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Contribution of saline shallow water table in crop water requirements: challenges and prospects

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Abstract: The increasing demand for food and fiber by its ever-increasing population put a high pressure onfresh water resources. Optimum utilization of surface and groundwaterresources has become extremely important to fill the gap between water demand and supply.Shallow groundwater found within about 180 cm of the soil surface can be a significant source of water for agricultural production, especially during drought periods. The fraction of the crop water demand that can be met by shallow water tables depends on the crops grown, irrigation and drainage management, the soil type, the depth to the water table, and the shallow groundwater salinity. Several researches focused on the upward flow possibilities of groundwater from shallow water tables in terms of root zone hydraulic characteristics and soil salinization and the need for subsurface drainage. Due in part to the greater capillary rise infine-textured soils, greater rates of upward flow have been found in loamy soils than in sandy soils with small capillary rise or in clayey soils with very slow permeability.This review highlights bothContribution of saline shallow water table in crop water requirement, and thepotential of biochar in alleviating salt stress inplants and future prospect of the role of biochar under salt stress in plants.

Key words: water table; crop water requirements; salinity; biochar;irrigation.

Introduction

The world's population today is about 6.5 billion people and is estimated to increase to 9.1 billion by 2050 (UN, 2006). Irrigation provides about 40% of global food on less than 18% of arable land and has a major role to play in meeting future global demand for food. (Ayars et al., 2006). It is estimated that irrigation consumes more than 80% of the water of good quality. This makes it the largest user of water, far from other competitors, ie urban, industrial and environmental use. More certainly, competition between agricultural, urban, industrial and environmental needs will be more acute in the near future. Any effort to improve irrigation efficiency is worthwhile because it can lead to saving large quantities of good quality water. In soil that is characterized by a subterranean layer slowly, the use of irrigation water that exceeds the amount already used by the plant in the transpiration creates underground water tables near the surface, which can be used to reduce irrigation requirements. Such ground water is referred to as a perched or shallow water table and is differentiated from a deep water table by its influence on plant growth.

The presence of a shallow water table increases the soil water storage available for plant transpiration and soil evaporation (ET). Root activity occurs in the unsaturated zone above the water table only. Thus, the soil water reservoir becomes available only if water moves against gravity from the shallow water table toward the plant roots by capillary rise. As a result, the extent to which shallow ground water contributes to plant transpiration depends on soil type and shallow water table depth.Shallow water table contributions to plant water use are high in loamy soils compared to clay and sandy soils. Water table contributions decrease as the distance between the plant roots and the shallow water table increases.Even where irrigation water is of high quality, salts will accumulate near the soil surface because of plant water uptake. With rainfall and irrigation, these salts move to the ground water and increase salinity in shallow ground water. However, because of capillary rise, this leaching process can be reversed; bringing salts back to the root zone.

Increasing salt concentrations make extracting soil water more difficult for the plant roots. High soil salinity generally reduces root growth and plant water uptake and increases plant water stress compared to low soil salinity and comparable soil water storage capacityExperimental data for cotton in California have shown that shallow water tables can contribute as much as 40% to 60% of the crop ET. Cotton is salt-tolerant and is thus less vulnerable to the increasing soil salinity created by capillary rise. In the short term, the use of shallow water tables will have a limited effect on soil salinity and crop production. In normal rainfall years, most of the salts brought into the root zone by capillarity will be leached back to the ground water by rainfall and pre-irrigations. However, managing soil salinity becomes important over the long term when maximum use of a shallow water table is encouraged for meeting crop ET requirements.In fields with subsurface drainage systems, ground water tables can be artificially elevated by temporarily raising the discharge end of the drains in the drain sump with an elbow configuration. The water table would be elevated before the pre-irrigation and lowered again after harvesting to promote leaching by winter rains.In summary, shallow water tables may significantly contribute to the total water demand of the crop, thereby reducing irrigation water requirements and drainage losses. However, if shallow water tables are to be used as a long-term strategy, the associated increase in soil salinity requires careful management.

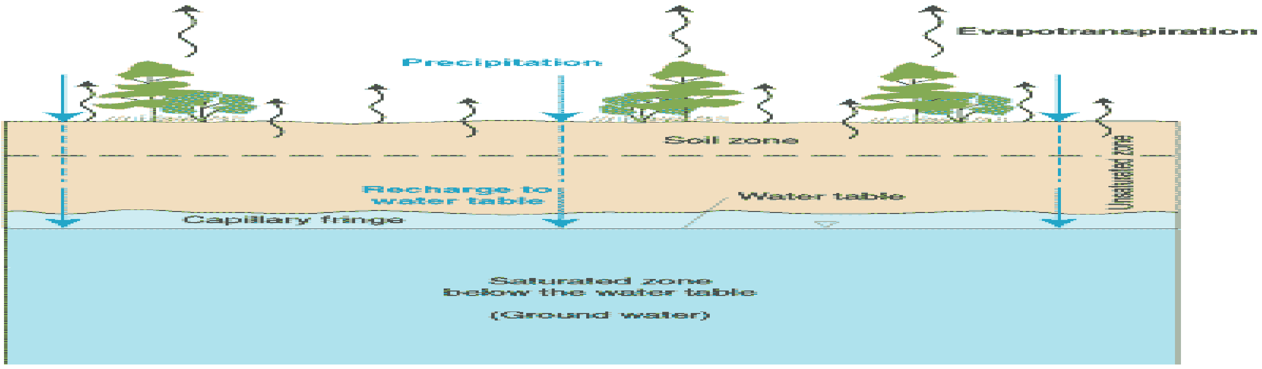

Figure 4. The unsaturated zone, capillary fringe, water table, and saturated zone.

Contribution to irrigation from shallow water

Contribution of shallow water table to crops water requirement varied with its depth and type of the cropspecies. It was found that the decrease in water table depth reduced the contribution to corn by 22% compared that of sorghum; while increasing of the irrigation interval of the sorghum increased the fraction of water that obtained from the ground water(Yang and Shiping, 2000). In another study, wheat met its required water from ground water with 0.5 meter of water table depth, (Kahlown et al. 2005). Moreover, contribution of ground water from 1.6 to 2.4 m depth to winter wheat water use grown into sand soil in a weighing lysimeter was found to be 16.6% of its total evapotranspiration (Yang and Shiping, 2000) .Recently many efforts have been devoted to the development of new irrigation techniques such as deficit irrigation and partial drying root zone irrigation with a view to improving the water use efficiency of field crops (Gowinget al 2009). In irrigated agriculture, many salinity problems are associated with or strongly influenced by a shallow ground water (Sepaskhah eta 2008). But, in this study fresh ground water (2.4 dS m1) was mainly used for irrigation.

Under rain-fed condition, groundwater contribution was able to meet more than 65% of the potential evapotranspiration of winter wheat when water table was at or above 150 cm depth. However, it could meet the entire water requirement at or above 110 cm water table depth (Liu, andLuo, 2011). The use of shallow ground water helps to reduce the reliance on irrigation (Gowing et al., 2009), and save water and energy, and avoid the risk of water table rising. Moreover, it is possible to control the water table depth by managing irrigation and drainage system to maximize the WUE and yield of winter wheat (Liu, andLuo, 2011). After winter wheat is planted, the water table depth can be controlled by extending the irrigation interval and reducing the applied irrigation water to extend the root system (Ayars et al., 1999)`

Quantification of the water taken by the roots from the shallow water table is of great significance and has been a topic of extensive research in the last few decades. Wallender et al. (1979) found that 60 % of the evapotranspiration (ET) of a cotton crop was extracted from a 6 dS m-1 shallow water table. Ayars and Schoneman (1986) found that capillary rise of water of ECe = 10 dS m-1 from a water table of 1.7 – 2.1 m deep contributed to up to 37% of evapotranspiration (ET) of a cotton crop. Prathapar and Qureshi (1998) observed that under shallow water table conditions irrigation can be reduced up to 80 % without affecting crop yield and increasing soil salinization. Soppe and Ayars (2003) by using weighing lysimeters maintained a saline (14 dS m^{-1}) water table at 1.5 m depth and found that ground water contributed of up to 40% of daily water used by safflower crop. On a seasonal basis 25% of the total crop water use originated from the ground water. The largest contribution occurred at the end of the growing season when roots were fully developed. The applied irrigation in the presence of a water table was 46 % less than irrigation applied to the crop without a water table.

Factors affecting utilization of shallow groundwater

Upward Flow of Soil-Water

For shallow groundwater to be available for crop water needs, the water must flow upward into the crop root zone. The rate at which this occurs depends on the distance between the water table and root zone base, as well as the soil type (Raes, 2003). This flow rate is determined from the soil hydraulic conductivity (which depends on soil moisture) and the upward driving force controlled by the water table depth and near-surface evapotranspiration rates. The smaller the distance between the water table and root zone, and the drier the root zone soils, the greater the upward flow rates from the water table, assumingall other factors are equal. Similarly, the finer (more clayey) the soil texture, the smaller the hydraulic conductivities and the smaller the upward flow rates into the root zone. This upward flow rate is also affected by the water table salinity: increased shallow groundwater salinity decreases the upward flow, due to plant preference for lower-salinity water(Narjary,2021).

Root Zone Conditions

Crop use of shallow groundwater will not be significant until the root system is adequately developed in the proximity of the water table, since the roots are the primary conduit between the water table and the crop. However, quantification of the root zone has been elusive, as little data is available about root development relative to crop growth stage, maximum rooting depth, and how these are affected by the presence of shallow groundwater of a particular salinity. Clearly, the more rapidly roots approach the water table, the greater the opportunity to extract shallow groundwater earlier in the growing season. The coarser the soil texture, the closer the roots will need to be to the water table to extract shallow groundwater because coarser soils can hold less water than finer-textured soils at the same soil-water suction (the same matric potential). While some research suggests that the top third of the root zone, where the root density is usually greatest, is the most important, research considering shallow groundwater extraction found that the smaller portion of the root zone closest to the water table capillary fringe was the origin of the greatest fraction of groundwater extracted (Soppe and Ayars 2002).

Table 1. The range of crop root depths.

	Conditions for root growth		
Crop	unfavourable	common	favourable
Winter cereals	60-80	80-100	100-140
Winter oilseed rape	60-80	80-110	110-160
Spring barley	40-50	50-80	80-110
Spring wheat, oats	50-70	70-100	100-120
Poppy	40-60	60-80	80-110
Pea	30-40	40-60	60-80
Potatoes	30-40	40-50	50-80
Maize	60-70	70-100	100-150
Sugar beet	80-90	90-130	130-180
Sun flower	70-100	100-130	130-200

Type of Crop

For a given field, crop selection is the key controllable management variable for maximizing plant use of shallow groundwater to meet evapotranspiration demand. While many plants can extract shallow groundwater, the agronomic plant characteristics that affect the contribution of shallow groundwater toward meeting crop water requirement include salt tolerance, length of growing season, and rooting characteristics. Plant salt tolerance is a dominant factor affecting crop water use, and shifting to salt-tolerant cropsshould be considered during drought periods. Maas and Hoffman (1977) and Maas (1986) characterized plant salt tolerance based on the loss of yield as a function of increased salinity in the root zone. Lysimeter and field studies have indicated that this salinity tolerance is, in practice, not a static value and that crops tend to become more salt tolerant as they mature, suggesting that the Mass- Hoffman salinity threshold value can be used as a starting point for consideration of saline shallow groundwater us.

A wide range of crops has been successfully grown that obtained a significant portion of the crop water requirement from shallow groundwater. The types of crops range from truck crops (peppers and carrots) to grain, hay, and some tree crops (e.g., date palms) that have salt tolerances from sensitive (lettuce) to tolerant (cotton). However, the majority of the crops that used shallow ground water are deep rooted and moderately salt tolerant or aresalt-tolerant crops based on the Maas-Hoffman (1977) salinity tolerance thresholds. Ayars et al. (2006) summarize, for crops that have successfully used significant amounts of shallow groundwater, the soils in which they were grown, the water table depths and salinity, and the irrigation management and associated climate conditions (e.g., average rainfall). Additional studies not included in the table in Ayars et al. (2006) that have similar results as those tabulated include those for sudangrass and alfalfa hay crops (Bali et al. 2001a and 2001b; Grismer and Bali 2001; Grismer et al. 2001), as well as corn (Kang et al. 2001), winter wheat (Kang et al. 2001; Karimov et al. 2014), safflower (Gharmarnia et al. 2011), and date palm trees (Zeineldin 2010).

As noted above, the total amount of shallow groundwater used by the crops varies widely, depending on the salinity of the groundwater in relation to the crop salinity tolerance, the irrigation and drainage system management, the irrigation water quality, the soil type, and the water table depth. Crops drawing in excess of 50% of the crop water requirement from shallow groundwater had reasonable groundwater salinity (4 to 6 dS/m) relative to the crop salt tolerance, were deeper rooted, and were subject to low irrigation frequency of less than once per week. The fraction of shallow groundwater used by the crop decreases dramatically as the soil and shallow groundwater salinity increases, though the crop can still draw shallow groundwater at three to four times the threshold salinity.

The length of the crop growing season can significantly impact the crop water use of shallow groundwater: the longer the growing season, the greater the potential water use from shallow groundwater. Perennial crops with deeper root systems, or longer-growing annual crops that develop such root systems, have a greater opportunity to extract shallow groundwater when the plants are mature and more salt tolerant. For annual crops, the majority of the crop water use of shallow groundwater occurs between the last irrigation and crop harvest, when the root zone is at maximum development and the plant is most salt tolerant.

Effect of salinity onshallow water table utilization

It has been well established that salt stress adversely affectedtheprocess ofseedgermination inplants (Pariharet al.2015). Saltstress negatively affected the plant growth, nutrient uptake, andyield (Azeem et al. 2015; Hussain et al. 2015; Rehman et al. 2016). Similarly, salt stress caused oxidative stress in plant andcaused the reduction in antioxidant enzyme activities (Khaliq et al. 2015; Mohamed et al. 2017). Salinity reduces crop growthby affecting multiple processes which are either dependent orindependent of salt accumulation in shoots (Roy et al. 2014; Rehman et al. 2016; Mohamed et al. 2017). The independentprocesses reduce shoot biomass predominately by closing stomataand inhibiting leaf expansion. Depending on the intensityand duration of salt exposure, shoot biomass is further reduceddue to premature leaf senescence on the accumulation of salts inleaves to toxic levels. Plant initial responses to salt stress aregenerally the reduction in leafexpansion and partial/full closureofstomata toconservewater resource(Tardieu al.2014). Theseresponses are coordinated by an increased accumulation of stresshormones, particularly abscisic acid (ABA). An increased levelof ABA in xylem stream is an indication of plant roots facingosmotic stress. Drought and salt stress at reproductive growthstage affect the grain setting and grain fillingwhich reduce grainyields.Reduction in crop yields under stress conditions are associatedwith the disruptions in carbon metabolism and transport (Muller et al. 2011).

Total Dissolve sold and sodium Adsorption Ratio (SAR) is the most important factors for irrigation quality evaluation. The constituent that can degrade water quality for irrigation include salts, nutrients and contaminants. Four categories of potential irrigation problems associated with water quality are salinity, permeability, ion toxicity and several other miscellaneous problems (EPB, 2004).A salinity problem exists when salt accumulated in the crop root zone to a concentration that causes a loss in yield. Salinity increases with depth and is greatest in lower part of root zone. As water salinity increase, greater care must be taken to leach salt out of root zone before their accumulation reaches a concentration which might affect yield.There are two common water quality assessments that characterize the salinity of irrigation water. The salinity of irrigation water is sometimes reported as the total salt concentration or total dissolved solids (TDS). The unit of total dissolved solids is usually expressed in milligram per liter (mg/L) of water. This term is still used by commercial analytical laboratories and represents the total number of milligram of salt that would remain after 1 liter of water is evaporated to dryness. Total dissolved solids is also often reported as part per million (ppm) and is the same numerically as mg/L. The other measure that is documented in water quality reports is called electrical conductivity (EC). Electrical conductivity is a much more useful measurement than total dissolved solids because it can be made instantaneously and easily by irrigators and/ or managers in the field. Salts that are dissolved in water conduct electricity and, therefore, the salt content in the water is directly related to the electrical conductivity. The electrical conductivity can be reported based on the irrigation water source (ECw) or on the saturated soil extract (ECe). Units of electrical conductivity reported by laboratories are usually in millmhos per centimeter (mmhos/cm) or decisimens per meter (ds/m). One mmhos/cm equal 1 ds/m. Electrical conductivity is also reported in micromhos per centimeter (µmhos/ cm). 1 µmhos equal 0.001mmhos.

Effect of Residual sodium carbonate on plant

Water containing carbonate-bicarbonate exceeds the calcium magnesium; result in increasing Na hazard, (Eaton, 1949). Eaton (1949) reported that: increasing the amount of residual sodium carbonate in irrigation water would accelerate the development of sodic soils. (Wilcox et al.(1954) stated that, water containing less than 1.25 me/l of residual sodium carbonate can be used safely, and those contain more than 2.4 me/l are not suitable for irrigation, and those containing between 1.25 and 2.25 me/L are marginal.

Effect of Electrical conductivity on plant growth

The most influential water quality guideline on crop productivity is the water salinity hazard as measured by electrical conductivity (ECw). The primary effect of high ECw on crop productivity is the inability of the plant to compete with ions in the soil solution for water (physiological drought) (Maas and Hoffman 1977). The usable water by plant in the soil solution decreases with increase of electrical conductivity. Maas, (1984) indicated that plant growth rate decreases linearly as salinity increases above a critical threshold

Impact of high Sodium adsorption ratio

Richards (1954) reported that where concentrations of cations are expressed in mmole\L, the alkali hazard involved in the use of water for irrigation is determined by the absolute and relative concentrations of the cations. When the sodium concentration is high, the alkali hazard is increasing and conversely, when the calcium and magnesium predominate, the hazard is low.Hamid and Mustafa (1975) stated that; the quality of irrigation water is adversely affected by high sodium concentration, because sodium adsorbed onto the soil cation exchange sites, disperses the soil aggregates, reduce the macro-pores of the soil and hydraulic conductivity. Infiltration problem related to water quality, which occurs when the normal infiltration rate is appreciably reduced and water remains on the soil surface for long time infiltrates too slowly to supply the crop with efficient water to maintain acceptable yield. The serious side effect of an infiltration problems are crusting of seed bed, excessive weeds, nutritional disorders and water logging of the crop, rottening of seeds and poor crops stands in low – laying wet spot, as well as the potential , to develop disease and vector problems.Infiltrations problems in most cases occurs in few centimeters of soil and linked to the structural stability of this surface soil and its low calcium content relative to that sodium. High sodium ions in water affects the permeability of soil and causes infiltration problems this because sodium when present in the soil in exchangeable form replaces calcium and magnesium adsorbed on the clays soil and cause dispersion of soil particles. The presence of carbonate and bicarbonate in water causes the precipitation of calcium and magnesium and increases the relative concentration of sodium which increases the SAR index (Ayers and Wescot, 1989).

Impact of high concentration of someiions

Toxicity problem occurs if a certain constituent (ion) in the soil or water taken up by the plant, and accumulates to concentrations high enough to cause crop damage or reduced yields. (Ayres and Westcot 1989). Irrigation water that contains certain ions at concentration above threshold values can cause plant toxicity problems. Toxicity normally results in impaired growth, reduced yield. The degree of damage depends on the crop, stage of growth, the concentration of toxic ion, climate and soil conditions (Pescod, 1992). The usual toxic ions in irrigation water are chloride, sodium and boron. Damage can be caused by each individuality or in combination. These ions can also be absorbed directly into the plant through the leaves moisture during sprinkler irrigation. This occurs typically during periods of high temperature and low humidity (Ayers and Wescot, 1989). The severity of toxicity problem will increase as the crop withdraws soil –water and soil dries between irrigation. The ions become concentrated in a similar volume of soil water. Toxicity often accompanies or complicates a salinity or infiltration problems although in many appear even when salinity is low (Ayers and Wescot, 1989).Some vegetable and row crops are sensitive to boron. Generally, leaf injury must be severe to cause reduced yields and crop quality. Long term use of irrigation water containing more than 0.5ppm boron can reduce the yields of bean, onion, garlic, and strawberry; 0.7 ppm can reduce the yield of broccoli, carrot, potato, and lettuce; and concentrations greater than 2 ppm can reduce yields of cabbage cauliflower.

Under cool, moist climatic conditions, greater levels of boron can be tolerated, and for short-term use, boron can be doubled. In addition, soil properties influence the time it takes for injury to occur. In the finer soil texture, occurrence of injury takes time to appear. Unlike most annual crops, tree and vine crops are generally sensitive to boron, chloride and sodium toxicity, tolerates vary among varieties and rootstocks, (FAO, 1976).Tolerant varieties and rootstocks resist the uptake and accumulation of toxic ions in the stem and leaf tissue. Continued used of irrigation water with boron concentration in excess of 0.75 ppm can reduce the yield of grapes and many deciduous tree and fruit crops. This represents a threshold concentration and does not imply that irrigation water with boron at or slightly above this level cannot be used successfully.

Chloride is a common ion in irrigation waters. Although chloride is essential to plants in very low amounts, it can cause toxicity to sensitive crops at high concentrations. Like sodium, high chloride concentrations cause more problems when applied with sprinkler irrigation. Leaf burn under sprinkler from both sodium and chloride can be reduced by night time irrigation or application on cool, cloudy days. Drop nozzles and drag hoses are also recommended when applying any saline irrigation water through a sprinkler system to avoid direct contact with leaf surfaces. Chloride moves readily with soil water which taken up by the roots, It is then transported to the stems and leaves. Sensitive berries and avocado rootstocks can tolerate only up to 120 ppm of chloride, while grapes can tolerates up to 700 ppm or more. The ability of a tree to tolerate sodium varies considerably. Sodium injury on avocado, citrus, and stone-fruit trees has been reported at concentration as low as 115 ppm, (Mass 1990).

The sulfate ion is a major contributor to salinity in many of irrigation waters. However, toxicity is rarely a problem, except at very high concentrations where high sulfate may interfere with uptake of other nutrients. As with boron, sulfate in irrigation water has fertility benefits. Exceptions are sandy fields with <1 percent organic matter and <10 ppm SO_4-S in irrigation water (Maas, 1990).Several other problems related to irrigation water quality occur with sufficient frequency for nitrogen, abnormal pH and magnesium problem. Nitrogen in irrigation water has much the same effect as nitrogen fertilizer applied to soil in excessive quantities, will lead to over stimulation of growth, delayed maturity or poor quantity (Ayers and Wescot, 1989).pH is seldom a problem by itself. The normal pH range for irrigation water is from 6.5 to 8.4; irrigation water with pH outside the normal range may cause a nutritional imbalance or may contain a toxic ion. Lime is commonly applied to the soil to correct a low pH and sulfur or other acid material may be used to correct a high pH (Ayers and Wescot, 1989). Irrigation water containing a high proportion of slitly soluble salt such as calcium, bicarbonate and sulfate presents a continual problem of white formation of leaves or fruit when sprinkler are used. Soil containing high levels of exchangeable magnesium is often thought to be troubled, with soil infiltration problems. Also, productivity reported to be low on high magnesium soil or on soils being irrigated with high magnesium water (Ayers and Wescot, 1989). High pH's are often caused by high bicarbonate (HCO3) and carbonate (CO3) concentrations, known as alkalinity. High carbonates cause calcium and magnesium ions to form insoluble minerals leaving sodium as the dominant ion in solution (Maas, 1990).

Mitigation of salinity using biochar soil amendments

The application of biochar has been shown to be effective inreducing salinity stress by improving soil physicochemicaland biological properties directly related to Na removal suchas Na leaching, Na adsorption ratio, and EC (e.g., Chaganti et al. 2015; Diacono and Montemurro, 2015; Oo et al. 2015; Drake et al. 2016; Sun et al. 2016). Biochar could improve thesoil physicochemical and biological properties under conditionsof abiotic stresses (Rizwan et al. 2016b). Lu et al. (2015a, b) reported that biochar poultry-manure compost (BPC) with pyroligneous solution (PS) in the saline soil increasedmicrobial biomass carbon and the activities of unease,invertase, and phosphatase in bulk soils and rhizosphere soilsunder maize cultivation. Similarly, Bhaduri et al. (2016) concludedthat the effects of biochar on soil enzyme activities insaline soil vary with biochar rate applied incubation time, andsoil enzyme types. Studies have also shown that the applicationof organic amendments improved the physicochemicalproperties of saline soil (Wang et al. 2014a, b). However, littledata is available on the effect of biochar on the saline soilproperties (Thomas et al. 2013; Wu et al. 2014; Almaroai et al. 2014). The biochar application in salt-stressed soil,30 g m^{-2}, did not affect the soil pH, but increased the soilEC as compared to the control (Thomas et al. 2013).Similarly, furfural biochar in saline soil decreased pH, whileincreasing the SOC and CEC and available P in the soil (Wu et al. 2014). When applied in saline soils, composted biocharincreased the soil organic matter content and CEC and decreasedthe exchangeable Na and soil pH (Luo et al. 2017).These studies showed that biochar addition in saline soilscould improve the plant growth by improving the soil biologicalactivity and physicochemical properties.

A notable number of studies reported that biochar decreasedsalt stress in plants by lower production of phytohormones (Akhtar et al. 2015a; Lashari et al. 2015). Combined BPCand PS applications in the saline soil under field conditionsdecreased the maize leaf sap ABA (Lashari et al. 2015). Inanother study, biochar decreased ABA concentrations in leafand xylem sap of salt-stressed potato (Akhtar et al. 2015a).Biochar in combination with endophytic bacteria also decreasedthe xylem ABA contents in wheat and maize undersaline conditions as compared to the unamended controls (Akhtar et al. 2015b, 2015c).

The biochar-mediated improvement in plant growth undersalt stress is often correlated with an increase in stomatal conductance.Many recent studies have shown that biochar applicationto saline soils improved the stomatal density and stomatalconductance in wheat, tomato, and herbaceous plants (Thomas et al. 2013; Akhtar et al. 2015b, 2015c). Improvedsoil properties, increased soil moisture, and Na binding inbiochar-amended soils decrease the root sensitivity to osmoticstress (Akhtar et al. 2015c). Roots then decrease the productionof ABA, and in response, stomatal conductance and leafgrowth are increased.Salinity is known to cause oxidative stress in plants by excessiveproduction of reactive oxygen species (Parihar et al. 2015;Fazal and Bano 2016; Farhangi-Abriz and Torabian2017). Organic amendments have been shown to alleviate saltstress in plants by regulating the synthesis of antioxidant enzymesin plants (Tartoura et al. 2014). However, a few studiesreported the effects of biochar on the oxidative stress and antioxidant enzyme activities in plants grown in saline soils.For example, the biochar application decreased the ascorbateperoxidase (APX) and glutathione reductase (GR) activities inmaize under salt stress as compared to the control (Kim et al2016).Lashari et al. (2015) reported that poultry manure compostplus diluted pyroligneous solution application decreasedthe malondialdehyde (MDA) contents in maize leaf sap. It hasrecently been reported that biochar reduced antioxidant enzymeactivities and oxidative stress in bean seedlings undersalt stress compared to the control (Farhangi-Abriz and Torabian 2017). These studies suggested that biochar couldimprove plant growth and biomass under salt stress by reducingoxidative stress and enhancing the activities of antioxidantenzymes.

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Reduction in Na ion toxicity in plants

The application of biochar significantly decreased Na+ concentrationsin the xylem sap of potato, while increasing K+concentrations and Na+/K+ ratio in the xylem sap as comparedto the control (Lashari et al. 2015; Akhtar et al. 2015a).Similarly, biochar decreased Na uptake by lettuce under saltstress (Hammer et al. 2015). In another study, it decreased Nauptake and increased K uptake in salt-stressed maize (Kim et al. 2016). In a field study, biochar increased maize leafsap K, P, and N and decreased Na as well as Na/K ratio (Lashari et al. 2015). The biochar application in a Cdcontaminatedsaline soil decreased Na and increased K concentrationsin wheat seedlings (Abbas et al. 2017b).

The beneficialeffect of biochar on ion-homeostasis under saline stresscould be further enhanced by co-application of biochar withendophytic bacteria (Akhtar et al. 2015b, 2015c). These studiesshowed that biochar might be effective in reducing Na+uptake by plants grown in saline soils.
Studies have shown that biochar application in saline soilsmay enhance plant tolerance to salt stress by enhancing theuptake and accumulation of mineral nutrients in plants. Forexample, the biochar and AM application increased the P andMn concentrations in lettuce plants under salt stress (Hammer et al. 2015). Biochar application increased the P concentrationin maize tissues under salt stress in a dose-dependent manner (Kim et al. 2016). In another study, biochar increased P, K, Fe,Mn, Zn, and Cu in tomato plants with saline irrigation ascompared to the nonsaline irrigation (Usman et al. 2016).However, the combined application of wheat straw-derivedbiochar and P increased the

phosphate precipitation/sorptionin the saline sodic soil and decreased P concentrations inplants (Xu et al. 2016). These studies showed that biocharapplication may increase the mineral uptake by plants undersaline conditions. However, further detailed studies are neededto evaluate the mechanisms of biochar-mediated mineraluptake by plants under saline conditions both at the soil andplant levels.

Conclusion

Shallow groundwater is a potentially valuable source of additional water supply to meet crop water requirements, especially during drought; however, developing this resource is site specific and requires an assessment of the projected cropping system, the soil and water resources, and the irrigation and drainage management available. Use of shallow groundwater will be limited by the water source supplying the groundwater and the associated salinity management of the soil profile. Shallow groundwater is likely a possible resource for a few years, but it is not likely to be sustainable over the much longer term unless the source of good-quality shallow groundwater is also sustainable over the longer term.Application of biochar, carbon-rich materialdeveloped from combustion of biomass under no orlimited oxygen supply, ameliorates the negative effects ofdrought and salt stress on plants. The biochar application increasedthe plant growth, biomass, and yield under eitherdrought and/or salt stress and also increased photosynthesis,nutrient uptake, and modified gas exchange characteristics indrought and salt-stressed plants. Under drought stress, biocharincreased the water holding capacity of soil and improved thephysical and biological properties of soils. Under salt stress,biochar decreased Na+ uptake, while increased K+ uptake byplants. Biochar-mediated increase in salt tolerance of plants isprimarily associated with improvement in soil properties, thusincreasing plant water status, reduction of Na+ uptake, increasinguptake of minerals, and regulation of stomatal conductanceand phytohormones.

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