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Reducing Deep Percolation Losses Using a Geotextile Layer at Different Soil Depths and Irrigation Levels for Lettuce Crop (*Lactuca sativa* L. var. *capitata*) (Limor)

Marwa M. Abdelbaset [1,*], Osama M. Dewedar [1], Ebtessam A. Youssef [1], José Miguel Molina-Martinez [2] and Ahmed F. El-Shafie [1]

[1] Water Relations and Field Irrigation Department, National Research Centre, Cairo 12622, Egypt; om.dewedar@nrc.sci.eg (O.M.D.); eb.youssef@nrc.sci.eg (E.A.Y.); af.el-shafie@nrc.sci.eg (A.F.E.-S.)
[2] Food Engineering and Agricultural Equipment Department, Technical University of Cartagena, 30203 Cartagena, Spain; josem.molina@upct.es
* Correspondence: bd.mahmoud@nrc.sci.eg

Abstract: Due to rising food demand and the limitation of water resources, achieving water security is essential. The lettuce crop is affected when grown under limited water supplies as it produces small heads, especially during the late growing stage. For this reason, it is important to maximize water use efficiency and crop productivity. Two successive experiments were conducted during 2021 and 2022 to reduce losses via deep percolation using a geotextile layer at different soil depths under different irrigation levels of the lettuce crop (*Lactuca sativa* L. var. *capitata*). This study aims to reduce water losses due to deep percolation and improve crop growth and yield parameters for iceberg lettuce under subsurface drip irrigation in sandy loam soil conditions. In order to achieve these aims, different amounts of irrigation (100, 80, and 60% of crop evapotranspiration "*ETc*") and a geotextile layer at different soil depths (20, 30, and 40 cm from the soil surface) were used. The results revealed that the use of a geotextile layer with 20 and 30 cm depths significantly improved irrigation application efficiency and noticeably increased soil water content in the root zone. The observed results during both seasons showed that geotextile layers at 20, 30, and 40 cm depths under irrigation of 100% *ETc* significantly increased vegetative growth characteristics (plant height, head diameter, head circumference, head volume, plant fresh weight, and leaf area) and crop productivity compared to the control (without geotextile). In particular, the geotextile layer at a 30 cm depth under irrigation of 100% of *ETc* was the most statistically effective treatment in this study, with yield values of 69.3 and 67.5 t ha^{-1} in the two seasons, respectively. However, the treatments of geotextile layers at 20 and 30 cm depths under irrigation of 80% of *ETc* also recorded statistically effective results for crop growth parameters and yield in this study. In general, geotextiles can be used at different depths as an irrigation management practice to reduce deep percolation in the field.

Keywords: lettuce; irrigation; evapotranspiration; water stress; geotextile; subsurface drip irrigation

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1. Introduction

Lettuce (*Lactuca sativa* L. var. *capitata*) (Limor) is an important vegetable crop worldwide. It plays a significant role in human nutrition and has both therapeutic and useful characteristics. In recent years, production areas have increased, especially in the Mediterranean region [1,2]. The lettuce crop is affected when grown under limited water supplies as it produces small heads, especially during the late growing stage, whereas under ideal conditions, the average lettuce yield ranges from 40 to 60 t ha^{-1} [3].

Drought causes a direct decrease in crop growth through a change in cell volume, a decrease in cell elongation, or cell flaccidity, which leads to a disruption of intracellular metabolism [4,5].

Due to changing climatic conditions, the water crisis is one of the most significant issues that limit plant growth and production, specifically in arid and semi-arid regions [6]. It is important to investigate deficit irrigation scenarios and their effect on crop productivity in order to fill the food gap and reduce pressure on water resources. [7].

Subsurface drip is considered to have the highest irrigation efficiency; exceeding 90% compared to other irrigation methods. Subsurface drip delivers water within the plant root zone as well as reduces irrigation water losses through the soil surface, such as evaporation, runoff, and wind drift [8]. Results have indicated that subsurface drip can improve productivity compared to that obtained with surface drip. Establishing the depth of the subsurface drip method depends on several factors, including those related to soil properties and those related to cultivated crops. Depths from 20 to 70 cm can provide an ideal wetting overlap along the emitter line under most crops, with the ability to adjust the discharge, number of emitters, and irrigation intervals [9–12]. Under subsurface drip irrigation, three drip line depths (0, 15, and 30 cm) with treatments (70, 100, and 130% of *ETc*) were studied. The results indicated that the emitter depth of 15 cm under lower water treatment reduces deep percolation. Otherwise, increasing drip line depth and increasing irrigation amount led to more deep percolation [13]. Moreover, deep percolation losses in drip irrigation areas ranged between 29 and 41% of the total applied water [14]. Irrigation management and the application of some agricultural practices are the most important methods to reduce deep percolation losses and evaporation from the soil [15].

The use of geotextile mats improved water distribution under sprinkler irrigation. Geotextile can be recommended for use in newly reclaimed regions to improve water application in the soil profile [16]. Utilizing geotextile mats enhances the delivery of water inside the crop root zone [17].

In addition, deep percolation is one of the challenging factors to estimate in the irrigation balance equation. Therefore, this study aimed to reduce the losses of deep percolation for lettuce growth and yield parameters in sandy loam soil conditions. Three layer depths of geotextile (20, 30, and 40 cm from the soil surface) and without geotextile with irrigation of 100, 80, and 60% *ETc* ("crop evapotranspiration") were selected under the subsurface drip irrigation method.

2. Material and Methods

2.1. The Field Trial Site

Two field trials were conducted in 2021 and 2022 in the Bilbeis region, Sharqia Governorate, Egypt, latitude 30°22′04.9″ N, longitude 31°37′38.2″ E, and mean altitude 21 m above sea level, Figure 1. The field trial included different layer depths of geotextile (20, 30, and 40 cm from the soil surface) and without geotextile (as a control). Three different irrigation levels (100, 80, and 60% of *ETc*) were considered under subsurface drip irrigation in sandy loam soil conditions. Table 1 presents some physical properties of the soil.

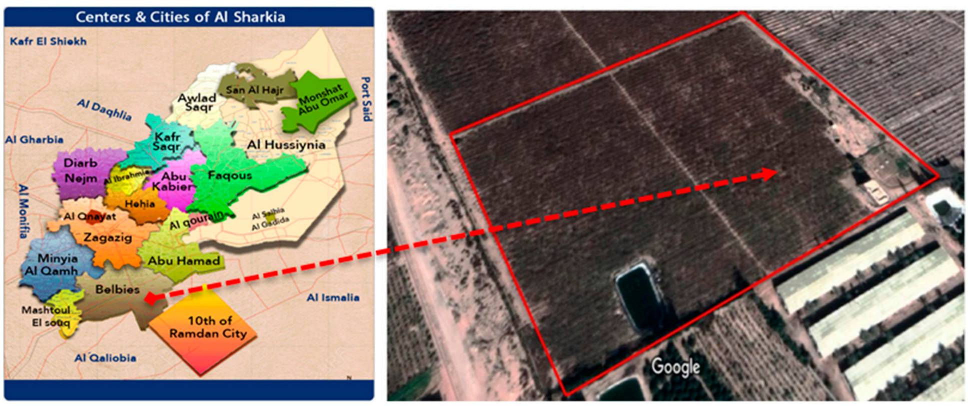

Figure 1. The field trial site, Bilbeis city, Sharqia Governorate, Egypt; source: "Sharqia Governorate Site and Google Maps".

Table 1. Relevant physical analysis of the soil for the experimental site.

Layer (cm)	Particle Size (%)				Soil Moisture (%)			
	Coarse Sand	Fine Sand	Silt	Clay	SP	FC	AW	PWP
0–30	43.2	19.5	24	13.3	28.6	14.3	7.15	7.15
30–60	44.1	18.5	24.2	13.2	28.6	14.5	7.4	7.1

SP: Saturation Point, FC: Field Capacity, PWP: Permanent Wilting Point, AW: Available Water.

2.2. Irrigation Method and Description

Automatic subsurface drip irrigation was used under all treatments at the experimental site. The system consisted of a pump, pressure gauges, a filter, an injection unit, a center control unit, a control panel, and solenoid valves. The emitter's lines were installed at a layer 15 cm from the soil surface [13]. The built-in emitters used 0.3 m emitter spacing, 0.7 m lateral spacing, and 4.0 L h^{-1} discharge at 1.0 bar pressure. The amount of irrigation was added using the control panel and was programmed based on the information obtained from the CROPWAT 2012 version 8.0.1.1 computer program. This involves starting the irrigation cycle through sending an order to turn the solenoid valves on or off.

2.3. Estimation the Seasonal Irrigation Water for Iceberg Lettuce

After transplanting, amounts of irrigation (60, 80, and 100% of evapotranspiration (*ETc*) were added. These values, as shown in Tables 2 and 3, resulted from the CROPWAT 2012 version 8.0.1.1 computer program (calculated using the "FAO-Penman-Moteith equation") [18] using local meteorological data (years 2021 and 2022) and the characteristics of the experimental plants. At last, except for the experimental treatments, all of the iceberg lettuce plants in this study underwent identical horticultural practices. Scheduling irrigation was calculated using Equation (1) for both seasons under the subsurface drip irrigation method [18]:

$$IR_g = \frac{(ET_o \times k_c \times K_r)}{E_i} - R + LR \quad (1)$$

where IR_g is the crop irrigation requirements (mm day^{-1}), ET_o is the reference evapotranspiration (mm day^{-1}), k_c is the crop coefficient [19], K_r is the ground cover reduction factor, E_i is the irrigation efficiency (%), R is the precipitation (mm), and LR is the leaching requirements (mm). Crop water requirements were calculated from "mm ha^{-1} day^{-1}" to "m^3 ha^{-1} day^{-1}" [20]. Daily meteorological data and reference evapotranspiration for the two seasons at the experiment site in the Bilbeis region are shown in Figure 2.

Table 2. Irrigation requirements (m^3 ha^{-1}) for irrigation treatments (2021 and 2022 seasons).

Stage	Number of Days	Kc	Average of ET_o (mm)		100% of *ETc* (mm)		80% of *ETc* (mm)		60% of *ETc* (mm)		W.R. for 100% *ETc* (m^3 ha^{-1})		W.R. for 80% *ETc* (m^3 ha^{-1})		W.R. for 60% *ETc* (m^3 ha^{-1})	
			1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Initial	20	0.7	3.6	3.6	66.4	67.2	53.12	53.76	39.84	40.32	822	821	658	657	493	493
Development	30	0.8	3.2	2.8	92.3	88.3	73.84	70.64	55.38	52.98	1065	1018	852	814	639	611
Mid-season	15	0.98	2.1	2.2	42.3	34.8	33.84	27.84	25.38	20.88	457	371	366	297	274	223
Late-season	10	0.95	1.9	1.8	26.8	16.8	21.44	13.44	16.08	10.08	282	177	226	142	169	106
Total	75										2626	2387	2102	1910	1575	1432

ETc: crop evapotranspiration, W.R.: water requirement.

Table 3. Some physical and mechanical properties of geotextile sample.

Thickness (mm)	GSM ($g\ m^{-2}$)	W.P. ($L\ m^{-2}\ s^{-1}$)	A.P. ($cm^3\ cm^{-2}\ s^{-1}$)	Bursting (kg)
3.13	275	1.168	330.03	68

GSM: weight per square meter, W.P: Water Permeability, A.P: Air Permeability, bursting under penetration force 7.64 KPa.

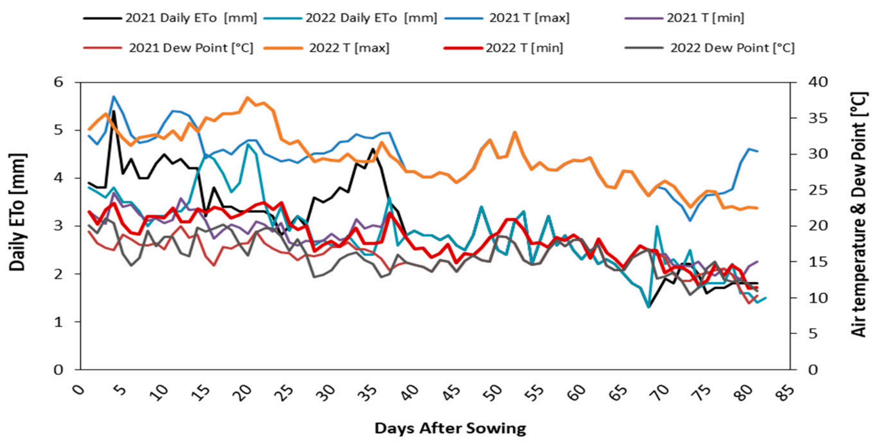

Figure 2. Daily air temperature (T min and max) and reference evapotranspiration (ET_o) at the experimental site during the two growing seasons (2021 and 2022).

2.4. Experimental Statistical Design

The experimental design was a split-plot system in a complete randomized block, including five replicates. The main plot was the irrigation amount (100, 80, and 60% of *ETc*), and the sub-main plot was the different layer depths of geotextile (20, 30, and 40 cm from the soil surface) and without geotextile (as control). To select a suitable geotextile material, the sample was analyzed in the Textile Testing Laboratory, National Research Center, Egypt. Some properties of the geotextile material are presented in Table 3. Moreover, the total experimental area was 630 m^2 and included 12 treatments, which were interactions between treatments. The seedlings of iceberg lettuce (*Lactuca sativa* L. var. *capitata*, Limor) were selected and cultivated on the 17th of September in both seasons. Then, at a distance of 0.3 m, they were grown on two sides of the drip line.

2.5. Soil Moisture Content in Root Zone of Iceberg Lettuce Crop

Soil moisture content (*SMC*) was estimated in the plant root zone after and before irrigation. Field capacity and wilting point were taken as comparison criteria for the non-vulnerability of plants to irrigation deficiency [21]. Moisture content was estimated using a "soil moisture profile probe device" at the crop mid-stage.

2.6. Water Application Efficiency

Water application efficiency (*WAE*) is the relationship between the net water content in the soil and the root zone compared to the actual irrigation rate, according to [22]. *WAE* was estimated using Equation (2):

$$WAE = \frac{D_s}{D_a} \tag{2}$$

where *WAE* is the water application efficiency (%), D_a is the depth of applied water (mm), and D_s is the depth of stored water in the soil (mm) according to Equation (3):

$$D_s = (\theta_1 - \theta_2) \times d \tag{3}$$

where d is the effective soil layer depth (mm) and θ_1 and θ_2 are the soil water content before and after irrigation (g g^{-1}) in the root zone, respectively.

2.7. Crop Growth Parameters

Iceberg lettuce plants were harvested after 75 days from transplanting on the 1st of December. The samples were taken to record crop growth and yield parameters such as plant height (cm), head diameter (cm), head circumference (cm), head volume (cm^3), plant fresh weight (g) "head, leaves and root fresh weight (g)", and numbers of leaves/plant. Moreover, the leaf area of iceberg lettuce (cm^2) was measured using plant leaf discs after being picked from the center of the plant head [23]. Additionally, the total chlorophyll of the leaves was measured with a chlorophyll meter, "SPAD 502" [24].

2.8. Crop Yield and Water Productivity of Iceberg Lettuce

After 75 days of cultivation, the yield of the lettuce crop (kg) was estimated at 1 m^2 for each treatment separately, and then it was converted to t ha^{-1}.

Water productivity "*WP*" (kg m^{-3}) results were estimated due to Equation (4) [25].

$$WP = \frac{Marketable\ Yield\ \left(kg\ ha^{-1}\right)}{Total\ appilied\ irrigation\ \left(m^3\ ha^{-1}\right)} \quad (4)$$

2.9. Statistical Analysis

Based on [26], the trial's design consisted of five replications of the split-plot system in a completely randomized block design. The recorded data were analyzed using the variance approach. Duncan's range test was used to identify the variations between the mean values [27].

3. Results

3.1. Soil Moisture Content in Root Zone of Iceberg Lettuce Crop

The highest significant soil moisture content was obtained at all layer depths of geotextile for both seasons (Figure 3), where it is observed that there is an increase in soil moisture content (SMC) in the root zone of an iceberg lettuce crop. During the 2021 and 2022 growing seasons, the highest SMC values were under all geotextile layer depths 20, 30, and 40 cm with irrigation levels 100, 80, and 60% of *ETc*, while the control treatment (without geotextile) with irrigation levels 100, 80, and 60% of *ETc* gave the lowest values of SMC.

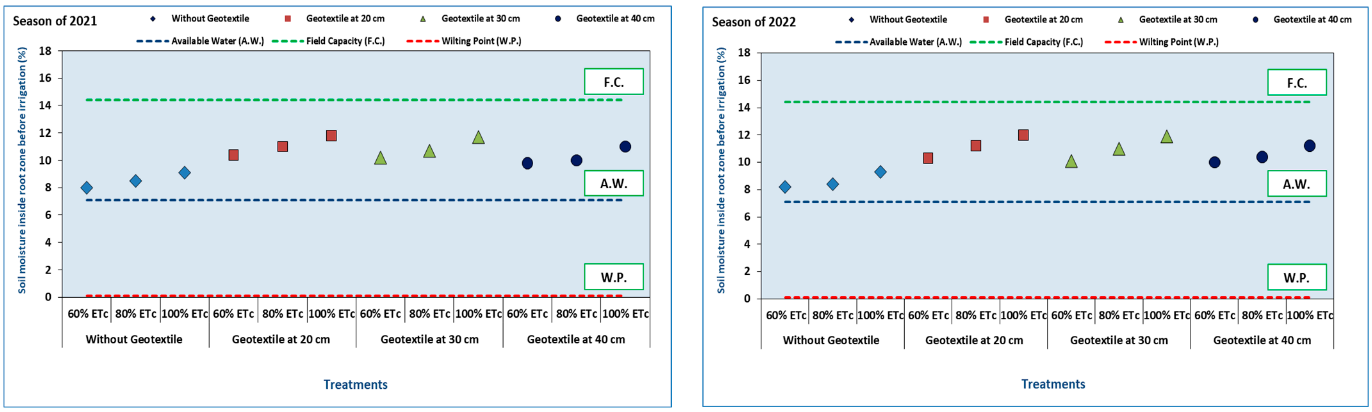

Figure 3. Soil moisture content under geotextile layer depths and irrigation treatments in the lettuce root zone for the 2021 and 2022 seasons.

For the first season (2021), the highest SMC value was under 100% of *ETc* and the geotextile layer at 20 cm depth (11.8%), followed by 30 cm depth (11.7%). The lowest SMC values were 8.0, 8.5, and 9.1% under control (without geotextile) with 60, 80, and 100% of *ETc*, respectively. Moreover, the SMC values were 11.0 and 11.0% under 100% of *ETc* with the geotextile layer at 40 cm depth and 80% of *ETc* with the geotextile layer at 20 cm depth, respectively. The SMC values with 100% of *ETc* were 11.8, 11.7, and 11.0% under 20, 30, and 40 cm geotextile layer depths, respectively, compared to the control (without geotextile), which recorded 9.3% of SMC. The SMC values with 80% of *ETc* were 11.0, 10.7, and 10.0% under 20, 30, and 40 cm geotextile layer depths, respectively, compared to the control (without geotextile), which recorded 8.5% of SMC. The SMC values with 60% of

ETc were 10.4, 10.2, and 9.8% under 20, 30, and 40 cm geotextile layer depths, respectively, compared to the control (without geotextile), which recorded 8.0% of SMC.

The same trend was established for the second season (2022). The highest SMC values were under the geotextile layer at 20 cm depth (12%), followed by the geotextile layer at 30 and 40 cm depths (11.9 and 11.2%), respectively, with 100% *ETc*. Otherwise, irrigation at 60, 80, and 100% of *ETc* and without geotextile recorded the lowest results (8.2, 8.4, and 9.3%, respectively). While the SMC data under irrigation with 80% of *ETc* recorded very close values to those for irrigation with 100% of *ETc* under all geotextile depths. The SMC was 11.2, 11, and 10.4% for irrigation with 80% of the *ETc* under geotextile depths 20, 30, and 40 cm, respectively, compared to the control (without geotextile), which recorded 8.4% (Figure 3).The data indicated that there are variations in the SMC in the plant root zone before irrigation with geotextile compared with the control treatment (without geotextile).

3.2. Water Application Efficiency

The water application efficiency under geotextile layer depths with irrigation treatments for the 2021–2022 seasons is shown in Figure 4. The observed data were measured for different geotextile layer depths under different irrigation at 100, 80, and 60% of *ETc*. During the first season, the highest water application efficiency was obtained under 100% *ETc* and the geotextile layer at 20 cm depth (98%), followed by 30 cm depth (97%), respectively. The lowest value was obtained under control (without geotextile) and 60% of *ETc* (78%), followed by 80% of *ETc* (82%). On the other hand, irrigation at 80% of *ETc* recorded outstanding results for water application efficiency of 96, 94, and 90% with geotextile layer depths of 20, 30, and 40 cm, respectively, when compared to control (82%). In addition, water application efficiency at 100% of *ETc* and 20, 30, and 40 cm geotextile depths was recorded at 98, 97, and 95%, respectively, when compared to the control (82%). This is evident in the water application efficiency values under irrigation at 80% of *ETc*, which recorded very close values to those for irrigation at 100% of *ETc* under all geotextile depths.

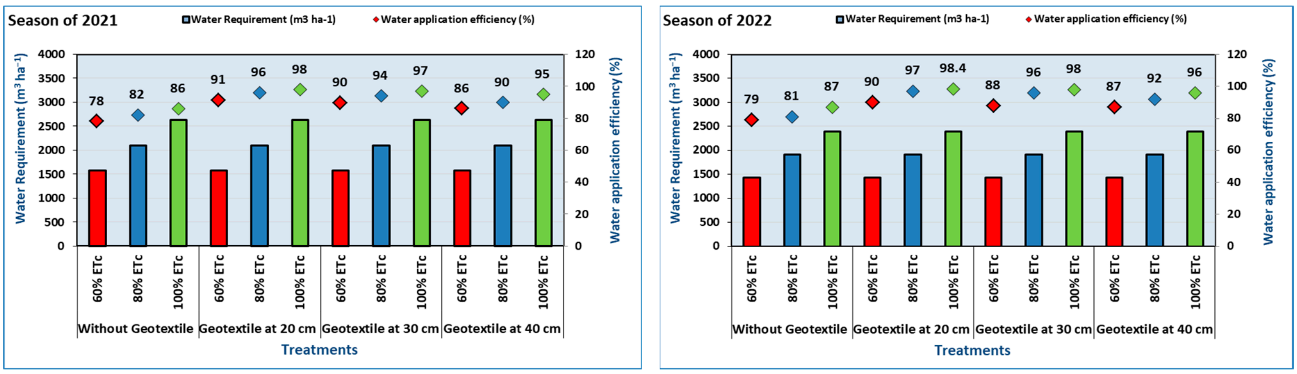

Figure 4. Water application efficiency and crop irrigation requirements under geotextile layer depths and water treatments for lettuce crop during the 2021 and 2022 seasons.

For the second season, the highest water application efficiency values were under the geotextile layer at 20 cm depth (98.4%), followed by the geotextile layer at 30 cm depth (98%) with irrigation at 100% of *ETc* (Figure 4). The irrigation at 60% *ETc* and the control (without geotextile) recorded the lowest values (79%). Generally, ideal data were recorded using all geotextile layer depths under all irrigation treatments. The water application efficiency under irrigation at 80% of *ETc* recorded very close values to those for irrigation at 100% of *ETc* under all geotextile depths. In addition, the water application efficiency for irrigation at 80% of *ETc* was 97, 96, and 92% under geotextile layer depths of 20, 30, and 40 cm, respectively, while under control (without geotextile) it was (81%) for the 2022 season. In general, geotextile layer treatments recorded higher water application efficiency as compared to the control treatment (without geotextile) for all irrigation levels during the two growing seasons.

3.3. Vegetative Growth and Crop Characteristics

There was a significant influence of the geotextile layer at different depths under different crop evapotranspiration rates and its interaction with the plant height and head (diameter, circumference, and volume) parameters of iceberg lettuce crop in both seasons (Table 4).

Table 4. Effect of geotextile layer depths under irrigation levels on plant height and head (diameter, circumference, and volume) of iceberg lettuce crop (seasons 2021–2022).

Treatments	Plant Height (cm)		Head Diameter (cm)		Head Circumference (cm)		Head Volume (cm^3)	
	2021	2022	2021	2022	2021	2022	2021	2022
Irrigation levels								
100% *ETc*	18.62 A	18.45 A	19.12 A	19.14 A	59.25 A	59.02 A	3516.37 A	3474.60 A
80% *ETc*	16.99 B	16.90 B	17.73 B	17.52 B	54.51 B	54.04 B	2737.96 B	2667.60 B
60% *ETc*	14.58 C	14.68 C	15.65 C	15.44 C	47.46 C	47.29 C	1807.19 C	1787.53 C
LSD at 5%	0.153	0.093	0.108	0.137	0.239	0.182	44.775	59.685
Geotextile layer depths								
Depth 0 cm	16.41 D	16.40 D	17.23 D	17.10 D	52.81 D	52.60 D	2490.33 D	2459.36 D
Depth 20 cm	17.07 B	16.89 B	17.66 B	17.56 B	54.53 B	54.09 B	2740.33 B	2674.58 B
Depth 30 cm	17.53 A	17.54 A	18.34 A	18.16 A	56.32 A	56.05 A	3019.14 A	2976.41 A
Depth 40 cm	16.81 C	16.71 C	17.51 C	17.33 C	53.88 C	53.44 C	2644.42 C	2580.22 C
LSD at 5%	0.198	0.119	0.139	0.177	0.309	0.235	57.805	77.053
Interaction								
100% *ETc* × Depth 0 cm	17.03 e	17.04 d	17.71 e	17.56 e	54.54 g	54.32 g	2742.70 g	2709.67 g
100% *ETc* × Depth 20 cm	18.73 b	18.54 b	19.13 b	19.29 b	59.44 b	59.39 b	3550.02 b	3541.58 b
100% *ETc* × Depth 30 cm	19.20 a	19.49 a	19.94 a	19.83 a	61.45 a	61.73 a	3922.39 a	3976.76 a
100% *ETc* × Depth 40 cm	18.62 b	18.23 c	19.04 b	19.11 b	59.13 c	58.62 c	3494.05 c	3405.74 c
80% *ETc* × Depth 0 cm	16.86 e	16.84 e	17.65 e	17.29 f	54.18 g	53.58 h	2688.58 h	2600.74 h
80% *ETc* × Depth 20 cm	17.59 c	17.21 d	18.14 d	18.21 d	56.10 e	55.61 e	2983.92 e	2906.93 e
80% *ETc* × Depth 30 cm	18.51 b	18.17 c	18.95 c	18.91 c	58.81 d	58.22 d	3438.68 d	3335.09 d
80% *ETc* × Depth 40 cm	17.19 d	17.10 d	17.85 e	17.67 e	55.01 f	54.59 f	2814.37 f	2749.81 f
60% *ETc* × Depth 0 cm	13.86 i	14.20 i	15.09 h	15.11 i	45.45 k	46.02 l	1587.21 l	1647.16 l
60% *ETc* × Depth 20 cm	15.79 f	15.93 f	16.95 f	16.45 g	51.40 h	50.84 j	2295.75 j	2220.85 i
60% *ETc* × Depth 30 cm	15.30 g	15.03 g	15.99 g	15.71 h	49.13 i	48.26 j	2004.03 j	1900.20 j
60% *ETc* × Depth 40 cm	14.77 h	14.87 h	15.77 g	15.33 h	47.95 j	47.41 k	1863.35 k	1801.81 k
LSD at 5%	0.343	0.207	0.242	0.306	0.353	0.407	133.461	100.122

ETc: Crop evapotranspiration; mean values for the same factor and parameter that follow the same letter are non-significant at a 0.5% level; the uppercases indicate the main and sub-main factors, while the lowercases indicate interactions.

For the 2021 season, regarding the irrigation level factor, the highest data for plant height and head diameter were under irrigation at 100% of *ETc* (18.62 and 19.2 cm), followed by 80% of *ETc* (16.99 and 15.65 cm), respectively. Otherwise, the irrigation of 60% *ETc* recorded the lowest values of plant height and head diameter (14.58 and 15.65 cm), respectively. The same direction was observed for head circumference and head volume. The highest head circumference and head volume values were under 100% of *ETc* (59.25 cm and 3516.37 cm^3), while the lowest value was under 60% of *ETc* (47.46 cm and 1807.19 cm^3), respectively.

In addition, the maximum results for plant height, head diameter, and head circumference were obtained using the geotextile at a depth of 30 cm (17.53, 18.34, and 56.32 cm, respectively), followed by the geotextile at a depth of 20 cm (17.07, 17.66, and 54.53 cm, respectively). Otherwise, the lowest values of plant height, head diameter, and head circumference under control (without the geotextile layer) were 16.41, 17.51, and 53.88 cm, respectively. The highest data for head volume were under geotextile at a depth of 30 cm (3019.14 cm^3), followed by geotextile at a depth of 20 cm (2740.33 cm^3), while the lowest value (2490.33 cm^3) was under control (without the geotextile layer) for the first season.

Regarding interaction, the maximum significant values for plant height, head diameter, and head circumference were 19.20, 19.83 and 61.45 cm, respectively, under irrigation of

100% *ETc* with a geotextile layer at 30 cm depth. The lowest values for plant height, head diameter, and head circumference were 13.86, 15.09 and 45.45 cm, respectively, under irrigation of 60% *ETc* with the control (without the geotextile layer). The maximum value for head volume was 3922.39 cm^3 under irrigation of 100% *ETc* with a geotextile layer at 30 cm depth, while the lowest value was 1587.21 cm^3 under irrigation of 60% *ETc* with the control (without the geotextile layer) in the 2021 season.

On the other hand, the treatment of 80% *ETc* with geotextile (30 cm) gave significant results (18.51 cm, 18.95 cm, 58.81 cm, and 3438.68 cm^3) compared to 100% of *ETc* and without geotextile "as a control" (17.03 cm, 17.71 cm, 54.54 cm, and 2742.7 cm^3) for plant height, head diameter, head circumference, and head volume, respectively, in the 2021 season.

The same trend was recorded in the data for the 2022 season. The same significant results were recorded for 80% of *ETc* with geotextile (20 cm) compared to 100% of *ETc* and control (without geotextile) for the two growing seasons (Table 4).

There was a significant statistical effect with used the geotextile layer at different depths and irrigation of 100, 80, and 60% *ETc* and the interaction on the (plant, head weight, and root fresh weight) parameters of an iceberg lettuce plant for both seasons (Table 5).

Table 5. Effect of geotextile layer depths under irrigation levels on (plant, head and root fresh weight) of iceberg lettuce crop (seasons 2021–2022).

Treatments	Plant Fresh Weight (g)				Head Fresh Weight (g)				Root Fresh Weight (g)			
	2021		2022		2021		2022		2021		2022	
Irrigation levels												
100% *ETc*	960.43	A	976.83	A	947.02	A	964.52	A	29.51	A	29.18	A
80% *ETc*	648.14	B	651.43	B	630.85	B	633.66	B	17.30	B	17.77	B
60% *ETc*	496.74	C	491.03	C	467.23	C	461.86	C	13.41	C	12.30	C
LSD at 5%	7.810		6.760		7.978		6.841		0.598		0.421	
Geotextile layer depths												
Depth 0 cm	662.69	D	663.80	D	641.18	D	643.14	D	19.26	D	19.39	C
Depth 20 cm	719.52	B	724.21	B	700.25	B	704.83	B	21.51	B	20.65	B
Depth 30 cm	778.29	A	789.70	A	761.73	A	772.66	A	22.81	A	21.80	A
Depth 40 cm	696.72	C	705.97	C	676.50	C	686.10	C	20.22	C	19.87	C
LSD at 5%	10.083		8.727		10.299		8.832		0.772		0.544	
Interaction												
100% *ETc* × Depth 0 cm	661.11	f	668.97	e	644.13	f	651.78	e	17.86	f	18.69	e
100% *ETc* × Depth 20 cm	996.68	b	1009.04	b	983.53	b	997.01	b	32.03	b	30.21	b
100% *ETc* × Depth 30 cm	1076.84	a	1112.47	a	1066.23	a	1101.82	a	35.16	a	32.66	a
100% *ETc* × Depth 40 cm	958.77	c	995.39	b	945.08	c	982.96	b	29.76	c	29.22	c
80% *ETc* × Depth 0 cm	607.39	h	625.23	f	589.53	h	606.53	f	16.97	f	17.20	f
80% *ETc* × Depth 20 cm	733.15	e	730.67	d	717.01	e	715.05	d	18.30	e	19.40	d
80% *ETc* × Depth 30 cm	894.69	d	890.75	c	880.06	d	877.69	c	27.67	d	28.93	c
80% *ETc* × Depth 40 cm	638.13	g	634.66	f	620.92	g	616.71	f	17.21	f	17.95	f
60% *ETc* × Depth 0 cm	485.98	k	475.41	j	453.95	k	445.20	i	13.15	g	12.03	i
60% *ETc* × Depth 20 cm	524.87	i	525.97	g	501.94	i	501.12	g	14.98	g	13.35	g
60% *ETc* × Depth 30 cm	500.76	j	494.62	h	473.09	j	465.69	h	14.63	g	13.06	h
60% *ETc* × Depth 40 cm	493.26	k	487.85	i	463.50	j	458.64	h	13.69	g	12.43	i
LSD at 5%	17.460		15.116		17.840		15.299		1.338		0.943	

ETc: crop evapotranspiration; mean values for the same factor and parameter that follow the same letter are non-significant at a 0.5% level; the uppercases indicate the main and sub-main factors, while the lowercases indicate the interaction.

Irrigation of 100% of *ETc* recorded the highest significant results for the total plant; head and root fresh weights were 960.43, 947.02, and 29.51 g, respectively. Otherwise, the lowest values for plant, head, and root fresh weight were recorded (496.74, 467.23, and 13.41 g), respectively, with 60% of *ETc* in the first season.

The observed data for the geotextile layer at different depths showed that the highest results for the total plant, head, and root fresh weight were 778.29, 761.73, and 22.81 g, respectively, under the geotextile layer at a depth of 30 cm. The observed data for the control (without geotextile) recorded the lowest result for the total plant, head, and root fresh weight (696.72, 641.18, and 19.26 g), respectively, in the first season.

There was a significant variation in the interaction between the geotextile layer at different depths and irrigation levels in the recorded data. The highest significant values for the total plant, head, and root fresh weight were (1076.84, 1066.23, and 35.16 g) under a geotextile layer depth of 30 cm, followed by a geotextile layer depth of 20 cm (996.68, 983.53, and 32.03 g), respectively, both combined with irrigation at 100% of *ETc* in the first season. While 80% of *ETc* recorded ideal data for the total plant, head, and fresh root weight (894.69, 880.06, and 27.67 g) and (733.15, 717.01, and 18.30) at geotextile layer depths (30 and 20 cm), respectively, compared to the control (without geotextiles) under 100% of *ETc* in the first season.

The vegetative growth parameters recorded the same trend for the two seasons. Additionally, the same significant results were recorded for 80% of *ETc* with geotextile (20 cm) compared to 100% of *ETc* and control (without geotextile) for the two growing seasons (Table 5).

There was a significant effect of the geotextile layer at different depths under different amounts of water and the interaction on the number of leaves per plant, leaf fresh weight, leaf area, and total chlorophyll of an iceberg lettuce crop in both seasons (Table 6).

Table 6. Effect of geotextile layer depths under irrigation levels on numbers of leaves per plant, leaf fresh weight, leaf area and total chlorophyll of iceberg lettuce crop (seasons 2021–2022).

Treatments	No. of Leaves per Plant				Leaf Fresh Weight (g)				Leaf Area (cm^2)				Total Chlorophyll SPAD			
	2021		2022		2021		2022		2021		2022		2021		2022	
Irrigation levels																
100% *ETc*	42.59	A	42.99	A	12.05	A	12.04	A	158.24	A	157.50	A	45.15	A	46.44	A
80% *ETc*	34.98	B	34.13	B	9.57	B	9.49	B	126.08	B	125.30	B	38.40	B	39.42	B
60% *ETc*	28.42	C	28.08	C	6.93	C	7.10	C	92.14	C	94.68	C	32.56	C	31.47	C
LSD at 5%	0.198		0.312		0.105		0.148		1.423		1.990		0.314		0.232	
Geotextile layer depths																
Depth 0 cm	34.43	C	34.04	D	8.82	D	8.96	D	115.10	D	116.89	D	37.83	C	38.20	D
Depth 20 cm	35.77	B	35.20	B	9.49	B	9.64	B	126.05	B	128.43	B	38.68	B	39.29	B
Depth 30 cm	37.99	A	38.77	A	11.61	A	11.40	A	151.52	A	148.76	A	41.86	A	42.87	A
Depth 40 cm	35.25	B	34.84	C	9.16	C	9.35	C	123.72	C	125.60	C	38.30	B	38.68	C
LSD at 5%	0.255		0.403		0.135		0.191		1.837		2.569		0.409		0.300	
Interaction																
100% *ETc* × Depth 0 cm	35.66	f	34.47	d	10.01	c	9.84	d	130.71	e	130.86	e	38.27	e	39.41	e
100% *ETc* × Depth 20 cm	42.75	b	42.84	b	11.27	b	11.58	b	150.55	b	152.03	b	44.97	b	46.37	b
100% *ETc* × Depth 30 cm	46.15	a	48.28	a	16.15	a	15.32	a	210.80	a	199.98	a	48.87	a	50.06	a
100% *ETc* × Depth 40 cm	42.16	c	42.62	b	11.16	b	11.48	b	147.05	c	150.79	b	44.63	b	45.93	c
80% *ETc* × Depth 0 cm	33.97	h	32.82	e	9.20	e	9.09	d	120.12	h	118.65	f	37.93	e	38.43	e
80% *ETc* × Depth 20 cm	37.44	e	37.32	c	10.29	c	10.38	c	134.36	f	135.48	d	40.50	d	42.77	d
80% *ETc* × Depth 30 cm	41.30	d	42.03	b	11.02	b	11.20	b	143.86	d	146.24	c	43.91	c	45.26	c
80% *ETc* × Depth 40 cm	34.99	g	33.85	d	9.57	d	9.48	d	130.49	g	128.33	e	38.20	e	38.73	e
60% *ETc* × Depth 0 cm	28.03	j	27.27	h	6.23	h	6.57	g	81.30	k	85.77	i	32.06	g	30.91	g
60% *ETc* × Depth 20 cm	30.39	i	30.72	f	8.38	e	8.49	e	109.41	i	110.82	g	36.22	f	35.80	f
60% *ETc* × Depth 30 cm	28.91	j	28.30	g	7.17	f	7.48	f	96.91	j	102.40	h	32.80	g	32.10	g
60% *ETc* × Depth 40 cm	28.61	j	28.05	g	6.76	g	7.09	f	93.64	j	97.66	h	31.63	g	31.38	g
LSD at 5%	0.442		0.699		0.235		0.332		3.182		4.450		0.702		0.520	

ETc: crop evapotranspiration; mean values for the same factor and parameter that follow the same letter are non-significant at a 0.5% level; the uppercases indicate the main and sub-main factors, while the lowercases indicate the interaction.

During the 2021 season, for the irrigation levels factor, the highest data for the number of leaves per plant, leaf fresh weight (g), and leaf area (cm^2) were under irrigation at 100% of *ETc* (42.59, 12.05 g and 158.24 cm^2), followed by 80% of *ETc* (34.98, 9.57 g and 126.08 cm^2), respectively. Otherwise, irrigation of 60% *ETc* recorded the lowest values of number of leaves per plant, leaf fresh weight (g), and leaf area (cm^2) (28.42, 6.93 g and 92.14 cm^2, respectively). The same pattern was observed for total chlorophyll. The highest total chlorophyll was under 100% of *ETc* (45.15), while the lowest value was under 60% of *ETc* (32.56), respectively.

In addition, the highest data values were obtained using the geotextile at a depth of 30 cm for number of leaves per plant, leaf fresh weight (g), and leaf area (cm^2) (37.99, 11.61 g and 151.52 cm^2, respectively), followed by the geotextile at a depth of 20 cm (35.77, 9.49 g and 126.05 cm^2, respectively). Otherwise, the lowest values of number of leaves per plant, leaf fresh weight (g), and leaf area (cm^2) under control (without the geotextile layer) were 34.43, 8.82 g and 115.1 cm^2, respectively. The highest data values for total chlorophyll were under geotextile at a depth of 30 cm (41.86), followed by geotextile at a depth of 20 cm (38.68), while the lowest value (37.83) was under control (without the geotextile layer) for the first season.

Regarding interaction, the maximum values for number of leaves per plant, leaf fresh weight (g), and leaf area (cm^2) were 46.15, 16.15 g and 210.8 cm^2, respectively, under irrigation of 100% *ETc* with a geotextile layer at 30 cm depth. The lowest values for number of leaves per plant, leaf fresh weight (g), and leaf area (cm^2) were 28.03, 6.23 g and 81.3 cm^2, respectively, under irrigation of 60% *ETc* with the control (without the geotextile layer). The maximum value for total chlorophyll was 48.87 under irrigation of 100% *ETc* with a geotextile layer at 30 cm depth, while the lowest value was 32.06 under irrigation of 60% *ETc* with a control (without the geotextile layer) in the 2021 season

On the other hand, the treatment of 80% *ETc* with geotextile (30 cm) gave significant results (41.3, 11.02 g, 143.86 cm^2, and 43.91) compared to 100% of *ETc* and without geotextile "as a control" (35.66, 10.01 g, 130.71 cm^2, and 38.27) for number of leaves per plant, leaf fresh weight (g), leaf area (cm^2), and total chlorophyll, respectively, in the 2021 season. The same trend was recorded in the data for the 2022 season. Additionally, the same significant results were recorded for 80% of *ETc* with geotextile (20 cm) compared to 100% of *ETc* and control (without geotextile) for the two growing seasons.

3.4. Crop Yield of Iceberg Lettuce

The impact of the geotextile layer at different depths under different amounts of irrigation (%*ETc*) on the crop yield and water productivity of the iceberg lettuce in both seasons is shown in Figures 5 and 6.

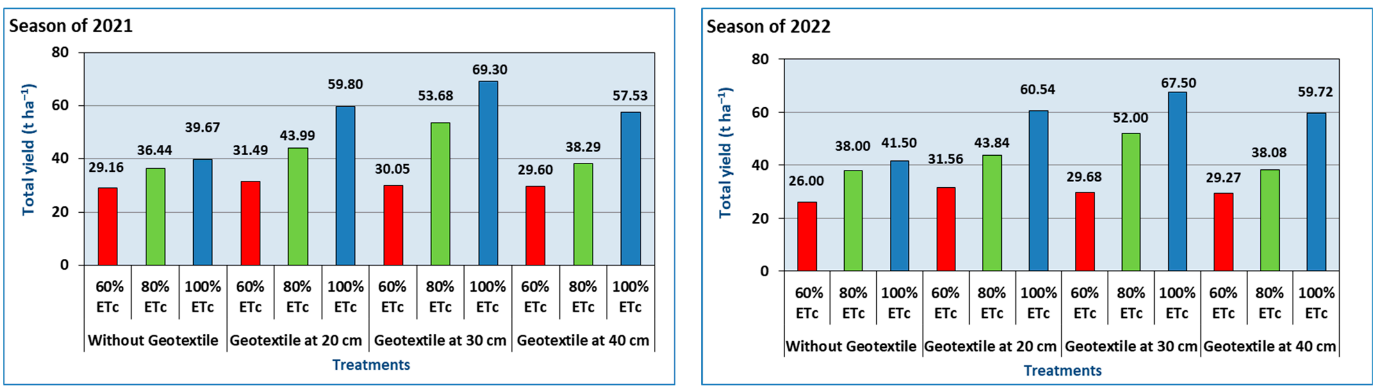

Figure 5. Effect of layer depths of geotextile under irrigation levels on the yield of iceberg lettuce for the two seasons.

The highest results for crop productivity were under all geotextile layer depths (20, 30, and 40 cm) with irrigation levels (100, 80, and 60% of *ETc*), while the control treatment (without geotextile) with irrigation levels (100, 80, and 60% of *ETc*) gave the lowest values of crop productivity for both seasons (Figure 5).

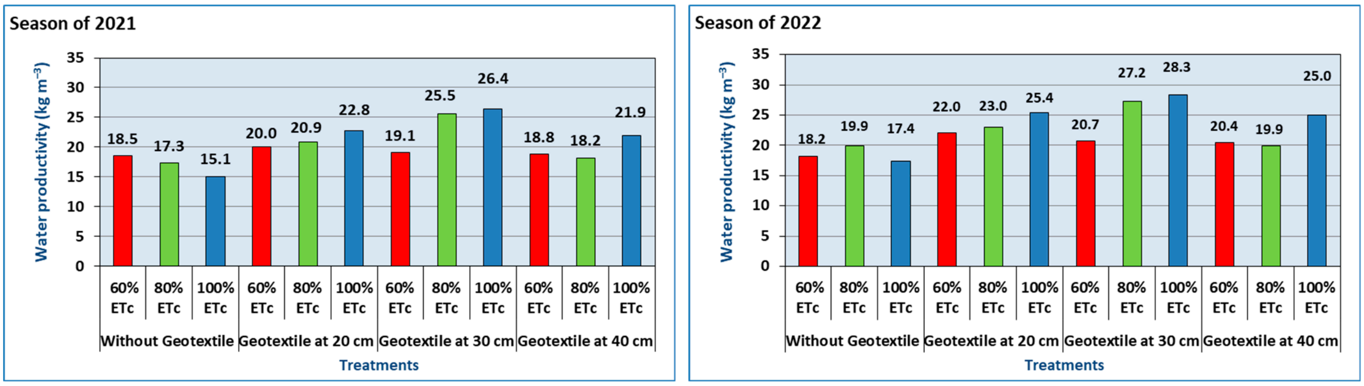

Figure 6. Effect of layer depths of geotextile under irrigation levels on water productivity of iceberg lettuce for the 2021 and 2022 growing seasons.

For the first season (2021), the highest crop productivity value was under 100% of *ETc* and the geotextile layer at 30 cm depth (69.3 t ha^{-1}), followed by 20 cm depth (59.8 t ha^{-1}). The lowest crop productivity was 29.16 and 29.6 t ha^{-1} under control and 40 cm layer depth, followed by 29.6 and 30.05 t ha^{-1} under 40 and 30 cm, respectively, with irrigation at 60% of *ETc*. The yield with 100% of *ETc* was 59.8, 69.3, and 57.53 t ha^{-1} under 20, 30, and 40 cm geotextile layer depths, respectively, compared to the control (without geotextile), which recorded 39.67 t ha^{-1}. The crop productivity with 80% of *ETc* was 43.99, 53.68, and 38.29 t ha^{-1} under 20, 30, and 40 cm geotextile layer depths, respectively, compared to the control (without geotextile), which recorded 36.44 t ha^{-1}.

The same trend was established for the second season (2022). The highest yield was under the geotextile layer at 30 cm depth (67.5 t ha^{-1}), followed by the geotextile layer at 20 and 40 cm depths (60.54 and 59.72 t ha^{-1}, respectively) with 100% *ETc*. Otherwise, the control (without geotextile) and a geotextile 40 cm layer depth recorded the lowest results (26.00 and 29.27 t ha^{-1}, respectively) with irrigation at 60 of *ETc*, while the yield under irrigation with 80% of *ETc* recorded ideal values compared to the control (without geotextile). The yield was 43.84, 52.00, and 38.08 t ha^{-1} for irrigation at 80% of *ETc* under geotextile depths of 20, 30, and 40 cm, respectively, compared to the control (without geotextile), which recorded 38 t ha^{-1} (Figure 5).

3.5. Water Productivity of Iceberg Lettuce

The water productivity under geotextile layer depths with irrigation treatments for the 2021–2022 seasons is shown in Figure 6. The observed data were estimated for different geotextile layer depths under different irrigation rates (100, 80, and 60% of *ETc*). During the first season, the highest water productivity was under 100% *ETc* with the geotextile layer at depths of 30 and 20 cm (26.4 and 25.5 kg m^{-3}, respectively). The lowest value was obtained under control (without geotextile) and 100% of *ETc* (15.1 kg m^{-3}), followed by 80% of *ETc* (17.3 kg m^{-3}). On the other hand, irrigation at 80% of *ETc* recorded outstanding results for water productivity (20.9, 25.5, and 18.2 kg m^{-3}) with geotextile layer depths (20, 30, and 40 cm, respectively), when compared to control (17.3 kg m^{-3}). In addition, the water productivity at 100% of *ETc* and geotextile depths of 20, 30, and 40 cm was recorded at 22.8, 26.4, and 21.9 kg m^{-3}, respectively, compared to the control at 15.1 kg m^{-3}. This is evident in the water productivity values under irrigation at 80% of *ETc*, which recorded very close values to those for irrigation at 100% of *ETc* under all geotextile depths.

For the second season, the highest water productivity was under 100% *ETc* with the geotextile layer at depths of 30 and 20 cm (28.3 and 27.2 kg m^{-3}, respectively). The irrigation at 100% *ETc* and the control (without geotextile) recorded the lowest values (17.4 kg m^{-3}). Generally, ideal data were recorded using all geotextile layer depths under all irrigation treatments. The water productivity under irrigation at 80% of *ETc* recorded very close values to those for irrigation at 100% of *ETc* under the same geotextile layer depth. In addition, the water productivity for irrigation at 80% of *ETc* was 23, 27.2, and 19.9 kg m^{-3} under the geotextile layer depths of 20, 30, and 40 cm, respectively, while under control (without geotextile) it was (19.9 kg m^{-3}) for the 2022 season. In general, geotextile layer depth treatments recorded higher water productivity as compared to the control treatment (without geotextile) for all irrigation levels during the two growing seasons.

4. Discussion

During the irrigation process, a large amount of water goes missing through deep percolation (more than 50% of the total applied water). In the field, deep percolation is one of the unknown parameters in the irrigation balance equation [28]. To reduce the losses of deep percolation and improve crop growth and yield parameters for iceberg lettuce under subsurface drip irrigation in sandy loam soil conditions, geotextile layers at different depths from the soil surface (20, 30, and 40 cm) with different amounts of irrigation (100, 80, and 60% of crop evapotranspiration, "*ETc*") were used. During the 2021 and 2022 growing seasons, the data indicated that there are variations in the soil moisture content (SMC) in the plant root zone before irrigation with geotextile compared with the control treatment (without geotextile). This is due to the geotextile layer increasing water movement in the horizontal direction over the vertical direction [29–31]. Additionally, the geotextile led to more water retention for some time. This improved the soil water content throughout the root zone. There was another explanation for this phenomenon: subsurface drip delivers water within the plant root zone as well as reduces irrigation water losses through the soil surface, such as evaporation, runoff, and wind drift [8,9], whereas the use of geotextile mats enhances the delivery of water inside the crop root zone. Additionally, subsurface drip and geotextile materials can improve hydraulic conductivity inside the root zone. However, shallow-rooted plants are the most suitable for geotextile materials [17]. It is observed that there is an increase in soil moisture content (SMC) in the root zone of an iceberg lettuce crop. On the other hand, soil moisture distribution in sand–loam soil and geotextile materials tends to be spread more horizontally as there is more contact between the soil and the geotextile envelope. The layers of geotextile material under the soil surface reduced deep percolation under the plant root zone [32].

The water application efficiency was measured during the two seasons. The geotextile layer depth treatments recorded higher water application efficiency as compared to the control treatment (without geotextile) for all irrigation levels during the two growing seasons. Subsurface drip is considered to have the highest irrigation efficiency, exceeding 90% compared to other irrigation methods [10,11]. Irrigation management and the application of some agricultural practices are the most important methods to reduce deep percolation losses and evaporation from the soil [15]. However, the use of subsurface geotextile layers at different irrigation levels reduced deep percolation and improved hydraulic conductivity and water application efficiency [17]. This is evident in the water application efficiency values under all geotextile depths with irrigation at 80% of *ETc*, which recorded very close values to those for irrigation at 100% of *ETc* [16,17,33]. Overall, the application of a geotextile layer under the soil surface gave regularity in water distribution and saved water for more time in the root zone, which leads to high water application efficiency [34–36].

During 2021 and 2022, crop growth parameters were measured to evaluate the effect of geotextile layers at different depths from the soil surface with different amounts of water (%*ETc*). Overall, the crop parameters were increased through increasing irrigation rates and geotextile, which reduced deep percolation losses and maximized water abundance within the root zone. This led to an increase in soil water contents, with slight evaporation from the soil, and the availability of nutrient values (N, P, and K) [37–39]. Optimal application of irrigation water enhanced crop growth parameters (such as plant height, head diameter, head circumference, and head volume), which improved crop yield and quality [40]. In addition, subsurface drip irrigation increases soil moisture availability, which leads to increased yield and enhanced water use [8–12]. Moreover, subsurface drip irrigation with a subsurface geotextile layer gives better results as it reduces evaporation from the soil and reduces the losses of deep percolation.

Regarding the lettuce crop yield, the highest results were obtained under the geotextile layer at different depths for both seasons. There is a positive effect of irrigation management on crop yield when using promising agricultural practices under subsurface irrigation [41]. The higher soil moisture level inside the root zone significantly increased the yield [42]. Additionally, the data of irrigation with 80% of *ETc* and a geotextile layer at different depths had a good effect on iceberg lettuce crop yield and water productivity compared with irrigation at 100% of *ETc* and control treatment (without geotextile) for the 2021 and 2022 seasons (Figures 5 and 6). As a result, 20% water reductions may be made without considerably lowering yield [43]. These results may be due to using a layer of geotextile under the soil, which led to an increase in soil moisture availability and reduced deep percolation [44,45].

This increase in yield may be due to the use of geotextile, which led to an abundance of water in the root zone and its effect on some metabolic processes in the plant cell. Besides, an increase in soil water content may lead to increased nutrient (N, P, and K) solubility and uptake in the root zone, as well as further improved photosynthesis, carbohydrate production, and crop yield [46–49]. In this respect, our results of water stress are in agreement with those obtained by other researchers [50,51].

Finally, there was a significant difference between the application of the geotextile layer at different depths and the control treatment (without geotextile) at all irrigation levels. Moreover, there are many implications for inadequate water resource management, especially excessive irrigation water use. Therefore, geotextile can be used at different depths as an irrigation management practice to reduce deep percolation in the field.

5. Conclusions

The lettuce crop is affected when grown under limited water supplies as it produces small heads, especially during the late growing stage. There are many implications for inadequate water resource management, especially excessive irrigation water use. Subsurface drip delivers water within the plant root zone as well as reduces irrigation water losses through the soil surface. During the irrigation process, a large amount of water goes missing through deep percolation. Moreover, in the field, deep percolation is one of the unknown parameters in the irrigation balance equation. Therefore, the main objective of this study is to reduce the losses of deep percolation using geotextile layer depths under different irrigation levels in sandy loam soil using subsurface drip irrigation. The experimental design was a geotextile layer at different soil surface depths (20, 30, 40 cm, and without geotextiles) and with different irrigation rates (100, 80, and 60% of *ETc*). For soil moisture content and water application efficiency, the ideal data were recorded under all geotextile layer depths with all irrigation treatments. Generally, the geotextile layer at 30 cm depth produced a significant increase in plant growth and yield parameters compared to the control (without geotextile). However, the geotextile at 30 cm depth under irrigation of 100% of *ETc* was statistically the most effective treatment in this study, with values reaching 69.3 and 67.5 t ha^{-1} for each season, respectively. The same trend was found during the two growing seasons for yield and water productivity. Moreover, the data indicated that irrigation at 80% of *ETc* and a geotextile layer at different depths had a significant effect on vegetative growth, yield, and water productivity of iceberg lettuce compared to irrigation with 100% of *ETc* and control (without geotextile treatment) for the two growing seasons. Thus, it is possible to achieve a higher yield through using a geotextile layer at a depth of 20 and 30 cm under irrigation requirements of 80% of *ETc* compared to the control (100% of *ETc* and without geotextile treatment).

In general, there was a significant difference between the application of the geotextile layer at different depths and the control treatment (without geotextile) at all irrigation levels. The results indicated that geotextile can be used at different depths as an irrigation management practice to reduce deep percolation on the field.

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