Advances in Agricultural Technology & Plant Sciences
ISSN: 2640-6586

Academic Strive
Researcher's perception is our reality

Review Article *Volume 1; Issue 2*

Harnessing the Potential of Superabsorbent Polymers for Alleviating Drought and Salt Stresses in Fruit Crops: a Brief Review

Arvind Kumar Verma[1] and Anshuman Singh[2]*

[1]ICAR-National Research Centre on Seed Spices, India

[2]ICAR-Central Soil Salinity Research Institute, India

***Corresponding author:** Anshuman Singh, ICAR-Central Soil Salinity Research Institute, Karnal, Haryana, India, Tel no: +91184-2209326, +91-8295068542; Email: Anshuman.Singh@icar.gov.in

Received Date: September 05, 2018; **Published Date:** October 10, 2018

Abstract

Most of the fruit crops are adversely affected by the osmotic stress arising due to poor water availability and/or excess salts in the root zone. In addition to water deficit, ion toxicities pose an additional risk to the crops grown in salt-affected soils. Even crops considered to be fairly drought and salt tolerant (*e.g*. olive) exhibit marked declines in growth and fruit yield upon prolonged exposure to these stresses. Climate change impacts are predicted to further accentuate drought and salt hazards in the foreseeable future. Although several biological and agronomic options have been suggested to improve plant tolerance to these stresses, there are constraints that hinder their widespread commercial applications. Of late, super absorbent polymers (hydrogels) are increasingly being tested to manage water and salt stresses in a number of field and horticultural crops. In this article, the potential of hydrogel use in alleviating drought and salt stresses in fruit crops is briefly reviewed.

Keywords: Drought stress; Hydrogels; Fruit crops; Salinity; Superabsorbent polymers; Water availability

Abbreviations: OH: Hydroxyl Radicals; SOM: Soil Organic Matter; WHC: Water Holding Capacity; ESP: Exchangeable Sodium Percentage: PG: Phosphor Gypsum; BD: Bulk Density

Introduction

Estimates suggest that ~3.5 billion ha of global land constituting ~30% of the total landmass suffers from various kinds of degradation [1]. Land degradation may either be caused by natural and/or anthropogenic factors. In areas where human interventions are absent or minimal, soil formation and degradation processes virtually remain in steady state over time. Human interference, however, disrupts the equilibrium by shifting the balance in the favour of degradation processes. Land clearing and irrigation development are the major anthropogenic factors accelerating secondary salinization in rainfed and irrigated areas, respectively. In certain cases, human-induced land degradation often attains critical levels such that restoration of soil productivity would not be possible without technological interventions [2]. Regardless of the causative factor, degraded lands are mostly deficient in soil organic matter (SOM) making them susceptible to further degradation by heavy rainfall and other factors. Reclamation of degraded lands is increasingly being seen as a viable option for bringing additional land under food production [1].

Drought is the most important environmental stress adversely affecting ecological balance, agricultural productivity and human well being in a myriad of ways across the globe. Although arid regions are relatively more sensitive, recurring droughts can have several negative impacts even in humid areas [3]. According to the Food and Agriculture Organization of the United Nations, drought has been the direct cause of over 11 million deaths since 1900. Again, about 2 billion people have faced extreme hardships due to direct and indirect consequences of drought. From an agricultural standpoint, drought can be defined as 'the period of insufficient soil moisture availability to a particular crop'. This period can vary from a few months to a year or even many years [4]. Repeated droughts accelerate land degradation and desertification. Climate warming is predicted to increase the extent of global drought affected area considerably with countries heavily dependent on rainfed agriculture likely to be hit hard. Between 2000 and 2008 alone, climate-related disasters including drought caused global annual economic loss of US$ 9.39 billion suggesting the need for measures to mitigate the drought risks [5].

Salinity is another severe constraint on crop production in many areas of the world. Although salt-affected soils are known to occur under virtually every climatic condition, irrigated lands in arid and semi-arid regions are particularly sensitive to salt-induced degradation. An estimate suggests that excess soluble salts and/or exchangeable sodium impair the productivity of over 1100 Million ha global land area to varying extents [6]. Climate change is predicted to have a profound adverse impact on crop production by altering the weather patterns and soil conditions. Specifically, drought and salinity risks are likely to multiply manifold suggesting the need for developing stress resilient cultivars and agronomic practices to maintain yields in a rapidly changing environment [7].

Constraints to Plant Growth in Drought- and Salt-Affected Soils

Drought and salinity stresses can affect fruit crops in multiple ways. Both the stresses create water deficit in the root zone giving rise to osmotic stress. While drought directly diminishes soil water availability, excess salts reduce soil water potential hindering water absorption by the plants. In addition to osmotic stress (*i.e.*, physiological drought), salinized plants also suffer from specific ion toxicities caused by Na^+ and Cl^-. A soil is considered to be 'salt-affected' when the saturation paste extract values of electrical conductivity (EC_e) or exchangeable sodium percentage (ESP) exceed the threshold values of 4.0 dS m^{-1} and 15.0, respectively. Under certain situations, both EC_e and ESP may be above these limits resulting in saline-sodic conditions.

Besides direct impact on crops, drought conditions also alter the properties and hydrological functions of soils including soil aggregate stability and water infiltration. It seems that during initial few days hormonal signals rather than osmotic or ionic stress play an important role in controlling plant growth under dry or saline conditions. This assumption stems from the fact that leaf growth remained suppressed even when shoot water status was maintained or increased in salt and water stressed plants [8]. While photosynthesis declines, photorespiration increases in plants facing low water availability or excess salts. This alters the normal homeostasis of cells resulting in increased production of reactive oxygen species (ROS) [9]. Increased accumulation of ROS like superoxide radical (O_2^-), hydrogen peroxide (H_2O_2), hydroxyl radicals (OH) and singlet oxygen ($^1O_2$) causes oxidative damage to cell lipids, proteins, nucleic acids and chlorophyll. In response, plants synthesize enzymatic (superoxide dismustase, peroxidase, catalase, glutathione reductase) and non-enzymatic (ascorbate and glutathione) antioxidant molecules to minimize the levels of such harmful ROS [10]. Although both drought and salinity affect photosynthetic assimilation in plants, either by reducing gaseous exchange through the stomata and mesophyll or by imposing ROS-mediated oxidative stress, salt stress can affect a large number of genes more intensely than drought [11]. While excess salts result in ion toxicities and mineral imbalances, reduced root zone water availability limits the uptake and transport of mineral ions from roots to shoots [12].

Of late, increased combined impacts of both drought and salinity stresses on cultivated lands across the globe imply that two events should no longer be viewed in isolation because co-existence of more than one stress can be more harmful. A particular crop or cultivar tolerant of salinity may not do well when both drought and salt stresses prevail together. For example, olive cv. 'Conservalia' showed tolerance to salinity (100 mM NaCl) but not to salinity plus drought treatment [13]. Again, crop cultivars also differ with each other in stress response. When subjected to PEG-induced drought, date palm cv. 'Nakhla Hamra' produced more aerial biomass and the longest main roots for enhanced water uptake. It also accumulated large amounts of proline for osmotic adjustment. In contrast, cultivar 'Tijib' showed similar adaptive traits under salinity stress [14].

Managing Drought and Salinity Risks

Given the fact that abiotic stresses, especially drought and salinity, are serious threats to natural resources and agricultural production, utmost attention is being paid to develop tolerant crops and agronomic solutions for minimizing the losses in crop production as well as to safeguard potentially arable lands from further degradation. In so far as crop improvement for drought and salt tolerance is concerned, past achievements have been limited as evidenced by rather slow progress in the commercial release of high yielding drought and salt hardy cultivars. Both drought and salinity tolerance are polygenic traits and the expression of traits governing water and salt stress responses is greatly influenced by environmental stimuli [15]. Poor understanding of morphological, physiological and genetic traits regulating stress response is a major barrier to the development of salt and drought tolerant plants. In woody perennial fruits, large tree size and prolonged juvenility are some additional constraints to genetic improvement in general and breeding for stress tolerance in particular [16]. In citrus, one of the most studied crops for understanding the physiological and genetic bases of salt tolerance, about 60 morphological and physiological traits are known to modulate the whole plant response to salinity [17]. Considering the slow progress in crop improvement, researchers are increasing tapping agronomic options for improving crop tolerance to drought and salinity stresses. It is worth mentioning, however, that most of the agronomic solutions suggested so far essentially revolve around the use of fresh water in soil reclamation and irrigation. Because fresh water itself has gradually become a scarce commodity, emphasis has increased on those practices that can simultaneously improve soil properties and water availability in drought and salt affected areas.

Improvements in Physico-Chemical Properties of Growing Media

Soil, the most common growing medium for field and garden crops, may not always be suitable for optimum production. A soil considered to be 'productive' for some crops can have certain limitations rendering it less suitable for other crops. This implies the need for either ameliorating the soil to rectify the potential deficiencies or to using alternative substrates for crop production [18]. Of the two strategies, the latter seems to be less appealing especially when a crop is to be grown over an extensive area. Although a substrate can hardly be an 'ideal', universally acceptable medium for all the crops, a best possible combination of available materials that ensures better anchorage of plants, supplies adequate water and essential nutrients, permits gaseous exchange between roots and atmosphere [19] and minimizes stress effects should be selected for optimum production. Growing media for horticultural plants may either be soil-based or soilless. Locally available organic manures are often added to the soil to improve its physico-chemical and biological properties. As previously shown, horticultural producers are increasingly facing a suit of production risks compelling them to adopt innovative agronomic techniques that can simultaneously address the concerns of higher input use efficiency, minimum yield losses and better produce quality. Specifically, horticultural expansion into 'marginal' drought and/or salinity prone areas has necessitated the development of measures that can lessen the possible adverse impacts by improving water and nutrient use efficiencies. Addition of hydrogels to the growing media (both soil and soil-less) significantly improves water availability to the plants showing the potential for diverse applications in alleviating water stress in crop production [20]. This has led to a new found interest in super absorbent hydrogels as efficient soil conditioners [21].

Super absorbent polymers

Superabsorbent polymer (also called slush powder/ polyacrylamide/hydrogel) is water-absorbing polymers, which are classified as hydrogels when cross-linked; absorb aqueous solutions through hydrogen bonding with water molecules. These hydrophilic gels are either natural or synthetic polymers exhibiting the properties of swelling and retaining considerable amounts of water [22]. Superabsorbent polymers (SAP) are special kinds of hydrogels synthesized by the chemical stabilization of hydrophilic polymers in a tridimensional network [23]. A very high molecular mass allows the SAP to absorb large quantities of water or aqueous solutions [24]. Polymeric soil conditioners in general and the SAP in particular are increasingly being used for improving the physical properties of soil by increasing the soil permeability, infiltration and water holding capacity (WHC) that in turn reduce soil compaction, run-off induced erosion and irrigation frequency translating into improved water use efficiency (WUE) and better plant performance [25]. Owing to hydrophilic properties and the presence of carboxylic groups, SAP act as 'artificial humus' by storing appreciable amounts of water and cations. In addition to improving the plant available water, SAPs also arrest the evapotranspiration (ET) losses, bind the heavy metals for preventing their entry into plants and mitigate the adverse effects of salinity [1]. While most of the currently available superabsorbent hydrogels are acrylic acid and acrylamide-based non-biodegradable products, growing environmental concerns have increased the interest in developing biodegradable hydrogels for commercial agricultural uses [23, 26]. In addition to poor degradability, most of the currently available super absorbents have low water absorption capacity especially under high electrolyte concentrations and come at a prohibitive cost. In order to tide over these problems, natural materials like polysaccharides and clay minerals are being explored for developing low cost, biodegradable products.

Classification of water absorbing polymers [27, 28]

a. Based on material used: Natural and synthetic
b. Classification according to polymeric composition: Homopolymeric, copolymeric and multipolymer interpenetrating polymeric hydrogel.
c. Based on cross-linking in superabsorbent polymers: Bulk or core cross-linking and surface cross-linkin
d. Classification based on configuration: Amorphous (non-crystalline), semicrystalline and crystalline
e. Classification according to network electrical charge: Nonionic (neutral), ionic (including anionic or cationic), amphoteric electrolyte (ampholytic) containing both acidic and basic groups and zwitterionic (polybetaines)

Effects on Soil Properties

Soil erosion control

Planting of perennial trees and shrubs can arrest soil erosion on steep slopes to some degree. While plant canopy lessens the erosive impact of rain drops, roots improve the soil structure. However, hostile conditions in arid and semi-arid areas including scarce rainfall and heat stress can hinder successful plant establishment. Application of certain soil conditioners reduces clay dispersion and increases infiltration rate, and hence can be an alternative means of soil erosion control. Some authors suggest that combining the two practices *viz*., drought tolerant perennial plants and soil conditions can give better results than either practice alone. It was found that application of a cationic polysaccharide (PS) or polyacrylamide (PAM) along with phosphor gypsum (PG) efficiently reduced soil erosion of steeply sloped (30-60%) soils having varying ESP and $CaCO_3$ levels. While erosion decreased by six- to eleven-fold than control in different treatments, PAM exhibited very low dissolution rate. They further observed that combination of PS + PG and drought hardy perennial plants also gave promising results in soil erosion control [29]. Effects of anionic polyacrylamide (PAM) evaluated and synthesized biopolymer (BP) applied at 200 kg ha^{-1} on soil erosion control and Chinese cabbage (*Brassica campestris* L.) growth in a loamy sand soil. Both PAM and BP considerably improved soil stability, clay flocculation and plant available water resulting in better seedling growth. Application of BP also decreased the soil pH presumably due to an increase in anionic sites to be protonated and the soil buffering capacity [30].

It was reported that a polyacrylamide-acrylic superabsorbent resin reduced soil erosion in a severely drought affected loess soil by decreasing the flow velocity, delaying the initial runoff time, and increasing the SOM and water stable aggregates. Higher concentrations of SAP increased the surface coverage and root growth reducing the direct erosive impact of rainfall [31]. PAM application, either on soil surface or through irrigation water, reduced soil and water losses under furrow irrigation with high SAR (sodium adsorption ratio) saline water. Although PAM applied trough irrigation water was more effective in controlling soil erosion than powdered form, it also adversely affected soil infiltration rate. When used in equal amounts, both infiltration rate and soil loss were higher with powdered PAM [32].

Bulk density

Bulk density (BD), an important soil property dependent on factors like soil texture and soil organic matter (SOM), influences a range of soil properties including rooting depth, infiltration, porosity, and water and nutrient availability which in turn influence soil productivity. In general, well aggregated and porous soils with high SOM have a lower BD. Certain crop management practices like use of organic manures, reduced tillage and crop rotation with deep rooted crops tend to reduce soil compaction and BD. Soils under organic management tend to have a low BD and high pore space resulting in the retention of high amounts of water [33]. Mixing of four different SAPs, including three cationic and one non-ionic type, decreased BD by up to 9.4% and increased soil moisture up to 32.8% than control in sandy soils subjected to different wetting and drying cycles. However, the highest decrease and increase in BD and soil moisture, respectively, were seen with the use of non-ionic (polyacrylamide) SAP [34]. While biochar treatment had no effect, SAP addition caused a slight decrease in BD of spent pig litter compost used as the growing substrate for water spinach (Ipomoea aquatica Forsk). Total porosity and air porosity also significantly increased after SAP treatment [35].

Soil aggregation

Soil aggregate stability is an important property influencing key soil functions. In general, light textured soils and those poor in SOM tend to have a poor structure and stability. Similarly, stresses like drying and high salt content often negatively affect soil structure and aggregate stability. Besides intrinsic soil textural properties, hydrogel polymers often induce additional stabilizing effects by gluing soil particles together [36]. Hydrogels including extracellular polymeric substances, root mucilage or synthetic polymers improve soil microstructural stability manifold by reducing the rotational mobility of water and promoting polyvalent cation bridging between the polymer and clay particles [37]. Bulk application of two SAPs (Jaguar C and Jaguar S) at 200 kg ha^{-1} promoted the formation of macro soil aggregates (particle size >0.25 mm) and significantly improved the soil water content and soil maximum hygroscopic moisture in a wheat field [38]. Addition of a gel-forming polymer (Aquanika) at 1 or 2 g kg^{-1} reduced bigger soil clods (>10 mm) with a concurrent increase in smaller air-dry aggregates in the soil surface. The proportion of water-stable aggregates (0.25-10 mm) also increased significantly [39].

Soil water retention

Super absorbent polymer treated dry land soils exhibit noticeable improvements in hydraulic conductivity, water retention and flow presumably because of SAPs positive effects on soil physical, chemical and biological properties, and root growth [40]. Soil applied SAP granules slowly release the absorbed water through diffusion in response to soil drying. It checks the deep percolation and evaporative losses so that applied water remains available for plant use for an extended period of time [41]. Citrus trees on hill slopes show gradual decline in fruit yield due to lack of irrigation. Application of SAP (Stocksorb @ 100 g $tree^{-1}$) and recommended dose of fertilizers increased the water holding capacity from 28.7% to 34.6% and thus extending moisture availability and reducing fruit drop in Assam lemon (Citrus limon). SAP treated soils retained sufficient water for meeting the crop water need up to 15 days after irrigation [42]. SAP application improved water use efficiency in apple trees; nearly 900 m^3/hm^2 of irrigation water could be saved when SAP was applied at 200 g $tree^{-1}$ [43]. Addition of different mulches and hydrogel enhanced water deficit tolerance in olive cultivars 'Konservolea' and 'Manzanilla' by improving antioxidant defence system, leaf relative water content and photosynthetic rate. Nonetheless, effects of hydrogel were less pronounced than de-oiled olive pomace and pistachio shell used as mulch [44]. Efficacy of hydrogels in improving water availability can vary with soil type, dose and the method of application. Hydrogel banding (0.4%) increased water retention by up to 33% in a calcareous sandy clay loam soil but had little effect on a highly calcareous clay soil in which water retention increased only by 4%. In contrast, hydrogel mixing in the soil did not have a measurable effect on water retention in either soil [45].

Reduction in salt stress

As mentioned previously, plant growth in salt-affected soils suffers due to constraints like reduced water availability, ion toxicities, deficiencies of essential nutrients and poor structure. Evidently, any soil or water management practice that overcomes one or more of these problems will be helpful in better plant growth and higher yields under such conditions. Hydrogel compounds can lessen salt stress in crop plants either directly by improving the soil properties or indirectly by upregulating plant metabolism to endure excess salts. Sometimes, both direct and indirect effects may account for plant adaptability to saline conditions. Application of a mixture of vinyl alcohol acrylic acid (0.1%) and municipal compost (10 t ha^{-1}) increased the structural stability and plant available water content in a saline-sodic soil [46]. SAP application reduced the adverse effects of saline irrigation (4.0 and 6.0 dS m^{-1}) in a sandy loam soil by improving the porosity and plant available water which were up to 40.8% and 2-times higher, respectively, than control [47].

Incorporation of SAP (0.6 % w/w) was found to increase available water content by 2.2 and 1.2 times than control in saline water irrigated sandy and loamy soils, respectively, suggesting that SAP application may particularly be beneficial in increasing WHC and decreasing salinity in light textured soils [48]. Hydrogel (Agrosoak®) application increased water availability and yield of saline water (1.9-7.8 dS m^{-1}) irrigated cabbage (Brassica oleraceae L.), but at the risk of enriching the soil solution with Na^+ indicating that effects were attributable to increased plant WUE and not to direct ameliorative effects on soil. This also implied the need to develop hydrogels that would not release sodium into the soil solution [49]. PAM application (10 mg l^{-1}) increased water movement through the root zone in a saline water irrigated shrink-swell pecan [Carya illinoinensis (Wangenh.) K. Koch] orchard hastening Na^+ leaching and $CaCO_3$ dissolution; and thus reducing soil EC_e and SAR at different depths. Together, these changes improved soil quality and pecan yields by about 34% over untreated soil. These effects were ascribed to improved soil permeability and increased availability of native Ca sources present in the experimental soil [50]. PAM (10 and 20 mg l^{-1}) applied through drip irrigation (EC_{iw} 6.2 dS m^{-1}) increased soil water sorptivity in pomegranate orchards by reducing the soil water repellency by up to 40% [51].

One of the early studies conducted with tomato (*Lycopersicon esculentum* Mill.), lettuce (*Lactuca sativa* L.) and cucumber (*Cucumis sativus* L.) revealed that mixing of hydrogel polymer in the growing substrate improved plant salt tolerance by enhancing the leaf area and succulence, protecting the chlorophyll and carotenoid pigments, and by increasing the photosynthetic activity, proline and protein contents [52]. Amendment of saline soils with 0.6% hydrogel (Stockosorb K410) led to marked increases in plant biomass in woody perennial *Populus euphratica*. Growth improvement occurred mainly because of salt exclusion and increased uptake of Ca^{2+}. Presence of polymer reduced apoplectic Na^{+} transport in both young and old roots, and Cl^{-} transport in old roots. Again, Cl^{-} was compartmentalized in the cortical vacuoles of roots. This reduced the loading of Na^{+} and Cl^{-} into the xylem limiting their translocation to aerial parts [53]. Hydrogel treatment improved salt tolerance index in bean plants by significantly reducing soil electricity conductivity, arresting electrolyte leakage and by modulating anti-oxidant enzyme activities, regardless of the type of salt and salinity level [54].

Effects on Fruit Crops

Early growth and establishment

Exogenously applied auxins promote root formation in cuttings of many fruit crops. Some studies suggest that substituting the auxin treatment by hydrogel can have a similar, and sometimes better, effect with regard to root initiation. While indole butyric acid (IBA) treatment did not have any effect on rooting, incorporation of hydrogel polymer in the substrate increased the rooting and seedling quality in blackberry cv. Brazos [55]. Similarly, survival and growth of mulberry cuttings was improved when a hydrogel polymer was added to the rooting substrate [56]. Frequent irrigation is one of the prerequisites for the production of elite planting stock in fruit crops. However, growing fresh water shortages are increasingly compelling the researchers and nursery managers for developing innovative agronomic practices for coping up with reduced water supplies in nursery plant production. Several studies have shown that addition of super absorbent hydrogels keeps the growing substrate moist for an extended period of time and thus helpful in reducing the irrigation frequency. Polymer incorporation in the nursery substrate improved the dry matter production and growth of yellow passion fruit seedlings. Seedlings irrigated every alternate day were similar in size and leaf area to the seedlings receiving daily irrigation [57]. Polymer application (20 g $tree^{-1}$) alleviated water stress in sweet cherry rootstock ‘Mahaleb’ (*Prunus mahaleb* L.) by improving leaf area, chlorophyll content, and stem diameter and root length [58]. Use of SAP (60 g) and irrigation at 24-d interval significantly increased branch height and canopy diameter in almond saplings [59]. Hydrogel incorporation in soil delayed the onset of drought stress symptoms in mango seedlings. In spite of more or less similar photosynthetic rate, stomatal conductance and leaf water potential, leaf turgidity was higher in hydrogel treatment than in control plants [60]. Myrobalan (*Prunus cerasifera*) seedlings displayed the highest plant height, leaf area and stem diameter when treated with 3% SAP and irrigated at 4 days interval. Contrarily, plants irrigated at 12 days interval without SAP application showed the lowest growth [61].

In dry and saline soils, osmotic stress often results in heavy seedling mortality necessitating adequate care in field preparation and subsequent upkeep. Some studies have shown that incorporation of hydrogels into the nursery substrate increases water holding capacity in the seedling root plugs which in turn minimizes post-transplant water stress and ensures better survival under water deficit conditions [62]. Many authors have reported better establishment of fruit saplings in hydrogel amended soils; obviously due to improvements in the root zone soil and higher water availability to plants. Hydrogel minimized the adverse effects of water deficit in tangerine (‘Okitsu’ and ‘Clemenules’) and orange (‘Navelina’ and ‘Lanelate’) cultivars grafted on *Poncirus trifoliata* by improving gas exchange and plant water status [63]. Use of hydrogel significantly improved the survival of oak (Quercus brantii L.), pistachio (*Pistacia atlantica* Desf.) and hackberry (Celtis caucasica Willd.) seedlings in a degraded land [64]. Application of dried domestic waste as an organic fertilizer and super absorbent hydrogel improved plant growth of apple seedlings in a reclaimed soil with the greatest increase seen in the plants receiving 75 kg sludge and 200 g gel. Further increase in hydrogel application rate, however, had an adverse effect on plant growth [65]. Hydrogel (Stockosorb Agro @ 0.2 or 0.4%) addition into the soilless media (perlite, or sphagnum peat and perlite) minimized drought injury in young citrus rootstocks (Carrizo citrange and Cleopatra mandarin) subjected to drying/rehydration cycles by reducing leaf abscission and improving photosynthetic rate, stomatal conductance and root growth [66].

Fruit yield and quality

Combined use of super absorbent (160 g $tree^{-1}$) and an organic fertilizer (1 kg $tree^{-1}$) considerably improved trunk cross sectional area and fruit yield in sweet cherry [67]. Polymer application decreased the accumulation Zn and Pb in leaves, and Cu, Ni and Pb in fruits of strawberry cv. Elsanta. These effects were especially pronounced in plants receiving the higher dose (3.6 g) of hydrogel than low dose (1.8 g) treatment [68]. Soil application of hydrogel (150 g plant^{-1}) and drip irrigation improved vegetative growth, bunch weight and fruit quality while saving 20% of irrigation water in 'Grand Nain' banana in a reclaimed saline soil (EC 3.3 dS m^{-1}) [69]. Under similar conditions, polymer addition at 1500 g mat^{-1} year^{-1} increased WUE and fruit yield in 'Grand Nain' resulting in 12.5% saving in irrigation water [70]. SAP (poly acrylat potassium) application considerably increased the canopy area, photosynthesis and berry yield in drip irrigated 'Kolahdary' grapevines in a loamy clay soil. Yield increase in 'Shastaros' cultivar under similar conditions was less pronounced suggesting a cultivar-specific response to SAP treatment [71]. Hydrogel (Ekosorb @ 3 g dm^3) treatment improved water availability to strawberry plants on both black and sandy soils, yet the effects were more pronounced in black soil. Notwithstanding higher frost injury in some of the cultivars, strawberry plants on hydrogel treated soils produced more fruit yield than those in control soils [72]. Hydrogel injection in the soil improved soil water content, midday stomatal conductance, maximal quantum efficiency (Fv/Fm), shoot growth, oil yield and rainwater use efficiency in an olive grove in a rainfed soil. Hydrogel absorbed more water during wetting events resulting in significantly high soil water retention at 20-60 cm depth- the zone of maximum fine root density. Results suggested that hydrogel incorporation may further improve the benefits of rainwater harvesting in arid olive orchards [73]. SAP application (200 g tree^{-1}) increased the WUE and fruit yield in apricot trees in a highly gravely soil subject to heavy water losses. SAP treatment enhanced average soil moisture by about 22.0% compared to control with concurrent improvements in fruit weight and Vitamin C content [74].

Conclusion

The preceding observations clearly indicate the potential of superabsorbent polymers in improving soil properties that greatly influence crop performance in drought and salt-affected soils. Increased and extended availability of plant available water and improvements in plant water use efficiency explain most of the beneficial effects in hydrogel treated soils. Given the fact that it is an emerging field of research, future commercial applications will depend to a great extent on economic efficiency and environmental sustainability aspects suggesting that long-term investigations are needed to establish hydrogel technology a viable practice.

References

1. Huettermann A, Orikiriza LJB, Agaba H (2009) Application of superabsorbent polymers for improving the ecological chemistry of degraded or polluted lands. Clean Soil Air Water 37(7): 517-526.

2. Fitzpatrick RW (2002) Land degradation processes. ACIAR Mono.Ser 84: 119-29.

3. Carrao H, Naumann G, Barbosa P (2016) Mapping global patterns of drought risk: An empirical framework based on sub-national estimates of hazard, exposure and vulnerability. Global Environmental Change 39: 108-124.

4. FAO (2013) Drought. FAO Land & Water.

5. Nkonya EM, Gerber N, Baumgartner P, von Braun J, De Pinto A, et al. (2011) The economics of desertification, land degradation, and drought toward an integrated global assessment. ZEF- DISCUSSION Papers on Development Policy No. 150. Center for Development Research, AgEcon search.

6. Wicke B, Smeets E, Dornburg V, Vashev B, Gaiser T, et al. (2011) The global technical and economic potential of bioenergy from salt-affected soils. Energy & Environmental Science 4(8): 2669-2681.

7. Tester M, Langridge P (2010) Breeding technologies to increase crop production in a changing world. Science 327(5967): 818-822.

8. Munns R (2002) Comparative physiology of salt and water stress. Plant, Cell & Environment 25(2): 239-250.

9. Miller G, Suzuki N, Ciftci-Yilmaz S, Mittler R (2010) Reactive oxygen species homeostasis and signalling during drought and salinity stresses. Plant Cell & Environment 33(4): 453-467.

10. Wu QS, Xia RX, Zou YN (2006) Reactive oxygen metabolism in mycorrhizal and non-mycorrhizal citrus (*Poncirus trifoliata*) seedlings subjected to water stress. J Plant Physiol 163(11): 1101-1110.

11. Chaves MM, Flexas J, Pinheiro C (2009) Photosynthesis under drought and salt stress: regulation mechanisms from whole plant to cell. Ann Bot 103(4): 551-560.

12. Hu Y, Schmidhalter U (2005) Drought and salinity: a comparison of their effects on mineral nutrition of plants. J Plant Nutr Soil Sci 168: 541-549.

13. Rezaie M, Lessani H, Soleimani A (2008) The linked effect of saline and drought stress on olive (*Olea*

europaea L.) plants. ISHS Acta Horticulturae 791: 493-496.

14. Sane D, Ould Kneyta M, Diouf D, Diouf D, Abaye Badiane F, et al. (2005) Growth and development of date palm (*Phoenix dactylifera* L.) seedlings under drought and salinity stresses. African Journal of Biotechnology 4(9): 968-972.
15. Bartels D, Sunkar R (2005) Drought and salt tolerance in plants. Critical Reviews in Plant Sciences 24(1): 23-58.
16. Singh A, Sharma PC (2018) Recent insights into physiological and molecular regulation of salt stress in fruit crops. Adv Plants Agric Res 8(2): 171-183.
17. Raga V, Intrigliolo DS, Bernet GP, Carbonell EA, Asins MJ (2016) Genetic analysis of salt tolerance in a progeny derived from the citrus rootstocks *Cleopatra mandarin* and trifoliate orange. Tree Genetics & Genomes 12: 34.
18. Verma AK, Sindhu SS, Janakiram T, Singh MC, Singh A, et al. (2013) Influence of vermi-products and pusa hydrogel on growth and flowering of landscape gerbera under greenhouse condition. International Journal of Agriculture, Environment and Biotechnology 6(1): 81-87.
19. Abad M, Noguera P, Puchades R, Maquieira A, Noguera V (2002) Physico-chemical and chemical properties of some coconut dusts for use as a peat substitute for containerized ornamental plants. Bioresour Technol 82(3): 241-245.
20. Singh A, Sarkar DJ, Singh AK, Parsad R, Kumar A, et al. (2011) Studies on novel nanosuperabsorbent composites: swelling behavior in different environments and effect on water absorption and retention properties of sandy loam soil and soil-less medium. Journal of Applied Polymer Science 120(3): 1448-1458.
21. Verma AK, Sindhu SS, Anand P, Singh A, Chauhan VBS, et al. (2018) Vermi products and biodegradable superabsorbent polymer improve physiological activities and leaf nutrient contents of gerbera. Research Journal of Biotechnology 13 (3): 8-18.
22. Zohuriaan-Mehr MJ, Kabiri K (2008) Superabsorbent polymer materials: a review. Iranian Polymer Journal 17(6): 451-477.
23. Montesano FF, Parente A, Santamaria P, Sannino A, Serio F (2015) Biodegradable superabsorbent hydrogel increases water retention properties of growing media and plant growth. Agriculture and Agricultural Science Procedia 4: 451-458.
24. Buchholz FL (2002) Superabsorbent polymers. Encyclopedia of Polymer Science and Technology.
25. Ekebafe LO, Ogbeifun DE, Okieimen FE (2011) Polymer applications in agriculture. Biokemistri 23(2): 81-89.
26. Ma Z, Li Q, Yue Q, Gao B, Xu X, et al. (2011) Synthesis and characterization of a novel super-absorbent based on wheat straw. Bioresource Technology 102(3): 2853-2858.
27. Elliott M 2004 Superabsorbent polymers. BASF Aktiengesellschaft p. 13.
28. Ahmed EM (2015) Hydrogel: Preparation, characterization, and applications: A review. Journal of Advanced Research 6(2): 105-121.
29. Agassi M, Ben-Hur M (1992) Stabilizing steep slopes with soil conditioners and plants. Soil Technology 5(3): 249-256.
30. Lee SS, Chang SX, Chang YY, Ok YS (2013) Commercial versus synthesized polymers for soil erosion control and growth of Chinese cabbage. SpringerPlus 2(1): 534.
31. Cao Y, Wang B, Guo H, Xiao H, Wei T (2017) The effect of super absorbent polymers on soil and water conservation on the terraces of the loess plateau. Ecological Engineering 102: 270-279.
32. Chao-Yin DOU, Fa-Hu LI, Wu LS (2012) Soil erosion as affected by polyacrylamide application under simulated furrow irrigation with saline water. Pedosphere 22(5): 681-688.
33. Glover JD, Reganold JP, Andrews PK (2000) Systematic method for rating soil quality of conventional, organic, and integrated apple orchards in Washington State. Agriculture, Ecosystems & Environment 80(1-2): 29-45.
34. Bai W, Zhang H, Liu B, Wu Y, Song J (2010) Effects of super-absorbent polymers on the physical and chemical properties of soil following different wetting and drying cycles. Soil Use and Management 26(3): 253-260.
35. Ruqin F Jia L, Shaohua Y, Yunlai Z, Zhang Z (2015) Effects of biochar and super absorbent polymer on substrate properties and water spinach growth. Pedosphere 25(5): 737-748.

36. Buchmann C, Bentz J, Schaumann GE (2015) Intrinsic and model polymer hydrogel-induced soil structural stability of a silty sand soil as affected by soil moisture dynamics. Soil and Tillage Research 154: 22-33.

37. Buchmann C, Schaumann GE (2017) Effect of water entrapment by a hydrogel on the microstructural stability of artificial soils with various clay content. Plant and Soil 414(1-2): 181-198.

38. Li X, He JZ, Hughes JM, Liu YR, Zheng YM (2014) Effects of super-absorbent polymers on a soil–wheat (*Triticum aestivum* L.) system in the field. Applied Soil Ecology 73: 58-63.

39. Paluszek J (2011) Physical quality of eroded soil amended with gel-forming polymer. International Agrophysics 25(4): 375-382.

40. Liao R, Wu W, Ren S, Yang P (2016) Effects of superabsorbent polymers on the hydraulic parameters and water retention properties of soil. Journal of Nanomaterials.

41. Cannazza G, Cataldo A, De Benedetto E, Demitri C, Madaghiele M, et al. (2014) Experimental assessment of the use of a novel superabsorbent polymer (SAP) for the optimization of water consumption in agricultural irrigation process. Water 6(7): 2056-2069.

42. Pattanaaik SK, Barun Singh LW, Debnath P, Hazarika BN, Pandey AK (2015) Effect of hydrogel on water and nutrient management of *Citrus limon*. International Journal of Agriculture Innovations and Research 3(5): 1656-1659.

43. Han YG, Yang PL, Ren SM, Liu H, Bi Y (2006) Effects of super absorbent polymers on water saving and irrigation schedule for apple irrigation. Transactions of the Chinese Society of Agricultural Engineering 22: 70-73.

44. Farzi R, Gholami M, Baninasab B (2017) Water-retention additives' effects on plant water status and some physiological parameters of two olive cultivars under reduced irrigation regimes. Acta Physiologiae Plantarum 39: 126.

45. El Asmar J, Jaafar H, Bashour I, Farran MT, Saoud IP (2017) Hydrogel banding improves plant growth, survival, and water use efficiency in two calcareous soils. Clean Soil Air Water 45(7): 170-250.

46. Emami H, Astaraei AR (2012) Effect of organic and inorganic amendments on parameters of water retention curve, bulk density and aggregate diameter of a saline-sodic soil. Journal of Agricultural Science and Technology 14(20): 1625-1636.

47. Shokuohifar M, Nasab SB, Mohammadi AS, Hooshmand AR (2016) The effect of salinity of irrigation water and super absorbent polymer on some hydraulic and physical properties of sandy loam soil. Irrigation Sciences and Engineering 39(2): 101-113.

48. Seyed DS, Golchin A, Ahmadi S (2010) The effects of different levels of a superabsorbent polymer and soil salinity on water holding capacity with three textures of sandy, loamy and clay. Journal of Water and Soil 24(2): 306-316.

49. Silberbush M, Adar E, De Malach Y (1993) Use of an hydrophilic polymer to improve water storage and availability to crops grown in sand dunes II. Cabbage irrigated by sprinkling with different water salinities. Agricultural Water Management 23(4): 315-327.

50. Ganjegunte GK, Sheng Z, Braun RJ (2011) Salinity management using an anionic polymer in a pecan field with calcareous–sodic soil. J Environ Qual 40(4): 1314-1321.

51. Tadayonnejad M, Mosaddeghi MR, Dashtaki SG (2017) Changing soil hydraulic properties and water repellency in a pomegranate orchard irrigated with saline water by applying polyacrylamide. Agricultural Water Management 188 (1): 12-20.

52. El-Sayed H, Kirkwood RC, Graham NB (1991) The effects of a hydrogel polymer on the growth of certain horticultural crops under saline conditions. Journal of Experimental Botany 42(240): 891-899.

53. 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(2): 175-183.

54. Aydin A, Kant C, Turan M (2011) Hydrogel substrate alleviates salt stress with increase antioxidant enzymes activity of bean (*Phaseolus vulgaris* L.) under salinity stress. African Journal of Agricultural Research 6(3): 715-724.

55. Moreira RA, Ramos JD, Cruz MCM, Villar L, Hafle OM (2012) Indolbutiric acid and hydrogel polymer in the rooting of blackberry. Scientia Agraria Paranaensis 11(1): 74-81.

56. Moreira RA, Ramos JD, Cruz MD, Villar L, Hafle OM (2010) Effect of hydrogel polymer concentration on rooting of mulberry. Revista Agrarian 3(8): 133-139.

57. de Carvalho RP, Cruz MCM, Martins LM (2013) Irrigation frequency using hydro-absorbent polymer in seedling production of yellow passion fruit. Revista Brasileira de Fruticultura, Jaboticabal 35(2): 518-526.

58. Zamanipour M, Moghadam EG, Tehranifar A (2014) Response of two selected *Prunus mahaleb* (*Prunus mahaleb* L.) genotypes to water stress and superabsorbent application. International Journal of AgriScience 4(4): 218-223.

59. Jalili K, Jalili J, Sohrabi H (2011) Effect of super absorbent polymer (Tarawat A200) and irrigation interval on growth of almond sapling. Water and Soil Science 21(2): 121-134.

60. Ismail I, Ismail R, Fauzirom S (2001) Improve survival of mango at establishment by hydrogel polymer incorporation. In: 12th Malaysian Society of Plant Physiology Conference the Mines Resort Hotel, Seri Kembangan, and Selangor.

61. Oraee A, Moghadam EG (2013) the effect of different levels of irrigation with superabsorbent (SAP) treatment on growth and development of myrobalan (*Prunus cerasifera*) seedling. African Journal of Agricultural Research 8(17): 1813-1816.

62. Chirino E, Vilagrosa A, Vallejo VR (2011) Using hydrogel and clay to improve the water status of seedlings for dryland restoration. Plant and Soil 344(1-2): 99-110.

63. Ferreira EA, Silva VA, Silva EA, Silveira HDRO (2014) Hydrogel efficiency and physiological responses of seedless citrus cultivars seedlings under water deficit. Pesquisa Agropecuária Tropical 44(2): 158-165.

64. Hosseinzadeh J (2016). Investigation on use of superabsorbent materials in forest seedling establishment. International Journal of Advanced Biotechnology and Research 7(4): 538-542.

65. Awad F, Kahl L, Kluge R (1995) Environmental aspects of sewage sludge and evaluation of super absorbent hydrogel under Egyptian conditions. Iron Nutrition in Soils and Plants 59: 91-97.

66. Arbona V, Iglesias DJ, Jacas J, Primo-Millo E, Talon M, et al. (2005) Hydrogel substrate amendment alleviates drought effects on young citrus plants. Plant Soil 270(1): 73-82.

67. Szwonek E (2012) Impact of a superabsorbent gel and organic-mineral fertilizer on growth, yield and quality of sweet cherry trees. Acta Horticulturae 940: 415-421.

68. Mikiciuk G, Mikiciuk M (2010) Effect of polymer supersorbent added to medium on the content of mineral elements in strawberry leaves and fruit. Journal of Elementology 15(2): 313-319.

69. Barakat MR, El-Kosary S, Borham TI, Abd-ElNafea MH (2015) Effect of Hydrogel Soil Addition under Different Irrigation Levels on Grandnain Banana Plants. Journal of Horticultural Science and Ornamental Plants 7(1): 18-28.

70. Kassim FS, El-Koly MF, Hosny SS (2017) Evaluation of Super Absorbent Polymer Application on Yield, and Water Use Efficiency of Grand Nain Banana Plant. Middle East Journal of Agriculture Research 6(1): 188-198.

71. Namvar H, Asgharzade A, Babaeian M, Hosseinzade E (2014) The effects of superabsorbent polymer on yield and yield component of two grape varieties. International Journal of Biosciences 4 (4): 18-23.

72. Makowska M, Borowski E (2004) The influence of the addition of Ekosorb to black soil and sandy soil on the content of water in soil, frost injury of flowers and on fruiting of strawberry. Folia Horticulturae 16(1): 87-93.

73. Chehab H, Tekaya M, Mechri B, Jemai A, Guiaa M, Mahjoub et al. (2017) Effect of the Super Absorbent Polymer Stockosorb® on leaf turgor pressure, tree performance and oil quality of olive trees cv. *Chemlali* grown under field conditions in an arid region of Tunisia. Agricultural Water Management 192: 221-231.

74. Li X, Yang P, Ren S, Zhang S (2009) Effects of super absorbent polymer on transpiration and fruit quality of apricot in soil with high gravel. Transactions of the Chinese Society of Agricultural Engineering 25(4): 78-81.