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The effect of soil moisture conservation techniques on almond seedling growth and survival rate

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ABSTRACT

This study was carried out in the semi-arid eastern slopes of Bethlehem during 2018/2019, in completely randomized design. The aim of this study is to evaluate and compare the effects of using different soil moisture conservation techniques on almond seedlings, in order to increase seedlings survival rate during the first year after planting under drought conditions. Four soil moisture conservation techniques (cocoon, superabsorbent-hydrogel, black plastic mulch and half-moon) and the control were examined to measure their impact on the survival rate, average increase in plant height, average increase in stem diameter, leaf area, branch length of almond (*Prunus amygdalus, var.* Um Al-Fahm) seedlings in addition to the soil moisture content during the first year after planting. The results of this study revealed significant positive effects for all the treatments compared to the control. At the end of the first summer season, the cocoon treatment was superior over the other treatments in term of survival rate (66.8%), average increase in plant height (22.75 cm), stem diameter (0.25 cm), branch length (94.33 cm), leaf area (4.83 cm^2) and soil moisture content followed by black plastic mulch. Cocoon is highly recommended in such conditions due to the highest results in term of soil moisture content, growth parameters and survival rate. Also, black plastic mulch revealed good results and it could be recommended due to the lower time consuming and implementing effort.

Keywords: Cocoon; Superabsorbent-hydrogel; Black plastic mulch; Half-moon; Drought; Fruit growth parameters; Soil moisture

1. Introduction

Almond (*Prunus amygdalus*) under the Rosaceae (rose) family it is originated in Asia, India and North Africa. The environmental condition for the Mediterranean basin [1] – including Palestine – is suitable for planting and producing almonds [2], especially in areas where the yearly rainfall is about 600 mm [3]. Almond have a strong and deep root system therefore it needs deep and fertile soils [4]. Moreover, the average annual temperature for almond is 10.5°C to 19.5°C and the dormancy period requires temperature falls between 0°C to 2.2°C. Regarding Um Al-Fahm *var.* the chilling requirement is considered medium (approximately 200 h during the year) [4]. Also, it's flowering period in Palestine from 4 Feb. to 26 Feb. [5,6]. Almond is one of the economic plants that considered valuable source of income for many Palestinian families, also, almond production reflects low rates of self-sufficiency and one of the food commodities that is imported from external markets [7].

Many studies revealed that climatic stress (e.g., drought, heat, etc.) has a direct effect on almond growth and productivity [3,8], and it was reported that Palestine is influenced by the global climate change, where the effects of high temperature and drought reduced the plants growth and development which led to lower production [9,10]. According to the statistics of the Ministry of Agriculture/State of Palestine

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and PCBS 2007 to 2017, the available data about almond (both of hard and soft varieties) revealed a significant decline in total area that planted with almond in the West Bank and Gaza Strip, where about 44,305 dunams (96.27% rain-fed) in 2009 were planted with almond trees, which gradually decreased to 26,760 dunams in 2017, which constitute 2.4% of total cultivated agricultural land [11,12]. In addition, rainfall fluctuation and scarcity during past decades [9], and the annual temperature rise by 0.8°C after 1990 as a result of climate changes, and all of these factors have a direct impact on Palestinian environment and agricultural sector [10], which make any improvement and development in these areas somewhat difficult.

Generally, the genus *Prunus* is typically severely impacted by abiotic stress particularly heat and drought stress [13] in semi-arid areas, which primarily affects the plant physiology like photosynthesis, germination, stunted seedlings, flowering, ripening stages and death of cells and tissues, in addition to plant survival, plant morphological and production parameters [14]. Drought and long summer causes a rapid loss of the water content of the soil, which causes an increase in the percentage of deaths of fruit trees and a decline in the agricultural area, which negatively effects on plant growth and productivity, simultaneously there is a lot of the obstacles and challenges that facing this sector according to the national strategy for the Palestinian agricultural sector 2017–2022 [15].

Therefore, there are endeavours to exploit all cultivable areas, through creating suitable environmental conditions to become more suitable for agriculture regardless of difficult environmental factors, to reduce the effects of the emerging challenges that cause stress on plants in the agricultural sector, that may cause a fail of the crops. Therefore, a paradigm shifts in soil and water conservation, and its management is needed for agricultural sustainability [16].

Over the past several years many of non-government organizations in Palestine have worked on water conservation but (to the best of our knowledge at the time of the experiment implementation) there is no scientific research studies to evaluate and compare the effects of using different water conservation techniques (cocoon, mulch, superabsorbent-hydrogel, half-moon harvesting technique and control) on growth and survival rate on almond seedlings in West Bank under semi-arid conditions.

Therefore, our results will be the main source for the efficiency of these techniques in soil moisture conservation under similar environmental conditions, in addition, if these techniques prove its positive effects on soil moisture conservation, then the cultivation of fruit trees in the semi-arid areas might be extended in the West Bank.

Consequently, agricultural sustainability can be achieved by providing holistic management of soil and water resources, through providing essential water to succeed the agriculture, especially in low-rainfall lands by finding solutions that help in increasing the water content in the soil through using improved technologies [16]. Also, many researchers indicated the positive effect of soil/water conservation techniques on the morphological characteristics and survival rate of almonds [17–19]. Some of the most important purposes of using soil moisture conservation techniques, that it used as measures for achieving greater water efficiency to enhance plant growth and produce more food with less water [20,21], and to reduce the water use accomplished by implementation of water conservation [22]. Moreover, to increase the period of moisture content in plant root zone after water harvesting [20,22], conserve the soil from erosion, moisture deficit and loss of fertility [23], and to increase the survival rate of seedlings [24]. And to reduce water losses by runoff and evaporation while maximizing soil moisture storage for crop production [25].

The aim of this study is to evaluate and compare the effects of using different soil moisture conservation techniques on almond seedlings, in order to increase seedlings survival rate during the first year after planting under drought conditions.

2. Materials and methods

2.1. Study site

This study was conducted at Za'tara town which is located at the eastern part of Bethlehem Governorate. It is located at an latitude N: 174326 and E: 119618, and altitude of 577 m above sea level [26,27]. The land is gently sloping (2%–3%). The land use during the last 10 y was for field crops cultivation.

The area was classified semi-arid. The amount of rainfall at the study site was highly fluctuated during the past two decades with an average yearly rainfall is about 324 mm [26]. However, according to Za'tara rain monitoring station 2019 the rainfall during the study year (2018/2019) was extraordinary high with 621 mm. Recorded about 35% of total annual rainfall in February 2019 (Fig. 1). In addition, during the 41 rainy days there were three heavy rain events that constitute more than 40% of the total precipitation during the rainy season 2018/2019 (Fig. 2).

The long term average annual temperature is 18°C, and the long term average annual humidity is about 60% [26]. According to Palestinian Astronomical Society [28], during years 2018/2019 the mean maximum temperature was in May (32.9°C), while the mean minimum temperature was in January (8.1°C) (Fig. 3).

2.2. Land preparation

The study land area is about 1.5 dunams (space between trees 4.5 m × 4.5 m), which was conventionally ploughed in 22-Oct/2018 at 25–30 cm depth before the first rainfall. Each 1.5 dunams where allocated for one plant species and planned to plant the seedling in a 4 m^2 × 5 m^2. The holes were drilled by mechanical auger. A seventy five seedling of 1 y old uniform in size and vigor were brought from a licensed nursery and certificated according to the regulations of the Palestinian Ministry of Agriculture. The rootstock was bitter almond. Moreover, the seedlings were bare rooted and free from mechanical injuries, pests and diseases and they were treated with systemic insecticide and fungicide in the field. The seedlings were planted in the field in January 2019. Other than the treatments applied, the traditional cultural practices were practiced after planting that included adding fertilizer (organic fermented sheep manure) 60 L manure/seedling. Also, in 10 to 14-April/2019, the grass was cut by using a hand held mechanical grass

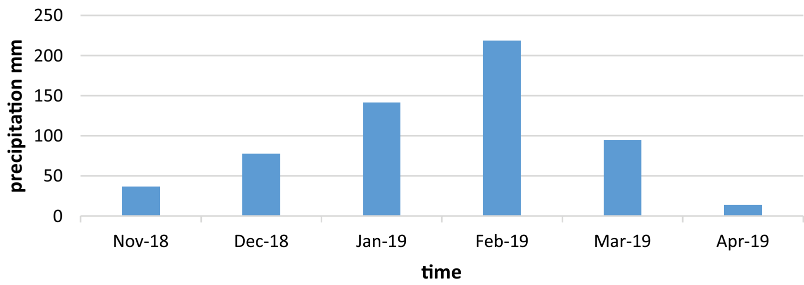


Fig. 1. Monthly precipitation (mm) in the experimental area during November 2018–April 2019 (*Source*: Za'tara Secondary School rainfall monitoring station).

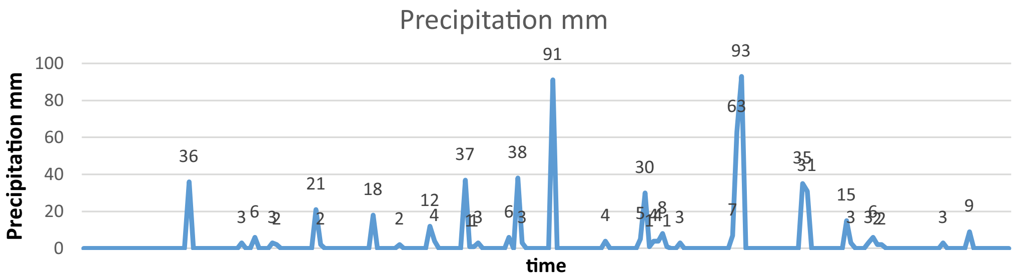


Fig. 2. Daily rain (mm) in the experiment area November 2018–April 2019 (*Source*: Za'tara Secondary School rainfall monitoring station).

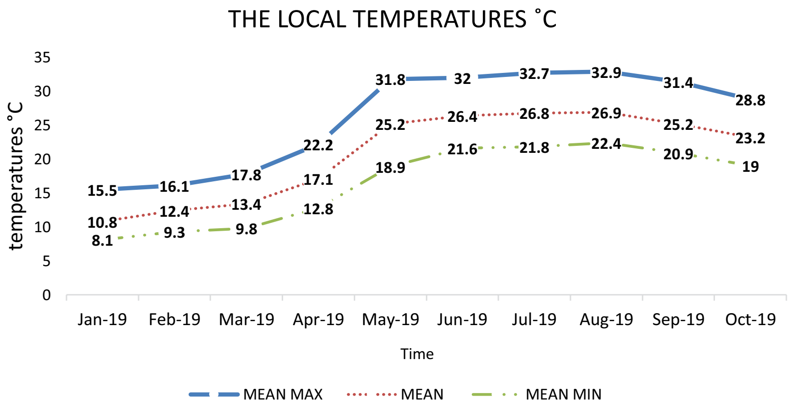


Fig. 3. Minimum, maximum, and mean monthly temperatures °C in the experiment area during Jan-2019–Oct-2019 (*Source*: The Palestinian Astronomical Society [28]).

cutter (STIHL/FS 260 C-E) and the mowed grasses were left on the ground, then the land was ploughed by tractor 30 cm depth on 10-May 2019.

2.3. Treatments and estimated parameters

The plant species under investigation is almond "*var.* Um Al-Fahm" were planted in an area of 1.5 dunams and four different water conservation techniques (treatments) and the traditional method (control) were applied as shown below:

(1) Cocoon: 25 L storage capacity; (2) half-moon bunds: 2 m^2 storage area; (3) mulch: 1 m^2/tree; (4) superabsorbent-hydrogel (ZEBA): 60 g/tree; (5) control: without any intervention.

Fifteen seedlings (replicates) were assigned for each treatment in a completely randomized design to measure the effects of these treatments on soil moisture content, survival rate, and plant growth (increase in plant height, increase in stem diameter, leaf area, and branches length) of almond seedlings in the first year after planting. The first measurement was recorded at the time of planting in January-2019, then the measurements for the whole parameters were taken monthly between July/2019 until October/2019.

2.3.1. Soil characteristics

In May 2019, soil samples were collected by hand using a manual soil auger from a soil depth of 30 cm. Three representative samples were taken from various locations on the land. The samples were air dried at room temperature, cleaned off from any unwanted materials (stones, plant residues), then crushed with a pestle and mortar and passed through a 2-mm sieve. Subsequently, the samples were examined in a labs in accordance with the soil and water analysis manual [29] as displayed in Table 1. All soil analysis were conducted in the labs of Agriculture College at Hebron University.

The level of elements content within the soil (low, medium, high, or excessive, and sufficient or not) were determined according to soil test interpretation guide [31] and [35].

2.3.2. Soil moisture content

From May-2019 until August-2019, mixed samples were collected monthly. With three replicates for each treatment, measurements were taken 25–40 cm away from the seedling trunk, and at 30 cm soil depth. Additionally, the initial soil sample was taken 20 d after the most recent rainfall, and it was then taken monthly. The soil moisture content was determined using a drying process in an oven set at 105°C (overnight for more than 16 h), in the soil and water lab at the College of Agriculture/Hebron University soil moisture was calculated as a follow:

$$\text{Soil moisture content} = \left[\frac{W - D}{W}\right] \times 100\% \tag{1}$$

where W: wet weight (g); D: dried weight (g).

2.3.3. Increase in plant height

The average increase in plant height was measured monthly from Feb-2019 until the growth was stopped in Oct-2019, average increase in plant height was measured from the grafting point to the highest active bud for 3 replicate/treatment by using the scale meter and expressed in (cm).

2.3.4. Stem diameter

The average increase in stem diameter were taken for 3 replicate/treatment, 5 times at one month interval through the experiment period ware measured from time of planting then continued monthly from June-2019 until Oct.-2019 at 1 cm above the grafting point by using manual calliper and expressed in (cm).

2.3.5. Leaf area

Seven mature green and fresh leaves/tree were randomly selected from different branches, and 3 replicates/treatment were measured with a specialized leaf area meter (CI-202 area meter) in the plant production lab at Hebron University. However, this parameter was measured once in July-2019, when the leaves were fully matured based on the climatic conditions of the site.

2.3.6. Branch length

The first branches lengths were measured for 3 replicates (seedling) per treatment, and the length of every single branch in every replicate (seedling) was measured only one time by using metallic meter scale in June-2019. Then the average length of the branches was calculated for every seedling and expressed in (cm).

2.3.7. Survival rate

The survival rate for the 15 seedlings/treatment was recorded, throughout the study period, observations were taken ten times, where the first observation recorded on 22-Feb.2019 and the last one being made on 21-Sep. 2019.

Table 1
Parameter and methods used for soil analysis

No.	Parameters	Method	References
1.	Soil texture	Pipette	[30]
2.	Nitrogen (N)	Kjeldahl	[30]
3.	Phosphorus (P)	(Olsen Test) by spectrophotometer	[31]
4.	Potassium (K^+)	Flame photometer or/atomic absorption	[32]
5.	Organic matter	Walkley–Black method (titration)	[33]
6.	Acidity	pH-meter method	[34]
7.	Salinity	Electrical conductivity meter	[34]
8.	Soil moisture	Gravimetric method (or drying method in the oven)	[30]
9.	Cation exchange capacity (CEC)	Atomic absorption spectrophotometer	[29]
10.	Sodium	Flame photometer	[29]
11.	Zinc (Zn)	Atomic absorption	[29,34]
12.	Manganese (Mn)	Atomic absorption	[29,33]
13.	Calcium (Ca^{+2})	Atomic absorption	[29,34]
14.	Magnesium (Mg^{+2})	Atomic absorption	[29,34]
15.	Nitrate (NO_3^-)	Spectrophotometer	[29,34]

The survival rate was calculated through follow formula:

$$\text{Survival Rate }\% = \frac{N}{15} \times 100\% \quad (2)$$

where N: Number of the monthly survived seedlings; 15: Replicates (15 seedlings).

2.3.8. Data analysis

Data were statistically analyzed using one-way analysis of variance (ANOVA), followed by Tukey's HSD test that was used to compare the mean of individual parameter by SigmaStat 3.5, at 95% confidence.

3. Results

3.1. Soil analysis

Soil analysis showed that the soil has clay texture (53.31%), moderately alkaline pH (pH = 7.86), low organic matter content (1.89%), low salinity (EC = 0.75 ds/m) and low sodium content (102.65 ppm). Meanwhile the phosphorus, calcium contents were medium (15.39 and 1,844.03 ppm which equal 9.61 meq/100 g soil, respectively), while there was high content of potassium and nitrogen (275.36 ppm, 3.15 g/kg soil, respectively) and magnesium (227.15 ppm), and excessive residual soil nitrate (NO_3^-) content (39.07 ppm). Also, the cation exchange capacity (CEC) was 12.27 meq/100 g soil which is within the range for clay soils [36]. Finally, sufficient levels of zinc (2.32 ppm) and manganese (51.33 ppm) were observed in the soil (Table 2).

3.2. Soil moisture content

The results of soil moisture in the experimental site showed significant variation due to the examined treatments (Fig. 4).

Basically, the highest soil moisture values were observed in cocoon, superabsorbent-hydrogel (S.HG.) and mulch in May and June were the difference was insignificant among each other, but it was significantly higher than that in control and half-moon (H.M.) treatments (Fig. 4). Starting from the end of June, a sharp decrease in soil moisture was observed in all treatments, at 18th of August all of the water conservation treatments were significantly have a higher soil moisture than control, where the cocoon treatment have significantly the highest SMC (13.83%) compared with mulch (12.66%), S.HG. (12.54%) and H.M. (11.97%).

3.3. Survival rate

The results showed that cocoon technique was superior to the other treatments in term of survival rate (Fig. 5), where 66.7% of the almond seedlings were survived by the end of September/2019. Black plastic mulch followed cocoon and it revealed a 40% survival rate until the end of September/2019, while H.M. and superabsorbent-hydrogel (S.HG.) have only 13.3% survival rate for both. Moreover, the sharpest decline in survival rate was recorded for the control, where most of the seedlings died in the beginning of May (20% survived) and all of them were died in August. Generally, most of the deaths in almond seedlings for all treatments except cocoon occurred before June/2019, after that time the survival rate dropped slowly for all treatments (Fig. 5).

3.4. Increase in plant height

The results showed a significant difference between the treatments in the average increase in plant height and it was significantly highest for the cocoon treatment (22.75 cm), followed by mulch treatment (14.5 cm) (Fig. 6). Furthermore, there was insignificant difference between the S.HG. (9.5 cm), the H.M. (4.3 cm) and control (2 cm).

3.5. Average increase in stem diameter

Regarding the plant stem diameter there was a significant effect on the average increase in stem diameter due to the treatments in almond seedlings (Fig. 7). Mulch and cocoon treatments presented the highest increase in stem diameter (0.28 and 0.25cm respectively) followed insignificantly by the H.M. and S.HG. that revealed the same results (0.18 cm). However, the control revealed significantly the lowest value. Furthermore, there was insignificant difference between the S.HG. (9.5 cm), the H.M. (4.3 cm) and control (2 cm).

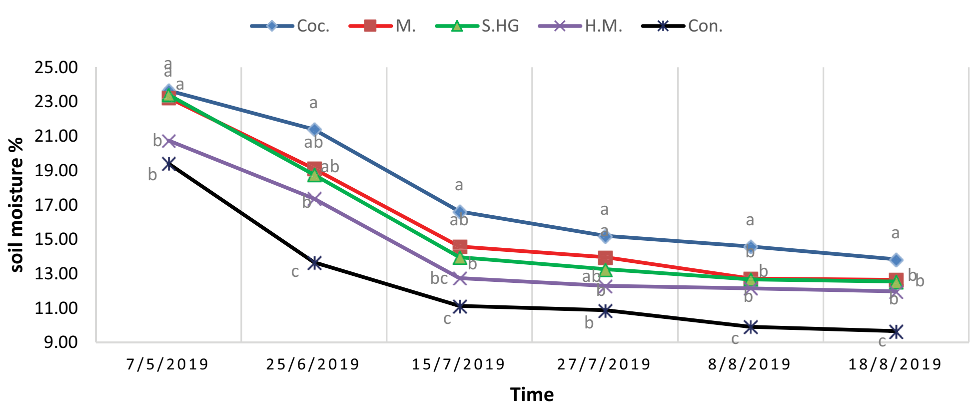


Fig. 4. Average soil moisture content for the examined treatments (vertical comparison) in the site during the period from May-2019 till Aug-2019. Coc. (cocoon), M. (mulch), S.HG. (superabsorbent-hydrogel), H.M. (half-moon) and Con. (control) treatments.

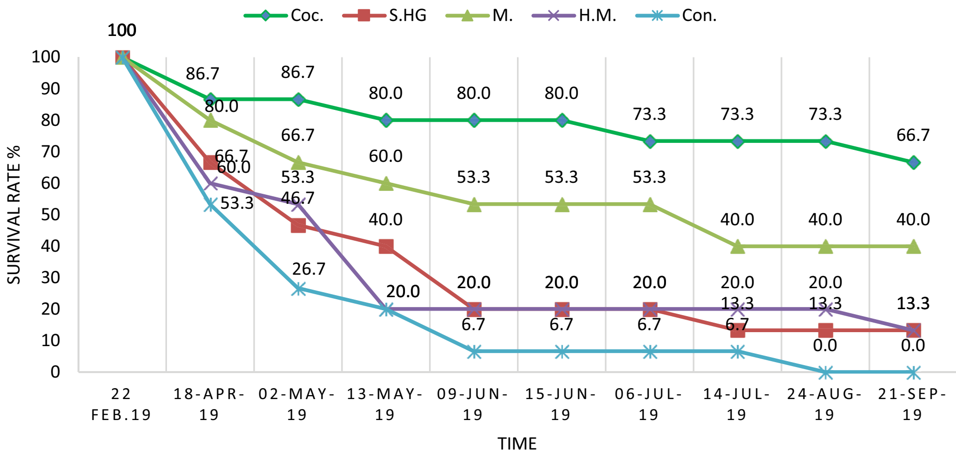
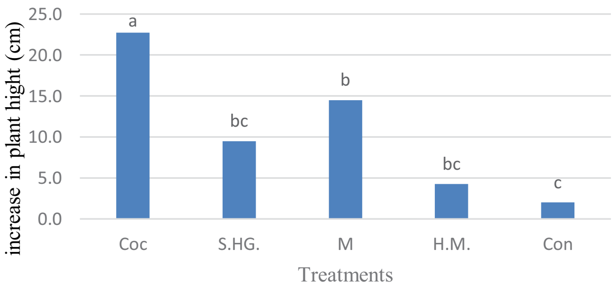
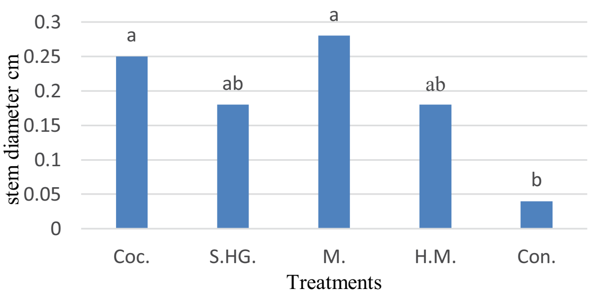


Fig. 5. Survival rate in almond seedlings, (vertical comparison). Coc. (cocoon), M. (mulch), S.HG. (superabsorbent-hydrogel), H.M. (half-moon) and Con. (control) treatments.



Treatment	Std. Dev.
Coc.	± 3.862
S.HG.	± 6.455
M.	± 7.234
H.M.	± 5.679
Con.	± 1.414

Fig. 6. Average increase in almond seedling height (plant height vertically). Coc. (cocoon), M. (mulch), S.HG. (superabsorbent-hydrogel), H.M. (half-moon), Con. (control) and Std. Dev. (standard deviation).



Treatment	Std Dev
Coc	± 0.0408
S.HG.	± 0.175
M.	± 0.275
H.M.	± 0.175
Con	± 0.0375

Fig. 7. Average increase in stem diameters (in almond), at 1 cm above the grafting point. Coc. (cocoon), M. (mulch), S.HG. (superabsorbent-hydrogel), H.M. (half-moon), Con. (control) treatments and Std. Dev. (standard deviation).

3.6. Total branch length

Total branch length was significantly affected by the treatments (Fig. 8). Cocoon showed the highest value for the average total branch length and significantly it was higher (94.33 cm) than H.M. and control. H.M. and control presented insignificantly lower values than the mulch and S.HG. treatments

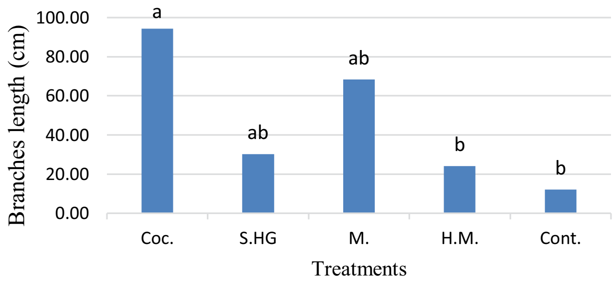
3.7. Leaf area

The highest value was revealed by the cocoon (4.83 cm^2), followed insignificantly by S.HG., mulch and H.M. (4.61, 3.86, and 3.32 cm^2, respectively). On the other hands, the results showed significantly higher average leaf area than the control that revealed the lowest value (1.7 cm^2) (Fig. 9). Also, the H.M. and the control treatments showed insignificant differences.

4. Discussion

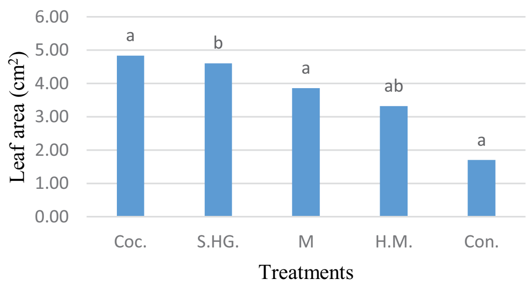
4.1. Soil moisture

The results of this study revealed significant positive effects for all the treatments compared to the control. At the end of the first summer season, the cocoon treatment



Treatment	Std. Dev.
Coc.	± 39.939
S.HG	± 6.453
M.	± 35.168
H.M.	± 18.520
Con	± 5.346

Fig. 8. Average total branch length for almond seedlings. Coc. (cocoon), M. (mulch), S.HG. (superabsorbent-hydrogel), H.M. (half-moon), Con. (control) treatments and Std. Dev. (standard deviation).



Treatment	Std. Dev.
Coc.	± 0.130
S.HG	± 1.231
M.	± 0.523
H.M.	± 1.091
Con.	± 0.117

Fig. 9. Average leaf area of almond per one leaf. Coc. (cocoon), M. (mulch), S.HG. (superabsorbent-hydrogel), H.M. (half-moon), Con. (control) treatments and Std. Dev. (standard deviation).

Table 2
Soil chemical and physical properties at the study site

pH	EC 1:2.5	Organic matter	Cation exchange capacity (CEC)	Soil texture				Sodium Na^+
				Sand	Silt	Clay	Texture	
–	ds/m	%	meq/100 g soil	%	ppm	%		ppm
7.86	0.75	1.89	12.27	31.05	103	53.31	Clay	103

was superior over the other treatments in term of survival rate (66.8%), average increase in plant height (22.75 cm), stem diameter (0.25 cm), branch length (94.33 cm), leaf area (4.83 cm^2) and soil moisture content followed by black plastic mulch.

Insufficient water in the new orchards of stone fruit cause slowing of vegetative growth in which maximum growth is needed to speed up the development of the orchards canopy. Hence, the measuring soil moisture is one of the most important criteria that must be done, due to their relation with the direct development of plant growth and its apparent effect on accelerating vegetative growth and increasing the size of root system, which is reflected on all plant physiology [37].

In spite of the high rainfall in the agricultural season 2018/2019 (621 mm), the rain was distributed unevenly, where the heavy rain during short times was obvious (40% of the rain was fallen heavily in three separated days). On the other hands, temperature records showed that the lowest degree was recorded in January 2019 (8.1°C) and the maximum in August 2019 (32.9°C) [28].

The variation in soil moisture content among the soil moisture conservation techniques that were studied in this experiment may be due to the differences in the mechanism of each technique used (amount and duration of moisture that they can keep [38]. The superiority of cocoon, mulch and S.HG. over H.M. and control through the experiment period might be related to the fact that the half-moon only works as a water harvesting technique, and there is no mechanism for storing water for longer time or to reduce evaporation. Despite that, half-moon showed a higher soil water content value than the control, which could be due to its ability to collect more water in the storage area and thus longer time to evaporate [39]. Another possible explanation for the dominance of cocoon, mulch and S.HG. over H.M. and control is the soil type, where the heavy clay soil in our experiment site is able to form a deep cracks when it dries [40] which encourage water evaporation from the soil especially in the absence of soil preservation techniques [41].

The superiority of cocoon treatment was related to the lower soil water evaporation which might be related to the design of the cocoon that composed from covered basin inside the soil that surrounding the plant roots, which also prevent growth of weeds near the seedling base [42], and preserve the water from lose due to many factors like temperature, wind and rapid infiltration [17,43–45]. Furthermore, the cocoon supplies water to the soil slowly and continuously via an extended wick that passes from the water basin of the cocoon to the seedling root zone and transports the water by the capillary action [45].

The slight variations among the cocoon technique and mulch until the end of July might be due to the ability of the mulch to work as protective layer to cover the top of the soil [46], to protect it from being eroded, regulate soil temperature, reduce evaporation, and thereby conserve soil moisture in the upper layer of soil beneath the mulch [47,48].

On the other hands, The S.HG. that was amended in the root zoon retains water during the rainy season and more than 90% of absorbed water by S.HG. is available to plant roots [49,50] and then the soil starts drying since the S.HG. starts gradually releases the retained water to the soil [51] through the diffusion mechanism [52], which may explain the closeness of the S.HG. soil moisture values between first measuring and until the end of June/2019 (Fig. 4). Furthermore, the efficacy of S.HG. during the first duration of the experiment could be related to the soil type, where S.HG. is reported to be more efficient in the clayey soil (higher water preserving) [53]. Also Yu et al. [53] found that the S.HG. that mixed with fine textured soil that include 18.5%–34.4% clay content preserved 51% higher water content than loamy sand soil (7.5%–12.5% clay content). Additionally, soil pH could affect the S.HG. water preservation capacity due to the fact that when soil pH around 7 or little bit above revealed the best efficacy for S.HG. [54] which fit with the pH result in our experiment site (pH = 7.86). Later, the decline of the S.HG. soil moisture values that appeared clearly at the beginning of July/2019 might be related to the lack of the function of S.HG. as a water retaining aid for irrigation due to the absence of supplementary irrigation [55] which upon time leads to desorb the water from the S.HG. particles to the soil until they dry together as a result of the high temperature and evaporation rate [56].

In addition to many factors that may accelerate the loss of the conserved water from S.HG. material and it's biodegradation, such as time of application and the amount and types of S.HG. that added to the soil [50,54]. Moreover, temperature, pH and light may influence the S.HG. efficacy [57]; [and lead to S.HG. biodegradation through collapse of hydrogels network via erosion and bacterial activities [57,58] and cause breakdown of the polymer into smaller fragments and ultimately loss of functional properties in these materials [57,59].

4.2. Survival rate

Usually, most of the seedlings mortality occurred during the initial life stage of orchards establishment due to many stress factors [60]. Generally, the low survival rate and plant growth could be related to the irregular precipitation and the high average temperature [14,61] in the experiment site.

Here, the superiority of cocoon technique in terms of survival rate (66.8%) until Aug-2019 was related to the higher soil moisture content [44]. Moreover, control, H.M. and S.HG. treatments survival rates declined sharply starting after May/2019 (Fig. 5), this could be interpreted by the lower soil moisture content that resulted from the irregular rainfall distribution during the wet season and the heavy rains could magnify the problem of water availability for plants [62], increase soil erosion, water runoff [21] and nutrients leaching [63]. Therefore, huge efforts and research have been implemented worldwide to mitigate the drought effects [64].

Environmental factors or influence of seasonality are the most important that may lead to seedling mortality such as high temperatures, drought, water stress, etc. also, root diseases reduce the survival rate after transplanting, in addition to the bad agricultural practices [65]. Macera et al. [64] indicated that the seedlings after 10 months from transplanting could become more tolerable to unfavorable conditions with less mortality and may develop a root system that has a better capacity to absorb nutrients and water from the soil.

The decrease of the survival rate to about less than 80% in all treatments just in the first three months after planting although soil moisture content is still high could be explained by the seedling transplantation form from the nursery (bare rooted or container), where it was reported that the survival rate in bare-root seedling was 10% to 20% lower comparing with container seedlings [1]. Moreover, many studies revealed that container seedlings were more tolerant to water stress [66], planting stress; [67,68], also, it's showed more tolerant to the environment harshness [68,69] more than bare-root seedlings directly after planting.

The tested soil in our experimental site was clayey soil that contains 53.31% clay, 31.05% sand, and 15.64% silt; it's high clay minerals content and heavy textured, in such soil, low soil moisture causes deep cracking in the soil [40,70]. Also, Haghnazari et al. [71] indicated that cracks volume increased as the soil got dryer. Indeed, soil cracks increase surface evaporation and make the soil more influenced by the air temperature [72]. Furthermore, the root may be snapped due to high cracks expanding force [40]. In techniques subjected to higher water loss from the soil such as control, H.M., and S.HG. which were lower than that in cocoon and mulching techniques that lead to less mortality as a result of decreasing evaporation and increasing soil moisture content.

4.3. Plant growth parameters

The significant differences within the growth parameters during the experiment life span could be related to the wide-range impact of the examined treatments on soil moisture content, water absorption [53], nutrients availability [73], soil physical, biological and chemical properties [74] and roots distribution [4].

As soil water conservation techniques (cocoon, mulch and S.HG.) work to increase the soil water content available to plants [44,47,48,50], accordingly, this increase in the content of plant available water can, under conditions of climate change, mitigate abiotic stress; it could thus enable longer intervals between consecutive supplemental irrigations, and improve plant growth rate and performance [18,20,53]. Also, increase in nutrient absorption, osmotic moisture of soil and decrease in transplanting stresses cause improvement in plant growth reaction [54].

4.4. Increase in the plant height

Our results showed that the highest increase in the height of almond seedling was in cocoon treatment (22.75 cm), this might be related to the higher moisture content [17]. The higher moisture content facilitates the nutrient absorption, which leads to better plants growth [50,56,75].

The reduction in seedlings height in (control, half-moon and S.HG. treatments) could be related directly to the drought effect, where the control treatment had significantly lower soil moisture than cocoon and consequently the control treatment showed the lowest increase in seedlings height (2 cm).

4.5. Increase in the stem diameter

Regarding the stem diameter, the highest values that were revealed by mulch and cocoon showed synchronously related to the higher soil moisture content parallel in these two treatments compared to the other treatments. Gohari et al. [76] studied the effect of different levels of drought stress on different varieties of almond seedlings and found that seedlings that were subjected to severe drought stress revealed lower stem diameter.

Our results showed that stem diameter significantly affected by soil moisture levels as shown in mulch and cocoon treatments (Fig. 7) where they showed the highest stem diameter respectively, which is associated with the highest soil moisture content, Notably, in our experiment the reduction in soil moisture content in all treatments was accompanied with reduction in stem diameter, which going on with, [77] who reported that the decrease of soil water content to 60% and 30% field capacity (FC) caused a 20% and 46% respectively reduction in stem diameter, as compared to the control.

4.6. Total branch length

The highest average total new branch length were shown in cocoon (94.33 cm) and in mulch (69 cm) treatments, which might be due to the effect of high soil moisture which lead to reduce the effect of abiotic factors such as soil cracking and high temperature [40]; where this explains the lowest mean branch length growth in control treatment (12.17 cm).

Many studies reported that the longitudinal growth of branches in young almond seedlings was highly affected by the different genotypes and morphological trails which have different response to drought stress [76]. Or even at the level of difference in irrigation intervals, as shown in Zamani et al. [78] study on different irrigation regimes on almond seedlings, where their results appeared that plant growth (including branch length) reduced with increase the intervals between irrigation times.

4.7. Leaf area

The insignificant variation in leaves area among the treatments (except the control) in almond – in spite of the drought stress-could be related to the almond genotype effect, where the almond leaves area responses to drought stress is varied among the almond species [79]. Keeping in mind that the reduction in leaf area is one of the avoidance mechanisms that is utilized by the almond to reduce water loss [80].

Zokaee-Khosroshah et al. [79] found a significant variation in the total leaves area as a result of drought stress effect. And the leaf area decreased by increasing the drought and water stress [81]. According to Romero et al. [82] the leaf area at the time of maximum stress was significantly lower for water-stressed trees than unstressed trees in other treatments. Which could be related to the reduction of water uptake in the leaves cytoplasm, which consequently minimize cell expansion and thus leaf area [83].

Moreover, reduction of the leaf area in fruit trees is one of the main factors that cause reduction in photosynthetic process [84]. Nortes et al. [85] reported a significant reduction in the photosynthetic capacity of young branch of almond trees under mild to moderate soil water deprivation. Not only that, but also water stress directly disturb the photosynthetic process by damaging the chloroplast membrane and disturbing the hormonal and chemical activities in the plant cell [83]. Moreover, the heat stress that accompanies the drought stress leads to increase the leaf temperature [86], which also disturbs the photosynthesis process [87].

5. Conclusion

- Under semi-arid conditions, soil moisture conservation techniques and water harvesting techniques can improve the survival rate and plant growth in fruit tree seedlings by using the suitable technique.
- The need for irrigation for almond seedling that planted under control and water harvesting technique (half-moon) treatments started from April (last rains), and due to increase the mortality through the summer should continue irrigation until first rains next season. The suitable time for irrigation mulch treatment start from beginning of May. While the cocoon may only need refilling the basin one time more in mid of June to keep the survival rate more than 80% in case of bare-root seedling.
- Our results indicate that under similar environmental conditions the SMC, survival rate and plant growth for almond can be improved by using cocoon technique.
- Also, black plastic mulch revealed good results and it could be recommended in such environmental conditions due to the lower time consuming, lower implementing efforts and lower cost.
- The hydrogel materials are not efficient in the drought conditions in the absence of supplementary irrigation, or according to the usage instructions of the producer.
- We recommend further studies to evaluate the effects of these techniques on almond seedling for more than 1 y by using bare root and containers/bags seedlings under similar environmental conditions.

References

[1] T. Javaid, S. Mahmood, W. Saeed, M.Q. Alam, A critical review on varieties and benefits of almond (Prunus dulcis) – review, Acta Sci. Nutr. Health, 3 (2019) 70–72.

[2] J.M.H. Ighbareyeh, A. Cano-Ortiz, E. Cano, Case study: analysis of the physical factors of Palestinian bioclimate, Am. J. Clim. Change, 3 (2014) 223–231.
[3] A. Yadollahi, K. Arzani, A. Ebadi, M. Wirthensohn, S. Karimi, The response of different almond genotypes to moderate and severe water stress in order to screen for drought tolerance, Sci. Hortic., 129 (2011) 403–413.
[4] J.M.H. Ighbareyeh, E.C. Carmona, A.C. Ortiz, A. Abdel-Rahim Ahmed Suliemieh, M.M.H. Ighbareyeh, A. Al-Qader Mohammed Daraweesh, Analysis of physical factors of climate and bioclimate and their effects on almonds production to increase the economy in Hebron area of Palestine, Arabian J. Geosci., 11 (2018) 683, doi: 10.1007/s12517-018-4026-0.
[5] M. Yunos, N. Abdul-Hady, Irrigated Almond Cultivation Manual, (AMENCA3 Program), Palestine, 2018.
[6] D. Holland, I. Bar-Ya'akov, K. Hatib, R. Birger, 'Matan', a new self-compatible almond cultivar with high-quality kernel and good yield, Am. Soc. Hortic. Sci., 51 (2016) 302–304.
[7] The Applied Research Institute – Jerusalem (ARIJ), Palestinian Agricultural Production and Marketing between Reality and Challenges, Food Production-Consumption Assessment to Improve Sustainable Agriculture & Food Security in the West Bank, The Ministry of National Economy and The Ministry of Agriculture, Palestine, 2015.
[8] J.M.H. Ighbareyeh, E.C. Carmona, Impact of environment conditions on grapevine (*Vitis vinifera* L.): to optimal production and sustainability, achieving food security and increasing the Palestinian economy, J. Geosci. Environ. Prot., 6 (2018) 62–73.
[9] I. Moh'd Albaba, P. Gupta, Assessment of climate change impacts on wheat and Barley production quality and quantity in Palestine, Int. J. Bot. Stud., 2 (2017) 52–54.
[10] A. Abu Hammad, A.M. Salameh, Temperature analysis as an indicator of climate change in the Central Palestinian Mountains, Theor. Appl. Climatol., 136 (2019) 1453–1464.
[11] Palestinian Central Bureau of Statistics (PCBS), Agricultural Census 2006 – Final Results, Palestinian Territory, Ramallah, Palestine, 2017.
[12] Palestinian Central Bureau of Statistics (PCBS), National Accounts at Current and Constant Prices, 2015, Ramallah, Palestine, 2016.
[13] I. Paudel, H. Gerbi, Y. Wagner, A. Zisovich, G. Sapir, V. Brumfeld, T. Klein, Drought tolerance of wild versus cultivated tree species of almond and plum in the field, Tree Physiol., 40 (2020) 454–466.
[14] S. Toscano, A. Trivellini, G. Cocetta, R. Bulgari, A. Francini, D. Romano, A. Ferrante, Effect of preharvest abiotic stresses on the accumulation of bioactive compounds in horticultural produce, Front. Plant Sci., 10 (2019) 01212, doi: 10.3389/fpls.2019.01212.
[15] Palestinian Ministry of Agriculture, National Agricultural Sector Strategy (2017–2022), Ramallah, Palestine, 2016.
[16] A. Kumawat, D. Yadav, K. Samadharmam, I. Rashmi, Soil and Water Conservation Measures for Agricultural Sustainability, R.S. Meena, R. Datta, Eds., Soil Moisture Importance, IntechOpen, 2020.
[17] W.A. Abdullah, Pilot Cocoon Planting Technology as a Model to Enable the Growing of Olive and Almond Trees in Arid Condition in Palestine, Special Report, MENAQUA Land Restoration of the Middle East and North Africa, 2017.
[18] A. Oraee, E.G. Moghadam, The effect of different levels of irrigation with superabsorbent (S.A.P) treatment on growth and development of Myrobalan (*Prunus cerasifera*) seedling, Afr. J. Agric. Res., 8 (2013) 1813–1816.
[19] S. Mehraj, F.A. Peer, B.A. Pandit, I.A. Bisati, I.H. Ganai, Effect of organic and inorganic mulch es on growth, yield and quality attributes of plum cv. Santa Rosa under temperate conditions, Green Farm. Int. J., 6 (2014) 1048–1051.
[20] S.H. Al-Seekh, A.G. Mohammad, The effect of water harvesting techniques on runoff, sedimentation, and soil properties, Environ. Manage., 44 (2009) 37–45.
[21] A.Y. Safi, A.G. Mohammad, Impacts of different water harvesting techniques on barley productivity under semi-arid conditions in Palestine, Hebron Univ. Res. J. (A), 8 (2019) 66–80.
[22] M. Kumari, D. Singh, Water conservation: strategies and solutions, Int. J. Adv. Res. Rev., 1 (2016) 75–79.
[23] A.B. Saeed, A.M.N. Hamid, M.A.M. Abdalhi, A.A. Mohamed, Evaluation the effects of water harvesting techniques in improving water conservation and increasing crop yields, Int. J. Sci. Eng. Invest., 8 (2019) 106–114.
[24] J. Abedi-Koupai, J. Asadkazemi, Effects of a hydrophilic polymer on the field performance of an ornamental plant (*Cupressus arizonica*) under reduced irrigation regimes, Iran. Polym. J., 15 (2006) 715–725.
[25] C.K.K. Gachene, S.O. Nyawade, N.N. Karanja, Soil and Water Conservation: An Overview, W. Leal Filho, A.M. Azul, L. Brandli, P.G. Özuyar, T. Wall, Eds., Zero Hunger, Encyclopedia of the UN Sustainable Development Goals, Springer, Cham, 2019, pp. 1–15.
[26] ARIJ GIS, The Palestinian Community Profiles and Needs Assessment, Applied Research Institute-Jerusalem, 2009. Available at: http://vprofile.arij.org/bethlehem/
[27] https://geomolg.ps/L5/index.html?viewer=A3.V1
[28] Palestinian Astronomical Society [Unpublished Raw Data on Precipitation and Temperature], 2019.
[29] H. AL-Bakier, S. Tomeizh, Soil and Irrigation Department – Laboratory Manual, Laboratory of Soil Science, Hebron University, Faculty of Agriculture, Palestine, 2011.
[30] M. Pansu, J. Gautheyrou, Handbook of Soil Analysis, Mineralogical, Organic and Inorganic Methods, Springer Berlin, Heidelberg, 2006.
[31] E.S. Marx, J. Hart, R.G. Stevens, Soil Test Interpretation Guide, Oregon State University Extension Service, EC 1478, 1999. Available at: https://piercecd.org/DocumentCenter/View/670/OSU-Soil-Test-Interpretation-002?bidId=
[32] D. Warncke, J.R. Brown, In: J.R. Brown, Ed., Potassium and Other Basic Cations: Recommended Chemical Soil Test Procedures for the North Central Region, North Central Regional Research Publication Bull. No. 221 (Revised), Missouri Agricultural Experiment Station SB 1001, University of Missouri, 1998, pp. 31–33.
[33] S.M. Combs, M.V. Nathan, In: J.R. Brown, Ed., Soil Organic Matter: Recommended Chemical Soil Test Procedures for the North Central Region, North Central Regional Research Publication Bull. No. 221 (Revised), Missouri Agricultural Experiment Station SB 1001, University of Missouri, 1998, pp. 53–58.
[34] D.A. Whitney, In: J.R. Brown, Ed., Soil Salinity: Recommended Chemical Soil Test Procedures for the North Central Region, North Central Regional Research Publication Bull. No. 221 (Revised), University of Missouri, 1998, pp. 59–60.
[35] D.A. Horneck, D.M. Sullivan, J.S. Owen, J.M. Hart, Soil Test Interpretation Guide, Oregon State University, EC 1478, 2011, pp. 1–12.
[36] H.D. Foth, Soil Mineralogy: Cation Exchange Capacity of Soils: Fundamentals of Soil Science, 8th ed., Published in Canada: Michigan State University, United States, Copyright by John Wiley and Sons, 1990, pp. 166–167.
[37] A. Pérez-Pastor, M.C. Ruiz-Sánchez, R. Domingo, Effects of timing and intensity of deficit irrigation on vegetative and fruit growth of apricot tree, Agric. Water Manage., 134 (2014) 110–118.
[38] T. Oweis, D. Prinz, A. Hachum, Water Harvesting: Indigenous Knowledge for the Future of the Drier Environments, ICARDA, Aleppo, Syria, 2001, 40 pages.
[39] P. Tamagnone, L. Cea, E. Comino, M. Rosso, Rainwater harvesting techniques to face water scarcity in African drylands: hydrological efficiency assessment, Water, 12 (2020) 2646, doi: 10.3390/w12092646.
[40] A.P. Whitmore, W. Richard Whalley, Physical effects of soil drying on roots and crop growth, J. Exp. Bot., 60 (2009) 2845–2857.
[41] A.M.A. Fattah, S.H. Khurshid, R.A. Ahmad, Soil Cracking Depth as Influenced by Soil Physical Properties, JZS, Special Issue, 2nd Int. Conference of Agricultural Sciences, The University of Sulaimani, Kurdistan Region, Iraq, 2018, pp. 105–114, doi: 10.17656/jzs.10657.

[42] W. Petros, G.B. Tesfahunegn, M. Berihu, J. Meinderts, Effectiveness of water-saving techniques on growth performance of Mango (*Mangifera indica* L.) Seedlings in Mihitsab-Azmati Watershed, Rama Area, Northern Ethiopia, Agric. Water Manage., 243 (2021) 106476, doi: 10.1016/j.agwat.2020.106476.

[43] Union of Agricultural Work Committees (UAWC), Fanack and Land Life Company (LLC), Pilot COCOON Planting Technology as a Model to Enable the Growing of Olive and Almond Trees in Arid Conditions in West Bank and Gaza Strip, Union of Agricultural Work Committees (UAWC), Palestine, 2017, pp. 1–21.

[44] Land Life Company (LLC), Benefits of the Cocoon Technology, 2015. Available at: https://landlifecompany.com/technology/ (Accessed on 28 March 2020).

[45] P.I. Tapia, L. Negoita, J.P. Gibbs, P. Jaramillo, Effectiveness of water-saving technologies during early stages of restoration of endemic *Opuntia cacti* in the Galápagos Islands, Ecuador, Peer J., 7 (2019) e8156, doi: 10.7717/peerj.8156.

[46] S. Bahadur, S. Pradhan, S. Verma, R. Maurya, S.K. Verma, Role of plastic mulch in soil health and crop productivity, Mulching Agric., 459 (2018) 338–344.

[47] K. Jabran, In: P.K. Sharma, B. Jirli, R.M. Cham, Role of Mulching in Pest Management and Agricultural Sustainability, Niğde, Turkey, 2019.

[48] H.-C. Pang, Y.-Y. Li, J.-S. Yang, Y.-S. Liang, Effect of brackish water irrigation and straw mulching on soil salinity and crop yields under monsoonal climatic conditions, Agric. Water Manage., 97 (2010) 1971–1977.

[49] J.C.M. Bordado, J.F.P. Gomes, New technologies for effective forest fire fighting, Int. J. Environ. Stud., 64 (2007) 243–251.

[50] A. Nirmala, T. Guvvali, Hydrogel/superabsorbent polymer for water and nutrient management in horticultural crops – review, Int. J. Chem. Stud., 7 (2019) 787–795.

[51] R. Liao, W. Wu, S. Ren, P. Yang, Effects of superabsorbent polymers on the hydraulic parameters and water retention properties of soil, J. Nanomater., 2016 (2016) 5403976, doi: 10.1155/2016/5403976.

[52] F. Demitri, C. Scalera, M. Madaghiele, A. Sannino, A. Maffezzoli, Potential of cellulose-based superabsorbent hydrogels as water reservoir in agriculture, Int. J. Polym. Sci., 2013 (2013) 435073, doi: 10.1155/2013/435073.

[53] J. Yu, J.G. Shi, X. Ma, P.F. Dang, Y.L. Yan, A.I. Mamedov, I. Shainberg, G.J. Levy, Superabsorbent polymer properties and concentration effects on water retention under drying conditions, Soil Sci. Soc. Am. J., 81 (2017) 889–901.

[54] D.K. Dehkordi, The effects of superabsorbent polymers on soils and plants, Pertanika J. Trop. Agric. Sci., 39 (2016) 267–298.

[55] F. Nnadi, C. Brave, Environmentally friendly superabsorbent polymers for water conservation in agricultural lands, J. Soil Sci. Environ. Manage., 2 (2011) 206–211.

[56] M. Bakass, A. Mokhlisse, M. Lallemant, Absorption and desorption of liquid water by a superabsorbent polymer: Effect of polymer in the drying of the soil and the quality of certain plants, J. Appl. Polym. Sci., 83 (2002) 234–243.

[57] S. Siyamak, Functional Starch-Based Hydrogels: Renewable Material Solutions for Wastewater and Agriculture Industries, A Thesis Submitted for the Degree of Doctor of Philosophy at The University of Queensland, School of Chemical Engineering, Australia, 2020.

[58] Y. Tang, A.P. Wheeler, Chapter 10 – Environmental Factors That Influence Biodegradation of Thermal Poly(aspartate), R.A. Gross, C. Scholz, Eds., Biopolymers from Polysaccharides and Agroproteins, ACS Symposium Series, American Chemical Society, Vol. 786, 2001, pp. 157–171.

[59] A. Mignon, N. De Belie, P. Dubruel, S. Van Vlierberghe, Superabsorbent polymers: a review on the characteristics and applications of synthetic, polysaccharide-based, semi-synthetic and 'smart' derivatives, Eur. Polym. J., 117 (2019) 165–178.

[60] S.C. Grossnickle, Importance of root growth in overcoming planting stress, New For., 30 (2005) 273–294.

[61] R. Basheer-Salimia, J.K. Ward, Climate change and its effects on olive tree physiology in Palestine, Rev. Res., 3 (2014) 1–7, doi: 10.9780/2249-894X/372014/688.

[62] C. Huang, U. Yermiyahu, M. Shenker, A. Ben-Gal, Effect of leaching events on the fate of polyhalite nutrient minerals used for crop fertilization, J. Plant Nutr., 43 (2020) 2518–2532.

[63] A. Eludoyin, O. Eludoyin, S. Eslamian, In: S. Eslamian, F. Eslamian, Eds., Drought Mitigation Practices, Handbook of Drought and Water Scarcity, Francis and Taylor, CRC Press, USA, 2017, pp. 391–400.

[64] L.G. Macera, S.R. Pereira, A.L.T. de Souza, Survival and growth of tree seedlings as a function of seed size in a gallery forest under restoration, Acta Bot. Bras., 31 (2017) 539–545.

[65] S.C. Grossnickle, Y.A. El-Kassaby, Bareroot versus container stocktypes: a performance comparison, New For., 47 (2016) 1–51.

[66] S.N. Jutras, N. Thiffault, A.D. Munson, Comparing large bareroot and container stock: water stress as influenced by peat and soil water availability, Tree Plant Notes, 52 (2007) 15–18.

[67] D.R. Gwaze, R. Melick, C. Studyvin, G. Hoss, In: L.E. Riley, R.K. Dumroese, T.D. Landis, Eds., Survival and Growth of Container and Bareroot Shortleaf Pine Seedlings in Missouri, National Proceedings: Forest and Conservation Nursery Associations – 2005, Proc. RMRS-P-43, Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, USDA Forest Services, 2006, pp. 123–127.

[68] E.R. Wilson, K.C. Vitols, A. Park, Root characteristics and growth potential of container and bare-root seedlings of red oak (*Quercus rubra* L.) in Ontario, Canada, New For., 34 (2007) 163–176.

[69] F. Renou-Wilson, U. Scallan, M. Keane, E.P. Farrell, Early performance of native birch (*Betula* spp.) planted on cutaway peatlands: influence of species, stock types and seedlings size, Eur. J. For. Res., 126 (2007) 545–554.

[70] V. Novak, Soil-Crack Characteristics — Estimation Methods Applied to Heavy Soils in the NOPEX Area, Agricultural and Forest Meteorology, 1999, pp. 98–99 & 501–507.

[71] F. Haghnazari, H. Shahgholi, M. Feizi, Factors affecting the infiltration of agricultural soils: review, Int. J. Agron. Agric. Res., 6 (2015) 21–35.

[72] W.-K. Song, Y.-J. Cui, A.M. Tang, W.-Q. Ding, Q. Wang, Experimental study on water evaporation from compacted clay using environmental chamber, Can. Geotech. J., 53 (2016) 1–57.

[73] C. Macci, S. Doni, E. Peruzzi, G. Masciandaro, C. Mennone, B. Ceccanti, Almond tree and organic fertilization for soil quality improvement in southern Italy, J. Environ. Manage., 95 (2012) S215–S222.

[74] M.E. Ramos, E. Benítez, P.A. García, A.B. Robles, Cover crops under different managements vs. frequent tillage in almond orchards in semiarid conditions: effects on soil quality, Appl. Soil Ecol., 44 (2010) 6–14.

[75] M. Kargar, R. Suresh, M. Legrand, P. Jutras, O.G. Clark, S.O. Prasher, Reduction in water stress for tree saplings using hydrogels in soil, J. Geosci. Environ. Prot., 5 (2017) 27–39.

[76] S. Gohari, A. Imani, A. Talaei, V. Bdossi, M.R. Sghari, Drought Effects on Growth, Water Content, and Organic Osmoprotectants in Promising Almond Genotypes with Different Drought Tolerance, This Work is Licensed Under a Creative Commons Attribution 4.0 International License, 2021, 12 pages.

[77] H. Nezami, R. Khazaei, Z.B. Rezazadeh, A. Hosseini, Effect of drought stress and defoliation on sunflower (*Helianthus annuus* L.) in controlled conditions, Desert, 12 (2008) 99–104.

[78] Z. Zamani, A. Taheri, A. Vezvaei, K. Poustini, Proline content and stomatal resistance of almond seedlings as affected by irrigation intervals, Acta Hortic., 591 (2002) 411–416.

[79] A. Zokaee-Khosroshah, M. Esna-Ashari, A. Ershadi, A. Imani, Morphological changes in response to drought stress in cultivated and wild almond species, Int. J. Hortic. Sci. Technol., 1 (2014) 79–92.

[80] T.S. Gikloo, B.E. Elhami, Physiological and morphological responses of two almond cultivars to drought stress and cycocel, Int. Res. J. Appl. Basic Sci., 3 (2012) 1000–1004.

[81] W. Hu, Z. Lu, F. Meng, X. Li, R. Cong, T. Ren, T.D. Sharkey, J. Lu, The reduction in leaf area precedes that in photosynthesis under potassium deficiency: the importance of leaf anatomy, New Phytol., 227 (2020) 1749–1763.

[82] P. Romero, J.M. Navarro, F. García, P.B. Ordaz, Effects of regulated deficit irrigation during the pre-harvest period on gas exchange, leaf development and crop yield of mature almond trees, Tree Physiol., 24 (2004) 303–312.
[83] V. Parkash, S. Singh, A review on potential plant-based water stress indicators for vegetable crops, Sustainability, 12 (2020) 3945, doi: 10.3390/su12103945.
[84] G.G. Marino, M. La Mantia, T. Caruso, F.P. Marra, Seasonal dynamics of photosynthesis and total carbon gain in bearing and nonbearing pistachio (*Pistacia vera* L.) shoots, Photosynthetica, 56 (2018) 932–941.
[85] P.A. Nortes, M.M. Gonzalez-Real, G. Egea, A. Baille, Seasonal effects of deficit irrigation on leaf photosynthetic traits of fruiting and non-fruiting shoots in almond trees, Tree Physiol., 29 (2009) 375–388.
[86] V. Udompetaikul, S.K. Upadhyaya, D.C. Slaughter, B.D. Lampinen, K. Shackel, Plant Water Stress Detection Using Leaf Temperature and Microclimatic Information, An ASABE Meeting Presentation, 2011, 10 pages.
[87] S. Karimi, A. Yadollahi, K. Arzani, A. Imani, M. Aghaalikhani, Gas-exchange response of almond genotypes to water stress, Photosynthetica, 53 (2015) 29–34.