soil." *Turk*. *J*. *Field Crops* 21(1): 1-9.

[24] Troeh, F. R., and Thompson, L. M. 2005. *Soils and Soil Fertility*. Blackwell Ames.

[25] Ashraf, M., and Harris, P. 2004. "Potential Biochemical Indicators of Salinity Tolerance in Plants." *Plant Sci*. 166: 3-16.

[26] Munns, R. 2005. "Genes and Salt Tolerance: Bringing Them Together." *New Phytologist* 167: 645-63.

[27] Thies, J. E., and Rillig, M. C. 2009. "Characteristics of Biochar: Biological Properties." In *Biochar for Environmental Management: Science and Technology,* 85-105.

[28] Glaser, B., and Birk, J. J. 2012. "State of the Scientific Knowledge on Properties and Genesis of Anthropogenic Dark Earths in Central Amazonia (Terra Preta de Índio)." *Geochimica et Cosmochimica Acta* 82: 39-51.

[29] Lu, H., Lashari, M. S., Liu, X., Ji, H., Li, L., Zheng, J., Kibue, G. W., Joseph, S., and Pan, G. 2015. "Changes in Soil Microbial Community Structure and Enzyme Activity with Amendment of Biochar-Manure Compost and Pyroligneous Solution in a Saline Soil from Central China Plain." *Soil Biol.* 70: 67-76.

[30] Bruun, S., Jensen, E. S., and Jensen, L. S. 2008. "Microbial Mineralization and Assimilation of Black Carbon: Dependency on Degree of Thermal Alteration." *Organic Geochem*. 39: 839-45.

[31] Jones, B., Haynes, R., and Phillips, I. 2010. "Effect of Amendment of Bauxite Processing Sand with Organic Materials on Its Chemical, Physical and Microbial Properties." *J. Environ. Manag.* 91: 2281-8.

[32] Schulz, H., Dunst, G., and Glaser, B. 2013. "Positive Effects of Composted Biochar on Plant Growth and Soil Fertility." *Agro. Sust. Develop*. 1-11.

[33] Mukherjee, A., and Lal, R. 2013. "Biochar Impacts on Soil Physical Properties and Greenhouse Gas Emissions." *Agronomy* 3: 313-9.

[34] Mehta, P., Jajoo, A., Mathur, S., and Bharti, S. 2010. "Chlorophyll Fluorescence Study Revealing Effects of High Salt Stress on Photosystem II in Wheat Leaves." *Plant Physio. Bioch.* 48: 16-20.

[35] Cuin, T. A., and Shabala, S. 2005. "Exogenously Supplied Compatible Solutes Rapidly Ameliorate NaCl-Induced Potassium Efflux from Barley Roots." *Plant and Cell Physiol*. 46: 1924-33.

[36] Glaser, B., Lehmann, J., and Zech, W. 2002. "Ameliorating Physical and Chemical Properties of Highly Weathered Soils in the Tropics with Charcoal—A Review." *Biol. & Fert. of Soils* 35: 219-30.

[37] Birk, J., Steiner, C., Teixiera, W., Zech, W., and Glaser, B. 2009. "Microbial Response to Charcoal Amendments and Fertilization of a Highly Weathered Tropical Soil." In *Amazonian Dark Earths: Wim Sombroek's Vision.* Springer, 309-24.

[38] Roberts, K. G., Gloy, B. A., Joseph, S., Scott, N. R., and Lehmann, J. 2009. "Life Cycle Assessment of Biochar Systems: Estimating the Energetic, Economic, and Climate Change Potential." *Environ. Scie. Tech*. 44: 827-33.

[39] Ogawa, M., and Okimori, Y. 2010. "Pioneering Works in Biochar Research, Japan." *Soil Res.* 48: 489-500.

[40] Naheed, G., Shahbaz, M., Latif, A., and Rha, E. S. 2007. "Alleviation of the Adverse Effects of Salt Stress on Rice (*Oryza sativa* L.) by Phosphorus Applied through Rooting Medium: Growth and Gas Exchange Characteristics." *Pak. J. Bot*. 39: 729-37.

[41] Jeffery, S., Verheijen, F., Van Der Velde, M., and Bastos, A. 2011. "A Quantitative Review of the Effects of Biochar Application to Soils on Crop Productivity Using Meta-Analysis." *Agric. Ecos. & Environ.* 144: 175-87.