Mesopotamia Journal of Agriculture

https://magrj.uomosul.edu.iq

CULTIVATION SANDY SOILS USING SUBSURFACE WATER RETENTION TECHNOLOGY (SWRT) UNDER DROUGHTS AND WATER SCARCITY IN IRAQ

Alvin J.M. Smucker [1], Shatha S. Majeed [2], Alaa S. Ati [3], Mahdi I. Aoda [3]
Department of Plant, Soil and Microbial Sciences, Michigan State University, East Lansing, MI, United States[1]
Food and Agriculture Organization of the United Nations in Iraq/FAO 2
College of Agricultural Engineering Sciences/ University of Baghdad, Baghdad, Iraq 3

Article information
Article history:
Received: 18/4/2025
Accepted: 21/9/2025
Available: 30/9/2025

Keywords:
SWRT, water use efficiency, chili pepper.

DOI:
https://doi.org/10.33899/mja.2025.163433.1683

Correspondence Email:
alaa.salih@coagri.uobaghdad.edu.iq

ABSTRACT

A study was carried out to assess the impact of using SWRT on irrigation water use efficient IWUE and yields of chili pepper. Experiments were performed by planting chili pepper in greenhouses during the spring of 2015 in Najaf Province. Soils of the location are classified as sandy loam texture. The experiments included four treatments: SWRT, organic matter, tillage and no–tillage farming, and the design was a randomized complete blocked design RCBD with four replications. Irrigation scheduling was performed according to soil moisture content, as 35% of available water was depleted, then irrigation water was added from the subsurface drip system to bring soil moisture content back to field capacity. Soil sensors GS3 from Decagon Devices, USA, were used to measure volumetric water content. The results showed the use of SWRT technology leads to saving 22% and 36% of the amount of irrigation water added to the pepper crop compared to the organic matter treatment and the tillage (Control) and no tillage treatments. Increasing the productivity of the agricultural unit in SWRT with improved quality of fruits, the increase percentage of pepper 13%, 8% and 20% compared to the treatment tillage, organic matter and no tillage treatments, respectively. The decrease in the amount of irrigation water added leads to an increase in water use efficiency in SWRT 78%, 38% and 89% compared with control treatment, organic matter and no tillage treatments, respectively.

College of Agriculture and Forestry, University of Mosul.

INTRODUCTION

Water scarcity is one of the most serious global challenges threatening life on Earth. Population growth and climate change have significantly altered water availability, while the demand for freshwater has risen sharply. Freshwater resources are rapidly declining, and many of the remaining water sources are increasingly endangered by mismanaged waste disposal, industrial pollutants, and contaminated runoff. These factors may contribute to future global crises, including conflicts over access to water resources. However, if water availability can be secured, it becomes possible to rehabilitate certain soils that are currently deemed non-arable into productive, sustainable lands. One such example is high-permeability sandy soils, which constitute a substantial portion of the cultivable lands in Iraq (Dawod *et al.*, 2024; Khamees *et al.*, 2023; Alwazzan and Ati, 2024). The sandy soils exist in the dry and semi-dry regions of the world and form a major part of the Arab states. In Iraq, about 19% of the total area of the country is under cultivation, and this area is affected by dunes. The mobility of the land, these sandy soils are most often regarded as unsuitable for farming. They have very poor physical and chemical properties, as most notably their hydraulic conductivity is high, the rate of infiltration is very fast, and the water retention capacity is very low. Specific surface area is reduced as well, which results in low nutrient-holding capacity, and in the end, plant production is reduced. Therefore, plant production does not keep its standard as it requires, on the part of the farmer, large quantities of applications. All these applications are hazardous and costly. All these cons may rationalize the rationale for avoiding them, leaving them risky to the surroundings and uneconomical to the farmer (Bahia *et al.*, 20205; Ati *et al*., 2025).

Since the 1960s, Michigan State University has worked on increasing the water-holding capacity of sandy soils that have a high degree of permeability. Initially, this was achieved by using asphalt barriers to stop the leaching of phosphates and nitrogen from wastewater into groundwater. This was also an enhancement to sugarcane production while conserving soil moisture (Erickson, 1969). The next advance enabled curved geometrically polyethylene monolayer membranes capable of holding water and nutrients and reducing groundwater pollution resulting from agricultural production. These brought forth development efforts of the Subsurface Water Retention Technology (SWRT) system, which was designed to improve sandy soil performance and alleviate water stress during the dry period; this does not work against the water shortage during crop development (Figure 1) (Smucker *et al.*, 2010).

The use of Subsurface Drip Irrigation (SDI) systems installed at some critical depth practically eliminates capillary rise of water in getting water to the ground where it evaporates. This phenomenon allows for much more evaporation loss from the surface. It is capillary action that normally supplies water to drier upper zones by countertop gravity flow from the completely wet or saturated zones. The trickle of water from SDI tends to wet the area right around the plant; thus, the plant uses water only from that region, or up to 50% less water than it normally would with other methods of irrigation. In turn, land areas can be made arable with such a volume of water supply in the development of irrigation projects, and therefore, agriculture will flourish (Smucker, 2011; Miller and Smucker, 2015).

Study of natural systems, the soil–water–plant continuum calls for monitoring continuously both spatial and temporal variations as the properties are dynamic, not static. This requires the deployment of sensor networks capable of converting physical and chemical changes in the soil into measurable data. Key variables include volumetric water content, electrical conductivity, and soil temperature, which are crucial for irrigation scheduling as well as for tracking salinity and thermal patterns with depth. GS3 sensors were used for this.

Hot pepper (Capsicum spp.) is considered a very water stress-sensitive crop and is usually grown under spring/fall conditions. Reports have indicated marked yield reductions with imposed water stress and around critical growth stages of flowering and fruiting. Therefore, this experiment was carried out to evaluate the efficacy of the technology improvement of Subsurface Water Retention in improving hydrological properties of sandy soils and its productivity on the hot pepper under water scarcity and drought stress.

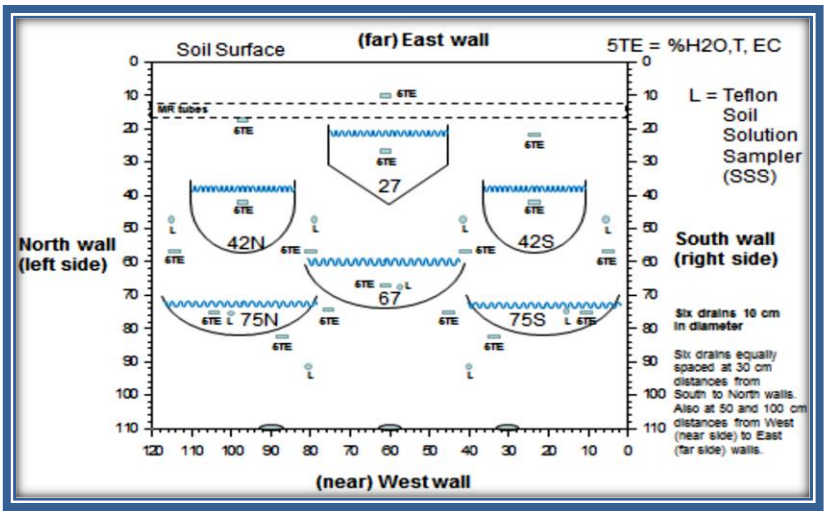

Figure (1): Installation of Subsurface Water Retention Technology (SWRT) membranes beneath the root zone.

MATERIALS AND METHODS

A field experiment was conducted during the spring season of 2015 in Najaf Governorate, specifically in the Al-Najaf Island area at the site of the Al-Nakheel Textiles Research Station, affiliated with the Ministry of Agriculture. The soil at the experimental site was classified as sandy loam in texture and belongs to the Typic Tropopsamments subgroup. Take random soil samples from three depths at 30, 60, and 90 cm. Air-dry and grind the samples, passing them through a 2 mm sieve; then use the prepared samples to analyze some selected physical and chemical properties of the soil prior to planting, by the standard methods of Black (1965). The measured soil properties are presented in Table 1. The properties were formed using a Randomized Complete Block Design (RCBD) with four replications and four treatments: Subsurface Water Retention Technology (SWRT), organic matter, tillage (control), and no-tillage. Facts were checked, and Least Significant Difference (LSD) at the 0.05 probability level was used to compare treatment means. The SWRT system was applied by laying polyethylene sheets under the plant zone with specific physical properties. These curved sheets measure 0.50 m wide and with a lifetime of 20–30 years. Installed at the center depth of 0.50 m and at the side depth of 0.10 m with a 3:1 side curve ratio, as described by Smucker *et al.* (2013, 2014) and installed as one membrane per raised bed (Figure 2). Harra variety hot pepper seedlings were planted in rows. Soil sensors (Figure 3), made by Decagon Devices, USA, were installed to watch changes in soil temperature, electrical conductivity (EC), and the amount of water present. These sensors were placed at three depths: 0.15 m, 0.30 m, and 0.45 m from the soil. Also, the amounts of nitrogen (N), phosphorus (P), and potassium (K) available in the soil were checked at three sampling times: 70, 140, and 210 days after planting. Irrigation scheduling was performed according to soil moisture content, as 35% of available water was depleted, then irrigation water was added from the subsurface drip system to bring soil moisture content back to field capacity. Soil sensors GS3 from Decagon Devices, USA, were used to measure volumetric water content.

RESULTS AND DISCUSSION

Table (2) presents the total volume of irrigation water applied under the different treatments. The lowest water volume was recorded in the SWRT treatment, which received only 3,335 m^3 ha^{-1}. In contrast, the tillage and no-tillage treatments required nearly double that amount, with 5,240 m^3 ha^{-1} applied in each. The implementation of SWRT technology led to a 22% reduction in irrigation water compared to organic matter treatment, and a 36% reduction when compared to both the tillage (control) and non-tillage treatments. These findings clearly demonstrate the high-water retention capacity of the SWRT system. This is consistent with (Al-Zebary *et al*., 2023; Hommadi *et al*., 2021; Mirza *et al*., 2024). Furthermore, the irrigation management relied on sensor-based readings of volumetric soil moisture, enabling precise and efficient control of water application. This system ensures that water is applied only when needed by the crop, based on real-time sensor data. As a result, it significantly reduced the volume of irrigation water applied and led to a decrease in fertilizer inputs, thereby minimizing the accumulation of dissolved salts in the soil due to irrigation or fertigation.

Table (1): Physical and chemical properties of the soil at the experimental site before planting

Property	Unit	Chemical Properties 0-0.3 m	0.3-0.6 m	0.6-0.9 m	Property	Unit	Physical Properties 0-0.3m	0.3-0.6 m	0.6-0.9 m
pH		7.3	7.3	7.2	Sand	$g\ kg^{-1}$	651.6	721.8	795.8
EC	$dS\ m^{-}$	3.2	3.5	3.1	Silt	$g\ kg^{-1}$	269.2	252.1	177.3
Ca	$meq\ L^{-1}$	11.7	14.3	14.3	Clay	$g\ kg^{-1}$	79.2	26.1	26.7
Mg	$meq\ L^{-1}$	6.4	5.8	5.2	Soil Texture		Sandy Loam	Loamy Sand	
Na	$meq\ L^{-1}$	17.1	19.1	18.3					
K	$meq\ L^{-1}$	0.1	0.2	0.2	Bulk Density	$\mu g\ m^{-3}$	1.564		
SO_4	$meq\ L^{-1}$	12.2	13.2	12.2					
Cl	$meq\ L^{-1}$	13.8	14.2	13.2	Particle Density	$\mu g\ m^{-3}$	2.707		
HCO_3	$meq\ L^{-1}$	3.2	3.5	3.0	Total Porosity		0.422		
OM	$g\ kg^{-1}$	12.1	10.3	9.5	Capillary Rise	cm	60.05		
$CaSO_4$	$g\ kg^{-1}$	2.4	2.5	2.8	FC	$cm^3\ cm^{-3}$	0.298		
$CaCO_3$	$g\ kg^{-1}$	141	221	227	WP	$cm^3\ cm^{-3}$	0.101		

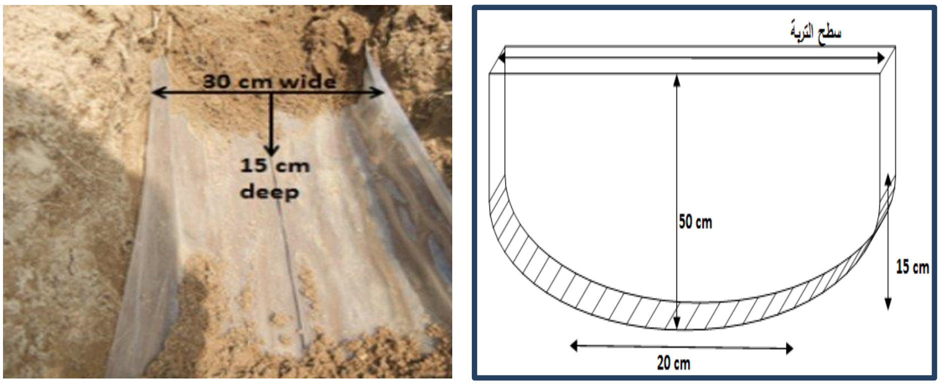

Figure (2): Installation method of polyethylene membranes in the Subsurface Water Retention Technology (SWRT) treatment.

Figure (3): GS3-type soil sensors used in the experiment.

Table (2): Amount of irrigation water applied ($m^3\ ha^{-1}$)

Treatments	Irrigation Water Applied ($m^3\ ha^{-1}$)
SWRT	3335
Organic Matter	4294
Tillage (Control)	5240
No Tillage	5240

Figure (4) illustrates the total yield of hot pepper, where the SWRT treatment significantly outperformed all other treatments, achieving the highest total yield of 124,208.3 kg ha^{-1}. The SWRT membranes used in the experiment were designed to be impermeable to water, enhancing both yield and cellulosic biomass in sandy soils when combined with subsurface drip irrigation systems and optimized fertilization practices. These practices help minimize groundwater contamination, as supported by Smucker *et al.*(2010) .

The superior productivity observed under the SWRT treatment aligns with findings reported by Amirpour *et al.* (2016). Overall, the SWRT treatment exhibited significant superiority in all yield components. This is attributed to the balanced and continuous supply of nutrients and moisture throughout the soil profile, which enhanced plant vigor and physiological activity, leading to improved fruit set and increased yield (Smucker and Basso, 2014). Furthermore, the SWRT system ensures a steady supply of nutrients during the later stages of plant growth, particularly beneficial for long-season crops, thereby promoting vigorous vegetative growth, nutrient assimilation, and ultimately, higher total productivity (Table 3).

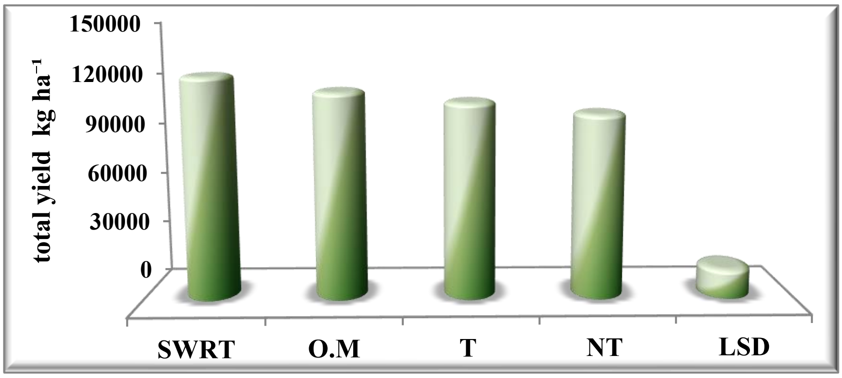

Figure (4): Total yield of hot pepper (kg ha^{-1}) under different treatments.

Figure (5) illustrates the efficiency of water use (WUE) of hot pepper under different treatments. The SWRT treatment demonstrated a significant improvement in water use efficiency, recording the highest WUE value of 37.2 kg m^{-3}. The use of subsurface drip irrigation has been shown to enhance water use efficiency by directly delivering water and nutrients to the root zone, leading to increased crop yield and more efficient utilization of water. This system promotes optimal moisture distribution within the root zone, thereby improving overall plant performance (Phene *et al*., 1987; Ayars *et al*., 1999). Additionally, the use of soil moisture sensors played a critical role in reducing the number of irrigation events. Sensor-based irrigation scheduling aims to maximize water use efficiency by maintaining soil moisture levels within optimal ranges. This results in higher crop productivity per square meter, particularly in vegetable production systems, while also minimizing irrigation losses..

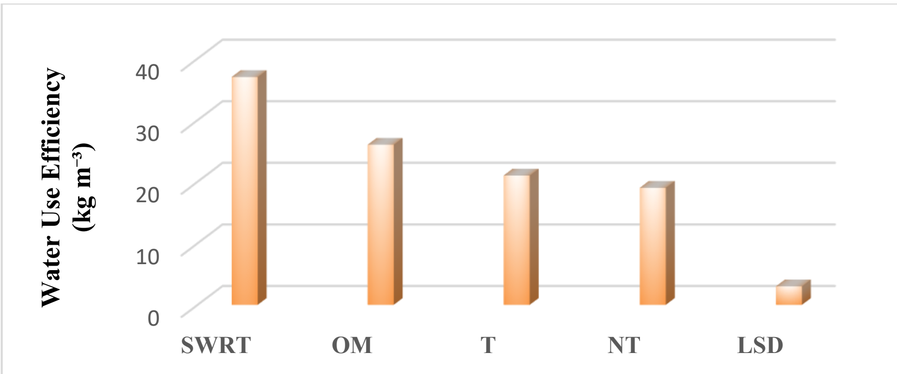

Figure (5): Water use efficiency (WUE) of hot pepper (kg m^{-3}) under different treatments.

Table (3) gives the concentrations of available nitrogen (N), phosphorus (P), and potassium (K) in the soil at three different plant growth stages: 70, 140, and 210 days after planting. The SWRT and organic matter treatments have significantly greater values of available nutrients than the other treatments. There was no significant difference between SWRT and organic matter after 70 and 210 days, while a significant difference was recorded between these two treatments after 140 days. The highest concentration of available nitrogen was recorded after 70 days under the SWRT treatment, while the highest values after 140 and 210 days were observed under the organic matter treatment, reaching 39.08 and 33.92 mg N kg^{-1} soil, respectively (Al-Shami and Al-Temimi, 2022; Jabbar and Ati, 2025; Almoosa *et al*., 2025). Regarding available phosphorus, both SWRT and organic matter treatments significantly outperformed the others throughout the crop cycle. The organic matter treatment recorded the highest phosphorus values at 70 and 140 days (19.25 and 17.58 mg P kg^{-1} soil, respectively), whereas the SWRT treatment showed the highest value at 210 days (15.48 mg P kg^{-1} soil). As for available potassium, the organic matter treatment was significantly superior after 70 and 140 days, with values of 164.0 and 152.42 mg K kg^{-1} soil, respectively. However, after 210 days, the SWRT treatment significantly outperformed both tillage and no-tillage treatments, but not the organic matter treatment, which recorded a closely comparable value (140 mg K kg^{-1} soil).

Table (3): available nitrogen, phosphorus, and potassium content (mg kg-1 soil) at three

Nutrient concentrations	N (mg N kg^{-1} Soil)		
growth stages	70 Day	140 Day	210 Day
SWRT	37.08	32.17	33.83
O.M	36.25	39.08	33.92
T	28.92	25.67	23.5
NT	30.17	27.5	23.67
LSD	1.68	1.41	1.03
	P (mg P kg^{-1} Soil)		
SWRT	17.83	16.25	15.48
O.M	19.25	17.58	15.08
T	12.67	9.17	10.67
NT	17.0	12.42	10.61
LSD	0.85	1.17	0.84
	K (mg K kg^{-1} Soil)		
SWRT	160.92	144.58	140
O.M	164.0	152.42	139.17
T	83.5	108.5	117.92
NT	96.0	137.0	123.42
LSD	4.22	2.53	2.40

These results highlight the positive impact of organic matter on the availability of nitrogen, phosphorus, and potassium in the soil. Organic matter plays a crucial role in improving soil physical and chemical properties, enhancing water retention and structure, and serving as a key source of essential nutrients for hot pepper growth. Additionally, organic fertilization significantly increased available potassium levels. The SWRT system also proved effective in retaining nutrients within the root zone of sandy soils, despite receiving approximately 50% less fertilizer than other treatments due to the use of fertigation the application of fertilizers through irrigation water (Kafkafi and Tarchitzky, 2011; Abdul Sayed and Al-Tameemi, 2019; Al-Obady *et al*., 2022). This approach not only accelerated plant growth but also enhanced productivity while conserving water.

Robertson and Vitousek (2009); Ajeel *et al*. (2025); Al-Hatem *et al*. (2025) noted that the biochemical conditions of low-organic-matter sandy soil can be improved using strategically installed membranes, which also increase carbon storage soil and reduce hydrological losses. The higher nutrient content observed in the SWRT treatment is attributed to its superior moisture retention capacity and increased soil temperature in the root zone, which create optimal conditions for nutrient uptake by plants. These findings underscore the role of the SWRT system in enhancing nutrient conservation and availability, while minimizing leaching losses and supporting sustainable crop production.

CONCLUSIONS

- Most water use efficient was in SWRT treatment because the use of SWRT technology minimized water consumption by 22% relative to treatment of organic matter, and by 36% relative to tillage and no-tillage.
- SWRT technology has been demonstrated to be beneficial in: water and fertilizer conservation, enhancing crop yield, enhancing water usage efficiency, and increasing the soil's availability of nutrients. Organic matter is equally a significant determinant in enhancing soil fertility, but with less effectiveness than SWRT in water retention and loss reduction.

ACKNOWLEDGMENT

The authors are very grateful to the University of Mosul.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

زراعة التربة الرملية باستخدام تقنية الاحتفاظ بالمياه تحت السطحية (SWRT) في ظل الجفاف وندرة المياه في العراق

ألفين ج. م. سمكر [1]، شذى سالم مجيد [2]، الاء صالح عاتي [3]، مهدي ابراهيم عودة [3]
جامعة ميشيغان / شرق لانسينغ / الولايات المتحدة الأمريكية [1]
منظمة الأغذية والزراعة للأمم المتحدة في العراق–الفاو [2]
كلية علوم الهندسة الزراعية / جامعة بغداد / العراق [3]

الخلاصة

تم إجراء دراسة لتقييم تأثير استخدام تقنية SWRT على كفاءة استخدام مياه الري (IWUE) وانتاج الفلفل الحار. تم إجراء التجارب بزراعة الفلفل الحار في البيوت المحمية خلال فصل الربيع من عام 2015 في محافظة النجف. صنفت تربة الحقل ذات نسجة مزيجة رملية. تضمنت التجربة أربع معاملات: SWRT، المادة العضوية، الحرثة، والزراعة بدون حرثة، وفق التصميم العشوائي الكامل التعشية (RCBD) مع أربع مكررات. تم جدولة الري وفقًا لمحتوى رطوبة التربة بحيث يتم الري عندما يتم استنفاد 35٪ من الماء الجاهز، ثم يتم إضافة مياه الري من نظام الري بالتنقيط تحت السطحي لإعادة محتوى رطوبة التربة إلى السعة الحقلية. تم استخدام أجهزة استشعار التربة GS3 من شركة Decagon Devices (الولايات المتحدة الأمريكية) لقياس المحتوى المائي الحجمي. أظهرت النتائج أن استخدام تقنية SWRT يؤدي إلى توفير 22 و36٪ من كمية مياه

الري المضافة لمحصول الفلفل مقارنة بمعاملة المادة العضوية ومعاملات الحرثة (الكنترول) وبدون حرثة. زيادة إنتاجية الوحدة الزراعية في نظام الري بالتنقيط السطحي مع تحسين جودة الثمار، وزيادة انتاجية الفلفل بنسبة 13 و8 و20٪ مقارنة بمعاملات الحرثة، والمادة العضوية، ومعاملات دون حرثة على التوالي. يؤدي الانخفاض في كمية مياه الري المضافة إلى زيادة كفاءة استخدام المياه في نظام الري بالتنقيط السطحي بنسبة 78 و38 و89٪ مقارنة بمعاملة الكنترول، والمادة العضوية، ومعاملات بدون حرثة على التوالي.

الكلمات المفتاحية: تقنية الاحتفاظ بالمياه تحت السطحية، كفاءة استخدام المياه، الفلفل الحار.

REFERENCES

AbdulSayed, O. D., & Al-Tameemi, H. J. (2019). Efficiency of prepared chelate fertilizer from humic acid in reducing ammonia volatilization from urea fertilizer. *Basrah Journal of Agricultural Sciences*, *32*, 231-245. https://doi.org/10.37077/25200860.2019.271

Ajeel, M. R., Hamid, M. M. H., & Al-Shahbani, I. R. (2025). The impact of biofertilizers, organic fertilizers, and foliar application of boron on yield characteristics of Maize (Zea mays L.). *Basrah Journal of Agricultural Sciences*, 38(1), 312-323. https://bjas.bajas.edu.iq/index.php/bjas/article/view/2548

Al-Hatem, J. Y., Kadhim, D. A., & Abid, M. A. (2025). Developing a nano-fertilizer of iron oxide NPs using yeast extract and studying its effectiveness on the growth and germination of Nigella sativa seeds. *Basrah Journal of Agricultural Sciences*, *38*(1), 235-247. https:/doi.org/10.37077/25200860

Almoosa, M. F., Almaliki, S. A., & Al-Atab, S. M. (2025). Prediction of traction requirements and slippage percentage for three plow types under various operational conditions. *Basrah Journal of Agricultural Sciences*, *38*(1), 288-311. https://doi.org/10.37077/25200860.2024.38.1.23

Al-Obady, R., Ghazal, S. A., & Al-Juheishy, W. K. (2022). Effect of some agricultural process on growth and yield of sorghum (sorghum bicolor l.) (article review). *Mesopotamia Journal of Agriculture*, *50*(4),17-26. https:/doi.org/10.33899/magrj.2022.136718.1206

Al-Shami, Y. A. O., & Al-Temimi, M. I. A. (2022). The effect of the use of subsurface water retention technology (SWRT) in the available content of nutrients in the soil under the subsurface drip irrigation system and for different management treatments. *Sumer Journal for Pure Science*, *1*(1), 1-11. https://journals.sujps.com/index.php/sj/article/view/1

Alwazzan, T. T., & Ati, A. S. (2024). Assessment of soil quality and health using some physical and biological properties for Fadak Farm Project. *Iraqi Journal of Agricultural Sciences*, *55*(3), 1011-1024. https://doi.org/10.36103/ddeegt17

Al-Zebary, A. A., Khessro, M. K., & Al-Ma'athedi, A. F. (2023). Effect of covering layers and NPK fertilizer types on the vegetative and flowering characteristics of Rosa Damascena Mill. under protected greenhouse conditions. *Mesopotamia Journal of Agriculture*, *51*(4),119-129. https://doi.org/10.33899/mja.2023.144119.1285

Amirpour, M., Shorafa, M., Gorji, M., & Naghavi, H. (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*, *8*(1), 33-41. http://www.aes.bioflux.com.ro

Ati, A. S., Bahia, M. H. S., & Jabbar, H. A. (2025). Effect of smart agriculture practices on yield and crop water productivity of sweet pepper. *International Journal of Environmental Sciences*, *11*(8s), 548-558. https://doi.org/10.64252/r7kx4231

Ayars, J. E., Phene, C. J., Hutmacher, R. B., Davis, K. R., Schoneman, R. A., Vail, S. S., & Mead, R. M. (1999). Subsurface drip irrigation of row crops: a review of 15 years of research at the water management research laboratory. *Agricultural water management*, 42(1), 1-27. https://doi.org/10.1016/S0378-3774(99)00025-6

Bahia, M. H. S., Ati, A. S., Majeed, S. S., Sami, G. T., Kudeir, A. T., & Wheib, K. A. (2025). Impact of reduced tillage on water use efficiency and tuber yield components of two variation potatoes under sprinkler irrigation in Jazeera Al-karma region/ Al-Anbar Governate. *Research on Crops*, 26(2), 312-318. https://doi.org/10.31830/2348-7542.2025.ROC-1210

Black, C. A., Evans, D. D., White, L. L., Ensminger, L. E., & Clark, F. E. (1965). Methods of Soil Analysis Am. Soc. Agron. *Inc., Madison, Wisconsin DC, USA*. https://ir.library.oregonstate.edu/downloads/db78td03c

Dawod, S. S., Ati, A. S., & Abdujabbar, I. A. (2024). Management of using saline irrigation water and tillage systems on the soil mechanical and hydraulic. Iraqi *Journal of Agricultural Sciences*, 55(6), 2050-2059. https://doi.org/10.36103/5b2srn23

Erickson, A. E. A. (1969). Subsurface asphalt barriers for the improvement of sugarcane production and the conservation of water on sand soil. Proceedings of the International Society of Sugarcane Technologists; 13th Congress, Taiwan, 787-791. Subsurface asphalt barriers for improvement of sugarcane.pdf

Hommadi A. H., Al-Mohammed F. M., Mutasher A. K. A., Al-Obaidy A. I., AL-Rawi S. S., Almasraf S. A., Alfawzy A. M. (2021). Application of SWRT technique to reduce stress and water supply. 1st international virtual conference of environmental sciences. *IOP Conf. Series: Earth and Environmental Science* 722, 1-13. https://doi.org/10.1088/1755-1315/722/1/012044

Jabbar, A. S., & Ati, A. S. (2025). Determining the water requirement of groundnut under different irrigation systems and irrigation intervals. *Iraqi Journal of Agricultural Sciences*, 56(2), 923-934. https://doi.org/10.36103/ejmvxp19

Kafkafi, U., & Tarchitzky, J. (2011). A tool for efficient fertilizer and water management. *international potash institute (IPI): Paris, France*, 1-123. https://www.haifa-group.com/sites/default/files/ifa_fertigation-Kafkafi-511.pdf

Khamees, A. A. H., Ati, A. S., & Hussein, H. H. (2023, April). Effect of surface and subsurface drip irrigation and furrows irrigation system on water productivity, growth and yield of lettuce (Lactuca Sativa L). *In IOP Conference Series: Earth* *and Environmental Science*, 1158(2), 022009. https://doi.org/10.1088/1755-1315/1158/2/022009

Miller, S. A., & Smucker, A. J. (2015). A new soil water retention technology for irrigated highly permeable soils. In *2015 ASABE/IA Irrigation Symposium: Emerging Technologies for Sustainable Irrigation-A Tribute to the Career of Terry Howell, Sr. Conference Proceedings* (pp. 1-4). American Society of Agricultural and Biological Engineers. https://elibrary.asabe.org/abstract.asp?aid=46469

Mirza, M. S., & Al-Mufti, S. A. (2024). Efficiency of different trap types for attracting tomato leaf moth total absolute under-field conditions. *Mesopotamia Journal of Agriculture*, 52(1). https://doi.org/10.33899/mja.2024.145274.1314

Phene, C. J., Davis, K. R., McCormick, R. I., Pincot, A., & Meek, D. W. (1987). Evapotranspiration and irrigation scheduling of drip irrigated cantaloupes. *American Society of Agricultural Engineers*. 87 (2526):13. https://www.cabidigitallibrary.org/doi/full/10.5555/19882437422

Robertson, G. P. and P. M. Vitousek. 2009. Nitrogen in agriculture: Balancing the cost of an essen¬tial resource. *Annual Review of Environmental Research* 34:97-125. https:/doi.org/10.1146/annurev. environ.032108.105046

Smucker A. J. M., Basso B., Guber A., Kavdir Y., & Yang Z. (2013). New technology retains soil water and nutrients in plant root zone and doubles plant production. http:/new technology retains soil water and nutrients.pdf

Smucker, A. (2011). New water retention technology improves corn yields and cellulosic biomass production on highly permeable soils. https://a-c-s.confex.com/scisoc/2011am/webprogram/Paper66395.html

Smucker, A. J., & Basso, B. (2014). Global potential for a new subsurface water retention technology-converting marginal soil into sustainable plant production. *The Soil Underfoot: infinite possibilities for a finite resource, Editors*, 315-324. https://www.academia.edu/25458680/

Smucker, A. J., Wang, W., Kravchenko, A. N., & Dick, W. A. (2010). Forms and functions of meso and micro-niches of carbon within soil aggregates. *Journal of nematology*, 42(1), 84. https:/doi.org/22736842