Soil Environ. 40(2): 157-164, 2021
DOI:10.25252/SE/2021/172400
Online ISSN: 2075-1141
Print ISSN: 2074-9546

Effects of hydrogels on citrus yield and soil physico-chemical properties in rainfed area of district Attock

Abid Ali*[*1], Ayesha Malik[1], Rahina Kausar[1], Muhammad Imran Akram[2] and Muhammad Akmal[3]
[1]Soil and Water Conservation Research Station, Fateh Jang, Pakistan
[2]Regional Agricultural Research Institute, Bahawalpur, Pakistan
[3]Institute of Soil Science, PMAS-Arid Agriculture University, Rawalpindi, Pakistan
[Received:** October 05, 2021 **Accepted:** September 28, 2021 **Published Online:** December 04, 2021**]

Abstract

The hydrogel polymer materials are gaining importance with time in the arid and semi-arid regions to retain sufficient moisture for crop use during periods of water shortage/drought and thus to enhance crop yield. A long-term field study was conducted at village Muqam, Tehsil Fateh Jang (District Attock) during 2011-2017 with the objective to observe the effect of two synthetic hydrogel polymers on the conservation of moisture in soil, physico-chemical properties of soil and fruit yield of citrus. For this purpose, Qemisoyl (cross-linked copolymer of acrylamide and potassium acrylate) and Soil Magic were applied at the rate of 100g plant^{-1} (as a single time application at the start of experiment) to five-year-old randomly selected five plants in five replicates. Recommended doses of fertilizers (N, P & K) were mixed into the soil under canopy area of selected plants. All the treatments were arranged in randomized completely block design (RCBD). To estimate moisture conservation, soil samples were collected at the end of every month and their moisture contents were recorded. For physico-chemical characteristics, soil samples were collected at harvesting time of fruit every year and data on growth and yield parameters were recorded. The data were statistically analyzed through Statistix 8.1 software. The results revealed a consistent significant increase of moisture conservation during seven years of the study by both hydrogels over control. However, the magnitude of increase was relatively higher in the treatment of Qemisoyl than Soil Magic. The effect of hydrogels on soil pH and bulk density was significant as compared to control. The porosity and organic matter of soil were also influenced by the application of Qemisoyl, and Soil Magic compared to control. Both the hydrogels caused a significant increase in plant height, plant periphery and number of fruits per plant. These results revealed that the application of Qemisoyl and Soil Magic had positive effect on soil moisture conservation, soil properties, growth and yield of citrus which enhanced profitability of the citrus growers in rainfed area of district Attock.

Keywords: Hydrogels, moisture retention, soil properties, citrus, rain-fed area

Introduction

Citrus was grown on an area of 430535 acres during 2017-18 in Punjab province out of which 2172 acres were occupied in Rawalpindi Division. The Attock District grew citrus on 1733 acres (80% of Rawalpindi Division) in 2017-18. In 2016-17, citrus was grown on 1290 acres which was increased up to 443 acres in 2017-18, showing an increasing interest of the farmers in the area. Out of the total 8886 tonnes production in Rawalpindi division during 2017-18, 7345 tonnes (82.66%) of citrus production was contributed by Attock District (Government of Punjab, 2018). Water requirements of citrus estimated from evapotranspiration (ET) may range from 760 to 1240 mm annually (Gerber *et al*., 1973; Ayyappan, 2011). Field measurements in Florida have shown that citrus uses 960 to 1120 mm of water a year depending on tree size. This does not include water lost through deep percolation or run off.

Soil moisture is considered as a restricting factor for crop production particularly in dryland regions (Hayat and Ali, 2004). The use of polymer as soil conditioners has been introduced since the 1950s (Hedrick, 1952) to conserve moisture in soils (Elshafie and Camele, 2021). Like other agricultural crops, citrus also confronts major limitation of ample and steady availability of water in rain-fed area of Attock district because rainfall is scarce with uncertain frequency and distribution. Such problem may initiate drought stress if dry conditions prevail for a longer period of time (Abdelfattah, 2013). Limited water

***Email:** sawcrs@gmail.com
Cite This Paper: Ali, A., A. Malik, R. Kausar, M.I. Akram and M. Akmal. 2021. Effects of hydrogels on citrus yield and soil physico-chemical properties in rainfed area of district Attock. *Soil Environ.* 40(2): 157-164.

resources is the main constraint to successful crop production in dry lands since the availability of water is the decisive feature for determination of crop cultivation (Han *et al.*, 2018). Its role is even more crucial in rainfed area, where rainfall is the only source of irrigation for growing crops. The damages caused to crop production from dry weather can be reduced by proper management practices and conservation of rainwater (Bhardwaj *et al.*, 2007). Thus, enhancing soil water retention capacity is the most vital factor for harvesting optimum economic yield in rain-fed area because these soils are mostly low in organic matter causing poor water holding capacity (Mandal *et al.*, 2011). Among such practices, addition of large quantity of organic biomass could be possible on small scale but not giving viable results for its non-adoption over large scale (Ankenbauer and Loheide, 2017; Minasny and McBratney, 2018). However, some research studies have indicated that hydrogels, containing porous channels of polymers, have ability to hold large quantities of water (Azevedo *et al.*, 2016; Abdallah, 2019) and they are effective to enhance water-holding capacity by minimizing the excessive water drainage and evaporation (Cannazza *et al.*, 2014; Guilherme *et al.*, 2015). The scientific literature suggests that incorporation of a precise number of hydrogels in the soil can improve water holding capacity; minimize evapotranspiration and mitigate drought stress symptoms (Li *et al.*, 2018; Yang *et al.*, 2020). Among these hydrogels, Qemisoyl and Soil Magic proved very useful for increasing water retention. The enhanced availability of water may assist to defer the water stress condition during long periods of drought. It is assumed that water release through the network of hydrogel will develop additional space in the soil which will facilitate the root growth and water penetration for long term storage. Additionally, this stored water will restrict the nutrient losses through leaching and percolation, consequently, extending the supply of water and nutrients for extended duration (Pattanaaik *et al.*, 2015). Moreover, these are also very useful under water-limited conditions to cope with plant water needs (Karimi and Naderi, 2007; Bagheri and Afrasiab, 2013) beside fertilizer use efficiency in soil by extending nutrient release period (Zhang *et al.*, 2006). The review of literature indicates that little work on hydrogels in relation to citrus has been done so far, particularly in the rainfed tract of district Attock. Therefore, considering the benefits of hydrogels in peculiar climatic and edaphic conditions of this area, a long-term field study was executed to assess the beneficial effect of two soil conditioners on soil moisture retention, physico-chemical characteristics of soil and citrus yield in the rain-fed area of district Attock.

Materials and Methods

Study site

The study was carried out at village Muqam (33.6402047° N Latitude and 72.5611411° E Longitude) in Fateh Jang (District Attock). The location of experiment was in the area where most of the soils were prone to erosion, gully development, and soil moisture shortage. The climate was sub-humid to humid with rainfall ranging from 700-1000 mm but receiving only 30% rainfall after September during the critical period of Citrus fruit setting (Figure 1). The soils were mostly deep, well-drained but alkaline and calcareous (Reconnaissance Soil Survey, 1970). Before executing the experiment, composite soil sample representing the study-site was collected, air-dried, ground, passed through 2 mm sieve and analyzed in the laboratory for physico-chemical properties. Soil pH and ECe was determined by McLean (1982) and Richards (1954), soil organic matter by Walkley (1947), soil potassium by Rhodes (1982), phosphorus by Watanabe and Olsen (1965), and soil particle size by Bouyoucus (Gee and Bauder, 1986) as are given in Table 1.

Table 1: Soil properties at the start of experiment

Soil property	Value	Unit
pH	8.1	-
EC_e	0.8	dS m^{-1}
Bulk density	1.61	g cm^{-3}
Organic matter	0.91	%
P_2O_5	4.10	mg kg^{-1}
K_2O	84	mg kg^{-1}
Soil Texture	Sandy loam	-

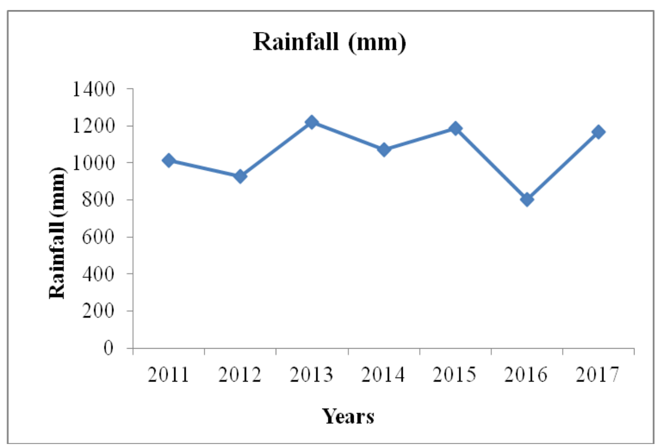

Figure 1: Annual average rainfall data as recorded at meteorological observatory of soil and water conservation research station, Fateh Jang (located at ~15 km of site of experiment)

Field experiment

The field study was carried at from 2011 to 2017. The experiment comprised of three treatments: T_1 (Control); T_2: Qemisoyl at 100 g plant^{-1}, and T_3: Soil Magic at 100 g plant^{-1}. These treatments were placed according to randomized complete block design (RCBD) with 5 replications. Both hydrogel materials were directly incorporated only once at the first year of study in the soil of canopy area of randomly selected citrus plants except control. For this purpose, five citrus plants having age of approximately five years were selected randomly. Blood red cultivar of citrus was chosen for this experiment. Their basins were prepared, and both the hydrogels were applied manually with one meter distance from trunk up to depth of 60 cm in all treatments except control. Recommended doses of fertilizers i.e., NPK at 900-250-500 g plant^{-1} were added every year along with 20 kg farmyard manure. Hoeing and weeding under the canopy area of plants and removal of diseased and dried plant parts were practiced as per need. Confidor at the rate of 2-2.5g L^{-1} was applied for sucking insects/pests. Bordeaux paste was applied on the cutting parts of branches and spray of fungicide 'Redomil' Gold was carried out at 5g L^{-1}. Chlorpyriphos was applied at the rate of 20 mL plant^{-1} to control termite attack. Pheromone traps 4-6 per plant were used to control fruit fly attack.

To monitor moisture conservation, soil samples were collected after every year, and their moisture contents were determined (Hess, 1971). For physico-chemical characteristics, composite soil samples were collected at the harvesting time of citrus fruit. Data on growth and yield parameters were recorded every year at the harvesting time of citrus fruit. The data were processed statistically using LSD test at 5% probability level (Steel *et al.*, 1997).

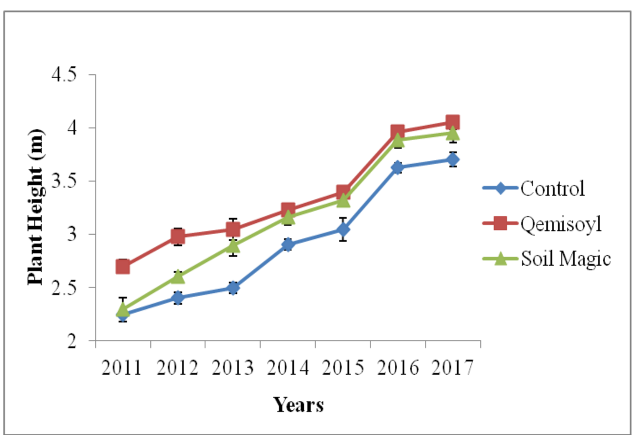

Figure 2: Impact of hydrogels on plant height of citrus

Results and Discussion

Impacts of hydrogels on citrus growth and yield

Plant height

The impact of hydrogels on plant height of citrus was obvious compared to control (Figure 2). Data revealed that plant height consistently increased in all the three treatments with time, however, the magnitude of increase was greater in hydrogels-treated plants than control plants. It could be noted that upsurge increase in plant height started during 2015 and onward. Overall, plant height over six subsequent years (2012 to 2017) significantly increased in hydrogels-treated plants compared to untreated control plants. No doubt, there was little increase in plant height till 2014, even then magnitude was still higher in the treated plants. Differences in plant height varied between the Soil Magic and Qemisoyl treated plants and these differences became conspicuous between both the hydrogels as well as compared to control during 2015, 2016 and 2017. These results elucidated that effect of Qemisoyl remained significant over control in contrast with that Soil Magic during the seven-year study. The overall effect of soil conditioners/hydrogels during 2011-17 remained statistically significant compared to control. Qemisoyl conditioner showed better performance than Soil Magic. It might be due to long and short-term moisture abilities of both the hydrogels. The results are in line with the earlier study of Keshavars *et al.* (2012) who observed positive effect of hydrogels in improving crop performance under dry conditions. A similar positive effect of hydrogels was also reported by Widiastuti *et al*. (2008) who concluded that hydrogels had potential to increase crop yield under arid conditions of world. Similar conclusions were also drawn by Elshafie and Camele (2021).

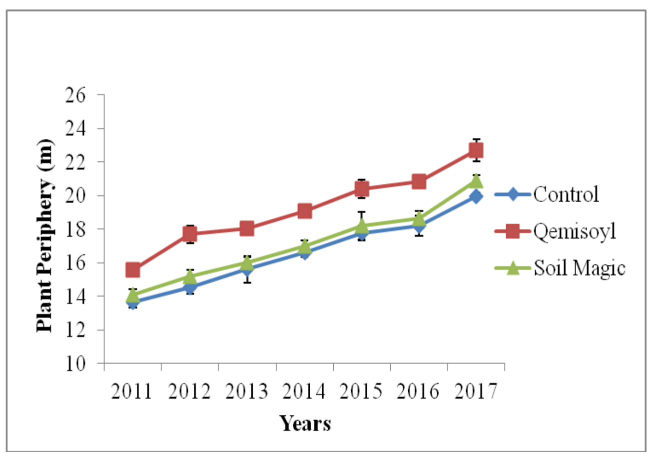

Figure 3: Impact of hydrogels on plant periphery of citrus

Plant Periphery

Effect of both hydrogels on plant periphery indicated increasing trend with time in all the three treatments (Figure 3). However, this increase was greater in the hydrogel treated plants than control. Seven-year study data highlighted that Qemisoyl not only caused significant increase in plant periphery over control but also with respect to Soil Magic. However, Soil Magic-treated plant showed significant increase over control from the start of experiment till 2017. It was also noted that increase caused by Soil Magic was little slower and lesser than Qemisoyl, might be due to less moisture holding power of Soil Magic. The results obtained by Johnson (1984) also confirmed increase of plant circumference with the application of hydrogel due to ability of rendering water in the root zone during acute periods and thus may prolong irrigation intervals and save wastage of water (Abdallah, 2019; Elshafie and Camele, 2021).

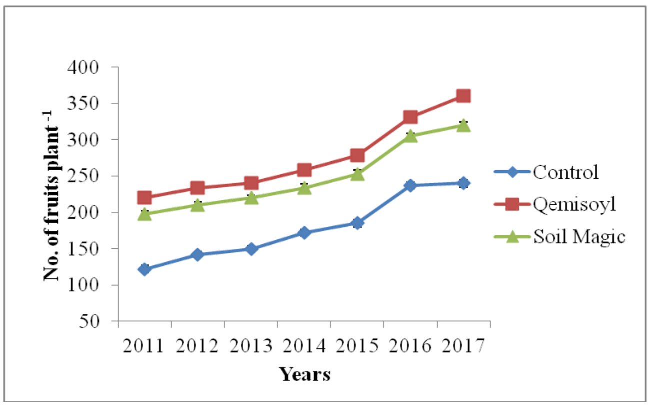

Figure 4: Impact of hydrogels on number of fruits plant^{-1}

Number of fruits plant^{-1}

Hydrogel treated plants depicted consistent and significant increase in fruit development and formation compared to untreated plants in control during the whole seven years of the study period (Figure 4). Relatively better fruit formation in Qemisoyl-treated plants compared to Soil Magic treated plants indicated its additive performance. The overall effect of both hydrogels on fruit formation in each year from 2011-17 was also statistically significant over control. Moreover, these results are in line with the findings of Keshavars *et al.* (2012), Abdallah (2019) and Yang *et al.* (2020) who observed positive effect of water absorbents on crop performance under dry conditions. Orikiriza *et al.* (2009) reported that hydrogel polymers enhanced plant growth by increasing water holding capacity in soil and prolonged the time till reaching wilting point and thus increasing plant survival under water stress conditions. Barakat *et al.* (2015) reported decrease in fruit drop ratio leading to more total yield and fruit weight under severe conditions in the presence of hydrogels.

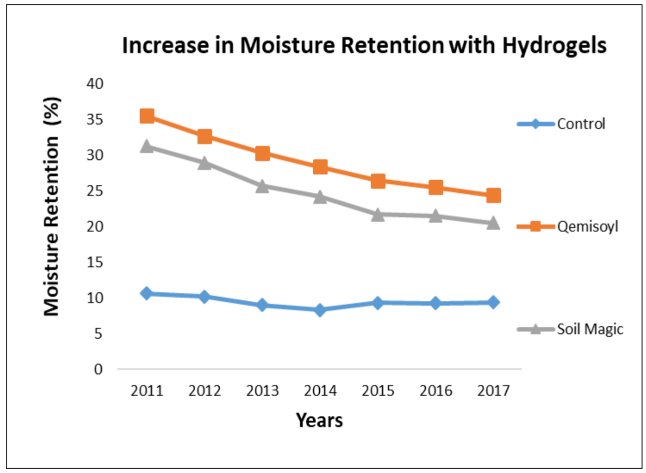

Figure 5: Effect of hydrogels on moisture retention in soil

Effect of hydrogels on moisture retention in soil

The cumulative effect of both the hydrogels on soil water holding capacity remained significant compared to control over the years as is depicted in Figure 5. The moisture content in control treatment remained more or less unchanged over the years. However, change in moisture retention over years in soil treated with both hydrogels was consistently decreasing but relatively less in Qemisoyl treated soil probably due to its more water retention ability. The data estimation over the years indicated that Qemisoyl held soil moisture in the range 35.5 to 24.3% while Soil Magic held 31.2 to 20.5% more compared to control starting from 2011 to 2017. This information suggested little differences in soil moisture holding ability of both the hydrogels. However, cost effectiveness should be determined in future studies for the practical application of these hydrogel. Losses of moisture over seven years of study were 11.1 and 10.7% in Qemisoyl and Soil Magic treated soil, respectively, which further confirmed the above inference of water holding ability of both the hydrogels. The previous studies indicated that after application of hydrogels, water absorbed by osmosis interacts with hydrogen atoms as positive ions leaving negative ions along length of the polymer chain. This yields several negative charges in its length which repel each other to unwind the polymer chain. The water molecules bind them with hydrogen bonding (Vicky, 2007). The hydrogels may serve as slow-release water reservoir in soil. They may retain soil water for extended time since they are capable of absorbing water several hundred times than their own weight (Orzolek, 1993). Monnig (2005) found in a study that the hydrogels have potential to absorb water as much as greater than four hundred times than their own weight. Nazarli *et al.* (2010) observed that hydrogels reduced the irrigation number to 50% by retaining maximum water in the soil. Similarly, Chirino *et al.* (2008) reported that hydrogel improves soil water holding capacity, minimizes evapotranspiration and allows plants to survive under water stress. Likewise, Wael *et al.* (2015) observed positive effect of hydrogel on soil moisture conservation along with improvement in other soil characteristics.

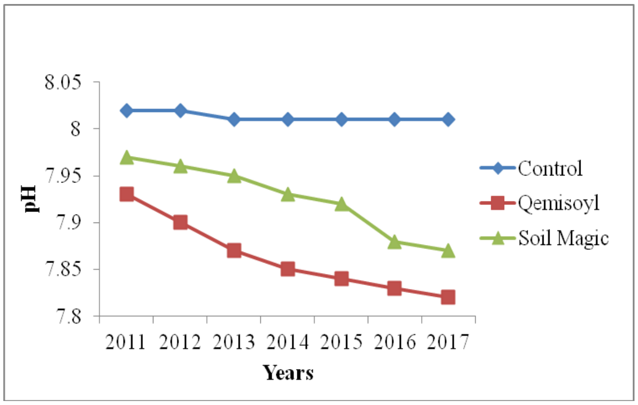

Figure 6: Effect of hydrogels on soil pH

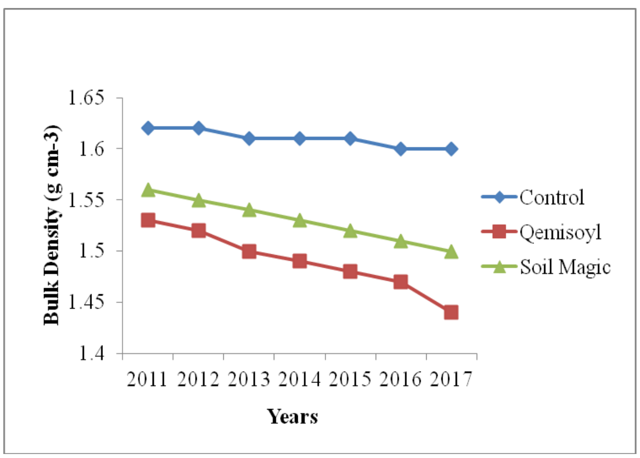

Figure 7: Effect of hydrogels on soil bulk density

Effect of hydrogels on soil physico-chemical properties

Effect of hydrogels on soil pH

The graphic line in Figure 6 indicated very little effect of hydrogels on pH of soil, however there was dropping effect in hydrogels-treated soil compared to no effect in control. The results indicated a little bit decrease in soil pH with the application of hydrogels compared to soil in control treatment over the whole period of seven years. There was 8.01 pH in the control soil which dropped to 7.86 in Qemisoyl treated soil and 7.93 Soil Magic treated soil. This drop in pH might be a consequence of varying moisture retention in the treatment of Qemisoyl and Soil Magic. Similar results have been reported by Wael *et al.* (2015) who observed that soil pH reduced significantly, and it was 7.28, 7.19, 7.11 and 7.02 at water absorbent concentration of 0.1, 0.2, 0.3 and 0.4%, respectively. The results of a field study conducted by El-Hady and Abo-Sedera (2006) further confirmed results of this study who recorded a slight reduction in pH with the use of hydrogel.

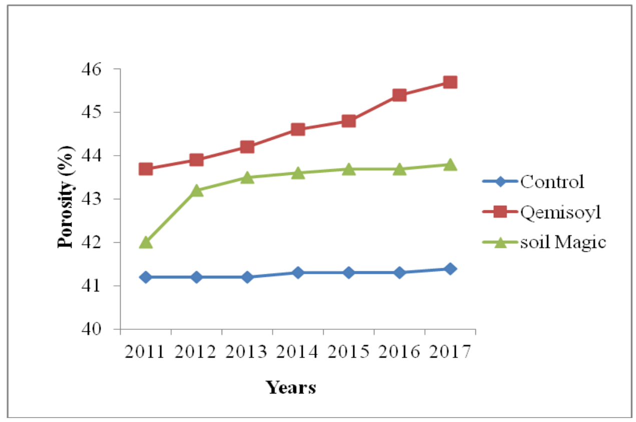

Figure 8: Effect of hydrogels on soil porosity

Effect of hydrogels on soil bulk density

The data recorded for the effect of hydrogels on bulk density of soil is presented in Figure 7. Mean value of bulk density for seven years period was 1.61 g cm^{-1} in control, and it dropped to 1.49 and 1.53 g cm^{-3} in Qemisoyl and Soil Magic-treated soils, respectively. The difference in the extent of reduction in bulk density might be due to hydrophilic characteristic of hydrogel which closely relates to increased microbial activity, soil organic matter and porosity of soil besides improved soil structure. Hayat and Ali (2004) reported similar results for a synthetic polymer on physico-chemical properties of a sandy loam soil and tomato yield. They observed that moisture content in the polymer-treated soil increased from 30 to 50%. The saturation percentage increased significantly, and the response was 17% better than the control. Soil density was reduced due to the application of polymer. The reduction in bulk density was 4 to 8%. Vegetative growth and fruit production of tomato crop increased significantly. In another study, Hayat and Chaudhry (2001) found that soil moisture content in the polymer treated soil noticeably varied than untreated soils. Saturation percentage increased from 30 (control) to 38% and particle density and bulk density reduced from 2.63 to 2.50 and 1.50 to 1.06%, respectively. In both the studies, the improvement of soil properties led to the significant increase in vegetative growth and fruit production of tomato crops. Similar kind of results have been reported by Wael *et al*. (2015) who observed effect of hydrogel on bulk density of the soil along with other characteristics. They amended the hydrogel in sandy soil at 0.0, 0.1, 0.2, 0.3 and 0.4% (w/w) and observed that bulk density got markedly reduced in the soil. The results of field study conducted by El-Hady and Abo-Sedera (2006) further confirmed the reduction in bulk density with the use of hydrogel.

Effect of hydrogels on soil porosity

The data regarding the effect of hydrogels on porosity of soil is presented in Figure 8. Data revealed that mean value over seven years period was 41.2% in control whereas it was 44.6 and 43.3% in Qemisoyl and Soil Magic treated soil, respectively. The increase in soil porosity was relatively more in Qemisoyl treated soil than Soil Magic treated soil. Narjary *et al*. (2012) concluded that hydrogels had potential to improve soil structure, thus resulting in good infiltration rate and availability of nutrients. El-Hady and Abo-Sedera (2006) and Wael *et al*. (2015) reported that use of hydrogel could improve water availability to crops by improving total porosity of soil with increasing water retention pores and decreasing drainage pores even under sandy soils.

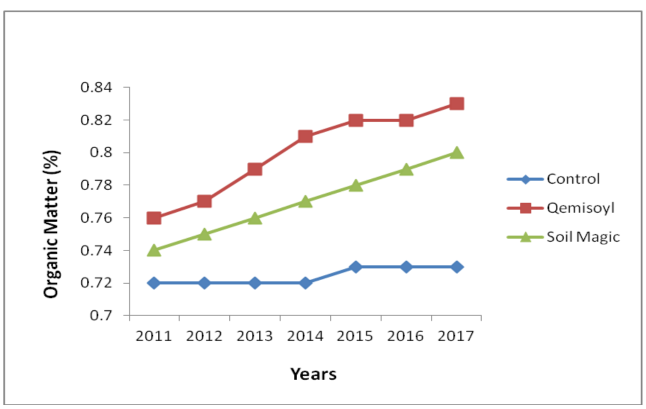

Figure 9: Effect of hydrogels on soil organic matter

Effect of hydrogels on soil organic matter

Effect of hydrogels on organic matter content of soil (Figure 9) indicated that mean value for soil organic matter over seven years period was 0.72% in control whereas it was 0.80 and 0.77 % in Qemisoyl and Soil Magic-treated soils, respectively. The increase in soil organic matter content by both the hydrogels may be due to availability of optimum moisture contents in soil for good growth, increased microbial activity resulting in increased degradation of organic substances. The results of field study conducted by El-Hady and Abo-Sedera (2006) have also confirmed an increase in organic carbon with the use of hydrogel.

Conclusion

The use of Qemisoyl and Soil Magic increased soil moisture in Rain-fed area. Their application also improved soil properties such as pH, bulk density, porosity and organic matter. The cumulative effect of increased moisture conservation and improvement of soil properties led to enhancement of citrus growth (in terms of plant height and periphery) and yield (in terms of number of fruits).

References

Abdallah, A.M. 2019. Influence of Hydrogel type and concentration, and water application rate on some hydraulic properties of a sandy soil. *Alexandria Science Exchange Journal* 40: 349–362.

Abdelfattah, M.A. 2013. Pedogenesis, land management and soil classification in hyper-arid environments: Results and implications from a case study in the United Arab Emirates. *Soil Use and Management* 29(2): 279-294**.**

Albaladejo, J., R. Ortiz, N.A. Garcia-Franco, R. Navarro, M. Almagro, J.G. Pintado and M. Martínez-Mena. 2012. Land use and climate change impacts on soil organic carbon stocks in semi-arid Spain. *Journal of Soils and Sediments* 13: 265–277.

Ankenbauer, K.J. and S.P. Loheide. 2017. The effects of soil organic matter on soil water retention and plant water use in a meadow of the Sierra Nevada, CA. *Hydrological Processes* 31(4): 891-901.

Asghari, S., F. Abbasi, and R.M. Neyshabouri. 2011. Effects of soil conditioners on physical quality and bromide transport properties in a sandy loam soil. *Biosystem Engineering* 109:90-97.

Ayyappan, S. 2011. NRCC Vision 2030. National Centre for Citrus Research, Nagpur, India.

Azevedo, G., G.B. de-Azevedo, A.M. de-Souza, C.L. Mews and J.R.L de-Sousa. 2016. Effect of hydrogel doses on the quality of *Corymbia citriodora* Hill & Johnson seedlings. *Nativa* 4: 244-248.

Bagheri, H. and P. Afrasiab. 2013. The effects of super-absorbent, vermicompost and different levels of irrigation water salinity on soil saturated hydraulic conductivity and porosity and bulk density. *International Research Journal of Applied and Basic Sciences* 4(8): 2381-2388.

Barakat M.R., S. El-Kosary, T.I. Borham and M.H. Abd-Einafea. 2015. Effect of hydrogel soil addition under different irrigation levels on Grand Nain banana plants. *Journal of Horticultural Science and Ornamental Plants* 7(1):19–28.

Bhardwaj, A.K., I. Shainberg, D. Goldstein, D. Warrington and G.J. Levy. 2007. Water retention and hydraulic conductivity of cross-linked polyacrylamides in sandy soils. *Soil Science Society of America Journal* 71(2): 406-412.

Cannazza, G., A. Cataldo, E. De-Benedetto, C. Demitri, M. Madaghiele and A. Sannino. 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.

Chirino, E., A. Vilagrosa, J. Cortina, A. Valdecantos, D. Fuentes, R. Trubat, V.C. Luis, J. Puértolas, S. Bautista, J. Baeza, J.L. Peñuelas and V.R. Vallejo. 2008. Ecological restoration in degraded drylands: The need to improve the seedling quality and site conditions in the field. p. 85-158. In: Forest Management. S.P. Grossberg (ed.). Nova Science Publishers, Inc. New York.

El-Hady, O.A. and S.A. Abo-Sedera. 2006. Conditioning effect of composts and acrylamide hydrogels on a sandy calcareous soil. II-Physico-bio-chemical properties of the soil. *International Journal of Agriculture and Biology* 8(6): 876-884.

Elshafie, H.S. and I. Camele. 2021. Applications of absorbent polymers for sustainable plant protection and crop yield. *Sustainability* 13: 3253.

Gee, G. and W. Bauder. 1986. Particle size analysis. p. 383-409. In: Methods of Soil Analysis, Part I, 2nd Ed. A. Klute (ed.). Madison, WI, USA.

Gerber, J.F., A.H. Krezdorn, J. F. Bartholic, J.R. Conner, H.H. Reitz, R.C. Koo, D.S. Harrison, E.T. Smerdon, J.G. Georg, L.D. Harris and J.T. Bradley. 1973. Water needs of Florida Citrus. *Proceedings of the Florida State Horticultural Society.* 86:61-64.

Govt. of the Punjab, Pakistan. 2018. Final Estimates of Citrus fruit (variety-wise) in the Punjab for the year 2017-18. Directorate of Agriculture, Crop Reporting Service Punjab, Lahore.

Guilherme, M.R., F.A. Aouada, A.R. Fajardo, A.F. Martins, A.T. Paulino and M.F.T. Davi. 2015. Superabsorbent hydrogels based on polysaccharides for application in agriculture as soil conditioner and nutrient carrier: A review. *European Polymer Journal* 72: 365-385.

Han, B., S.G Benner and A.N. Flores. 2018. Evaluating impacts of climate change on future water scarcity in an intensively managed semi-arid region using a coupled model of biophysical processes and water rights. *Hydrology and Earth System Sciences Discussions* 1-53.

Hayat, R. and M.A. Chaudhry. 2001. Effect of polymer (Aquasorb) on physicochemical properties of soil and response of tomato crop. *Pakistan Journal of Biological Sciences* 4(6):574-577.

Hayat, R. and S. Ali. 2004. Water absorption by synthetic polymer (Aquasorb) and its effect on soil properties and tomato yield. *International Journal of Agriculture and Biology* 6(6): 998-1002.

Hedrick, R.M. and D.T. Mowry. 1952. Effect of synthetic polyelectrolytes on aggregation, aeration and water relationships of soil. *Soil Science* 73(6): 427–441.

Hess, P.R. 1971. A Textbook of Soil Chemicals Analysis. John Murray, London.

Johnson, M.S. 1984. Effect of soluble salts on water absorption by gel forming soil conditioners. *Journal of Science and Food Agriculture* 35(10):1063– 1066.

Karimi, A. and M. Naderi. 2007. Yield and water use efficiency of forage corn as influenced by superabsorbent polymer application in soils with different textures. *Agricultural Research* 7(3): 187-198.

Keshavars L., H. Farahbakhsh and P. Golkar. 2012. The Effects of drought stress and super absorbent polymer on morpho physiological traits of pearl millet (*Pennisetum glaucum*). *International Research Journal of Applied and Basic Science* 3(1):148-154.

Li, J. X. Ma, G. Sa, D. Zhou, X. Zheng, X. Zhou, C. Lu, S. Lin, R. Zhao and S. Chen. 2018. Natural and synthetic hydrophilic polymers enhance salt and drought tolerance of *Metasequoia glyptostroboides* Hu and WC Cheng seedlings. *Forests* 9: 643.

Mandal, U.K., R. Kausalya, K.L. Sharma, B. Satyam, K. Venkanna, M.U. Bhanu, M. Mandal, R.N. Masane, B. Narsimlu, K.V. Rao, G.RS.C. Korwar and B. Venkateswarlu. 2011. Assessing soil quality under different land-use systems in a watershed of semi-arid tropics in India using GIS. *Soil Science Society of America Journal* 75(3): 1144-1160.

McLean, E.O. 1982. Soil pH and lime requirement. p. 199-224. In: Methods of Soil Analysis, part 2: Chemical and Microbiological Properties. A.L. Page (ed.). American Society of Agronomy, Madison, WI, USA.

Minasny, B. and A.B. McBratney. 2018. Limited effect of organic matter on soil available water capacity. *European Journal of Soil Science* 69 (1): 39-47.

Monnig S. 2005. Water saturated super- absorbent polymers used in high strength concrete. *Otto- Graf- Journal* 16: 193-202.

Narjary, B., P. Aggarwal, A. Singh, D. Chakraborty and R. Singh. 2012. Water availability in different soils in relation to hydrogel application. *Geoderma* 187–188:94–101.

Nazarli, H., M.R. Zardashti, R. Dravishzade and S. Najafi. 2010. The effect of water stress and polymer on water use efficiency, yield and several morphological traits of sunflower. *Notulae Scientia Biologicae* 2(4): 53-58.

Newman, J.E. 1968. Estimating water needs of citrus orchards. Citrus Industry 49(1):19-24.

Orikiriza, L.J.B., H. Agaba, M. Tweheyo, G. Eilu, J.D. Kabasa and A. Hüttermann. 2009. Amending soils with hydrogels increases the biomass of nine tree species under non-water stress conditions. *Clean-Soil Air Water* 37(8):615–620.

Orzolek, M.D. 1993. Use of hydrophilic polymers in horticulture. *Horticulture Technology* 3:41-44.

Pattanaaik, S.K., L. Wangchu, B. Singh, B.N. Hazarika, S.M. Singh and A.K. Pandey. 2015. Effect of hydrogel on water and nutrient management of *Citrus reticulate. Research on Crops* 16(1): 98-103.

Reconnaissance Soil Survey Campbellpur. 1970. Soil Survey of Pakistan.

Rhoades, J.D. 1982. Cation exchange capacity. p. 149-158 In: Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties. A.L. Page (ed.). American Society of Agronomy, Madison, Wisconsin, USA.

Richards, L.A. 1954. Diagnosis and Improvement of Saline and Alkali Soils. USDA Handbook 60.

Steel, R.G.D., J.H. Torrie and M.A. Boston. 1997. Principles and Procedures of Statistics: A biometrical approach. McGraw Hill Book Company Inc. New York. p. 633.

Vicky, W. 2007. Hydrogels: Water-absorbing polymers. *Catalyst* 18(1): 18-21.

Wael, M., Nada and O. Blumenstein, 2015. Characterization and impact of newly synthesized superabsorbent hydrogel nanocomposite on water retention characteristics of sandy soil and grass seedling growth. *International Journal of Soil Science* 10: 153-165.

Walkley, A. 1947. A critical examination of a rapid method for determining organic carbon in soils – effect of variations in digestion conditions and of inorganic soil constituents. *Soil Science* 63(4): 251-264.

Watanabe, F.S. and S.O. Olsen. 1965. Method for determination of phosphorus in water and $NaHCO_3$ extracts from soil. *Soil Science Society of America Proceeding* 29:677–678.

Widiastuti, N., H. Wu, M. Ang and D.K. Zhang. 2008. The potential application of natural zeolite for greater treatment. *Desalination* 218: 271-280.

Yang, F., R. Cen, W. Feng, J. Liu, Z. Qu and Q. Miao. 2020. Effects of super-absorbent polymer on soil remediation and crop growth in arid and semi-arid areas. *Sustainability* 12(18), 7825.

Zhang, J., H. Chen, P. Li and A. Wang. 2006. Preparation of poly (acrylic acid)/organo-attapulgite composite hydrogels and swelling behaviors in aqueous electrolyte solution. *Macromolecular Material Engineering*. 291: 1529-1538.