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Improving Water Use Efficiency and Water Productivity for Okra Crop by using Subsurface Water Retention Technology

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ABSTRACT

Utilizing the modern technologies in agriculture such as subsurface water retention techniques were developed to improve water storage capacities in the root zone depth. Moreover, this technique was maximizing the reduction in irrigation losses and increasing the water use efficiency. In this paper, a polyethylene membrane was installed within the root zone of okra crop through the spring growing season 2017 inside the greenhouse to improve water use efficiency and water productivity of okra crop. The research work was conducted in the field located in the north of Babylon Governorate in Sadat Al Hindiya Township seventy-eight kilometers from Baghdad city. Three treatments plots were used for the comparison using surface trickle irrigation system: Polyethylene sheet (SWRT) was used in plot T1, controlled irrigation in plot T2 and uncontrolled irrigation in plot T3. Irrigation quantities, time of irrigation, soil water contents were measured for all treatments plots. The results indicated that water use efficiency for the three experimental plots, T1, T2, and T3 were: 2.43, 1.94 and 0.98 kg/m^3, respectively. The increasing value in water use efficiency of T1 plot compared with T2 and T3 plots were 25 and 148 %, respectively. Additionally, the water productivity of okra crop for T1, T2, and T3 plots was: 12800.9, 8744.8, and 4736.3 ID/m^3, respectively. The increasing value of the water productivity of T1 compared with plots T2 and T3 was 46 and 170 %, respectively. From this study, the benefit of using membrane sheet below the soil surface resulted in an increase in the value of yield, water use efficiency and water productivity. Moreover, saving water and reduced the water losses by deep percolation were resulted.

Keywords: okra, water use efficiency, subsurface water retention technology, water productivity.

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تحسين كفاءة استخدام المياه وانتاجية المياه لنبات الباميا باستخدام تقنية حجز المياه تحت سطح التربة

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الخلاصة

استخدام التقنيات الحديثة في الزراعة مثلا تقنية حجز المياه تحت سطح التربة لتحسين حجوم المياه المخزونة في عمق الطبقة الجذرية والحصول على أعظم نقصان في ضائعات الري وزيادة في كفاءة أستخدام المياه. في هذا البحث تم تثبيت طبقة من البولي أثيلين ضمن الطبقة الجذرية لنبات الباميا خلال الموسم الربيعي 2017 داخل البيت الاخضر لغرض تحسين كفاءة أستخدام المياه وانتاجية المياه لنبات الباميا. تم أجراء البحث في حقل واقع في شمال محافظة بابل في ناحية سدة الهندية التي تبعد سبعة وثمانون كيلومتر عن مدينة بغداد. استخدمت ثلاثة معاملات زراعية لغرض المقارنة باستخدام الري بالتنقيط السطحي وكما يلي: الغشاء من البولي أثيلين في T1, قطعة مسيطر عليها في أضافة المياه T2 وقطعة غير مسيطر عليها في اضافة المياه T3. كميات وزمن الري والمحتويات الرطوبة قيست لكل المعاملات. أظهرت النتائج ان قيم كفاءة استخدام المياه للمعاملات الزراعية T1, و T2 وT3: 2.43 و 1.94 و 0.98 كغم\م^3 على التوالي. قيمة الزيادة في معامل كفاءة استخدام المياه للمعاملة الزراعية T1 و T2 و T3 مقارنة مع المعاملات كانت 25 و 148 % على التوالي. أضافة الى ان قيم إنتاجية المياه لنبات الباميا كانت للمعاملات الثلاث: 12800.9 و 8744.8 و 4736.3 دينار عراقي لكل متر مكعب من المياه على التوالي. أن الزيادة في قيمة معامل إنتاجية المياه في المعاملة الزراعيةT1 كانت 46 و 170 % مقارنة مع المعاملات T2وT3 على التوالي. من هذه الدراسة وعند أستخدام الاغطية الغشائية تحت سطح التربة تم الحصول على زيادة في المحصول وكفاءة استخدام المياه و انتاجية المياه وبالإضافة الى حفظ وتقنين المياه وخفض الضائعات المائية.

الكلمات المفتاحية: الباميا, كفاءة توزيع المياه, تقنية حجز المياه تحت السطحي, انتاجية المياه.

1. INTRODUCTION

Water productivity (WP) is the net return dividing on water utilized. With no gains in water productivity, average annual agricultural evapotranspiration could double in the next 50 years. Better understanding, measurement, and improvement of WP thus constitute a strategic response to growing water scarcity, optimization of other production inputs, and enhanced farm incomes and livelihoods, **Molden, et al., 2010**. **Nagaz, et al., 2012**, assess the influence of various irrigation scheduling regimes with saline water on yield and WP of pepper crop for two years 2008 and 2009 in the arid region of Tunisia using trickle irrigation system. The applied water of irrigation electric conductivity (ECi) is equal to 3.6 ds/m. Four irrigation treatments plots are used and soil water balance model is used to calculate irrigation quantity when readily available water is consumed with levels of 100% (full irrigation), 80% and 60%. The results showed that the maximum yield is found under full irrigation with value equals to 22.3 and 24.4 t/ha. While WP values varied significantly between 2.31 and 5.49 kg/m^3. The lowest value was under 60 % level of irrigation. For water saving, the full irrigation scheduling was recommended for trickle irrigation. Using new technology named subsurface water retention technology (SWRT) led to enhance the agriculture in the soils that have light texture by setting up the polyethylene membrane under the soil in the root zone. This membrane saves the water, fertilizer, and pesticide over the membrane and inhibits the water losses via deep percolation. **Smucker, et al., 2016,** constructed a greenhouse lysimeter evaluate equipped with sand soil with spatially distributed impermeable subsurface soil water retaining membranes to evaluate the production of maize. Membranes are installed at multiple depths, and the lysimeter volume of sand provided with soil water sensors. The results show that these membranes doubled the water holding capacity and increased maize production by 240 %. Additionally, water use efficiency is increased by 77 %. They conclude that the new SWRT will develop sustainable agricultural production of maize in sandy soil by 20 metric ton of grain per hectare. **Berhanu**, **et al., 2014,** defined the optimal geometric parameters of the SWRT membranes and the most accurate irrigation rates for corn production in sandy soil. They setup subsurface water retention membrane in three depths: 20 cm, 40 cm, and 60 cm, in large sand-filled lysimeter, with aspect ratios: 2:1, 3:1, 5:1 and 10:1 controlled by aspect ratios of SWRT membranes. Moreover, SWRT membrane with an aspect ratio of 2:1 basically increased soil moisture content at 20 cm soil layer above the membrane. The overall conclusion was that SWRT appeared to be an encouraging technology for precision water content in the plant root zone and for minimizing water and nutrient losses during deep infiltration. **Al-Rawi, et al., 2017,** studied the effect of using polyethylene sheet, organic matter, tillage and no-tillage on irrigation water use efficiency (IWUE) of hot pepper. The experiment was conducted in two fields sites located in Diyala and Najaf Cities. The results indicated that in Diyala field site, the IWUE value of hot pepper for SWRT plot is the highest value among organic matter; tillage and no-tillage by 106, 167 and 135 %, respectively, and with saving in water almost have of the quantity applied. Additionally, the IWUE for hot pepper in Najaf field site is also the highest value by 38, 79 and 89 %, respectively, and with saving in water almost 33 %. **Yang, et al., 2017,** evaluated the higher value of WUE and enhance fruit quality of greenhouse crops with minimal water with regulated deficit irrigation (RDI) on hot pepper at season 2011–2012 in the solar greenhouse. The results show that the better RDI strategy to enhance both WUE and fruit quality was keeping soil water content at 70 % of F.C throughout the growth season except at the late fruit bearing and harvesting stage, due to this stage sufficient water of 90 % should be applied.

The objectives of this study were to evaluate the effects of subsurface water retention membranes on yield (production per planted area), water use efficiency (WUE) and on water productivity of okra crops inside the greenhouse based on comparison among SWRT, without SWRT and line controlled from the farmer treatment plots.

2. MATERIALS AND METHODS

2.1 Study Area and Experimental Conditions

The field study was located in Sadat Al Hindiya Township, in Babylon Governorate 78 km south of Baghdad city. The latitude 32 º 40’ 47.62”N and longitude 44º 15'55.42"E, and altitude: 30 m. **Fig.1** shows Google map for the location of the study fieldwork. The main source of the water is from a water pond connected with the local stream from branch canal which takes its water from Al-Kifil main canal. Soil samples from the fieldwork were carried out in the laboratories of the College of Agriculture-University of Baghdad. The aim of the analysis was to identify the physical characteristics of the soil so as to locate soil texture and physical properties of the soil that included bulk density, soil texture, field capacity, and permanent wilting point. The soil texture type of the field is classified as loam soil for depth ranges 0 to 30 cm and loam soil for depth ranges 30 cm to 60 cm. The field capacity at depth 0-30 cm was 33.14% by volume and the permanent wilting point was 13.23 % by volume.

2.2 Treatments, Experimental Design and Crop Material

Three treatments plots were utilized: first treatment T1 was using membrane sheet installed under the soil surface, while the second treatment T2 plot was without SWRT (controlled irrigation) and the final treatment plot T3 was without using SWRT and uncontrolled of irrigation process. Each treatment area was of total area equal to 63.75 m^2. The whole treatments were treated by pesticides, chemical fertilizers at a certain time with suitable quantities. The membrane sheet was of 51 m and of width 47.1 cm installed as has U shape with aspect ratio 2:1 (length to height), installed under the soil surface and 45 cm below the root zone of thickness 180 μm. The installation process of the film was done manually as shown in **Fig.2**. **Fig.3** shows a cross-section through the location of the membrane. Okra (*Abelmoschus esculentus L.*) was planted at a distance of 0.2 m among each plant of plots T1, T2, and T3. The spacing of emitters was(Se) 0.19 cm in T1 and T2 plots, while in T3 plot the spacing of the emitter was(Se) 40 cm. The planting date was started in January 2017 and the harvested date was the end of July 2017. The dimension of the greenhouse was: 51 m long, 9 m wide and 3 m height with the total area of 459 m^2. A polyethylene membrane was utilized for covering the structure of the greenhouse by 180 μm treated against ultraviolet radiation. The greenhouse was without air ventilation or heating in this case the greenhouse was classified as low technology greenhouse. The surface drip irrigation system has been utilized in the greenhouse. The drip system consists of five double irrigation lines and two single line at two sides of greenhouse have 51m long. The average discharge of each emitter was 34.83 cm^3/min for treatment plots T1 and T2, while emitter flow rate was 75.31 cm^3/min for treatment plot T3 (as required by the farmer). The irrigation processes were controlled by the farmer, however, for each irrigation process, date, the flow rate from the emitter, the duration time of the irrigation and soil water content before and after irrigation were recorded.

2.3 Yield, Water Use Efficiency (WUE) and Water Productivity (WP)

2.3.1 Yield index

The total production from the summation of whole pickings crop's production was used as a total fruit yield. The unit yield was kg/m^2 expressed as described by **FAO, 1982:**

$$Yield = \frac{total\ weight\ of\ crop\ (kg)}{total\ area\ of\ crop\ (m^2)} \quad (1)$$

2.3.2 Water use efficiency

The water use efficiency (WUE) can be defined as is the result of a full range of plant and environmental operations that work over the life of a crop to locate both yield and water utilize. The following equation was utilized for estimating the WUE (kg/m^3) **Naroua et al., 2014**:

$$WUE = \frac{yield(\frac{Kg}{m^2})}{total\ depth\ of\ applied\ water\ (m)} \quad (2)$$

2.3.3 Water Productivity

The term water productivity (WP) could be described as the ratio between the amount of cultivation product (biomass, yield) and the amount of water depleted or supplied. In this paper, WP was used as described by **Molden, et al., 2010**:

$$WP = \frac{\text{Return}}{\text{Unit of volume water applied}(\text{m}^3)} \quad (3)$$

Where:

Return represents cost (for example ID), kg, protein…

In this paper yield, water use efficiency and water productivity values of okra crop for the three treatment plots were calculated and compared.

3. RESULTS AND DISCUSSION

3.1 Frequency of Irrigation and Applied Water Depth

The recorded temperature inside the greenhouse through the growing season 2017 was ranged between 25 to 50 C^o and the relative humidity was between 40 to 80 %. The irrigation schedule was carried out for treatments T1 and T2 through the growing season when the soil water depletion reached 50 % from the available water. The monthly applied water depths and frequency of irrigation for okra through the growing season 2017 for treatments T1, T2 and T3 were as listed in **Table 1**. The frequency of irrigation processes needed for okra crop in treatment plots T1 and T2 were less than in the treatment plots T3 by 13.64 %. Additionally, the total sum of the depth of applied water in treatments T2 and T3 were more than that in treatment T1 by about 7 % and 77 %, respectively. Treatment plot T1 was saving more water within the soil root depth due to the membrane sheet. The crop's root has used the water which exists in the soil profile above the membrane sheet by capillary rise. Moreover, following irrigation scheduling in treatment plots T1 and T2 as much as possible saved more irrigation water. While the treatment plot T3 was uncontrolled irrigation process beside to existing four emitters per crop.

3.2 Yield and Water Use Efficiency of Okra Crop

Crop yield was calculated by applying **Eq. 1** for treatments T1, T2 and T3. They were 1.08 kg/m^2, 0.92 kg/m^2 and 0.77 kg/m^2, respectively. The total collection of the yield value for treatment T1 was more than that in treatments T2 and T3 by 17.4 % and 40.3 %, respectively. This increase in the crop yield in treatment T1 was due to the water and fertilizer materials which were detente above the membrane sheet which utilized by the plant by capillary rise. **Table 2** shows the crop yield for each production month of okra crop for treatments T1, T2, and T3 for the growing season 2017. By applying **Eq.2**, the calculated values of water use efficiency (WUE) for treatments T1, T2, and T3 were: 2.43 kg/m^3, 1.94 kg/m^{3,} and 0.98 kg/m^3, respectively. WUE in treatment T1 was more than that in treatments T2 and T3 by 25 % and 148 %, respectively. The yield and WUE values of the treatment T1 were more than other treatment due to utilizing membrane sheet which helps on conserve water, fertilizers, and pesticides in the root zone of plant and prevents water losses by deep percolation. **Fig.5** shows the crop yield and WUE values for treatment plots T1, T2, and T3.

3.3 Water Productivity

Water productivity (WP) was a natural definition in units of kg/m^3, where crop production was scaled in kg/ha and water applied was calculated as mm of water irrigation supplied converted to m^3/ha. Alternatively, in this work, WP represented monetary value ID/m^3 estimated by applying **Eq.3, Molden, et al., 2010**. The initial and variable expansive costs were estimated for the three treatments T1, T2, and T3 including the following costs: seeds, fertilizers, pesticides, irrigation systems, greenhouse (materials and installation), membrane sheets, water application, gasoline consumption by pump and labors cost. **Table 3** shows the production, average total cost (ID), return (ID), net return (ID), applied volume of water (m^3) water productivity (ID/m^3) of all treatments plots T1, T2 and T3 of okra crop through the growing season. From the analysis and from **Table 3,** the water productivity of treatment plot T1 was more than other treatments T2 and T3 by 46 and 170 %, respectively, the increasing value in productivity and reduction amount in applied water was due to utilizing the membrane sheet under the root zone which helps on conserve water and nutrient at root zone and to utilize the plant at the need that helps on raising the net return more than other treatment. F**ig.6** shows the comparison in WP among treatments plot T1, T2, and T3 of okra in the growing season 2017.

In this work study, using the subsurface water retention technology was assisted on increasing water productivity, saving water and reducing water losses due to deep percolation and the then more benefits to the farmer as net return as long the farmer looking for more income. The method of installing the membrane sheet below the soil surface will be more benefits in coarse-textured soils and an area of heavy rainfall. The membrane will reserve irrigation and or rainfall water within the crop's root additional to saving the fertilizers materials. More desert lands or unused lands could be used and transfer to production lands with less water and more crop's production.

4. CONCLUSIONS

Utilizing the membrane sheet under the root zone of the plant assisted on saving the water, fertilizer, and pesticide and helps on decreasing the number of irrigation and quantities of applied water, increasing crop yield, water use efficiency and water productivity values:

1- In treatment plot T1, the quantities of applied water were reduced by 7 %, among T2. While, the frequency of irrigation and quantities of applied water in treatment T1 were reduced by 13.64 % and 77%, respectively among T3.
2- Crop yield in treatment plot T1 was more than treatment plots T2 and T3 by 17.4 % and 40.3 %, respectively.
3- Water use efficiency of okra crop in treatment plot T1 was higher than in treatment plots T2 and T3 by 25 % and 148 %, respectively.
4- Water productivity of okra crop in treatment plot T1 was higher than in treatment plots T2 and T3 by 46 and 170 %, respectively.
5- The membrane sheet blows the soil surface conserving the applied water efficiently; therefore subsurface water retention technology (SWRT) enhanced the crop yield, water use efficiency and water productivity successfully.
6- For further studies, SWRT could be applied in coarse-textured soils in open field area with the rainy season for improving the yield and water use efficiency.

7- Multilayers of the membrane sheet installed at different depths with different aspect ratio could be investigated under different crops.

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NOMENCLATURE

SWRT= subsurface water retention technology.
T1, T2, and T3 = treatment plots.
WP = water productivity (ID/m^3).
ID = Iraqi dinar
WUE = water use efficiency (kg/m^3).
Se =emitter spacing (m).
Sl = lateral spacing (m).

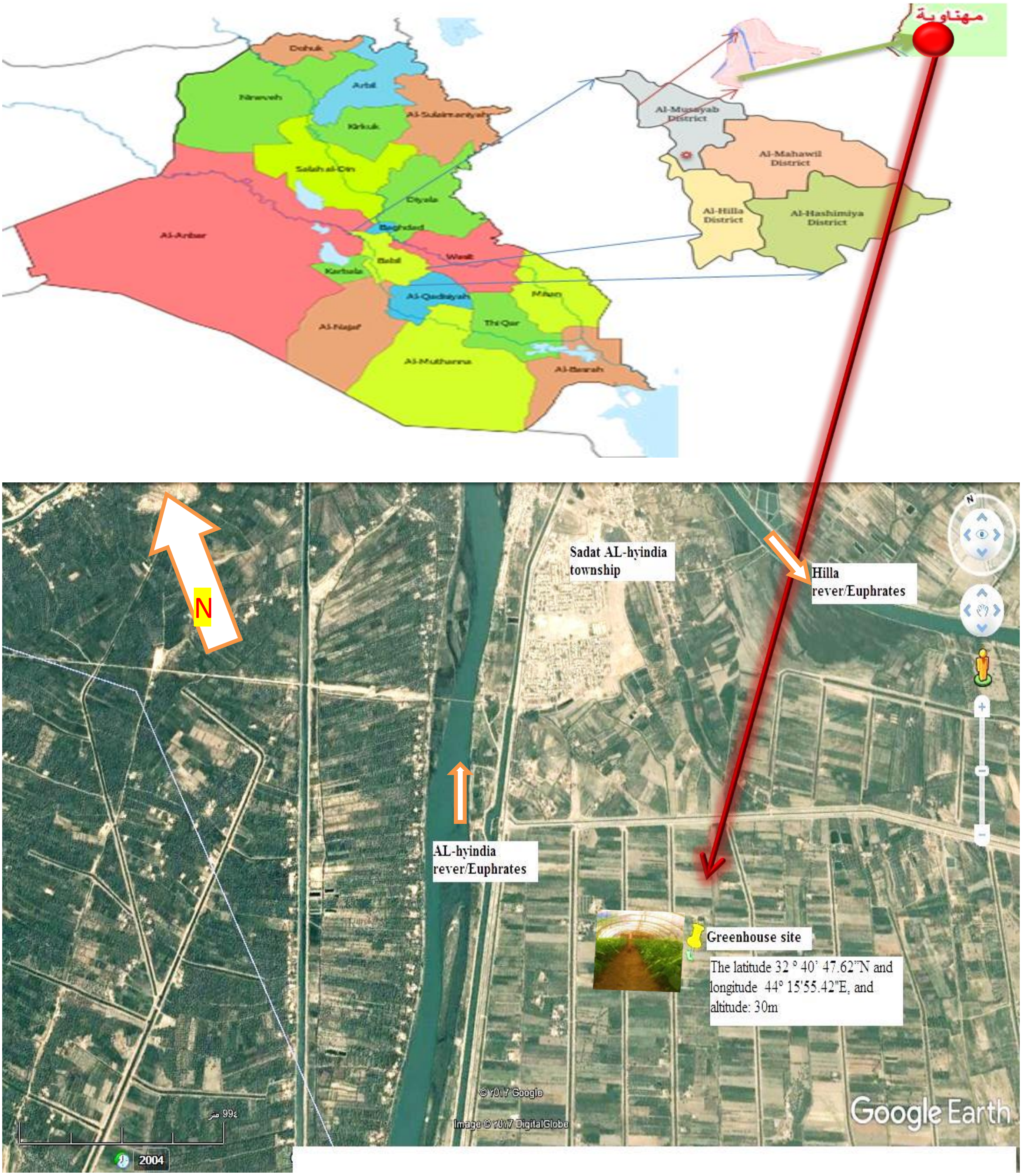

Figure 1. Google map for the research site work.

Figure 2. The installation process of the polyethylene sheet below the soil surface.

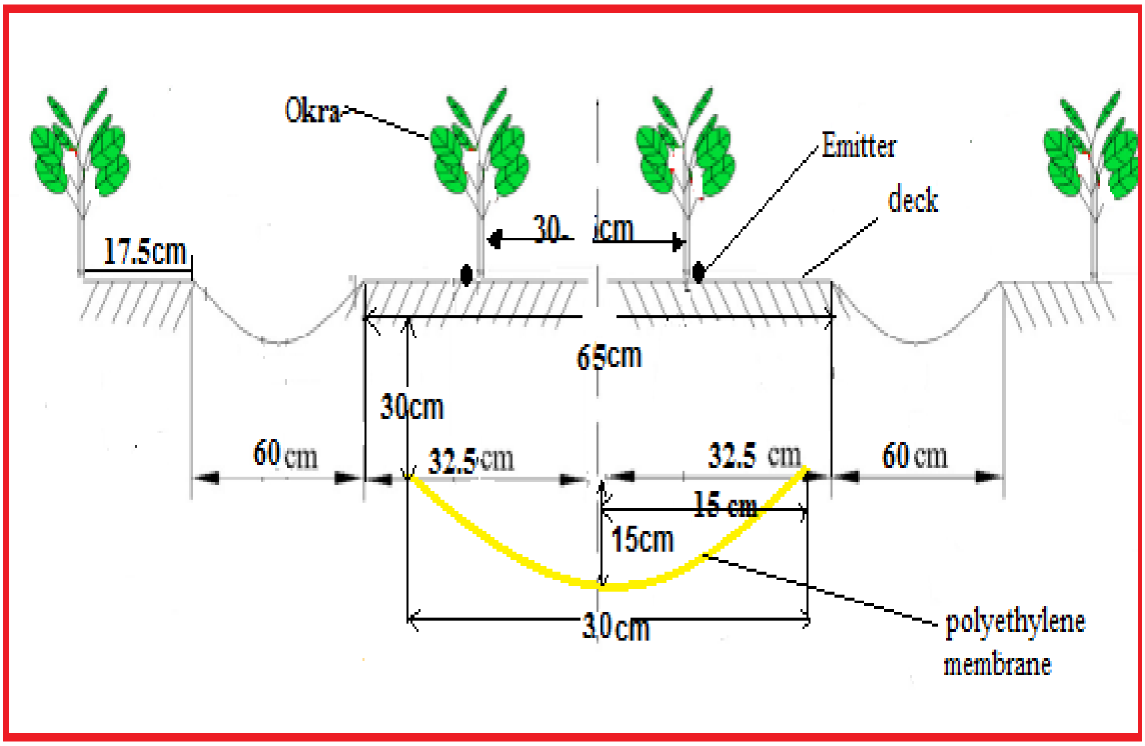

Figure 3. Cross section through soil deck and the location of the membrane sheet.

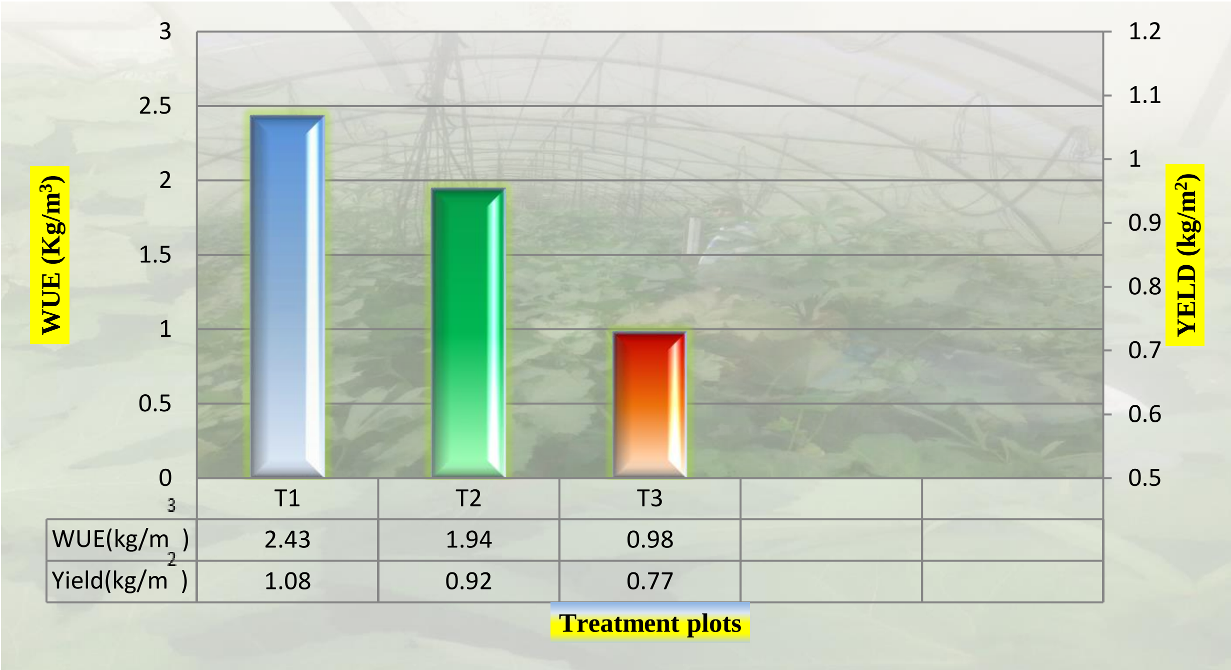

Figure 4. Yield and WUE values for treatments plots T1, T2 and T3 of okra in the growing season 2017.

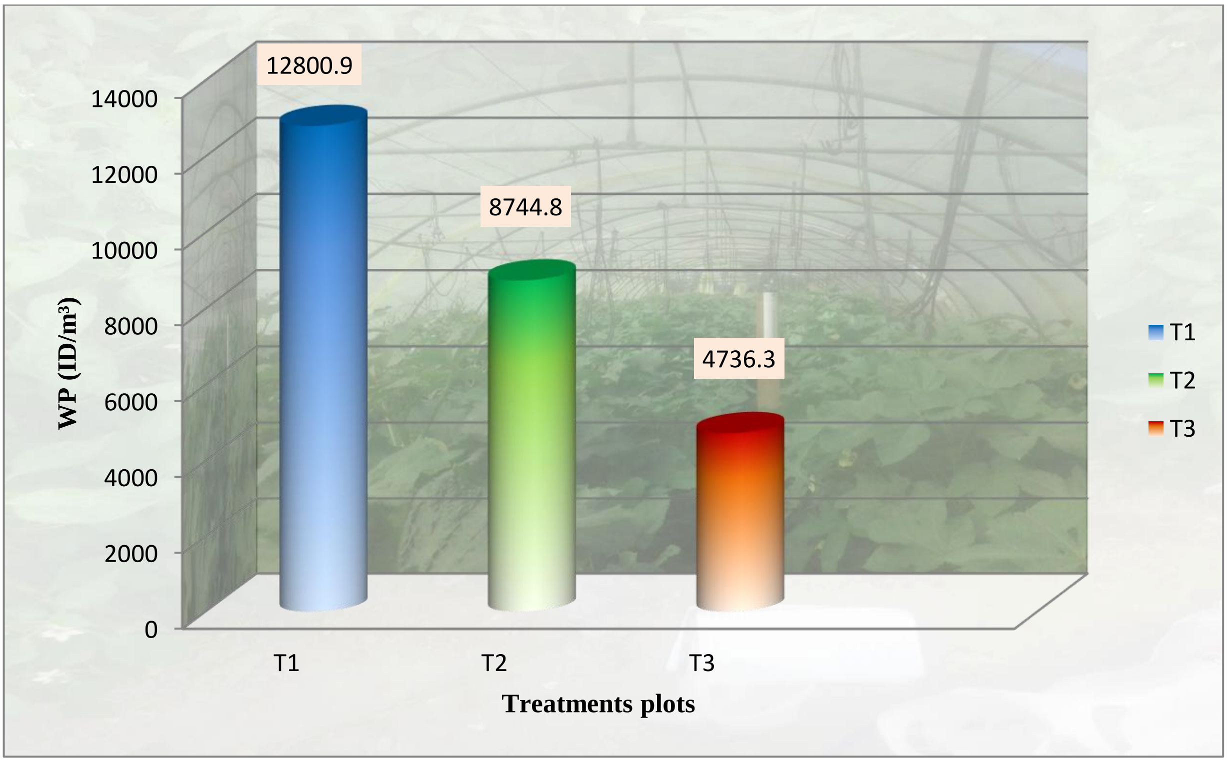

Figure 5. Water productivity for treatments T1, T2 and T3 of okra in the growing season 2017.

Table 1. The depth of applied water and frequency of irrigation of okra in treatment plots T1, T2, and T3 for the growing season 2017.

Month	Depth of applied water in T1 (mm)	Frequency of irrigation In T1 and T2 (day)	Depth of applied water in T2 (mm)	Depth of applied Water in T3 (mm)	The frequency of irrigation in T3 (day)
Jan.	23.31	2	23.31	49.15	2
Feb.	11.11	2	17.78	39.92	2
Mar.	64.8	5	75.9	144.92	5
April	59.25	4	59.25	143.78	6
May	91.59	4	91.59	134.44	5
June	146.89	4	156.22	204.73	4
July	47.86	1	50.25	71.53	1
Total	444.81	**22**	474.34	788.48	**25**

Table 2. Crop yield of okra for treatment T1, T2, and T3 for the growing season 2017.

Month	Yield for T1 (kg/m^2)	Yield for T2 (kg/m^2)	Yield for T3 (kg/m^2)
April	0.07	0.07	0.06
May	0.39	0.35	0.30
June	0.51	0.43	0.38
July	0.11	0.07	0.03
Total sum	**1.08**	**0.92**	**0.77**

Table 3. Production, average total cost, return, net return and applied volume of water and water productivity of all Treatments T1, T2 and T3 calculated by **Molden, et al., 2010**.

Parameters	**Treatment T1**	**Treatment T2**	**Treatment T3**
Production (kg)	67.82	57.14	49.82
Average price selling (ID)	3325	3325	3325
Average total cost (ID)	104917	103417	103417
Return (ID)	225501.5	189990.5	165651.5
Net return (ID)	120584.5	86573.5	62234.5
The volume of applied water (m^3)	9.42	9.9	13.14
Water productivity (ID/m^3)	**12800.9**	**8744.8**	**4736.3**