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Comparative Effects of Different Soil Conditioners on Wheat Growth and Yield Grown in Saline-sodic Soils

(Kesan Bandingan Penyubur Tanah Berbeza ke atas Tumbesaran Gandum dan Pengeluaran dalam Tanah Salin-sodik)

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ABSTRACT

*Among abiotic stresses, salinity is the main abiotic stress limiting crop growth and yield worldwide. Improving agri-food production in salt-prone areas is the key to meet the increasing food demands in near future. A greenhouse experiment was conducted to investigate the effect of different soil conditioners, gypsum (GYP), citric acid (CA), ethylene diamine tetraacetic acid (EDTA) and polyvinyl alcohol (PVA), on growth and yield of wheat (*Triticum aestivum *L.) grown in saline-sodic soil. Gypsum was applied at a rate of 100% soil gypsum requirement while other amendments were applied each at a rate of 5 g kg^{-1} of soil. The results showed that EDTA treatment increased pH and electrical conductivity (ECe) of soil while pH significantly decreased when treated with citric acid. Soil sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) decreased in all treatments following the order: CT > PVA > EDTA > CA > GYP. Addition of CA positively affected growth parameters as compared to other soil conditioners including plant height, number of tillers per plant, number of spikes per plant, plant dry weight and grain yield while EDTA negatively affected these parameters. Addition of CA also significantly increased photosynthetic rate, stomatal conductance, transpiration rate and chlorophyll contents while EDTA decreased these parameters. We conclude that increase in plant growth and yield with CA might be due to the effect of CA on soil properties which positively affected plant physiological parameters.*

Keywords: Biomass; photosynthesis; salinity; soil amendments; wheat

ABSTRAK

*Antara tekanan abiotik, kemasinan ialah tekanan abiotik utama yang menghadkan pertumbuhan tanaman dan hasil di seluruh dunia. Meningkatkan pengeluaran makanan pertanian di kawasan terdedah garam adalah kunci untuk memenuhi permintaan makanan yang semakin meningkat pada masa hadapan. Percubaan rumah hijau telah dijalankan untuk mengkaji kesan berbeza penyubur tanah, Gipsum (GYP), asid sitrik (CA), asid tetraasetik diamina etilena (EDTA) dan alkohol polivinil (PVA) ke atas pertumbuhan dan hasil gandum (*Triticum aestivum *L.) yang ditanam di tanah saline sodic. Gipsum diaplikasikan pada kadar 100% di tanah keperluan Gipsum manakala pindaan lain digunakan masing-masing pada kadar 5 g kg^{-1} tanah. Hasil kajian menunjukkan bahawa rawatan EDTA meningkatkan pH dan pengaliran elektrik (ECe) tanah manakala pH ketara berkurangan apabila dirawat dengan asid sitrik. Nisbah penjerapan tanah sodium (SAR) dan peratus sodium boleh tukar (ESP) menurun pada semua rawatan diikuti aturan berikut: CT > PVA > EDTA > CA > GYP. Penambahan CA mempengaruhi parameter pertumbuhan secara positif jika dibandingkan dengah penyubur tanah lain termasuk ketinggian tumbuhan, bilangan tiler setiap pokok, bilangan pancang setiap pokok, berat kering tanaman dan hasil bijirin manakala EDTA mempengaruhi parameter pertumbuhan ini secara negatif. Penambahan CA turut meningkatkan kadar fotosintetik, penggunaan stomatal, kadar transpirasi dan kandungan klorofil manakala EDTA menurunkan parameter ini. Kami menyimpulkan bahawa peningkatan dalam pertumbuhan tumbuhan dan hasil dengan CA mungkin disebabkan oleh kesan CA terhadap sifat tanah yang mempengaruhi parameter fisiologi pertumbuhan secara positif.*

Kata kunci: Biojisim; fotosintesis; gandum; kemasinan; pindaan tanah

INTRODUCTION

Soil salinity and sodicity are among the serious threats to irrigated agriculture in arid and semi-arid regions worldwide (Ayars & Tanji, 1999; Farooq et al. 2015). At world level, about 800 million hectares (mha) of land is salt affected which is about 20% of the total arable area and is increasing by 1-2% each year. In Pakistan, about 6.3 mha land is salt affected with 4000 hectares affected by salinity every year (Munns & Tester 2008). Soil salination and sodication are mainly caused due to low rainfall, use of un-managed water resources and high evaporation in these regions. Soil sodic nature generally showedsoil structural problems causing decreased water uptake by plants, seedling emergence and root penetration (Qadir

& Schubert 2002). Soil salinity is a global problem and results in reduction in plant growth and yield and in severe cases total crop failure (Farooq et al. 2015; Qadiret al. 2001). Pakistan is facing an acute shortage of good quality irrigation water to grow cropsand groundwater is pumped and used for irrigation (Ghafoor et al. 2001; Latif & Beg 2004). Continuous use of low quality water without the application of any amendment could make saline/sodic soils.These soils possess poor physical properties and fertility problems that adversely affect the growth and yield of most crops (Grattan & Grieve 1999). Therefore, there is need of efficient, inexpensive and environmentally acceptable management practices to grow crops in these soils.

The reclamation of saline-sodic soils may be possible with different methods which include physical and chemical amelioration. The most effective methods are based on the removal and exchange of soluble sodium and changing the ionic composition of soils by added chemicals with simultaneous leaching of sodium salts out of the soil profile (Chhabra 1994). Moreover, the reclamation of saline-sodic soils may also be possible by the application of different soil conditioners. A soil conditioner is a material having the ability to improve both soil physical and chemical characteristic like infiltration rate, water holding capacity, bulk density, soil pH, soil electrical conductivity, sodium adsorption ratio and availability of nutrient in soil.

There are different types of soil conditioners such as organic soil conditioners comprising of farmyard manure, green manure, humic substances, peat and mulch and inorganic including gypsum, crude sulfur and water soluble polymeric (Polyethylene glycol, polyvinyl alcohol) and hydro gel polymeric compounds (Jhurry 1997). The use of gypsum as a source of Ca^{2+} is a well-established practice for the amelioration of sodic soils (Bresler et al. 1982). Gypsum is commonly used in Pakistan due to its frequent availability. However, its efficiency is reduced due to low solubility of gypsum and calcareous nature of soils (Sharma et al. 1996). Similarly, organic acids and EDTA are also used as soil conditioners (Yang & Wang 2005). It is also reported that anionic polyacrylamides and cationic polysaccharides have been used in sodic/saline-sodic soils and evaluated that these conditioners increase infiltration rate and stabilize aggregate like other soil conditioners with different mode of action (Ben-Hur & Keren 1997). However, there is still a need to find more efficient soil conditioners with better ability to grow crops in saline and saline sodic soils that may occur in large areas.

Wheat is the main staple food in Pakistan and worldwide and is the largest grain source of the country. It contributes about 13.1% to the value added in agriculture and 2.7% to GDP. In 2010-2011, wheat was cultivated on an area of 8.805 m ha which was 3.6% lower than the previous year with an annual production of 24.2 million tons (Anonymous 2011). In Pakistan, lower wheat yield was due to the salt affected soils of the country along with other factors. Wheat is sensitive to saline and saline-sodic soil conditions that may cause specific ion toxicity, ion imbalance and water stress in wheat plants. In order to make effective utilization of saline-sodic soils, there is a need to grow wheat crop in these soils with the addition of soil conditioners so that this crop can face adverse conditions of salinity and sodicity. Thus, the present study was carried out to analyze the potential of different soil conditioners against salt stress in wheat plants and their effects on soil chemical attributes and wheat growth and yield by monitoring plant morphological and physiological parameters.

MATERIALS AND METHODS

MATERIALS

Soil was collected from Proka farm II, University of Agriculture Faisalabad from the surface (0-15 cm). Soil was alkaline (pH8.35) and was classified as saline-sodic soil due to larger values of electrical conductivity (EC), sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) (Table 1). Soil was air dried and then passed through 2 mm sieve. After that, soil was analysed for initial physico-chemical properties like pHs, ECe, soluble cations and anions, SAR and ESP (U.S. Salinity Lab. Staff 1954). Soil gypsum requirement was calculated with the method described by Schoonover (1952). Particle size analysis was done according to Bouyoucos (1962). All these initial soil properties are given in (Table 1). Wheat (*Triticum aestivum* cv. Lasani 2008) was grown in the soil with and without application of four different soil conditioners including gypsum (GYP), citric acid (CA), ethylene diaminetetraacetic acid (EDTA) and polyvinyl alcohol (PVA). The selected wheat cultivar is grown mainly in the area from which soil samples were taken and also reported in recent studies (Ali et al. 2015a, 2015b).

EXPERIMENTAL DETAILS

The pot experiment was conducted in the wire house at 25-35°C. Five treatments were applied at doses of 100% soil gypsum requirement, citric acid, EDTA and polyvinyl alcohol each at a rate of 5g kg^{-1} of soil and a treatment without any amendment. After this, each pot was filled with 10 kg of soil. The soil was incubated at field capacity for two weeks prior to sow the crop. There were three replicates with complete randomized design. Pots were initially seeded at a density of ten seeds per pot, then thinned to four individuals per pot after one week of germination. Each pot was fertilized with 120 kg ha^{-1} N (as urea), 90 kg ha^{-1} P (as single super phosphate) and 60 kg ha^{-1} K (as sulphate of potash). Half of N and full doses of P and K were applied at the time of sowing and remaining half of nitrogen was applied at tillering stage. Pots were regularly watered and randomly rotated when required and weeds were removed regularly when present.

TABLE 1. Physicochemical properties of soil used in the pot experiment

Characteristics	Amount
Sand (%age)	42
Silt (%age)	20
Clay (%age)	38
pH (1/2.5 soil to water ratio)	8.35
ECe (dSm^{-1})	6.3
CO_3^{-2} ($mmol^+ L^{-1}$)	-
HCO_3^{-1} ($mmol^+ L^{-1}$)	23
Cl^{-1} ($mmol^+ L^{-1}$)	2.75
SO_4^{-2} ($mmol^+ L^{-1}$)	0.23
$Ca^{+2} + Mg^{+2}$ ($mmol^+ L^{-1}$)	16.78
Na^{+1} ($mmol_c L^{-1}$)	42
Sodium absorption ratio ($(mmolL^{-1})^{1/2}$)	14.53
Exchangeable sodium percentage (%age)	17.5
Saturation percentage (%age)	30.25
Cation exchange capacity ($cmol^+ Kg^{-1}$)	2.4
Soil gypsium requirements ($g\ kg^{-1}$)	4.1

PLANT SAMPLING AND ANALYSIS

Different physiological parameters including photosynthetic rate, stomatal conductance and transpiration rate were recorded using Infra Red Gas Analyser (IRGA). At booting stage, chlorophyll contents in fresh leaves were extracted with 85% (v/v, Sigma) aqueous acetone solution at 4°C in the dark by continuous shaking until color had completely disappeared from the leaves. Then, the assay mixture was centrifuged at 4000 × g for 10 min at 4°C and then supernatant was taken. Light absorbance at 645 and 663 nm was determined by spectrophotometer (Halo DB-20/DB-20S, Dynamica Company, London, UK). Concentrations of chlorophylls were calculated by using equations (Nagata & Yamashota 1992). Plants were harvested after 130 days of sowing. The crop growth and yield parameters were recorded including no of tillers per plant, plant height, spike length, no of spikelets per spike, no of grain per spike, dry weight and total grain yield. Plant samples were washed with distilled water and oven dried at 70°C until a constant weight was reached then total dry weight of shoots were measured.

SOIL SAMPLING AND ANALYSIS

Soil samples were also taken at the end of experiment. The samples were oven dried at 40°C until constant weight and then sieved at 2 mm before analysis. Soil was analyzed forpHs, ECe and soluble cations (Na^+, K^+ and $Ca^{+2} + Mg^{+2}$) and anions (CO_3^{-1}, HCO_3^{-1} and Cl^{-1}) following the methods described by the U.S. Salinity Lab. Staff (1954).

The ECe was measured with the help of AANNA Model HI 8033 conductivity meter using 0.01 N KCl solutions for standardization. Soluble and exchangeable sodium and potassium were measured with the help of flame photometer (Jenway PEP-7) having Na^+ and K^+ filters.

Sodium adsorption ratio (SAR) was calculated by the equation given below and by using the concentrations of Ca^{+2}, Mg^{+2} and Na^{+2} in $meql^{-1}$.

$$SAR = Na^+ / [(Ca^{+2} + Mg^{+2}) / 2]^{1/2}$$

Exchangeable sodium percentage (ESP) was calculated by the formula given:

$$ESP = (\text{exchangeable sodium concentration } (cmolkg^{-1}) / \text{cation exchange capacity } (cmolkg^{-1})) \times 100$$

STATISTICAL TREATMENT

The data collected was subjected to statistical analysis using Statistix version 8.1 computer softwarepackage (Steel et al. 1997). Analysis of variance (ANOVA) techniques and LSD test were applied to differentiate the effectiveness of treatments.

RESULTS

EFFECT OF TREATMENTS ON SOIL CHARACTERISTICS

The results related to soil pH_s, EC_e, SAR and ESP aregiven in Table 2. Post-harvest soil pH_s was significantly affected by application of soil conditioners. Minimum pH_s was observed in citric acid treated soil as compared with control. pH_s significantly increased in EDTA treated soil than those of control soil. EC_e of EDTA and CA treated soil was 5.98% and 5.37%, respectively, larger as compared with control soil. The maximum decrease in EC_e was observed in gypsum (5.24%) and PVA (5.25%) treated soil as compared with control. Maximum reduction in SAR was observed in gypsum treated soil as compared to control. Minimum reduction in SAR was observed in PVA treated soil than those of control soil. There were significant changes in exchangeable sodium percentage (ESP) as compared with control soil after crop harvest. Maximum decrease in ESP was observed in gypsum treated soil and minimum decrease was observed in PVA treated soil than those of control soil.

EFFECT OF TREATMENTS ON PLANT PARAMETERS

Plant growth Height of wheat plants increased with application of soil conditioners except EDTA treated soil (Figure 1(a)). Largest plant height was observed in CA treated soil followed by gypsum and PVA treated soil than those of control plants. This increase in plant height was about 23.76, 18.81 and 16.09% for CA, gypsum and PVA, respectively, as compared with control. Plant height significantly decreased in EDTA treated soil as compared with control plants and this decrease in plant height was about 14.6%. Number of tillers per plant increased with the application of soil conditioners being maximum in CA treated soil (18.18%) and minimum in EDTA treated soil than those of control plants (Figure 1(b)). The maximum number of spikes per plant was observed in CA treated soil while minimum spikes per plant were observed in EDTA treated soil than those of control plants (Figure 1(c)). In gypsum and PVA treated soil there was slight larger spikes per plant as compared with control plants. The similar trend was observed in spikelets per spike being maximum in CA treated soil and minimum in EDTA treated soil as compared to control plants (Figure 1(d)).

Plant biomass and grain yield Shoot dry weight positively affected by addition of soil conditioners except EDTA than those of control plants (Figure 2(a)). Largest significant increase in plant dry weight was observed by the addition of CA in the soil following GYP and PVA treatments. This increase in dry weight was about 42.41, 26.68 and 0.92% for CA, gypsum and PVA, respectively, as compared with control. However, plant dry weight decreased with the application of EDTA in the soil as compared with control plants. This decrease in dry weight was about 28.23% as compared with control. Grain yield was also largest when there was CA application in the soil as compared with control following GYP and PVA while decreasing trend was observed in the presence of EDTA in the soil (Figure 2(b)). The increase in grain yield was about 63.27, 36.13 and 20.33% for CA, gypsum and PVA, respectively, while decrease was about 9.45% for EDTA as compared with control.

Physiological parameters Photosynthetic rate significantly affected by the addition of soil conditioners (Figure 3(a)). Maximum photosynthetic activity was observed in plants treated with CA followed by GYP and PVA while minimum activity was observed in EDTA treated plants as compare with control treatments. Maximum stomatal conductance was also observed in plants treated with CA while minimum stomatal conductance was observed in plants grown in EDTA treated soil as compared with control (Figure 3(b)). In addition, PVA application did not affect the stomatal conductance when compared with control. Application of soil conditioners significantly increased the transpiration rate as compared with control except in plants treated with EDTA where opposite results were observed (Figure 3(c)). Maximum transpiration rate was observed in CA treated soil. Decreasing order of transpiration rate was CA>GYP>PVA> CT> EDTA. The maximum total chlorophyll contents were observed in CA treatment while the minimum chlorophyll contents were observed in EDTA and control plants (Figure 3(d)). The decreasing order in chlorophyll contents were as CA>GYP>PVA>CT and EDTA.

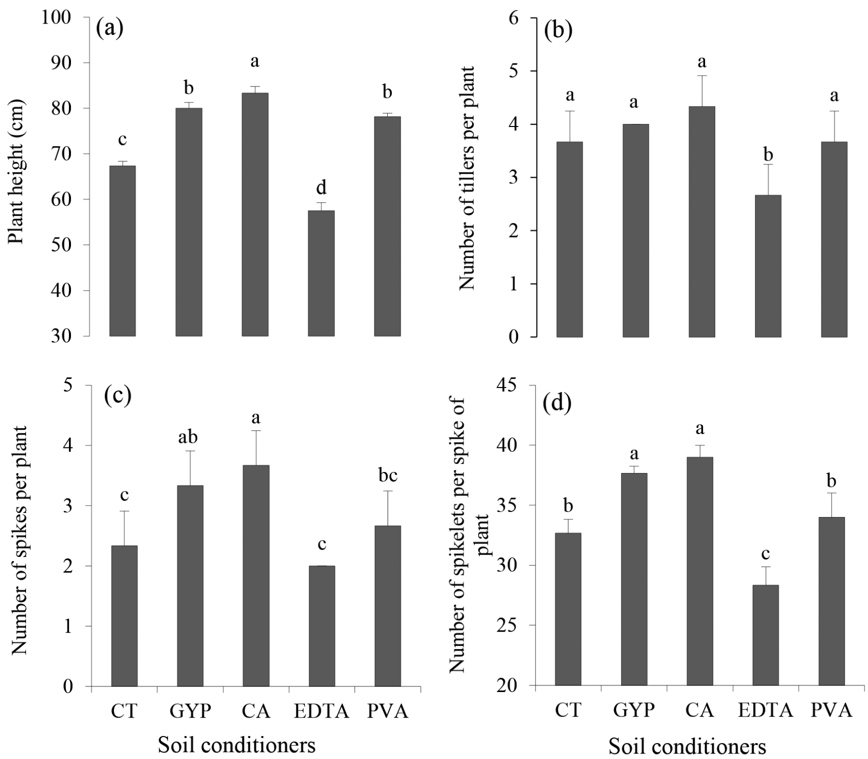

FIGURE 1. Effect of soil conditioners on plant height (a), number of tillers (b), number of spikes per plant (c) and number of spikelets per spike of wheat plant (d) grown on a saline-sodic soil treated with CT = control, GYP = gypsum, CA = citric acid, EDTA ethylene diamine tetra acetic acid and PVA = Polyvinyl alcohol. Bars represent SD of three replicates. Different letters indicate significant differences among the treatments at a $p<0.05$

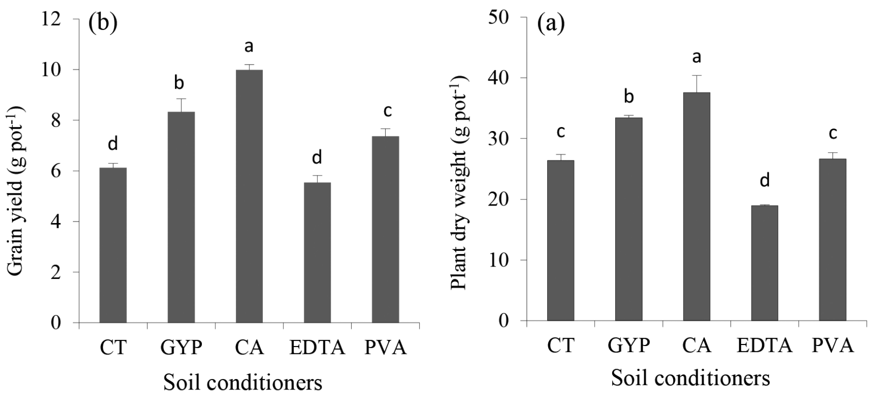

FIGURE 2. Effect of soil conditioners on dry weight (a) and grain yield (b) of wheat grown on a saline-sodic soil treated with CT = control, GYP = gypsum, CA = citric acid, EDTA ethylene diamine tetra acetic acid and PVA = Polyvinyl alcohol. Bars represent SD of three replicates. Different letters indicate significant differences among the treatments at a p<0.05

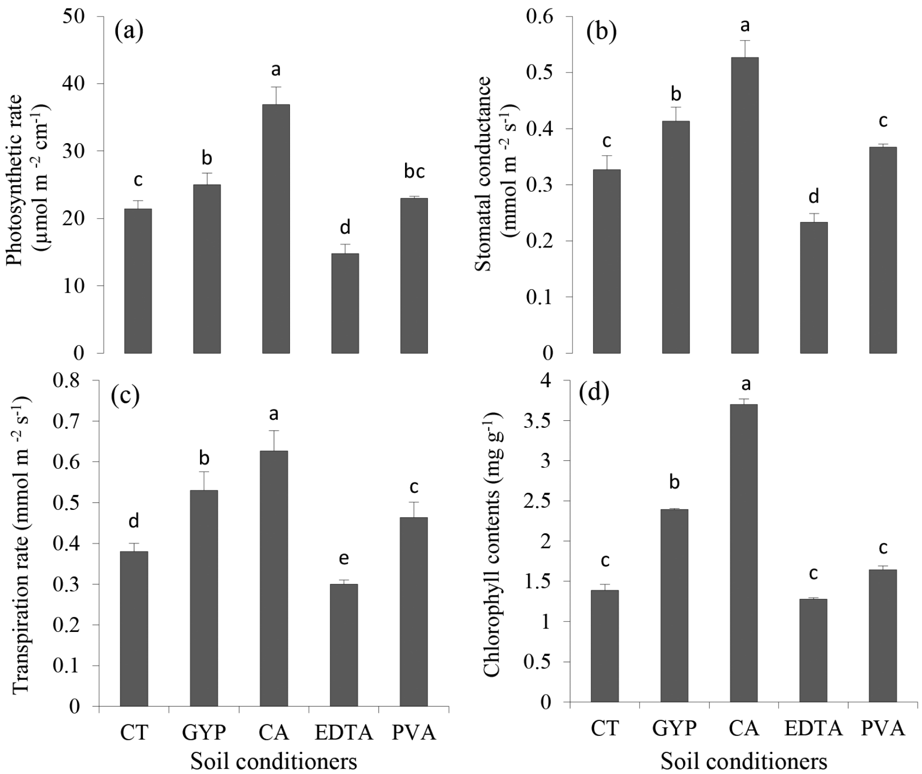

FIGURE 3. Effect of soil conditioners on photosynthetic rate (a), stomatal conductance (b), transpiration rate (c) and chlorophyll contents (d) of wheat grown on a saline-sodic soil treated with CT = control, GYP = gypsum, CA = citric acid, EDTA ethylene diamine tetra acetic acid and PVA = Polyvinyl alcohol. Bars represent SD of three replicates. Different letters indicate significant differences among the treatments at a p<0.05

DISCUSSION

CHANGES IN SOIL PROPERTIES

This study indicated that soil salinity (indirectly measured through EC of soil) slightly decreased as a result of all treatments as compared with control except EDTA (Table 2). Decrease in EC_e may be due to effectiveness of the soil conditioners in removing salts from soil to leachates (Mahdy 2011). In the present study, EC_e increased with the application of EDTA (Table 2). Increase in EC by application of soil conditioner, polyacrylamide (PAM) has also been reported by Rajpar and Sial (2002). In our results, increase in EC_e may be due to increase in concentration of other ions that make salts with combination of opposite ions like NaCl salt formation. Sodium absorption ratios decreased with the application of amendments (Table 2). Sodium adsorption ratio in amended soil reached a value slightly lower than the critical value for saline-sodic soils

(> 13). This reduction in SAR might be due to reasonable amount of Ca^{+2} + Mg^{+2}present in irrigation water used for the experiment. Moreover, lime of the soil undergoes dissolution under influence of CO_2 released by plant roots and set Ca^{+2} free in this way favors Na- Ca^{+2} exchange which ultimately reduce SAR (Qadir & Oster 2004). In sodic soil, by application of chelating agents, SAR reduced because Ca^{+2} remove Na^+ from exchange site, which come into soil solution and further leached down by application of heavy irrigation (Naidu & Rengasamy 1993). ESP also showed a significant reduction in treated soil as compared to untreated soil. It was reported that poor structure and high concentration of sodium are main adverse physio-chemical features of sodic soils (Barzegar et al. 1997). This limit seedling emergence, plant growth and increase in concentration of toxic ions in plants. In the present study, addition of soil conditioners reduced the SAR and ESP of soil which positively affected the plant growth and yield (Figures 1 & 2).

Soil pH decreased with the application of CA (Table 2). Wang et al. (2011) reported that CA application decreased soil pH and as a resultbioavailability of other nutrients increased. Soil pH has great impact on controlling the dynamic of plant nutrients, especially accessibility of micronutrients such as Cu, Mn, Fe and Zn (Naidu & Rengasamy 1993). Salt affected soils deteriorate due to changes in soil reaction (pHs) and in proportions of certain cations and anions present both in the soil solution and on the exchange sites. These changes lead to osmotic and ion-specific effects as well as to imbalances in plant nutrition, which may range from deficiencies in several nutrients to high level of sodium (Na^+). Such changes have a direct impact on activities of plant roots and soil microbes, and ultimately on crop growth and yield (Grattan & Grieve 1999; Mengel & Kirkby 2001; Naidu & Rengasamy 1993). In the present study, decrease in pH by the application of CA may be responsible for increased crop growth and yield (Figures 1, 2 & 3).

PLANT GROWTH AND BIOMASS RESPONSE

Plant height and number of tillers per plant was lower in control treatment (Figure 1). The decrease in plant height under saline condition may be due to the accumulation of salts in plant tissues (Farooq et al. 2015). Numerous studies have shown that tiller appearance is affected by salt stress (Mass & Grieve 1990; Nicolas et al. 1993). Plant height increased in CA treatment (Figure 1). This increase in plant height may be due to decrease in soil pH (Table 2) because under low pH availability of nutrients especially phosphorus is increased that is essential for proper growth of plant. Similarly, the increase in plant height in GYP treatment may be due to improvement in soil physical properties that helps to improve plant growth. The use of selected inorganic salts applied singly or in mixture was reported to improve the root system leading to increase in plant height. Many researchers reported that acid application like HCl and H_2SO_4 had significantly positive effect on tillering and plant height of wheat and help to reclaim saline-sodic soil (Akhtar & Niazi 1986). Similarly, Rashid et al. (2009) reported that in wheat crop application of gypsum in salt affected soils increased the number of tillers, spike length and number of spikelets per spike and grains per spike as compared to deep tillage and H_2SO_4 treated soil. However, in our study all these growth parameters were increased by the application of CA in the soil as compared to GYP (Figures 1 and 2). This showed that CA application is more effective as compared with other treatments including GYP in saline sodic soils and may be used for the reclamation of these soils.

Plant dry weight and grain yield increased in all treatments over control except EDTA treated soil (Figure 3). Reduction in weight and yield in EDTA treated soil may be due to reduction in all physiological parameters including the rate of photosynthesis, stomatal conductance, transpiration rate and chlorophyll contents (Figure 3). Several studies reported that decrease in plant growth might be due to reduction in the rate of photosynthesis in leaves along with other factors (Ali et al. 2005; Ouerghi et al. 2000). The lowest photosynthetic activity in plants treated with EDTA in the soil might be associated with the loss of Rubp carboxylase/oxygenize (Koyro 2006; Wei et al. 2006). In general, photosynthesis is inhibited by salt stress that affects photosynthetic activity and chloroplast structure (Fidalgo et al. 2004). In our study, the application of EDTA changed the soil chemical properties (EC and pH) that affected photosynthetic activity.Photosynthesis is inhibited in the presence of salinity through either reduction in stomatal conductance (g_s) or reduction in chlorophyll pigments to absorb enough light (James et al. 2002; Moradi & Ismail 2007; Ouerghi et al. 2000). Another

TABLE 2. Effect of soil conditioners on soil pH, soil electrical conductivity (ECe), sodium absorption ratio (SAR) and exchangeable sodium percentage (ESP) after harvesting of wheat treated with different conditioners i.e. CT = control, GYP = gypsum, CA = citric acid, EDTA ethylene diamine tetra acetic acid and PVA = Polyvinyl alcohol. Values are means of three replicates. Different letters indicate significant differences among the treatments at a $P<0.05$ for pH, ECe, SAR and ESP separately

Treatments	pH	ECe (dSm^{-1})	SAR ($(mmolL^{-1})^{1/2}$)	ESP (%)
CT	8.34±0.01b	6.28±0.01b	14.25±0.08a	17.02±0.14a
GYP	8.33±0.01b	6.24±0.01c	13.03±0.28b	15.32±0.15c
CA	8.27±0.03c	6.24±0.01c	13.07±0.37b	15.47±0.16c
EDTA	8.38±0.02a	6.98±0.02a	13.37±0.13b	16.02±0.20b
PVA	8.33±0.01b	6.26±0.02bc	14.00±0.25a	16.94±0.06a

possible factor contributing to decreased photosynthesis is the inhibitory effect of salt stress on the efficiency of translocation and assimilation of photosynthetic products (Chen et al. 1999). High concentration of Na^+ causes osmotic imbalance, membrane disorganization, reduction in growth, inhibition of cell division and expansion and reduction in photosynthetic rate (Mahajan & Tuteja 2005). Kamboh et al. (2000) reported that salinity stress decreased the transpiration rate and stomatal conductance in wheat. Grover, (1993) also reported that with increasing salinity level,the reduction in stomatal conductance in wheat crop occurred.

In the present study, application of CA positively affected all physiological parameters as compared with other treatments including photosynthetic rate, stomatal conductance, transpiration rate and chlorophyll contents (Figure 3). Increase in chlorophyll contents play important role in photosynthesis thatare mostly lower in plants exposed to salinity (Parida & Das 2005). Similarly, Chen et al. (1999) reported that leaf photosynthetic capacity depends on physiological characteristics such as chlorophyll contents, Rubisco activity and photosystem efficiency. In our study, increase in physiological parameters increased photosynthetic rate that resulted in increased plant height and number of tillers per plant and ultimately increase in plant dry weight and grain yield.

Conclusion

The findings of this study showed that citric acid application in saline-sodic soils improved soil properties and positively affected plant physiological parameters that lead to increase in wheat growth and yield. Thus,it can be concluded that application of citric acid can be used to combat salt effects on plant growth and grain yield. However, field experiments are necessary to draw conclusion and to recommend end users to grow crops in saline-sodic soils.

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