© by PSP Volume 30– No. 11A/2021 pages 12241-12249 Fresenius Environmental Bulletin

SUPER ABSORBENT POLYMER APPLICATION IMPROVES PLANT GROWTH IN SALINE SOILS OVERVIEW AND CHALLENGES

Muhammad Adnan Tabassum[1], Guanglong Zhu[1], Guisheng Zhou[1], Li Song[1,*]
Muhammad Amjad Bashir[2], Mohamed Hashem[3,4], Saad Alamri[3], Manal A El-Zohri[4]

[1]Joint International Research Laboratory of Agriculture and Agri-Product Safety, The Ministry of Education of China, Institutes of Agricultural Science and Technology Development, Yangzhou University, Yangzhou, Jiangsu, China
[2]Department of Plant Protection faculty of Agricultural Sciences, Ghazi University Dera Ghazi Khan Punjab, Pakistan
[3]King Khalid University, College of Science, Department of Biology, Abha 61413, Saudi Arabia
[4]Assiut University, Faculty of Science, Botany and Microbiology Department, Assiut, 71516, Egypt

ABSTRACT

Soil salinity and water scarcity has been recognized as an emerging threat towards food security globally. Since the beginning of the 21st century, it is projected that the salinity poses detrimental effects on the arable lands. It affects around 60 Mha or 20% of the total farmlands that accounts for more than 6% of the total cultivated area worldwide. This leads to the accumulation of various kinds of soluble salts (NaCl, KCl, $MgCl_2$, and Na_2SO_4) in productive soils probably because of lack of good quality irrigation water. Altogether, salinity arises osmotic stress, ion toxicities, and water deficit in the root zone of saline soils which poses severe risks to crop growth and productivity. Several conventional methods (e.g., excavation, flushing, and addition of organic and inorganic amendments) have been used to reclaim salt-affected soils hence, disturbing the agro-ecosystems. Therefore, to address these risks, a novel approach using super absorbent polymers (SAPs) has been adopted for soil restoration. These SAPs have the potential to absorb water up to 500 times of its size as well as store water and dissolve nutrients in it so that plants can use them accordingly. In the agriculture sector, SAP water crystals acts as a water reservoir for plants during the water shortage period. These SAPs can retain in the soil for one year and reduce osmotic stress by enhancing soil water holding capacity. Moreover, the addition of SAPs in the saline soil improves soil health by reducing soil bulk density and various other plant growth variables such as nutrients uptake and leaf pigments however, it enhances C assimilation in early crop growth, thereby decreasing antioxidant activity and EC of saline soils. It is necessary to carry out field research on a large-scale using Sap in different soil types in order to standardize the quality and quantity of different soils. Overall, the use of SAPs can be adopted as a possible novel approach to cope with the increasing salinity problems that directly affetcs the global food security.

KEYWORDS:
Super absorbent polymer, Saline soils, Osmotic potential, Electrical conductivity, Plant growth and development

INTRODUCTION

The establishment of new agricultural technologies is questionable for how to improve the growth and yield of edible crops in order to overcome the requirement of increasing population. Recently, the report on global agriculture production estimated that the current growth rate of agricultural commodities is not sufficient to fulfill the needs of 10 billion people in 2050 [1]. In light of this report, it is important to mention the basic limitations in the agriculture sector especially in arid areas such as shortage of water, degradation of productive soils due to erosion and salinization. Besides this, several abiotic factors including irregular use of fertilizers and pesticides, high temperature, soil pH, drought and salinity also have a contribution in declining crop production [2]. Above all, salinity is considered the major constraints for arable lands to produce healthy crops. Previous studies have explained the effects of salinity on plant growth and development with slight amendments to ameliorate this stress. This review will focus to highlight the application of super absorbent polymer in saline soils that could enhance plant growth including the challenges and future recommendations.

Saline soils and their distribution: The soil is considered to be salt-affected if total salt concentration, individual salt/mixture of salts in the soil reaches its highest limit to impede plant growth, damage plant tissues, and decline yields [3]. In addition, saline soil is a soil having 15% exchangeable sodium or electrical conductivity of saturation extract (EC_e) in the root zone above four dSm^{-1} (about 40 mM NaCl) at 25 ^{0}C is called saline soil (Munns, 2005; Jamil et al., 2011). Saline soils generally contains a diversity of cautions like sodium, calcium, magnesium and potassium as well as a variety of anions like chloride, sulfate, bicarbonate, and carbonate while occasionally borate and nitrate. Salt-affected soils have been classified into three categories: 1) soils having excess soluble salts are called saline soils2) soils having excess exchangeable sodium are called sodic soils and 3) soils having both excess soluble salts as well as excess exchangeable sodium are called saline-sodic soils. Therefore, based on the above facts the soil salinity is probably the key devastating environmental stress that reduces cultivated soil, crop yield and crop quality [4, 5].

Furthermore, soil salinization is a massive threat to irrigated agriculture, especially in arid and semi-arid regions. Around 20% of the total cultivated soils among which 33% of world irrigated areas are severely threatened by salinity which accounts one-third of the world's food requirement [6]. Salinization is increasing abruptly by 10% annually. Major sources of salinization includes the weathering of native rocks, high surface evaporation, low precipitation, irrigation with saline water and poor cultural practices It has been estimated that salinization would spread over 50% of the arable land by 2050 [7].

The salinization is increasing continuously in soils of hot and dry regions of the world, which reduces the production potential of the respective lands. Irrigation water used to grow crops in these areas and inadequate irrigation management resulted in secondary salinization that affects 20% of irrigated land worldwide [8]. Secondary salinization of water as well as soil resources is common in arid and semiarid areas. Recently, excessive use of fertilizers in agricultural production to feed the massive population imposes the induction of salts in the productive lands which might hinder plant growth due to the osmotic effects. Apart from this, presence of salts in irrigation water may also enhance the chances of salinity in productive lands [9]. Presence of salts in soils as an ionic form during weathering of mineral poses harmful impact on the vegetative growth of plants additionally, ions can be transported from irrigation water or fertilizers or occasionally come out in soil profile from shallow groundwater also impose osmotic stress [10].

Soil is considered as a sink of essential nutrients and harmful ions, which are easily taken up by plants to fulfill their needs throughout their life cycle. Excessive accumulation of soluble salts instead of essential nutrients may have the ability to induce morpho-physiological disorders in plants. Moreover, severe disturbance in soil physical, chemical, and biological properties might result in serious consequences in terms of natural resources, e.g. compaction, inorganic/organic contamination, and diminished microbial activity/diversity [11].

Osmotic stress in saline soil affects optimum growth and development: Saline soils poses threats to plants in various ways. One of the possible outcomes is water scarcity in the rhizosphere that leads to osmotic stress. The higher contents of salts effectively reduce water potential and hinder water absorption through roots. Along with the osmotic stress, some plants species have also been affected by specific ions especially Na and Cl ions. Saline soils are recognized because of its higher electrical conductivity (4 dS m sodium percentage (154 dS m^{-1}), respectively.

Additionally, the increasing soluble salt concentrations in soil solutions up to 40 mM NaCl can create osmotic pressure (-0.2 MPa) and decrease soil water energy gradients, which hinders the water movement through root membranes into plant tissues. The water uptake rate gradually slows down because of excessive soluble salts in soils through several mechanisms including diffusion, mass flow and root interception within the plant's cell. Such kind of salt induced osmotic stress encountered at root membrane poses drastic effects on the internal cell membranes of the plants [12, 13]. [14] Suggested that the osmotic potential (Ψ_O) of the solution in the growing media was considered as a suitable candidate to examine the whole-plant response to salinity in terms of ions concentration. On the other hand, [15] briefly explained the significant importance of water potential to judge the salinity and drought stress on the soil-plant ecosystem. Besides this, they have suggested that total soil water potential ($\Psi_{w\text{-soil}}$) is a summation of Ψ_O and matric potential (Ψ_m) (Equation. 1). At the same time, presence of soluble salts in irrigation water is also the key factor that may have potential to decreases Ψ_O and Ψ_w of soil [16]. It is noticed that soil Ψ_O play a vital role to influence the total soil water potential ($\Psi_{w\text{-soil}}$). [17] reported that Ψ_O, as well as $\Psi_{w\text{-soil}}$, declined linearly with the prominent increment in EC of irrigation water whereas the composition of salts in irrigation water has no significant effect on $\Psi_{w\text{-soil}}$.

$$\Psi_{w\text{-soil}} = \Psi_{O\text{-soil}} + \Psi_{m\text{-soil}} \qquad \text{(Equation 1)}$$

Where $\Psi_{w\text{-soil}}$ refers to the total water potential of soil, $\Psi_{O\text{-soil}}$ as the osmotic potential of soil and $\Psi_{m\text{-soil}}$ as the matric potential of soil. The osmotic stress has a flow-on-effect that causes reduction in the cell expansion rate of growing tissues and minimize the size of leaf stomatal apertures via internal signals, which effectively influence CO_2 stomatal conductance that leads to reduced photosynthesis. Such a depression in photosynthesis negatively affects the leaf area formation that reduces translocation towards meristematic as well as growing leaves and root tissues. On the whole, it is concluded that the significant increment in EC can lower the soil osmotic potential that reduced soil water potentialin which hinders the water movement from soil to plant under saline conditions.

Maintaining lower Ψw-plant than Ψw-soil as main regulatory mechanism to keep the normal

growth: Plants are facing salinity problems that should be addressed in order to adjust their water potential by decreasing their leaf/plant osmotic potential. It can be achieved by absorbing water and nutrients from saline soilsthat may lead to lower the soil osmotic potential against the normal soils. It is necessary to maintain the energy gradients between soil and plant water potentials ashe accumulation of a higher quantity of organic or inorganic solutes in salt-tolerant plants under saline conditions can consider osmotic adjustments. There are 3 key possibilities available for osmotic adjustments of plants: (i) Organic osmolytes/compatible solutes accumulation from the external environment; (ii) Denovo synthesis of organic/compatible solutes and (iii) Inorganic osmolytes like Na^+, Cl^- and K^+ accumulation in plant cell vacuoles [18-20].

The prominent variation was observed between the two types of plants 1) very sensitive "glycophytes" and 2) less/non-sensitive "halophytes" with reference to adjustments in saline media. Glycophytes showed the effects of salinity at the concentration of less than 50 mol m^{-3}salt, while halophytes showed effects at 500 mol m^{-3} salt [21]. The *Suaeda maritime* L. is a halophyte that showed optimum growth at around 200 mol $m^{-3,}$ and it can tolerate up to 1000 mol m^{-3} salinity levels [22]. Unfortunately, the major field crops are non-halophytic universally, like bean yield is suppressed almost completely at 50 mol m^{-3} [23]. The plants can synthesize organic solutes or accumulate inorganic components to make osmotic adjustments under salinity stress. Moreover, plants used extra energy in osmotic adjustments rather than using for growth that leads to a reduction in plant growth and ultimately yield. The reduction in the water contents occurs due to the accumulation of higher salt concentration in saline soils to keep root/plant water potential lower than external growth medium [24]. Thus, learning from the osmotic adjustment in plants, it was hypothesized that the soil water potential can be kept higher by keeping the osmotic potential higher and adding the super absorbent polymers (SAPs) in saline soils to maintain water potential gradients between soil and plants. Figure 1 shows the pictorial view of this key amendment.

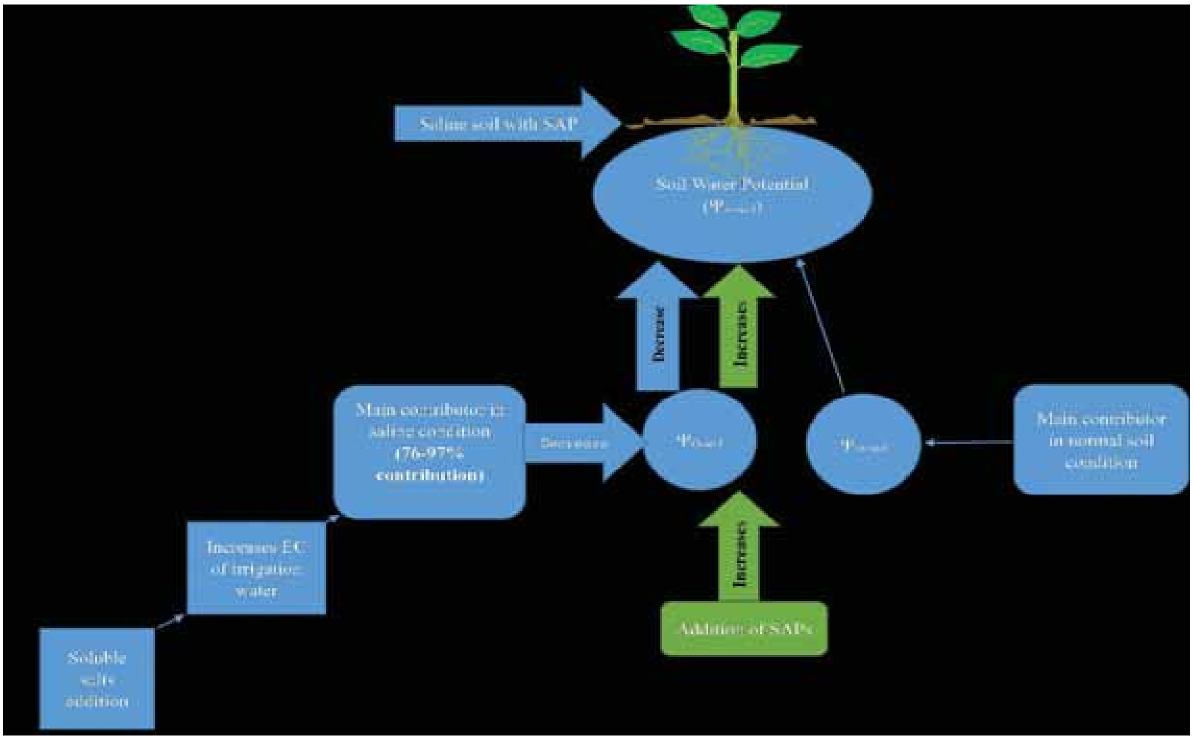

FIGURE 1
Soil water potential mainly consists of 2 components, soil osmotic potential ($\Psi_{O\text{-soil}}$) and soil matric potential ($\Psi_{m\text{-soil}}$).

The $\Psi_{m\text{-soil}}$ is main contributor under normal condition while, $\Psi_{O\text{-soil}}$ is main contributor under saline condition. Addition of soluble salts increases the EC of soil solution, and in saline soils, the contribution of $\Psi_{O\text{-soil}}$ is considered about 76-97% depending upon the salinity level [25]. On the other fk-q hand, addition of super absorbent polymer (SAP) increases the soil osmotic potential as well as soil water potential that maintain energy gradient between soil and plant for water uptake.

WHETHER OSMOTIC STRESS CAN BE REDUCED BY INCREASING SOIL WATER HOLDING CAPACITY THROUGH SAP INCORPORATION IN SALINE SOILS OR NOT?

Abiotic stress especially, salinity stress impose severe threats to natural agro-ecosystem. Thus, urgent measures need to be taken to develop salt resistance varieties and possible inventive agronomic approaches to protect the further degradation of productive farmlands. There are hydrophilic polymers which are used in agriculture and are commonly made up of starch-polyacrylonitrile graft co-polymers (starch co-polymers: SCP), acrylamide sodium acrylate co-polymers (cross-linked polyacrylamides: PAM) and vinyl alcohol-acrylic acid copolymers (polyvinyl alcohols: PVA) [26]. Synthetic polymers such as PAM and PVA are generally used than natural polymers like SCP [27]. They were made in Japan during the mid-1970s as personal care and hygienic products (disposable diapers, surgical pads, sanitary napkins) and were firstly originated in the United States of America as water-retaining agents in agriculture. These are considered as a hydrophilic gell, present both in natural and artificial formations that have swelling and shrinking properties. They are used as artificial snow for skiing areas, soil conditioner or as artificial soil medium for hydroponics, as controlled releasing agents for pharmaceuticals or agrochemicals, and other numerous applications [28'29]. These can be used to enhance soil water holding capacity and known as powdered water. Powdered water is also known as rain/solid rain/hydrogels/super absorbent polymers (SAP) [30]. These polymers can be retained in the soil for one year and can absorb water up to 500 to 1000 times and even up to 1500 times of its size [31]. Ten-gram solid rain can absorb one liter of water by transforming it into gel-like solid/water crystals. It acts like a sponge and keeps the surrounding material damp but not wet [32, 33].

These water crystals absorb and store water as well as dissolve nutrients in it so that plants can use it when required. In the agriculture sector, these water crystals acts as a water reservoir for plants during water shortage period and did not compete with plants for moisture. Water crystals gradually drained water by transpiring plants. When soil is irrigated again, then water crystals will absorb water again and this process continues many times [34]. Super absorbents acts as cross linked hydrophilic polymers that were widely applied to preserve agricultural, horticultural, artificial snow, sanitary goods and drugs delivery [35]. Due to their greater molecular mass, they have the potential to absorb liquids solutions and water in large quantity. The SAP addition in sandy soil increased its water holding capacity against salty, clayey and loamy textured soils [36, 37]. They are widely used to improve soil physical properties including soil permeability, infiltration rate and water holding capacity that may reduce soil compaction and soil erosion and thereby improve soil water use efficiency. It also increased the water availability to plants for a long time under normal and restricted irrigation conditions[38] .

Furthermore, it was reported that the addition of SAP increased soil water holding capacity as well as available water to plants. SAP has the potential to maintain plants growth until plants started to die after 19 days during their growth in SAP amended soils while plants died within five days in those soils where SAP amendments have not been used [39,40] SAP has the ability to minimize the rate of evapotranspiration as well as minimize the chances of salts accumulation into plants tissues through roots and thereby improve nutrients status in the soils [41]. Drought sensitive plant *Petunia parviflora* (petunia) responded well to SAP under water deficit environment and increased flower numbers as well as dry matter accumulation [42]. Apart from this, lettuce (*Lactuca sativai*), radish (*Rhaphanus sativa*), and wheat (*Triticum aestivum*) showed an increase in wilting time and dry matter accumulation under water deficit conditions than SAP treated environment [43,44]. Therefore, considering the suitable solution to the salinity stress, SAP can be used as super water-absorbent to improve plant growth and development.

SAP ADDITION IMPROVES PLANT GROWTH UNDER SALINITY STRESS

It has been observed that the addition of super-absorbent acrylate polymers (SAPs) in dry lands areas can enhance water usage [45]. Recently, use of SAPs is considered as an innovative approach that has been endorsed by farmers to improve soil moisture content [46], minimize soil water loss and promote crop yield across the globe [47] investigated that the efficiency of SAP "Stock absorb K 410" with dose levels 0, 0.5%, and 1.0% w/w along with various salt concentrations (0, 30, 60 and 120) reduced root and shoot biomass, chlorophyll content, nitrate content and as well as reduced macro-element uptake by bean (*Phaseolus vulgaris* L.) plant tissues. The different salt sources and doses drastically affected the studied parameters, while an ionic balance in soil solution might be essential for plant growth and salinity tolerance. Plant N, P, K, Ca, Mg, NO_3^-, total leaf chlorophyll content, and leaf area had a negative relation to salt concentrations. In contrast, proline content and electrolyte leakage had a positive relation to salt concentrations. Bean plants evolved complex mechanisms to adapt themselves against osmotic and ionic stress under high salinity. [48] reported that the incorporation of SAPs into salt-affected soils could prominently enhance maize yield by improving soil physical properties and water use efficiency in arid lands. A similar study was reported by [49] indicated that the use of SAP along with chemical fertilizer significantly improved plant dry biomass and yield along with promoting seed sprouting time of *Pinus pinaster*. [50] observed that the addition of SAP "Stockosorb K-400" at 0.4–0.6% in the salt-affected soils could promote *Conocarpus erectus* L. seed emergence by improving drought tolerance. Moreover, the SAP application effectively enhanced N and P uptake by plants and thereby reduced other harmful ions accumulation into plants tissues by reducing saline toxicity. [51] studied bean plant (*Phaseolus vulgaris*) to evaluate the efficiency of SAP on the key antioxidant enzymatic activity like superoxide dismutase (SOD), catalase (CAT) and peroxidase (POD), membrane permeability and salt tolerance index (STI) under saline conditions. They had used SAP at 3 levels (0, 0.05, and 0.1% w/w) along with four salinity concentrations of eight salt sources. Furthermore, they revealed that the SAP addition in saline soil improved the high salinity affected variables and decreased soil EC and electrolyte leakage enhanced salt tolerance index and declined SOD and POD enzyme activity. The results of this study projected that SAPs have great potential to reduce salinity stress on plant growth and growth parameters in saline soils under arid and semi-arid regions. A general model shows how SAP addition improves plant growth by holding more water per unit soil area (Figure 2).

The SAP effect under saline condition was evaluated on woody plant *Populus euphratica* growth and their relationship with specific ions. The SAP "Stockosorb K410" treated plants showed higher root surface area and root length than saline soil without SAP amendment. SAP amendment had cation exchange character, salt-buffering capacity and enriching Ca^{2+} uptake property, which improved the soil solution quality by reducing the salt level (lowering $\Psi_{o\text{-soil}}$). [52] explained the tolerance mechanisms of *Populus euphratica* where 6% of the total roots area was covered with SAP fragments that provide the best contact between roots and Ca^{2+} source however, this contact was reduced when sodium (Na^+) and chloride (Cl^-) ion availability was increased.

[53] incorporated sands with SAP to study the potential of SAP on maize (*Zea mays*) crop development under saline conditions. The seeds were germinated in sand/SASP mixture (80:20 v/v) with Hoagland nutrient solution. Later on, the seeds were transplanted after seven days of germination into a 90:10 v/v sand/SAP mixture in plastic bags. The five concentrations (0, 2000, 4000, 6000, and 8000 ppm) of three salts NaCl, $CaCl_2$, $MgCl_2$ solutions were applied to field capacity twice a week. The SAP incorporation with sand decreased salinity effects. The germination percentage, shoot height, root extension, shoot dry mass, root dry mass, shoot succulence, grain weight per pot, straw weight per pot, harvest index, chlorophyll a, chlorophyll b, carotenoids, and photosynthetic activity were increased under SAP treated sand than pure sands. The results revealed that the greater adaptation of maize under salinity stress might be due to the significant contributions of SAP in improving soil properties.

Dorraji et al. (2010) studied the different ratios of SAP (0, 0.2, 0.6% w/w) named as "Superb A200" under three salinity levels (initial salinity, 4 and 8 ms/cm) on available water content (AWC), water use efficiency, and plant dry mass of maize (Table 1). Maize crop was grown as a test plant in SAP amended loamy sand and sandy clay loam soils. The results revealed that the addition of SAP at 0.6% w/w prominently improved available water content by 2.2 and 1.2 times higher than the controlled loamy sand and sandy clay loam soils, respectively. The maximum quantities of studied traits were recorded in soils having the lowest salinity level. The SAP

FIGURE 2
The effects of salinity on plant growth and SAP addition in saline soil.
Initially, the growth was stunted under saline conditions (left side) while the addition of SAP increased plant growth (right side) relative to saline soil only. Also, the addition of SAP increased water holding capacity of saline soil that increased the soil osmotic and water potential to maintain an energy gradient between soil and plant for water uptake. In figure red circles indicate salt particles, light blue circles indicate water molecules while purple circles indicate super absorbent polymers (SAP).

TABLE 1
Effect of different rates of salinity and SAP application on maize crop biomass under sandy clay loam and sandy loam soils

Salinity ms/cm	SAP application amount (%)	Sandy clay loam		Sandy loam	
		Aerial biomass	Root biomass	Aerial biomass	Root biomass
Initial salinity	0	0.90cde	0.37bcd	0.45f	0.43d
Initial salinity	0.2	1.52a	0.70a	0.83b	0.58bc
Initial salinity	0.6	1.23b	0.47b	1.02a	0.84a
4 ms/cm	0	0.83ef	0.30cd	0.28g	0.38d
4 ms/cm	0.2	1.33b	0.44bc	0.73c	0.58bc
4 ms/cm	0.6	1.06c	0.44bc	0.65cd	0.77a
8 ms/cm	0	0.69f	0.27d	0.24g	0.36d
8 ms/cm	0.2	1.02cd	0.43bcd	0.49ef	0.56c
8 ms/cm	0.6	0.86def	0.33bcd	0.57de	0.67b
Standard deviation		0.06	0.05	0.03	0.03

This data was taken from Dorraji et al. (2010) to show the effect of SAP on maize biomass.

amendment at 0.6% and 0.2% w/w dose levels in sandy loam soil and sandy clay loam soil improved the highest aerial and root biomass as well as water use efficiency of corn. The current polymer application rates showed an increase of 2.6 and 1.7 times in water use efficiency than control, i.e. sandy loam and sandy clay loam soils, respectively. Thus, soil water holding capacity, crop production and water use efficiency of corn were increased with the use of SAP in soils generally and especially in sandy soils however, decreased the negative effects of salinity on the plant in arid and semi-arid areas.

MOUNTING CHALLENGES AND FUTURE PERSPECTIVES

Various countries are facing water shortage problems to meet their urban, environmental, and agricultural needs. The continuous increment in the population growth leads to water shortage, which is becoming an alarming situation for coming generationss [54,55] Therefore, it is difficult to use excessive freshwater to treat increasing salinity problem. In addition, another challenge is to feed more than 2 billion people in the next 50 years while maintaining the rising water needs [56,57] as well as the increasing saline area across the globe. So, it is difficult to leach down the soluble salts with freshwater irrigation and to use the SAPs with standing salinity which is one of the economic techniques to grow more crops to feed the increasing population with dwindling water supply. When sandy loam and clay loam soils were amended with different rates of SAPs, barley (*Hordeum vulgare* L.), wheat (*Triticum aestivum* L.) and chickpea (*Cicer arietinum* L.) plant species showed significant variations at their different growth stages. Furthermore, SAPs have more potential to absorb distilled water than the water having soluble salts. Thus, detailed studies are needed for the recommendations of specific SAPs according to various soil types, plant species and water with varying salinity levels [58].To date, most of the studies have been conducted in pots under controlled conditions. Based on this information, large-scale field studies should be conducted to prove the effects of SAPs on crops grown in different types of saline soils under diverse climatic conditions. More large-scale studies are also essential to determine rational quantity for different soil types, application depth and efficiency of SAP materials under natural field conditions, especially in arid and semi-arid regions in the world. Overall, It can be demonstrated that more studies are required to find the insight reasons of the said questions, whether the use of a super-absorbent polymer is beneficial for improving cash-crop yields and alters the socio-economic values of small scale farmers or not? Besides this, several workshops and seminars might be arranged in collaboration with public and private sector organizations in order to strengthen the research and development in both sectors. . It is also suggested to conduct several trials to analyse SAPs effects on soil health just to ensure the environment friendly and sustainable approach for arid and semi-arid regions.

CONCLUSIONS

Salinity is one of the major abiotic stresses and a great threat to irrigated agriculture. Soil osmotic potential depression diminishes water energy gradients and hinders water uptake by plants. The present study suggested that the superabsorbent polymers can improve soil properties that may have a great contribution to improve crop performance under drought and salinity stress. The prominent increase in water use efficiency and availability for the plant could explain the beneficial effects of SAP when incorporated into the salt-affected soils. The SAPs can hold water up to 1500 times of their size and they are used to enhance soil water holding capacity as well as available water to plants. The addition of SAPs in saline soils for different plant species revealed positive effects on plant development, growth, physiology, nutrient uptake and biochemical characteristics. Therefore, SAPs can be adopted as a soil amendment to increase water uptake of the crop in order to maintain crop yield and to cope with increasing salinity problems.

ABBREVIATIONS

SAPs, Super absorbent polymers; $\Psi_{\text{w-soil}}$,Total soil water potential; Ψ_{O} , Osmotic potential; Ψ_{m}, Matric potential

ACKNOWLEDGEMENTS

The authors extend their appreciation to the Deanship of Scientific Research, King Khalid University for funding this work through research groups program under grant number R.G.P. 2/101/41.

REFERENCES

[1] Abedi–Koupai, J., Asadkazemi, J. (2006) Effects of a hydrophilic polymer on the field performance of an ornamental plant (Cupressus arizonica) under reduced irrigation regimes. Iran Polym. J. 15(9), 715–725.

[2] Ahmad, P. (2014) Oxidative Damage to Plants, Antioxidant Networks and Signaling. Waltham, MA, Academic Press.

[3] Akhter, J., Mahmood, K., Malik, K., Mardan, A., Ahmad, M., Iqbal, M. (2004) Effects of hydrogel amendment on water storage of sandy loam and loam soils and seedling growth of barley, wheat and chickpea. Plant Soil Environ. 50, 463–469.

[4] Al–Humaid, A.I., Moftah, A.E. (2007) Effects of hydrophilic polymer on the survival of buttonwood seedlings grown under drought stress. J. Plant Nutr. 30(1), 53–66.

[5] Aly, S.M., Letey, J. (1989) The effect of two polymers and water qualities on dry cohesive strength of three soils. Soil Sci. Soc. Am. J. 53, 255–259.

[6] Aydin, A., Turan, M. (2008) Ameliorative effect of hydro gel substrate on growth, inorganic ions, proline, and nitrate contents of bean under salinity stress. J. Plant Nutr. 31(8), 1420–1439.

[7] Aydin, A., Canan, K., Turan, M. (2011) Hydrogel substrate alleviates salt stress with increase antioxidant enzymes activity of bean (Phaseolus vulgaris L.) under salinity stress. Afr. J. Agric. Res. 6, 715–724.

[8] Ben–Gal, A., Borochov–Neori, H., Yermiyahu, U., Shani, U. (2009) Is osmotic potential a more appropriate property than electrical conductivity for evaluating whole–plant response to salinity? Environ. Exp. Bot. 65, 232–237.

[9] Blaylock, A.D. (1994) Soil salinity, salt tolerance, and growth potential of horticultural and landscape plants. University of Wyoming, Cooperative Extension Service, Department of Plant, Soil, and Insect Sciences, College of Agriculture.

[10] Blodgett, J.G., Granbois, D.H., Walters, R.G. (1993) The effects of perceived justice on complainants' negative word–of–mouth behavior and repatronage intentions. J. Retail. 69, 399–428.

[11] Boatright, J.H., Borst, D.E., Peoples, J.W., Bruno, J., Edwards, C.L., Si, J.S., Nickerson, J.M. (1997) A major cis activator of the IRBP gene contains CRX–binding and Ret–1/PCE–I elements. Mol. Vis. 3, 15.

[12] Bouwer, H. (2002) Integrated water management for the 21st century, problems and solutions. J. Irrig. Drain. Eng. 128, 193–202.

[13] Buchholz, F., Graham, T. (1998) Modern superabsorbent polymer technology. Wiley–VCH, New York. Pages.

[14] Buchholz, F.L. (2002) Superabsorbent polymers. Encyclopedia of Polymer Science and Technology. Pages.

[15] Chen, S., Zommorodi, M., Fritz, E., Wang, S., Hüttermann, A. (2004) Hydrogel modified uptake of salt ions and calcium in Populus euphratica under saline conditions. Trees. 18, 175–183.

[16] Chen, X., Mao, X., Lu, Q., Liao, Z., He, Z. (2016) Characteristics and mechanisms of acrylate polymer damage to maize seedlings. Ecotoxicol. Environ. Saf. 129, 228–234.

[17] Clipson, N.J.W., Tomos, A.D., Flowers, T.J., Jones, R.G.W. (1985) Salt tolerance in the halophyte Suaeda maritima L. Dum, The maintenance of turgor pressure and water–potential gradients in plants growing at different salinities. Planta. 165, 392–396.

[18] David, C. (2007) Superabsorbent Polymers Chem 13 News. 6.

[19] De Melo, H.F., de Souza, E.R., de Almeida, B.G., Mulas, M. (2018) Water potential in soil and Atriplex nummularia (phytoremediator halophyte) under drought and salt stresses. Int. J. Phytoremediat. 20, 249–255.
[20] Dorraji, S.S., Golchin, A., Ahmadi, S. (2010) The effects of hydrophilic polymer and soil salinity on corn growth in sandy and loamy soils. Clean–Soil Air Water, 38, 584–591.
[21] Duarte, H.H.F., Souza, E.R.D. (2016) Soil Water Potentials and Capsicum annuum L. under Salinity. Rev. Bras. Ciênc. Solo. 40, e0150220.
[22] El Sayed, H.E.S.A. (2011) Influence of salinity stress on growth parameters, photosynthetic activity and cytological studies of Zea mays L. plant using hydrogel polymer. Agric. Biol. J. N. Am. 2, 907–920.
[23] GAP Report. (2018) Global Agricultural Productivity Report (GAP Report). Global Harvest Initiative,Washington. https://globalagriculturalproductivity.org/wp-content/uploads/2019/01/GHI_2018–GAP–Report_FINAL–10.03.pdf (Assessed April 15, 2019).
[24] Gordon, L.J., Steffen, W., Jönsson, B.F., Folke, C., Falkenmark, M., Johannessen, Å. (2005) Human modification of global water vapor flows from the land surface. Proc. Natl. Acad. Sci. 102(21), 7612–7617.
[25] Guilherme, M.R. (2015). Superabsorbent hydrogels based on polysaccharides for application in agriculture as soil conditioner and nutrient carrier: A review. Eur. Polym. J. 72, 365–385.
[26] Gupta, S., Deshpande, R.D. (2004) Water for India in 2050, first–order assessment of available options. Curr. Sci. 86(9), 1216–1224.
[27] Henderson, J., Hensley, D.L. (1986) Efficacy of a hydrophilic gel as a transplant aid. Hort. Sci. 21(4), 991–992.
[28] Hüttermann, A., Zommorodi, M., Reise, K. (1999) Addition of hydrogels to soil for prolonging the survival of Pinus halepensis seedlings subjected to drought. Soil Till. Res. 50, 295–304.
[29] Jamil, A., Riaz, S., Ashraf, M., Foolad, M.R. (2011) Gene expression profiling of plants under salt stress. Crit. Rev. Plant Sci. 30(5), 435–458.
[30] Johnson, M.S., Leah, R.T. (1990) Effects of superabsorbent polyacrylamides on efficiency of water use by crop seedlings. J. Sci. Food Agric. 52 (3), 431–434.
[31] Kumar, R. (2015) Evaluation of hydrogel on the performance of Rabi maize. Dissertation, Department of Agronomy, Bihar Agriculture University, Sabour.
[32] Liao, R., Yang, P., Wu, W., Ren, S. (2016) An inverse method to estimate the root water uptake source–sink term in soil water transport equation under the effect of superabsorbent polymer. PloS One. 11(8), e0159936.
[33] Li, X., He, J.Z., Hughes, J.M., Liu, Y.R., Zheng, Y.M. (2014) Effects of super–absorbent polymers on a soil–wheat (Triticum aestivum L.) system in the field. Appl. Soil Ecol. 73, 58–63.
[34] Liu, Z., Miao, Y., Wang, Z., Yin, G. (2009) Synthesis and characterization of a novel superabsorbent based on chemically modified pulverized wheat straw and acrylic acid. Carbohydr. Polym. 77(1), 131–135.
[35] Liu, R.F., Yang, H.S., Li, A., Wang, A.Q. (2006) Effects of polyacrylic ⁄ attapulgite superabsorbent composition on soil physical properties. China J. Soil. Sci. 37, 321–325. (in Chinese, with English abstract).
[36] Maas, E.V., Grieve, C.M. (1987) Sodium-induced calcium deficiency in salt-stressed corn. Plant Cell Environ. 10(7), 559–564.
[37] Mayak, S., Tirosh, T., Glick, B.R. (2004) Plant growth–promoting bacteria confer resistance in tomato plants to salt stress. Plant Physiol. Bioch. 42 (6), 565–572.
[38] Munns, R. (2005). Genes and salt tolerance, bringing them together. New Phytol. 167(3), 645–663.
[39] Munns, R., Sharp, R.E. (1993) Involvement of abscisic acid in controlling plant growth in soil of low water potential. Aust. J. Plant Physiol. 20(5), 425–437.
[40] Nori, J.M., Reddy, R.L. (2014) Powdered Water–A Compact Solution for Drought Stricken Farms. Int. J. Curr. Eng. Technol. 4(4), 2604–2607.
[41] Ogle, D., John, L.S. (2010) Plants for saline to sodic soil conditions. USDA Natural Resources Conservation Service Boise. Idaho Technical Note. 10150.
[42] Patel, B.B., Patel, B.B., Dave, R.S. (2011) Studies on infiltration of saline–alkali soils of several parts of Mehsana and Patan districts of north Gujarat. J. Appl. Technol. Environ. Sanitat. 1(1), 87–92.
[43] Peterson, D.L. (2002) Hydrophilic Polymers–Effect and Uses in the Landscape Restoration and Reclamation. Review J. Hortic. 75, 75.
[44] Postel, S.L., Daily, G.C., Ehrlich, P.R. (1996) Human appropriation of renewable fresh water. Science. 271, 785–788.
[45] Qiao, D., Liu, H., Yu, L., Bao, X., Simon, G.P., Petinakis, E., Chen, L. (2016) Preparation and characterization of slow–release fertilizer encapsulated by starch–based superabsorbent polymer. Carbohydr. Polym. 147, 146–154.
[46] Rütting, T., Aronsson, H., Delin, S. (2018) Efficient use of nitrogen in agriculture. Nutr. Cycl. Agroecosys. 110, 1–5.
[47] Shabala, S., Munns, R. (2012) Salinity stress, physiological constraints and adaptive mechanisms. In: Shabala S (ed) Plant stress physiology, 2nd edn. CABI Publishing. 24–64.

[48] Shabala, S., Shabala, L. (2011) Ion transport and osmotic adjustment in plants and bacteria. Biomol. Concepts. 2(5), 407–419.

[49] Shrivastava, P., Kumar, R. (2015) Soil salinity: a serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. Saudi J. Biol. Sci. 22(2), 123–131.

[50] Tabassum, M.A., Zhu, G., Hafeez, A., Wahid, M.A., Shaban, M., Li, Y. (2016) Influence of leaf vein density and thickness on hydraulic conductance and photosynthesis in rice (Oryza sativa L.) during water stress. Sci. Rep. 6, 36894.

[51] Ungar, I.A. (1991) Ecophysiology of vascular halophytes. CRC press, By I. A. Ungar. Boca Raton, Florida, CRC Press (1991). 108. ISBN 0–8493–6217–2.

[52] Yamaguchi, T., Blumwald, E. (2005) Developing salt–tolerant crop plants, challenges and opportunities. Trends Plant Sci. 10(12), 615–620.

[53] Zhang, X., Gu, P., Liu, Y. (2019) Decontamination of radioactive wastewater, State of the art and challenges forward. Chemosphere. 215, 543–553.

[54] Arif M, Atta S, Bashir MA, Khan MI, Hussain A, Shahjahan M. (2021) The impact of Fosetyl-Aluminium application timing on Karnal bunt suppression and economic returns of bread wheat (Triticum aestivum L.). PLoS ONE. 16(1), e0244931.

[55] Metwally, D.M.; Albasyouni, S.A.; Barakat, I.A.H.; Al-Turaiki, I.M.; Almuhanna, A.M.; Bashir, M.A.; Baghdadi, H.B.; ElKhadragy, M.F.; Alajmi, R.A. Prevalence Rate and Molecular Characteristics of Oestrus ovis L. (Diptera, Oestridae) in Sheep and Goats from Riyadh, Saudi Arabia. Animals. 2021(11), 689.

[56] Hasnain Farooq, M.A. Bashir , K.A. Khan, M. Arif Laosheng Wu Jiří Šimůnek I. Aziz , H. Al Gumrah, Milt M., Suilman Mohammad Alghanem. (2021). Interactive effects of saline water irrigation and nitrogen fertilization on tomato growth and yield. Fresen. Environ. Bull. 30(4), 3557-3564.

[57] Irum Aziz, A.A Khan A. Tabasum, M.A. Bashir, M. Batool K.A. Khan H. Farooq M. Warburtin and S.A Ghanem (2021). Estimation of genetic components and heterosis for nursery traits in tomato hybrids (Solanum esculentum, mill). Fresen. Environ. Bull. 30(4), 3371-3376.

[58] Saeed. S., M.A., Bashir, Khan. K.A., Sajjad. A., Alvi. A.M., Atta. S. and Ansar.J. (2019). Assemblage of pollinator communities in four widely isolated natural reserves of Southern Punjab, Pakistan. Saudi Journal of Biological Sciences. 26(4-May 2019), 860-865.

Received: **02.04.2021**
Accepted: **06.06.2021**

CORRESPONDING AUTHOR

Li Song
Joint International Research Laboratory of
Agriculture and Agri-Product Safety,
The Ministry of Education of China,
Institutes of Agricultural Science and Technology
Development, Yangzhou University,
Yangzhou Jiangsu – China

e-mail: songli@yzu.edu.cn