Subsurface Water Retention Technology Improves Water Use Efficiency and Water Productivity for Hot Pepper

تقنية حجز المياه تحت سطح التربة تحسن كفاءة استخدام المياه وانتاجية المياه لنبات الفلفل الحار

Ali Hassan Hommadi
Graduate student
Water Resources Eng. Dept.
College of Engineering
E-mail:alihassan197949@yahoo.com

Sabah Anwer Almasraf
Assist. Professor
Water Resources Eng. Dept.
College of Engineering- University of Baghdad
E-mail: sabah_dawood@yahoo.com

Abstract

The subsurface water retention technology (SWRT) is modern method for detention irrigation or rainfall water under surface soil in root zone depth in order to save water in soil profile for long period. In this study water use efficiency and water productivity for hot pepper inside greenhouse were evaluated and compared using in three treatments plots planted with hot pepper using: subsurface water retention technology (T1), organic matter (T2) and tillage (T3). The study work was conducted in the field located in Sadat Al Hindiya, north of Babylon governorate 78 km south of Baghdad. The growing season of hot pepper was starting on September 2016 and ended on May 2017. Irrigation quantities, time of irrigation and soil moisture contents were measured daily and sometimes weekly for all treatments plots. The results indicated that crop yield and water use efficiency for the three experimental plots, T1, T2 and T3 were: 4.151, 3.476 and 3.272 kg/m^2 and 5.54, 3.7 and 3.48 kg/m^3, respectively with increasing values in yield and water use efficiency in T1 comparing with T2 and T3 by 19.42, 26.87% and 50 and 59 %, respectively. Additionally, the new concept of water productivity of hot pepper for T1, T2 and T3 was: 66836.4, 36812.9, and 33909.2 ID/m^3, respectively, with increasing value in T1 comparing with T2 and T3 by 81.6 and 97.1 %, respectively.

Keywords: hot pepper, water use efficiency, subsurface water retention technology, water productivity.

الخلاصة:-

تقنية حجز المياه تحت السطحي (SWRT) هي طريقة حديثة لحجز مياه السقي او مياه الامطار تحت سطح التربة في المنطقة الجذرية من اجل خزن المياه في مقد التربة لفترة طويلة. في هذه الدراسة تم تقييم كفاءة استخدام المياه وانتاجية المياه لنبات الفلفل الحار داخل البيوت الخضراء(البلاستكية) و مقارنتها باستخدام ثلاث قطع أختبارية زراعية مزروعة بنبات الفلفل الحار وباستخدام :تقنية حجز المياه تحت السطح (T1)، المادة العضوية (T2) والحراثة (T3). اجريت الدراسة في حقل يقع في سدة الهندية ،شمال محافظة بابل 78كم جنوب محافظة بغداد. بدا الموسم الزراعي في ايلول 2016 وانتهى في ايار2017. كميات الري، وقت الارواء، والمحتوى الرطوبة للتربة قد تم قياسها يوميا او اسبوعيا في بعض الاوقات ولكل المعالجات الزراعية. كانت النتائج المستحصلة لإنتاجية النبات و كفاءة توزيع المياه لثلاث معاملات تجريبية (T2) , (T1) و (T3): 4.151، 3.476 و 3.273 كغم / م^2 و 5.54 ، 3.7 و 3.48 كغم/م^3،على التوالي مع زيادة في قيم الانتاجية في المعالجة T1 بمقدار 19.42 و26.87% على التوالي. وزيادة في قيم كفاءة أستخدام المياه في المعالجة T1 بمقدار 49.73 و 59.2% على التوالي . أضافة لذلك كان المفهوم الحديث لإنتاجية المياه لنبات الفلفل الحار: 66836.4 و 36812.9 و 33909.2 دينار عراقي /م^3، على التوالي، بزيادة في المعالجة الزراعية T1 مقارنة مع T2 و T3 قدرها 81.6% و 97.1% على التوالي.

الكلمات المفتاحية: الفلفل الحار، كفاءة توزيع المياه، تقنية حجز المياه تحت السطحي، انتاجية المياه .

1- Introduction

The utilization modern technology that named subsurface water retention technology (SWRT) led to improve the cultivation in the soils that have light texture by installation the membrane in the root zone. This membrane keeps the water and nutrient over the membrane and prevents the lost water by deep percolation.

Searchers **[1]** use a greenhouse lysimeter evaluate equipped with sand soil with spatially distributed impermeable subsurface soil water retaining membranes to evaluate 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.

Subsurface soil water retention membranes installed within plant root zones, comprise a self-regulating type of technology that improves the production of food and cellulosic biomass and increases water use efficiencies for the dramatic expansion of food and fiber production Searchers **[2]**.

Searchers **[3]** identify membrane shape and placement to maximize the reduction in irrigation water losses. The experiment is conducted in a lysimeter inside a greenhouse using six membrane of different geometry polyethylene sheet installed at four depths. Membrane with 2:1, 3:1 and 5:1 aspect ratio installed at depth 20 to 40 cm in sand, sandy loam and loamy sand soil textures. The results show that the highest reduction in water losses for most soil texture in the study case are achieve with a 2:1 aspect ratio (width to depth of the U shape) membrane installed at depth 20 cm. Moreover, the SWRT is sensitive to uncontrolled irrigation process. Additional tests are required for membrane performance in a field for different crops across a range of different climates conditions. They conclude that the increasing in crops yield by using SWRT film is due to double the soil moisture contents in the root zone of plants in coarse textured soil.

Searchers **[4]** explain the influence of soil water retention barriers (SWRB) and irrigation levels effect on soil moisture content, perennial ryegrass moisture consumption and on fresh yield. They installed SWRT at two various soil depths 30 and 40 cm, and three various irrigation levels of 100, 66 and 33 % of available water-holding capacity are used in sandy soil. The results show that when SWRT installed at depth 40 cm together with 34 % water deficit save 52 % of irrigation water compared with no SWRT is used.

Searchers **[5]** carry out and analyze the water use efficiency for different crops. The study is conducted in Spanish irrigation district “Rio Adaja” for three years 2010-2011, 2011-2012 and 2012-2-13. Crop water requirements are calculated based on Penman-Montieth model considering the readily available soil water content for Alfalfa, Barley, Bean, Carrot, Maize, Onion, Potato, Soryhun, Sugar beet, Sunflower, and Winter Wheat. The results show that in most deficit irrigation is applied in the first two years, but irrigation water productivity (IWP) is improved. In general IWP varied among crops but IWP for Onion, Potato, Carrot, and Barley are showing the higher values. Type of irrigation system with high sufficient and efficient performance may effect on saving water and results in high grain yield and low in irrigation cost. Searcher **[6]** evaluate the water use efficiency of hot pepper in fields located in Diyala and Najaf Cities using SWRT, organic, tillage and no tillage treatment experiments. The results indicate that the WUE of hot pepper in Diyala site is: 16.65, 8.09, 7.08, and 6.24 kg/m^3, respectively, with average increasing value of about 233% when using SWRT membrane. On other hands, WUE value of hot pepper in Najaf site work is: 3.72, 2.69, 1.97, and 2.09 kg/m^3, respectively with average increasing value of about 165% when using SWRT membrane.

Searcher**s [7]** examine the influence of irrigation treatment during the growth duration of hot pepper of various drought stress patterns application through field experiment inside the greenhouse. They found that the highest crop yield is 19.57 ton /ha under full water irrigation of field capacity. Additionally, the WUE of hot pepper is equal to 67.78 kg/ (ha/mm).

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 hot pepper crops inside the greenhouse based on comparison among SWRT, organic matter and tillage treatment plots.

2- Material and Method

2-1 Experimental Conditions and Location of the Field Study

The research field was located within Sadat Al Hindiya Township, in the Governorate of Babylon 80 km south of Baghdad and 25 km west of Al Hilla. The latitude: 32 º 40’ 8.96”N and longitude: 44º 15'E, and altitude: 29.5m. **Figure (1)** shows Google map for the Location of the experimental field work. The main source of the water is from a water pond charged continuously from the local stream from Al- Kifil main canal. Laboratory analyses of soil samples were conducted in the laboratories of the College of Agriculture-University of Baghdad. The goal of the analysis was to identify the physical characteristics of the soil in order to determine soil texture and physical properties of the soil which included bulk density, soil texture, field capacity, and permanent wilting point. The soil texture type of the field is classified as sandy clay soil for depth ranges 0 to30 cm and clay for depth ranges 30 cm to50 cm. The field capacity (F.C) of sandy clay was 33.6% and permanent wilting point (P.W.P)of sandy clay was 16.6% (all by volume).

2-2 Treatments, Experimental Design and Crop Material

Hot pepper crop (*Capsicum annuum L.*) was planted inside the greenhouse with the followings dimensions: 51 m in long, 9 m in wide and 3 m in height of total area 459 m^2. A transparent polyethylene film was used for covering the structure of the greenhouse by 180 μm thickness of treated material against ultraviolet radiation. The greenhouse was without heating and no air ventilation, in this case the greenhouse was classified as low technology greenhouse. Trickle irrigation system has been used in the greenhouse. **Figure (2)** shows the internal layout of the greenhouse. The trickle system consists of seven double irrigation lines of 51m long. Each line consists of two trickle tapes; the distance between the two trickle tapes was 0.3 m. The average flow rate for each emitter was 33.5 cm^3/min. The crop was planted at a distance of 0.57 m among each plant. For treatments one emitter was provided for each plant as required by the design requirement. The planting date was started at first week of September 2016 and the harvested date was end of May 2017. The irrigation processes were controlled by the farmer, however for each irrigation process, date, flow rate from the emitter, duration time of the irrigation and soil water content before and after irrigation were recorded.

2-3 Treatment Experimental Plots

Three equals treatments plots in area were used of total area 63.75 m^2 (each): the first treatment plot using membrane sheet installed under soil surface (T1), while the second treatment plot (T2) was used soil treated with organic matter of 375 kg with thickness of 5 cm and finally the third treatment plot (T3) the soil surface was treated by using tillage only. The whole treatments plots were treated by the same pesticides, chemical fertilizers and nutrients at a certain time with suitable quantities.

2-4 Description of the Subsurface Water Retention Technology (SWRT), Procedure and Installing

Subsurface water retention membrane was made of low density polyethylene with thickness of 180 µm and width 40 cm, was installed below the soil surface with aspect ratio 2.6:1 (width to height). The total length of the membrane was 51 m. The root depth of the hot pepper was reached about 30 cm deep. The installation process of the membrane was conducted manually as shown in **Figure (3)**. **Figure (4)** shown cross sectional through soil deck. The bottom depth of the membrane sheet was 25 cm below the soil surface, with width of 40 cm. The width of the membrane sheet covered two lines of the crops. The aspect ratio was difficult to set as 2:1, due to hand installing process.

2-5 Yield, Water Use Efficiency (WUE) and Water Productivity (WP)

The sum of all pickings crop's production was expressed as a total fruit yield. The crop yield (kg/m^2) was expressed as described by Searchers **[8].**

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

The water use efficiency is the outcome of an entire suite of plant and environmental processes operating over the life of a crop to determine both yield and water use. The following equation was used for calculating the WUE (kg/m^3) **(FAO, 1982) [8].**

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

Water productivity has more definitions for example it is the net return in numerator and a unit of water used in denominator. WP term describes the ratio between the quantity of agricultural product (biomass, yield) and the amount of water depleted or diverted. In this study, water productivity was expressed as described by Searchers **[5]**.

$$W\,P = \frac{Return}{Unit\ of\ volume\ water\ applied(m^3)} \qquad (3)$$

Where:
Return represent cost in ID, €, £, $, kg, protein, etc…,
In this study crop yield, water use efficiency and water productivity for the three experimental treatment plots for hot pepper were estimated and compared.

3- Results and Discussions

3-1 Frequency of Irrigation and Depth of Applied Water

Monthly depths of applied water and frequency of irrigation for hot pepper through the growing season 2016 and 2017 for treatments T1, T2 and T3 were shown in **Table (1)**. The recorded temperature inside the greenhouse in season 2016 was ranged between 25 to 35 C^o and the relative humidity was between 65 to 85 %. The frequency of irrigation processes needed for hot pepper in treatment T1 was reduced compared to the treatments plots T2 and T3 by 20 %. Additionally, the total sum of depth of applied water in treatments T2andT3 were more than that in treatment T1by about18 %.

Table (1) Month, depth of applied water and frequency of irrigation of hot pepper for the growing season 2016-2017.

Month – Year	Depth of applied water in T1 (mm)	Frequency of irrigation in T1 (day)	Depth of applied water in (each) T2 and T3 (mm)	Frequency of irrigation in T2 and T3 (day)
September-2016	55.23	3	55.23	3
October-2016	138.32	8	179.07	10
November-2016	107.62	6	136.24	7
December-2016	35.7	2	48.89	2
January-2017	50.866	3	48.97	3
February-2017	48.3	3	58.32	3
March-2017	82.32	3	141.61	6
April-2017	126.2	4	128.63	4
May-2017	104.28	3	143.93	4
Total	748.8	35	940.9	42

In each irrigation process, emitter’s flow rate, time of irrigation and wetted area under the emitter were measured. Depth of applied water was calculated on basis of emitter’s flow rate, time of irrigation and the wetted area under the emitter. The frequency of irrigation represent number of irrigation in each month of the growing season, and the total sum of 42 represented the total number of frequency of irrigation processes through the growing season..

3-2 Crop Yield and Water Use Efficiency

Crop yield of hot pepper was calculated based on **Eq. 1** for treatments plots T1, T2 and T3 were: 4.151 kg/m^2, 3.476 kg/m^2 and 3.272 kg/m^2, respectively. The total sum of the crop yield value for treatment T1 was more than that in treatments T2 and T3 by19.42% and 26.87%, respectively. This increasing in the crop yield in treatment T1 was due to the water and fertilizer materials which were retained above the membrane sheet and used through the plant by capillary rise. **Table (2)** showed crop yield for each production month of hot pepper for treatments T1, T2 and T3 for the growing season 2016-2017. By applying **Eq.2**, the calculated values of water use efficiency of the hot pepper for treatments T1, T2 and T3 were: 5.54 kg/m^3, 3.7 kg/m^3 and 3.48 kg/m^3, respectively.

Table (2) Month and crop yield of hot pepper for treatment plots T1, T2 and T3 for the growing season 2016-2017.

Month	Yield for T1 (kg/m^2)	Yield for T2 (kg/m^2)	Yield for T3 (kg/m^2)
Nov.2016	0.106	0.071	0.043
Dec.2016	0.071	0.053	0.043
Jan.2017	0.244	0.207	0.203
Feb.2017	0.397	0.289	0.265
Apr.2017	0.247	0.185	0.210
May 2017	1.474	1.217	1.250
Jun.2017	1.610	1.455	1.258
Total sum	4.151	3.476	3.272

Figure (5) showed the comparison values of crop yield and WUE for treatments plots T1, T2 and T3. The WUE in treatment T1 was more than treatment plots T2 and T3 by 49.73%and59.2%, respectively due to using less amount of applied water and more crop yield production. The saving water was due to use the membrane sheet below the soil surface In treatment T2 was utilize organic matter which assist on increasing in productivity more than T3 but less than T1.

3-3 Water Productivity

Water productivity was normal to define in units of kg/m^3, where crop production was measured in kg/ha and water use was estimated as mm of water applied converted to m^3/ha. Alternatively, the new concept of water productivity in this work represented as monetary value in Iraqi Dinars/m^3 and was calculated by utilizing **Eq.3** for the three treatments plots T1, T2 and T3. The initial and variable costs were calculated and included the following items: seeds, fertilizers, pesticides, irrigation systems, greenhouse (materials and installation), membrane sheet , water application, electrical consumption and worker wages. **Table (3)** showed the crop production, average total cost (ID), return (ID), net return (ID), applied volume of water (m^3) and water productivity of all Treatments plots (T1, T2 and T3) of hot pepper. The average total cost for all treatments were almost equal, the cost of polyethylene sheet was cheap and the durability of the material was too long as longer as no damage taken place. The installation by machine may be cost more than by hands; however the crop yield, net return and then water productivity in treatment plot T1 were more than in T2 and T3.

Table (3) Crop productivity, average total cost (ID) , return (ID), net return (ID) and applied volume of water (m^3) and water productivity of all Treatments plots (T1,T2 andT3).

Parameters	Treatment T1	Treatment T2	Treatment T3
Crop production (kg)	264.62	221.60	208.58
average price selling*	1400	1400	1400
Average total cost (ID/kg)**	129857	129857	125857
Return (ID)***	370468	310240	292012
Net return (ID)****	240611	180383	166155
Applied volume of water (m^3)*****	3.6	4.90	4.90
Water productivity (ID/m^3)	66836.4	36812.9	33909.2

The water productivity for treatment plot T1 was more than treatment T2 and T3 by 81.6% and 97.1%, respectively. The high value of the net return in treatment T1 among T2 and T3 was caused to increase the water productivity. Additionally, the low value of the applied volume of water in treatment T1 was also the factor to cause in increasing the water productivity. The water productivity in treatment plot T1 was the maximum value among T2 and T3 as showed in **Figure (6).** The membrane sheet was sufficient techniques in increasing water use efficiency and water productivity.

*average price selling (ID) represent average price selling of hot pepper production in season.

**Average total cost (ID) was Sum of the initial cost and variable cost at the season = seed, fertilizer, pesticide, irrigation system, cost of greenhouse, membrane sheet, water cost, electric consumption cost, worker wages equal 129857 ID as average cost of one line of T1 and T2 because the total cost of line T1 equal T2 due to price of the membrane sheet of T1 equal price of selling and set up of organic matter but in T3 was 125857 ID due to without using the membrane sheet and organic matter.

*** Return (ID) = Crop production x average price selling

****Net return (ID) = Return (ID) - initial and variable cost (129857 ID of T1 and T2 and 125857 ID of T3)

The volume of water applied of T1 = 19993.5 cm^3 ($\Sigma Q*T$ = average wetted area*Σ depth applied) of one emitter at season *180 no. of emitter /10^6 m^3 =3.6 m^3

The volume of water applied of T2 = 27195.75cm^3 of one emitter at season *180 no. of emitter /$10^6 m^3$ =4.9 m^3

The volume of water applied of T3 = 27195.75 cm^3 of one emitter at the season*180 no. of emitter /10^6 m^3/cm^3 = 4.9m^3

$1cm^3=1/10^6 m^3$

Note : the volume of applied water of one emitter at the season equal accumulated volume of water of the emitter at the season = discharge of emitter * time of irrigation = depth of applied *wetted area

***** Applied volume of water (m^3): average wetted area of T1 = 267cm^2 and average wetted area of T2 and T3= 289 cm^2 (each).

Volume of water of T1 = (267 cm^2 * 748.8mm /10mm /cm)/ 10^6 m/ cm *180 no. of emitter =3.6m^3

Volume of water of T2 and T3 = (289cm^2 * 940.9mm /10mm/cm)/ 10^6m/cm *180 no. of emitter = 4.9m^3.

Percentage of Wetting (Pw) = wetted area /total area of line

Pw of T1=43% and Pw of T2 and T3 =46%

Percentage of Shaded area (Ps) = 80-100% at the mid-term of the growing season through flowering and fruiting.

4- Conclusions

Using the polyethylene membranes under root zone of the plant helped on conserve the water and nutrient and assisted on reducing the number of irrigation and quantities of applied water, increasing crop yield, water use efficiency and water productivity:

1- Frequency of irrigation and quantities of applied water were reduced by 20% and 25.7 %, respectively.

2- Crop yield in treatment plot T1 was more than Treatment plots T2 and T3 by 19.42 % and 26.87%, respectively.

3- Water use efficiency (WUE) of hot pepper in Treatment plot T1 was higher than in treatment plots T2 and T3 by 49.73 and 59.2 %, respectively.

4- Water productivity (WP) of hot pepper in Treatment plot T1 was higher than in treatment plots T2 and T3 by 81.6% and 97.1 %, respectively.

5- The polyethylene sheet saving the applied water efficiently, therefore subsurface water retention technology improved the crop yield, water use efficiency and water productivity successfully.

5- Recommendations

For further studies in the same topic the following recommendations were suggested:

1- Study the possibility of utilizing SWRT in strategic crops for example wheat, barley and rice especially in coarse texture soils especially in region of heavy rainfall.

2- Study the possibility of using SWRT in clay soil to cultivate the rice crops especially in Najaf in order to increase the national product and support of agriculture in Iraq.

3- The techniques of retention the water is serves desert soil (desert of holly Karbala and other governorates) and in green belt planting due to saving water and nutrient in the root zone of plant therefore increasing the production.

References

1. Smucker, A.J.M., Yang, Z., Guber, A. K., He, X.C., Lai, F.H., and Berhanu, S., 2016, *"A new Revolutionary Technology to Feed Billions by Establishing Sustainable Agriculture on Small and Large Landscapes Including Urban Regions Globally*", International Journal of Development Research, Vol. 06, Issue, 10, pp. 9596-9602.
2. Smucker, A. J. M., Kavdir, Y., Zhang W., 2014, "*Root zone soil water retention technology: a historic review and modern potential ",* Soil Science Society of America Journal (in review).
3. Guber, Andrey K., Smucker, A. J. M., Berhanu, Samrawi, and Miller, James, M. L., 2015, "*Subsurface Water Retention Technology Improves Root Zone Water Storage for Corn Production on Coarse-Textured Soils"*, Vadose Zone Journal, Soil Science Society of America, July, 14(7).
4. Demirelasz, Kursad, and Kavdır, Yasemin, 2012, "*Effect of soil water retention barriers on turf grass growth and soil water content*", Irrig. Sci. 31, pp. 689–700.
5. Naroua, Illiassou, Sinobas, Leonor Rodríguez, and Calvo, Raúl Sánchez, 2014, *"Water use efficiency and water productivity in the Spanish irrigation district "Río Adaja"".*International Journal of Agricultural Policy and Research Vol.2 (12), pp. 484-491.

6. Isa, Hussein Abbas Mohammed, 2016, "*Effect of SWRT technology on water productivity of tomato and Chili pepper in sandy soil under water scarcity* ", PhD thesis College of Agriculture/ Baghdad University, Iraq.
7. Guang-Chenga, Shao, Na, Liu, Zhan-Yua, Zhang, Shuang-Ena, Yu, and Chang-ren, Chen, 2010, "*Growth, yield and water use efficiency response of greenhouse-grown hot pepper under Time-Space deficit irrigation*", Scientia Horticulturae 126, pp. 172–179.
8. Mady, A.A., and Derees, Abd H., 2007,"*Effect of water stress and application and water use efficiency* ", Acta Hort.719, pp. 471-478.
9. FAO, 1982, "Crop water requirement irrigation and drainage ".paper no.24, FAO, Rome, Italy.
10. Amirpour, Mehdi, Shorafa, Mehdi, Gorji, Manouchehr, and Naghavi, Hormazd, 2016, "*Effect of subsurface water retention using polyethylene membranes with surface mulch and irrigation on moisture, temperature and salinity of sandy soil of an arid region in Iran*", Advances in Environmental Sciences-International Journal of the Bio flux Society, Vol.8, Issue 1.

NOMENCLATURE

SWRT= subsurface water retention technology.
T1,T2 and T3= treatment plot no.1, no.2 and no.3
WP = water productivity (ID/m^3).
ID=Iraqi dinar.
WUE = water use efficiency (kg/m^3).

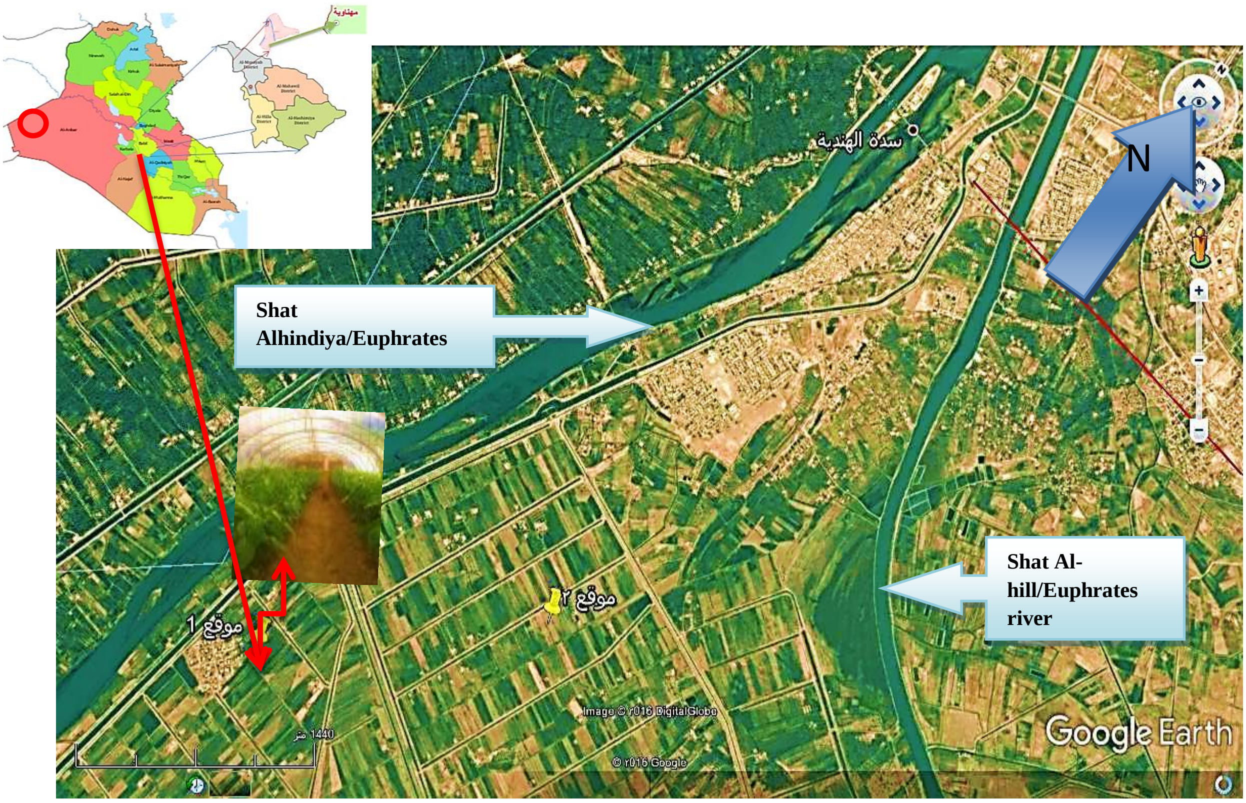

Figure 1 Google map for the site work.

Figure (2) Internal layout of the greenhouse (hot pepper at age120 days).

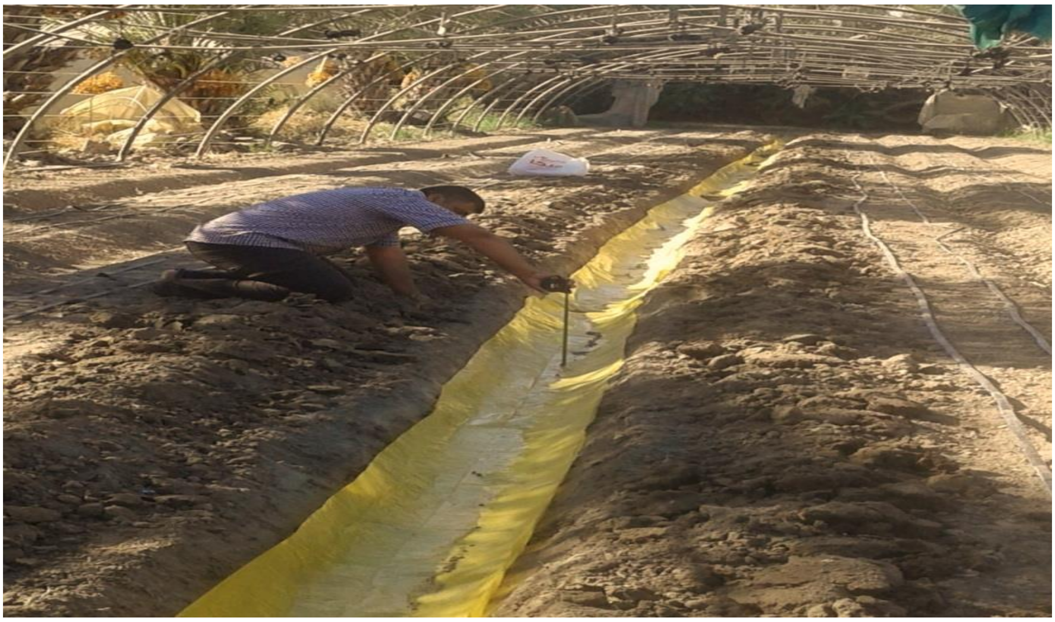

Figure (3) Installation of the polyethylene sheet below the soil surface.

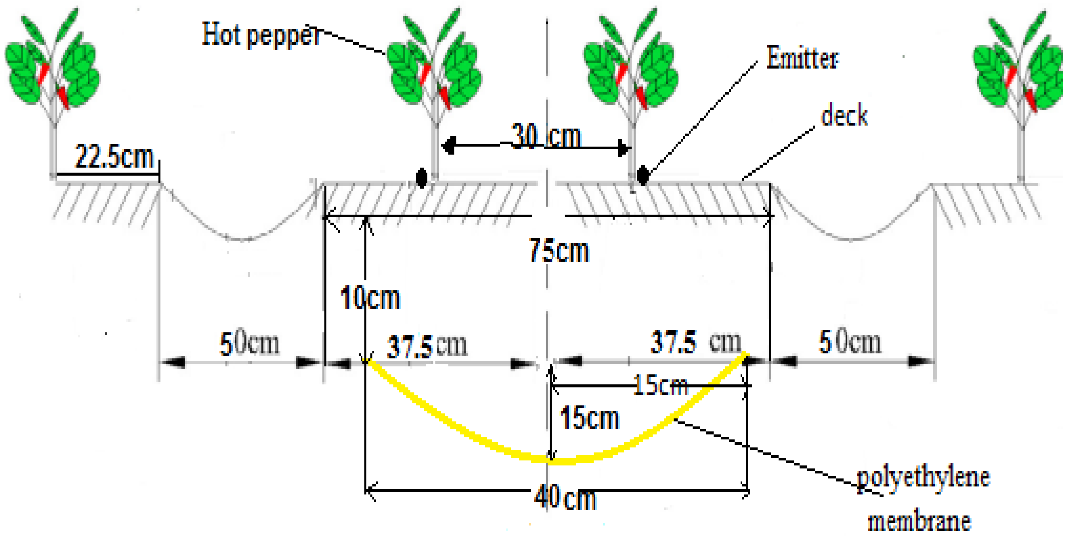

Figure (4) Cross sectional through soil deck and the location of the polyethylene sheet.

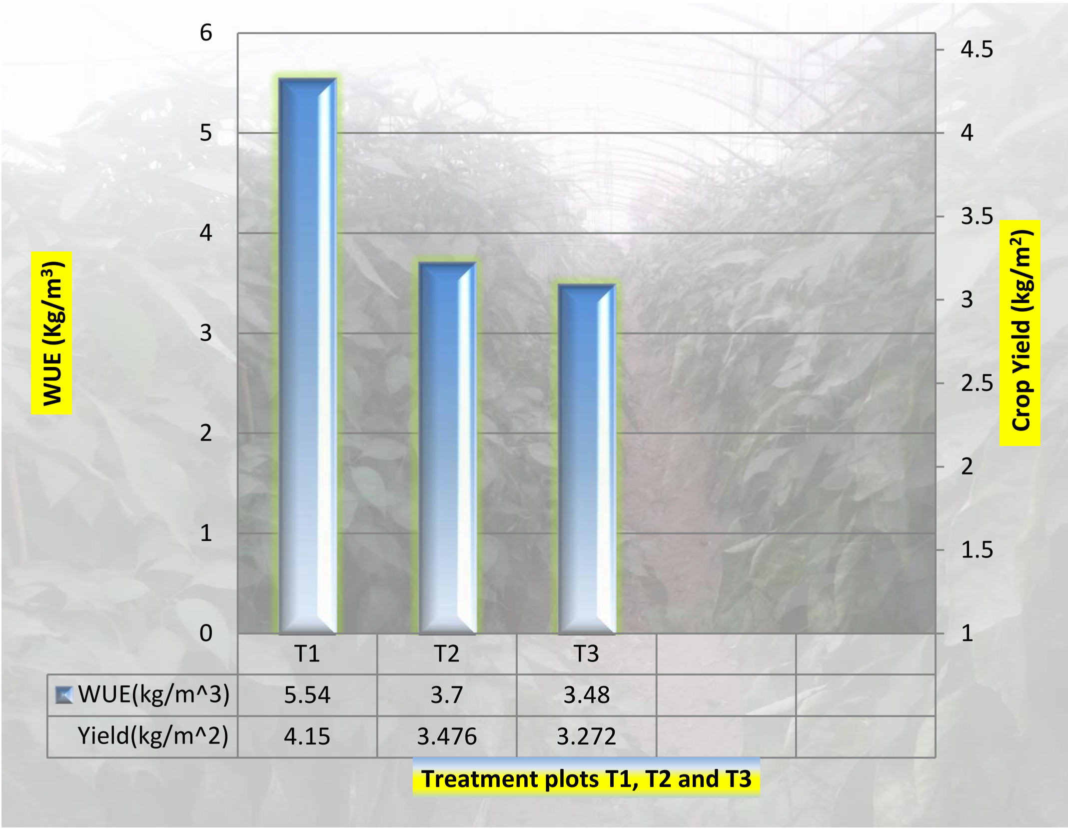

Figure (5) Crop yield and WUE for treatments plots T1, T2 and T3 of hot pepper in the growing season 2016-2017.

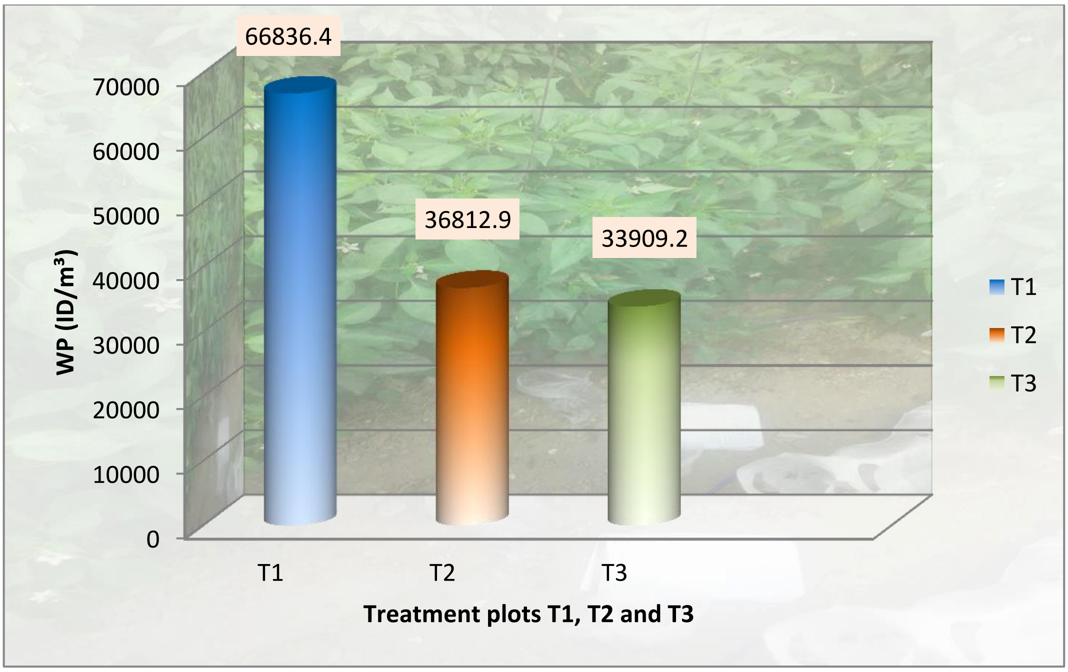

Figure (6) Water productivity for treatments plots T1, T2 and T3 of hot pepper in the growing season 2016-2017.