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Hydrogel/superabsorbent polymer for water and nutrient management in horticultural crops-review

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Abstract
The hydrogel is a soil conditioner able to retain water and plant nutrients. Hydrogel is commercially available as Stockosorb/Raindrop/Agrosorb. Stockosorb releases water and nutrient to the plants, when surrounding soil near root zone of plants starts to dry up. Hydrogel polymers are synthetic, water-absorbing monomers of high molecular weight. Polymers differ from each other in the specific monomer building block, amount of water absorbed per gram of material, particle size and distribution, response to salinity and cost. Benefits derived from polymer application to soil or artificial medium include: increase in water-holding capacity, increase in pore size/number, increase in soil nutrient reserves, and reduction in soil compaction. Initial use of polymers was reported in greenhouse production in the late 1970s, but is now used in the production of fruits, vegetables, and turf. Development of application equipment has the potential to expand the use of polymers to large commercial growers. Planting of horticulture crops on steep hill slopes and lack of supplementary irrigation and application of nutrients, cause gradual decrease in their productivity. So, this review was made elucidate the effect of hydrogels (Stockosorb) on the growth, yield, quality, nutrient absorption and retention, water conservation efficiency in horticulture sector.

Keywords: Hydrogel, growth, yield, quality, water and nutrients

Introduction

The optimization of the utilization of water resources is strategic for the long-term competitiveness of the agricultural industry in the world. Water management is considered one of the major challenges of the near future (Saguy *et al.*, 2013) [56]; in-fact, by 2030, water demand is expected to be 50 per cent higher than today and withdrawals could exceed natural renewal by over 60 per cent, which resulting in to water scarcity (Nestlé, 2011) [46]. Irrigation water stress is one of the major limiting factors that, affect the crop growth, fruit productivity and quality. Crop productivity is often also limited by adverse physical and chemical soil properties such as low infiltration rates as well as low water retention and low cation exchange capacity. The water and nutrient holding capacity of sandy and permeable soils, in particular, are extremely limited. These soil types are characterized by excessive drainage of rain and irrigation water, as well as nutrients leaching below the root zone (Kazanskii and Dubrovskii, 1992; Al-Omran and Al-Harbi, 1998) [39, 5] and it leads to inefficient water and fertilizer for crops. These conditions are intensified in shallow-rooted crops or when irrigation water or irrigation systems are missing. Water stress from drought will also affects multiple physiological parameters in citrus including a reduction in water potential and stomatal conductance (Gómez-Cadenas *et al*., 1996) [29]. Severe water deprivation leads to stomata close very rapidly, arresting water flux almost completely within two hours (Tudela and Primo-Millo, 1992) [63]. Continuous water stress condition inhibits plant growth and also reduces the CO_2 assimilation (Brakke and Allen, 1995) [17]. In citrus drought deprivation reduces peel thickness, making citrus fruits more vulnerable to damage during manipulation and shipping (Agustí, 1999) [4]. In citrus and other plants, a period of drought followed by a restoration of hydration conditions will favorable to promote of flowering (Lovatt *et al*., 1988; Southwick and Davenport, 1986) [41, 59]. In this case, a direct relation between the general effect of water stress on growth inhibition and the promotion of flowering has been proposed. In citrus plants subjected to severe drought can show leaf injuries and even wilting without leaf abscission (Tudela and Primo-Millo, 1992) [63].

However, when water stress is relieved by rain or irrigation, results into leaves recover turgor and shortly thereafter, some of them may abscise (Gómez-Cadenas *et al*., 1996; [29] Tudela and Primo-Millo, 1992) [63]. The hormonal regulation of this response may be related to severe water stress conditions promoting synthesis and accumulation of 1-aminocyclopropane-1-carboxylic acid (ACC, the ethylene metabolic precursor) in roots. Rehydration of plants results in ACC transport to the shoots, where it is oxidized to ethylene and subsequently promotes leaf abscission (Tudela and Primo-Millo, 1992) [63]. Moreover, abscisic acid (ABA) seems to be the mediator between water stress conditions and ethylene production. Therefore, these plant growth regulators link water status to a plant survival response such as leaf abscission (Gómez-Cadenas *et al*., 1996) [29]. Not only is total production decreased by drought stress but also fruit size, acid and total soluble solid contents in juice (Sánchez *et al*., 1978) [57].

The damage caused by water deprivation, different soil conditioners have been assayed in crops and landscape plants would mitigated by hydrogels. These hydrogels are (Polymers) play important role in agricultural sector (Dehkordi, 2017) [20]. During the last decade, hydrogels have been used broadly for improving water availability for plants, by increasing water holding properties of soil and growing media, application of hydrogel polymers may be a proper technique to enhance water and fertilizers use efficiencies (Dehkordi and Seyyedboveir 2013) [70] it might absorb and store water many times of their weight and work as a tank to forestall water waste and increase irrigation potency, also, superabsorbent polymers improve some soil physical properties. The hydrogel polymer compound seems to be extremely effective to be used as a soil conditioner in agricultural sector, to boost crop tolerance and growth in a sandy or light-weight gravel substrate. Hydrogel polymer has been established as a soil conditioner to reduce soil water loss and increase crop yield (Ovalesha *et al*., 2017) [50] Beneficial effects were obtained with a new group of soil conditioners, known as hydrogels which are highly cross-linked olyacrylamides with 40 per cent of the amides hydrolyzed to carboxylic groups (Hüttermann *et al*., 1999) [32].

Research evidences suggests that, when the soil is treated with super absorbent polymers (SAP), the water volumetric content of the soil increases significantly and as the soil dries, the stored water is released back slowly into soil. Further, fertigation is also possible by the application of SAP to the soil as the same is capable of absorbing the fertilizer and releasing the same with water (Rajiv *et al.*, 2014) [55]. In Egypt, water requirements of banana reached to 8000-12000 m^3 fed^{-1} $year^{-1}$ as affected by irrigation system (Ibrahim, 2003) [71]. El-Sayed *et al.* (2002) [22] and Sivapalan (2006) [58] stated that yield efficiency tended to increase as quantity of applied irrigation water increased. Additionally, polymers are effective in correction of aggregation, prohibiting of capillary water soar, decreasing cumulative evaporation and improving growth, efficiency in vast range of plant species. In arid and semiarid regions of the world, use of super absorbent polymers (SAP) may effectively increase water and fertilizer use efficiency in crops. When polymers are incorporated with soil, it is presumed that they retain large quantities of water and nutrients, which are released as required by the plant. Thus, plant growth could be improved with limited water supply (Islam *et al.,* 2011) [33]. Addition of a polymer to peat decreased water stress and increased the time to wilt. The incorporation of SAP with soil improved physical properties of soil, crop growth and yields (Yazdani *et al.*, 2007) [69] and reduced the irrigation requirement of plants Blodgett *et al*, (1993) [16]. The use of hydrophilic polymer materials as carrier and regulator of nutrient release was helpful in reducing undesired fertilizer losses, while sustaining vigorous plant growth Mikkelsen, (1994) [43]. Furthermore, SAP-amended soil can store a considerable amount of water and can release it gradually to the plant roots when needed. The adoption of the proposed SAP in cultivations could thus represent promising solution for the rationalization of water resources, especially in desert areas (Giuseppe *et al.,* 2014) [28].

For enhancing water use efficiency, reduced drought impact and increased nutrient use efficiency of horticultural crops increased hydrogel technique. But the information regarding to its application still limited, there has been some of research on the hydrogel application technique in the last few decades, but scattered in diverse sources and therefore this review attempts to outline some of the important findings on role hydrogel for water and nutrient management in horticultural crops.

Various groups of Polymes

1. Starch-polyacrylo-nitrile graft polymers (starch co-polymers),
2. Vinyl alcohol-acrylic acid co-polymers (polyvinyl alcohols)
3. Acrylamide sodium acrylate co-polymers-cross-linked polyacryl-amides (Woodhouse and Johnson 1991) [68]

Mode of action for polymer hydrogel

When the hydrogel is mixed with the soil, it forms an associate amorphous gelatin-like mass on hydration and is helps in absorption and desorption for an extended time, thus acts as a slow release of water within the soil. The hydrogel particles are also taken as “miniature water reservoir” in the soil and water will be detached from these reservoirs upon the root mandate through osmotic pressure difference (Woodhouse *et al*., 1991) [68]. Due to the respectable volume reduction of the hydrogel as water is released to the plant, hydrogel creates at intervals the soil, free pore volume providing further space for air and water infiltration, storage and root growth (Azzam, 1980) [8]. Hence, the hydrogel polymer delivered an affective transfer of property as a slow-release basis of water and dissolved fertilizers in the soil. The water conservation by hydrogel creates a buffered setting being effectiveness in short-run drought and losses reduction in institution phase. Ability in water consumption and dry matter production square measure positive crop reactions to hydrogel, once polymers are mixed into soil, they preserved vast quantities of water and nutrients reach up to hundred times of its original weight and conserve regarding ninety-five percent of keep water out there for plant absorption (Johnson, 1984) [35] and which are released as required by the plant, therefore, plant growth was enhanced with limited water supply, however, in rainfall region adding hydrogel polymer to soil implement soil infiltration rates.

General description

Polymers are generally high-molecular-weight materials that can be synthesized from a variety of monomers. The resulting materials can be either hydrophylic or hydrophobic (Tess and Poehlein, 1985) [61] Ideal with only the hydrophylic-type polymers. The chemical composition of these hydrophylic polymers includes: crosslinked acrylamide: sodium polyacrylates; swellable starch; cross linked acrylamide: potassium polyacrylates; starch: acrylate copolymers; and acrylonitrile. Cross linking in polymers appears to contribute to the increased storage of plant-available water in addition to acting as a physical barrier to the outflow of water from the gel (Johnson and Veltkamp, 1985) [36]. Such polymer types differ in the total amount of water absorbed per gram of material, particle size and distribution, response to salinity, and cost. Polymers can absorb extremely high rates of distilled water (as much as 1000 times their weight), but, in field applications, hydration seldom exceeds 400 to 500 times their weight (g g^{-1}) due to the level of salinity in most water sources. As the concentration of ions increases in water, the amount of hydration by the polymer decreases (Evans *et al*., 1990) [23]. Particle size will vary from 5μm to 2 mm within a specific polymer and among polymer types. Most polymers targeted for the horticultural industry are manufactured to meet the following criteria: increase a soil's water-holding capacity, increase pore size/number in soil, increase transplant survival rates, increase germination rates, and decrease or mitigate the effect of soil compaction on plant growth. In addition, several manufacturers have substituted potassium for sodium (commonly found in disposable baby diapers) in their products because of reduced toxicity to the plant. There has been very few, if any, long-term studies conducted to measure the breakdown rate of polymers under field conditions. Several manufacturers suggest that polymers will produce a significant benefit (water retention) for 5 years. Controlled degradation studies by me on several polymers indicated that polymers will lose 10% to 15% of their activity each year. The avenues of polymer degradation appear to be from microorganisms, modification of physical structure over time, and chemical decomposition (Johnson, 1985) [36].

Uses hydrogels in horticulture

In greenhouse

The use of polymers was projected to increase the water-holding capacity of soil and soilless mixes used in the production of floral and nursery crops in the greenhouse, many of the early recommendations were developed for various greenhouse crops (Bearce and McCollum, 1977; Foster and Keever, 1990; Gegring and Lewis III, 1980; Letey *et al*., 1992; Want, 1989) [14, 26, 27, 40, 67]. Growers were searching for methods that would increase the number of days between watering crops as well as reduce the total amount of water needed to grow their crops to maturity. Crop response to the addition of polymers in soil and/or soilless media appeared to be greatest when incorporated in sands or media with low organic matter. The rates of polymer application were recommended by manufacturers range from 1 to 5 lb yd^{-3} of media. One unusual use of a polymer modified soil was found for rooted cuttings. Banko (1984) [11] also reported that, an improvement in rooted cuttings of holly and azalea from polymer incorporation into the rooting media. One potential application of polymers in greenhouse production is the use of polymer modules as a substrate for tomato production developed in England (American Greenhouse Vegetable Growers News, 1989) [6]. Each black or white polyethylene module contains two sheets of paper with polymer particles sandwiched between them. In comparison to tomato growth in rockwool, there was no difference in yield with the polymer substrate. However, the advantage of using polymers is the ease of disposal compared to other soilless substrates.

In vegetables

Use of polymers in the production of vegetables was accelerated greatly by the nationwide drought in 1991. Evaluation of polymers in various sizes of field trials was widespread in California, Arizona, and New Mexico. In 1991-92, a total of 2000 acres of various crops were treated with polymer in California alone (C.B. Wilde, personal communication). However, the increase in water holding capacity of soils with the addition of polymers is dependent on soil type and level of organic matter found in the soil. Objectives of the applications were to reduce water application by 30 per cent to 50 per cent and to reduce fertilizer applications. Preliminary results appear to confirm the objectives of the field application of polymers in California. A reduction in time for crop maturity, yield increase of 30%, and potentially higher soluble solids in the fruit were reported with an application of 15lb of polyacrylamide to processing tomatoes grown in California (Pvor, 1988) [54].

There also has been some indication that polymers will enhance the root development, resulting in improved plant growth. Trials on a much smaller scale also were conducted by growers in Texas and Florida. The crop responses observed have been the elimination of plant growth cessation due to drought stress increased the nutrient uptake and increased crop yields. The recommendations based on academic and industrial research indicate that both broadcast and banded in the row applications of dry polymers produce a significant reduction in moisture stress and higher yields compared to crops produced without the application of polymers. The big difference between the two methods of application is the cost and total amount of polymer required. Advocates of broadcasting the polymer recommend applications between 150 and 800 lb $acre^{-1}$ with incorporation to a depth of 6 to 8 inches. Banding the polymer in the furrow at transplanting required as little as 15 lb $acre^{-1}$, with maximum application at 40 lb $acre^{-1}$ (46 kg· ha^{-1}). Initial research with banding the polymer in the furrow also indicated that total nutrient requirements for a specific crop could be reduced, because the polymer increased the reserve pool of nutrients in the soil and increased uptake efficiency in the plant (Orzolek, 1991) [49]. No response in muskmelon, tomato, or bell pepper was observed when polymer was broadcast prior to laying polyethylene plastic mulch in Florida, Texas, and South Carolina (D. Wofford, Jr., personal communication). Rates applied were 15 to 40 lb $acre^{-1}$ on different soil types.

In fruit crops

Various research findings suggested that, the lower tree mortality in newly established orchards and sustained active growth in established orchards under stress conditions. Because of the interest in injecting hydrated polymers in orchards, several injection machines have been designed in the western United States. In addition to applying polymers in the hydrated state, the application equipment has been designed to apply dry polymer at four or more different sites located around the drip line of trees. Initial reports from developers of equipment indicated good results with the equipment and with placement of the polymer in the drip-line area. The optimum polymer rate has been calculated to be 8 oz of polymer in 80 gal of water per tree in orchards (C.B. Wilde, personal communication). However, the rate of polymer application at each location should be determined by tree size, tree species, location, soil type, and rainfall amounts and distribution patterns.

In turf

Because the turf has shallow root system of many in species (as compared to most other horticultural crops) and continual traffic that occurs on a daily basis, many researchers have reported there was a significant response in growth and appearance of turf following polymer applications (Nus *et al*., 1991; Van Hoozer, 1991; Vlack, 1990) [48, 62, 66]. Of all the different plant species evaluated with polymer trials, turf seems to be especially sensitive to high rates of polymer (>3 lb 1000^{-1} ft^{-2} for established turf and >160 lb $acre^{-1}$ broadcast for newly seeded turf) incorporated into the. Soil (MacPhail *et al*., 1980) [42]. However, researchers in the western United States have suggested that, the success with injection of 4 to 5 lb of polymer 1000^{-1} ft^{-2} and have incorporated up to 30 lb of polymer/1000ft in extremely sandy soils (D. Wofford, Jr., personal communication).

The trials have been made in golf courses, soccer fields, cemeteries, and country clubs in both new plantings and established turf (Baker, 1991) [10]. Polymer incorporated into soccer fields has resulted in increased water retention, reduction in hardness due to dry weather, maintaining ground cover health after games, and a potential for reducing sports injuries. In new plantings, polymers can be applied (broadcast and incorporated) as dry material at the rate of 2 to 7 lb 1000^{-1} ft^{-2}. In established turf, a uniform application of dry polymers can be difficult when knifed in at 9-inch spacing. However, it appears that injection of hydrated polymers in established turf is more successful and efficient than dry polymer application. Several individuals or companies have developed injectors for the application of hydrated polymers into turf.

Application equipment

Several companies that are recently have started to market polymer injection equipment nationally. Gene Seifert (Condor Industries Inc., Ogden, Utah) developed the Aqua-Life Tree Injector, which will inject either dry or hydrated polymers. The unit operates through an air compressor that fractures the soil near the tree stem prior to the polymer's being dispensed through the injector into the soil. The injector has been tested in orchards, street tree plantings, parks, and roadsides for establishment of trees and shrubs. Injection Aeration Systems Inc. (IAS) (Cerritos, Calif.) will be marketing three different polymer injectors: for orchard and vineyards, turf, and landscaping and home yards. All of these injectors from IAS are designed to inject the dry polymer using high pressure water injection (3000 psi) and a Venturi chamber. The Venturi chamber creates a vacuum that sucks the dry polymer from the polymer hopper into the stream of water. The injectors can place the polymer from 4 to 20 inches (10 to 50 cm) beneath the soil surface, depending on individual crop application. Both polymer injectors also will aerate the soil and inject the polymer. The aeration of the soil can be as beneficial to the plant as the polymer application itself.

Hydrogel application in agriculture (Waleed Abobatta, 2018) [3].

Hydrogel polymers play a vital role in agricultural uses as structural materials for creating a climate beneficial to plant growth in arid and semi-arid regions; it could use as retaining ingredients in different forms as follow:

1. Seed additives to support seed germination or seed coatings.
2. Dipping of seedling roots before establishment.
3. Immobilizing plant growth substances.
4. Coating protecting agents (herbicides and pesticides) for slow release.
5. Polymeric Biocides and Herbicides.
6. Water-insoluble polymers.
7. Polymers for soil remediation.
8. In particular, hydrogel absorbs soluble fertilizer, water and then releases it in proper time for plants.

Effect of the hydrogel in retaining the water

Hydrogel polymer improve water penetration rate, hydrogel polymer have been used as water retaining material in arid and semiarid region under limitation of supplementary irrigation sources and salinity conditions which affect negatively on gradual growth and productivity of crops, hydrogel used to increase a water reservoir near the root zone and increased the field capacity of different soils, also, increased both water available for plants and the period of its availability (Montesano *et al*., 2015) [72]. Moreover, the previous studies point to good ability of hydrogel polymer for increasing water retention, water uptake and water use efficiency which help reduce water stress of plants and implement plant performance resulting in increased growth (Belen-Hinojosa *et al*., 2004) [15]. Hydrogels are also claimed to reduce fertilizer leaching, which seems to occur through interaction of the fertilizer with the polymer, polymer is also being considered as a potential carrier for protected agent like pesticides and herbicides (El-Hady *et al*., 1981) [21]. The use of hydrogels is particularly useful in dry and semi-dry regions where irrigation water is limited (Bakass *et al*., 2002) [9]. Similarly in citrus the application of stockosorb (Hydrogel) @100-150 g had show increased period (15 days) of water availability to the plant compared to control, The application of stockosorb under treatment 100 g per plant increased the water holding capacity of the soil from 28.74 to 34.63per cent (Pattanaaik *et al*., 2015) [52].

Water utilization efficiency or water use efficiency (WUE) is expressed as the amount of Grand Nain banana fruits in Kg that could be produced from one cubic meter of water. WUE clearly affected by polymer and the amount of applied water. Therefore, applying polymer with 1500 and 1000gm mat^{-1} $year^{-1}$ gave the same highest value of WUE (5.2 & 4.8 Kg per m^3) compared with all other treatments in both tested seasons. The obtained results show that the highest value of WUE (5.2 & 4.8 Kg fruit per m^3 water) was obtained from plants applied with 1500 or 1000 gm SAP mat^{-1} $year^{-1}$ followed by plants applied with 500 g polymer mat^{-1} $year^{-1}$ (4.2 & 4.3 Kg per m^3) while as, the lowest value of W.U.E. (3.1 & 2.9 Kg. fruit per m^3 water) was obtained from un applied planted in both seasons, respectively. The results proved that water regime at 87.5 per cent of the recommended amount of irrigation gave the highest value concerning WUE (4.4 & 4.2 Kg fruit/m3 water) compared with water regime at 75 per cent (4.0 &4.1 kg per m^3) Kassim *et al*. (2017) [38].

The effects of hydrogel on soil properties

Soil moister considered as a restricting factor for crop production in arid and semi-arid regions. The polymer as soil conditioners was recognized since the 1950s.

Agricultural hydrogels can change the different soil properties through various mechanisms like:

1. Implement water-holding capacity of the soil.
2. Increasing soil permeability.
3. Improving water retention on different soil types.

4. Increase the water use efficiency.
5. Increase irrigation intervals due to increasing the time to reach a permanent wilting point.
6. Minimizing soil erosion and water run-off.
7. Implement soil penetration and infiltration.
8. Decrease soil compaction tendency.
9. Improving soil drainage.
10. Support crop growth performance under reduced irrigation conditions.
11. Enhance nutrient retention as a result of solute release from hydrogel polymer particles and delay the dissolution of fertilizers. Also, hydrogel application expected to have wide potential applications in light soil, and actually influence soil penetration, texture, and evaporation, also, increased infiltration rates of water through the soils. Super absorbent polymer affect water penetration rate, density, structure, compactness, texture and crust hardiness of soil, aggregate anchorage evaporation, soil infiltration and aeration, size and the number of aggregates, water tension, available water (Abedi-Koupai and Sohrab 2004) [2], soil crispiness and finally cause better water management practices in soil.

Effect of hydrogel on in nursery management

It is necessary for the germination to be uniform and occurs as soon as possible. To promote germination, water availability is a major factor to guarantee ideal conditions for seed imbibitions, initial rapid growth of seedlings will assures the quality planting material and initial rapid growth of rootstocks are characteristics that contribute to advance the appropriate time of grafting point. In order to improve the availability of water in the substrate, the addition of hydrogel polymer to the soil favors seed germination, root development, plant growth, and contribute to improving aeration and soil drainage, minimize nutrient losses by leaching (Azevedo *et al*., 2002) [7]. The polymers are arrangements of organic molecules (Fonteno and Bilderback, 1993) [25] that exhibit granular when in dry form. When hydrated, these are transformed into a soft elastic gel (Prevedello and Loyola, 2007) [53] that, capable of absorbing about a hundred or more times its weight in water. Furthermore, the containers used for the production of rootstocks comprise small volume of substrate, which limits the availability of water to plants making necessary frequent irrigation, resulting in significant loss of some nutrients (Cruz *et al*., 2008) [19]. Thus, the use of the hydrogel polymer on substrate is an alternative to improve the process of production of citrus rootstocks, because it keeps the substrate humid, minimizes nutrient leaching and increases growth of plants. The addition of hydrogel polymer to substrate showed satisfactory results for the rootstock 'Cleopatra' mandarin (Cruz *et al*., 2008) [19] and propagation by cuttings of sweet passion fruit (Hafle *et al*., 2008) [31]. Also, it favored the highest percentage of survival, length of roots and shoots of blackberry cv. 'Brazos' (*Rubus* sp.) (Moreira *et al*., 2012) [45] and in reducing the frequency of irrigation for the production of passion fruit seedlings (Carvalho *et al*., 2013) [18]. In citrus the additions of the hydrogel polymer to the substrate had increased the uniformity of seed emergence and reduced the time for the production of rootstocks due to the increase in water availability. Three rootstocks ['Rangpur' lime (*Citrus limonia* Osbeck), *Poncirus trifoliata* (L.) and 'Sunki' mandarin (*Citrus sunki* Hort. ex Tanaka); the addition of the polymer (0.4 g per container of Hidroplan-EB/HyB-M® polymer) to the substrate favored the percentage of emergence and EVI of 'Rangpur' lime and of mandarin 'Sunki' seeds in the growth chamber. The 'Rangpur' lime was the rootstock which presented the highest percentage of emergence and uniformity in both environments. The addition of the hydrogel polymer to substrate favored initial growth of citrus rootstocks (Fagundes *et al*., 2014) [24].

Vicent *et al*. (2005) [65] studied that, the performance citrus plants under repeated cycles of water deprivation followed by rehydration was studied. Twelve percent of the four month-old seedlings of the citrus rootstock, Carrizo citrange, grown on perlite survived after 6 complete cycles. Substrate amendment with 0.4 per cent hydrogel was effective in increasing plant survival to 79 per cent after 6 cycles. The behavior of one-year-old Cleopatra mandarin seedlings was comparable to Carrizo citrange despite differences in the duration of the drought period and in the substrate used. After 4 complete cycles of dry recovery, 63 per cent of plants survived. Addition of hydrogel (0.4%) to the substrate had a positive effect on Cleopatra mandarin survival although lower concentrations of hydrogel (0.2%) rendered erratic results. The hydrogel did not affect normal growth in well-watered plants. In view of these results, the concentration of hydrogel used for following experiments was 0.4 per cent and similarly Lawrence *et al*. (2013) [73] noticed higher root biomass in hydrogel amended sandy soil compared to other soils. In the case of *P. sylivestris* and *F. sylvatica*, however, shoot biomass was higher in hydrogel amended clay and loam soils compared to the sandy soil. Total biomass (root and shoot) in hydrogel amended soils ranged from 5 to 45 times higher in hydrogel amended soils when compared to the controls after subjecting trees o water stress.

Effect of hydrogel on plant growth

Kassim *et al*. (2017) [38] reported that, the highest pseudostem height was increased with water regime of the optimum amount of irrigation and 87.5 per cent of recommended amount of water and recorded (305, 310 and 296, 302.5 cm) respectively as compared with water regime of 75 per cent from recommended amount of water that recorded 286.25 and 293.75 cm in both tested seasons. The number of green leaves sprout on the plant and assimilation area (All the leaves blade area plant^{-1}) at bunch shooting stage was increased with increasing polymer quantity under any irrigation regimes. High rate of polymer (1500 g mat^{-1} year^{-1}) increased the emerged green leaves (13&13 leaf plant^{-1}) and assimilation area (26.3&27.37 m^2 plant^{-1}) in comparison with the control (without which polymers) or low amount of water (75%) since they recorded 11&12 leaf plant^{-1} or 9&9 leaf plant^{-1} as number of leaves and 15.5&16.5 m^2 plant^{-1} or 12.7 &12.8 m^2 plant^{-1} as number of leaves in Grand Nain cultivars in the two tested seasons, respectively. Differences in this respect between polymer amounts of 1500 and 500 g mat^{-1} year^{-1} were statistically insignificant in both tested seasons. Concerning the interaction, it is clear that, the highest value of pseudostem height, circumference, number of green leaves plant^{-1} and assimilation area were obtaind with 1500 g mat^{-1} year^{-1} SAP with the 8000 m^3 fed^{-1} year^{-1} water regime comparing with the lowest water regime (75%) or control (without SAP) in both seasons. Similarly Barakat *et al*. (2015) [12] also reported increased plant growth parameters like plant height (254.7 to 257.0 cm), circumference (79.43 to 79.70 cm), leaf area (1.43 m^2) and number of green leaves (11.82 to 11.87) plant^{-1} was recorded by using 150 g plant^{-1} of hydrogel with irrigation by 80% of irrigation requirement (IR). In potato the application of soil conditioner veterra hydrogel (VH) and irrigation every 26 days with 150 kg N fed-1 positively affected on vegetative growth characters like highest plant height (50.0 to 51.33 cm), relative growth rate (49.415 to50.424 mg g^{-1} day^{-1} and net assimilation rate (0.115 to0.117 mg cm^{-1} day^{-1} (Abd El-Badea *et al*., 2011) [1].

Flowering and harvesting time

In banana increasing amount of applied polymer significantly shortended the flowering and harvesting time of plants. Time to flowering tended to decrease with increasing water quantity. High applying polymer dose (1500 gm mat^{-1} $year^{-1}$) also high amount of irrigation (8000 m^3 fed^{-1} $year^{-1}$) decreased the period of flower compared with the control and the other polymer and irrigation treatments (361.7, 346.3 against 411.7, 418.3 days or 425 & 420 days) in both tested seasons. Time to harvesting of plants was clearly decreased by increasing the amount of polymer in both seasons. In this respect manner, 1500 and 1000 gm mat^{-1} $year^{-1}$ treatments were shortened the period to harvesting (122.7, 120.7 and 125, 123.7 days) in both tested seasons, respectively. The interaction between the SAP and the water regime indicated that the decrease of days to flower and period to harvest was detected when applyed SAP at the doses of 1500 and 1000 g mat^{-1} $year^{-1}$ with the 87.5% (7000 m^3 fed^{-1} $year^{-1}$) water regime comparing with the other treatments (Kassim *et al*., 2017) [38]. In Pot Mums (*Dendranthema grandiflora* L.) the highest, total number of flowers per plant (75.91), inflorescence width (30.68 cm), number of flowers per spray (8.69), number of sprays per plant (8.60), diameter of flower (1.23 cm), average flower weight (0.92 g), duration of flowering (47.57 days) and minimum days taken for the appearance of first flower bud (51.46 days) were obtained with the application of hydrogel at 0.5% concentration along with vermicompost (Tarun *et al*., 2016) [60].

Yield

Barakat *et al*. (2015) [12] reported that, the increased banana bunch weight (27.75 to 27.88 kg $plant^{-1}$), hand number per bunch (11.00 to 11.21), net bunch weight (2.31 to 2.36 kg), number of fingers per bunch (189-194) and finger weight (123.98 to 133.70 g) was recorded by using 150 g $plant^{-1}$ of hydrogel with irrigation by 80% of IR. The stockosorb technology was applied in the Khasi mandarin along with application of recommended doses of N: P: K (*i. e.,* 450, 450 and 900 g, respectively, to each tree). Irrigation was applied equally to all the plants. Yield per tree were recorded the maximum number (283) of fruits for the treatment 100 g of stock absorb application. This was the highest yield among all the treatments (Pattanaaik *et al*., 2015) [52]. Kassim *et al*. (2017) [38] The maximum average of bunch wt. $plant^{-1}$ and yield fed^{-1} were produced with the plants received polymer at 1500 and 1000 gm mat^{-1} $year^{-1}$ treatments which gave 31.0 & 29 for bunch wt. and 31.0 & 29.7 kg or 34.1& 32.6 and 34.1& 32.6 tons fed^{-1}. On both tested seasons, and the lightest average of bunches $plants^{-1}$ and yield fed^{-1} were obtained from the plants did not receive any polymers with low amounts of water. Tabulated results prove that the high amount of water gave the heaviest yield (as bunch weight Kg $plant^{-1}$ and tons fed^{-1}) compared with the lowest water regime. Interaction between the two main factors SAP and water regime was statistically significant. Higher yield was obtained due to the treatment of 1500 or 1000 g mat^{-1} $year^{-1}$ with the 100 per cent or 87.5 per cent water regime comparing with all other treatments.

In pot mums the application of hydrogel at 0.5% concentration along with vermicompost. Influence of irrigation intervals on the observed characters showed that the total yield of flowers per plant (58.92), inflorescene width (27.52 cm), number of flowers per spray (7.59), number of sprays per plant (7.49), diameter of flower (1.17 cm), average flower weight (0.75 cm), duration of flowering (45.98 days) and minimum days taken for the appearance of first flower bud (60.07 days) were highest by applying irrigations at an interval of 6 days. In treatment composition of, without hydrogel application (control) and irrigation interval of every 9 days, the attributes recorded minimum values (Tarun *et al*., 2016) [60]. Nikoorazm *et al.* (2009) [47] evaluated the effects of applying SAP (Tarawat A 200), irrigation regimes and polymer usage style on lettuce growth. In their study, four levels of SAP (0, 20, 40 and 60 g per plant), four irrigation regimes (5, 8, 11 and 14 days) and polymer usage style (layering and mixed whit soil) were performed on growth lettuce under greenhouse conditions. The results showed no significant differences between the irrigation regimes on fresh and dry weight. Moreover, the high level of SAP (60 gr per plant) increased fresh and dry weight compared with the control (without polymer) and the lowest level of polymer (20 per plant). These results indicated that high amounts of SAP had positive effects on growth lettuce.

Abd El-Badea *et al*. (2011) [1] found that, the application of soil conditioner veterra hydrogel (VH) and irrigation every 26 days with 150 kg N fed-1 positively affected on yield attributes like total yield (14.50 to 14.64 t fed^{-1}, highest grade-I (6.45 t fed^{-1}) and grade-II (7.60 t fed^{-1}) potatoes are harvested. Kassim *et al*. (2017) [38] reported that, the highest values of finger parameters were noticed with the plants received with 1500gm mat^1 $year^{-1}$ of polymer while the lowest values of finger parameters were noticed with the control plants. The tallest finger (21.05 & 18.82 cm), widest finger (3.57 & 3.60 cm) and heaviest finger (113.69, 121.93 g) were obtained from plants received 1500gm polymer mat^{-1} $year^{-1}$ while the shortest finger (14.5, 14.3 cm), narrowest one (3.0 & 2.98 cm) and lightest finger (94.93, 95.27g) were obtained from the plants did not received any of polymer amounts (control) in both tested seasons, respectively.

Fruit quality

The treatment 100 g stockabsorb resulted in highest reducing sugar content and was significantly higher than that of control. The fruit was of largest size. The ascorbic acid content in these fruits was also recorded highest *i.e.,* 106.613 mg 100 g^{-1} (Pattanaaik *et al*., 2015) [52]. Abd El-Badea *et al*. (2011) [1] reported that, the application of soil conditioner veterra hydrogel (VH) and irrigation every 26 days with 150 kg N fed^{-1} positively affected on potato tuber quality attributes like total dry matter (22.71 to 22.83%), starch content (14.78 to 15.70%), lowest sprouting percentage (18.10 to 18.60%), weight loss (4.0 to 4.18%) and decay percentage (3.80 to 4.11%) where as in control highest sprouting percentage (35 to 40%), weight loss (7 to 10%) and decay percentage (10.0 to 11.3%) was recorded.

Nutrition

Hydrogel application minimizes micronutrients from washing out to water tables and increase water consumption efficiency; also, they reduce the quantity of fertilization, since the nutrient leaching is prohibited by decreasing runoff. The nutrients are release and soil nitrification (El-Hady, 1981) [21], increase in nutrient absorption, osmotic moisture of soil and decrease in transplanting stresses that cause an improvement in plant growth reaction and increase in yield and reduction in production costs of plant. The highest values of macro (870.50 to 890.20, 93.6 to 95.2 and 1390 to 1412.40 mg 100 g^{-1} NPK) and micro-nutrients (42.6 to 43.8, 17.3 to 18.0 and 14.0 to 14.08 mg kg^{-1} Fe, Mn and Zn respectively) was obtained from potato receiving 150 kg N fed-1 and soil amending with VH under 26 days irrigation intervals (Abd El-Badea *et al*., 2011) [1].

Effect of hydrogel on water saving

The Stockosorb/ Raindrop/ Agrosorb (soil conditioner) able to retain water and plant nutrients. Stockosorb releases water and nutrient to the plants when surrounding soil near root zone of plants starts to dry up. Planting on well drained, gravely and sandy soils of Pasighat and lack of supplementary irrigation and application of nutrients causes gradual decrease in productivity of crops. The soils added with 100 g of stockosorb granule per plant reduced the irrigation interval considerably for Assam lemon (*Citrus limon*) with an increased yield and quality attributes (Pattanaaik *et al*., 2015b) [51]. Barakat *et al*. (2015) [12] reported that, by using 150 g $plant^{-1}$ of hydrogel with irrigation by 80 per cent of IR was helped in saving of 20% irrigation water without compromising yield and quality of banana. Uttam *et al*. (2015) [64] Bhagiratha along with other four groups of hydrogels were studied in the laboratory for its efficacy. On an average, polymers hold 332-465 times water of its weight. Around 72-82% of absorbed water was released within zero to 0.33 bar soil moisture tension. When subjected to 15 bar tension, about 91-96% of absorbed water was released. These results clearly show that the water held in polymer can easily be available to plants.

Joao *et al.* (2007) [34] also, reported that more than 90% of water absorbed by polymer was available to plant roots. On an average, at 15 bar tension, polymers hold water only 23 times of its weight. The available water to plant in polymers varied between 313-427 times of its weight. The wetting and drying cycles were studied for eight cycles to know if the polymers were equally effective in hydration in each wetting and drying cycle and after eight cycles of wetting and drying, it was noted that around 46-64% of its water absorbing capacity was reduced. Generally, in each crop growth period, there was at least 8-10 cycles of wetting and drying through intermittent rain or irrigation and drought. After 8 cycles of wetting and drying, the residual effect of polymer was around 50% in terms of water absorbing capacity. The data on soil moisture content recorded after applying water to saturation in different polymer treatments showed that moisture content was influenced by time and amount of polymers added in soils. During all the 24 days of study, soils treated with polymers showed higher moisture content than those without polymers. When normal soils reached permanent wilting point (w/w % soil moisture content around 5%) in ten days, it took around 16 days for 0.25% treated polymers soils and 20 days for 0.5% polymers treated soil to attain PWP. After 13 days of drying, when soils without polymer held just 1.9% moisture, the soils amended with 0.5% polymers treatment recoded 14% moisture and 0.25% polymers mixed soil recorded 9% moisture. Even after 24 days, soils with polymers SB3 and SB4 held around 6% moisture, which was more than PWP of the untreated soils studied. Cannazza *et al*. (2014) [74] results demonstrated that, the effectiveness of the superabsorbent polymer (SAP) in view of application in open-field cultivations. In this regard, it is worth emphasizing that the considered types of plants need substantial amount of water, and that a 50 per cent reduction of water (to the plants with SAP) was a water intentionally critical condition to demonstrate the beneficial effect of the SAP. This is particularly true considering that this experiment was carried out in summer, inside a greenhouse; in harsh environmental conditions (the temperature often exceeded 45 °C).

Conclusion

The application of hydrogel in arid and semi-arid regions improve soil properties, increases the water holding capacity of the soil, enhance of the soil water retention, improving irrigation efficiency, increasing the growth of various crops, and enhancement water productivity of the crop. It also provides a conducive atmosphere for the better growth of roots in well-drained soils and ultimately increases yield. According to chemical and physical structures of hydrogels, it can be used as absorbent in environment preservation in the agricultural sector as water retention, soil conditioners, and nutrient carriers. The employment of an innovative class of cellulose-based SAPs for optimizing water consumption in agriculture was assessed. The used SAP exhibited absorption capacities suitable for the envisaged application. The water-retaining properties of the SAP were studied through several experiments that allowed evaluate the beneficial effect on the optimization of irrigation. Indeed, the obtained results showed that the addition of SAP to the soil delays water evaporation, thus making water available to plants over a longer period of time. The experiments performed in conditions simulating open-field cultivations showed that, in spite of a significantly sharp reduction of supplied water (50%) for SAP-amended soils, the plants grew regularly.

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