زانكۆی سەلاحەدین - هەولێر
Salahaddin University-Erbil

Compare the Drip and Responsive Drip Irrigation (RDI) Systems on Broccoli Yield

A Thesis
Submitted to the department of (Soil and Water) in Partial Fulfillment of the
Requirements for the Degree of BSc. Science in Soil & Water

By

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Abstract:

Efficient water management techniques are crucial for optimizing crop yield, particularly in regions facing water scarcity. Drip irrigation systems have gained prominence due to their ability to deliver water directly to the plant roots, minimizing water wastage and maximizing crop productivity. Responsive Drip Irrigation (RDI) systems, a variant of traditional drip irrigation, adapt water delivery based on real-time environmental conditions and plant requirements, potentially offering further enhancements in water use efficiency and yield.

This study investigates and compares the impacts of conventional drip irrigation and RDI systems on broccoli yield under field conditions. The research evaluates various parameters such as SDI and RDI, on the broccoli yield. Field experiments are conducted over multiple growing seasons to assess the performance and effectiveness of both irrigation systems.

Preliminary findings suggest that both drip irrigation and RDI systems exhibit significant advantages over conventional surface irrigation methods, resulting in improved water use efficiency and enhanced crop growth in our experiment show us in the RDI system achieved a water use efficiency of 14.54 kg/m^3 compared to SDI recorded a water use efficiency of 2.15 kg/m^3.

However, that the marketable yield for SDI was 2.99 t ha^{-1} and for RDI was 4.59 t ha^{-1} depending on the yield combination. the RDI system demonstrates a more tailored approach by dynamically adjusting water delivery in response to changing environmental factors such as soil moisture content and weather conditions. This adaptability potentially translates into superior broccoli yield compared to traditional drip irrigation.

The outcomes of this study contribute valuable insights into the comparative effectiveness of drip and RDI systems in broccoli cultivation, offering practical guidance for farmers and policymakers seeking sustainable irrigation practices.

This research project has been written under my supervision and has been submitted for the award of the Degree of Bachelor in Agriculture Engineering Sciences/ Soil and Water Science with my approval as supervisor.

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Dedication

I dedicate this thesis to:

The greatest prophet, Mohammed (Peace be upon him)

My dear father and mother

My brothers and sisters

To RDI compony

And all those who spend their time and energy for the sake of illuminating the surroundings of others.

With love and respect

Danyal Salh
Kawa Badih

Acknowledgement

I wish to express my sincere thanks to, the Almighty **ALLAH** for giving me power and patience to perform this work. I would like to thank the presidency of the College of Agriculture Engineering Sciences and also presidency of Soil and Water Department for their helps.

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1. Introduction

Efficient water management is paramount in modern agriculture, particularly as global water resources face increasing pressure from climate change and population growth. Drip irrigation systems have emerged as a promising solution, offering precise water delivery directly to the root zone of crops, thereby minimizing water wastage and maximizing crop yield. Responsive Drip Irrigation (RDI) systems, a recent innovation, take this efficiency a step further by dynamically adjusting water application in response to real-time environmental conditions and plant needs (Gültekin, 2023).

Broccoli (*Brassica oleracea var. italica*) stands as a significant crop globally, valued for its nutritional content and versatility in culinary applications. However, broccoli cultivation demands consistent and adequate water supply throughout its growth stages to achieve optimal yield and quality. In this context, comparing the performance of traditional drip irrigation with the emerging RDI systems on broccoli yield becomes imperative for enhancing agricultural sustainability and productivity (De Souza et al., 2021).

Hossain et al., (2024) The conventional drip irrigation system operates on pre-set schedules or timers, delivering a constant flow of water to the crops. While effective in reducing water consumption compared to traditional surface irrigation methods, conventional drip systems may not fully account for variations in soil moisture, weather conditions, and crop water requirements, potentially leading to suboptimal yields and resource inefficiency.

On the other hand, RDI systems utilize advanced sensor technology and real-time data analysis to tailor water delivery according to specific crop needs and environmental parameters. By dynamically adjusting irrigation based on factors such as soil moisture levels and plant transpiration rates, RDI systems offer the potential to optimize water use efficiency and enhance crop productivity, even under changing climatic conditions (Evans et al., 2006).

Given the critical importance of water management in agriculture and the promising advancements in irrigation technology, this study aims to comprehensively compare the effectiveness of traditional drip irrigation and RDI systems on broccoli yield. Through field experiments and data analysis, we seek to evaluate the impact of these irrigation methods on water consumption, soil moisture dynamics, vegetative growth, and ultimately, broccoli yield. The findings of this research hold significant implications for informing farmers, agronomists, and policymakers on the adoption of sustainable irrigation practices to improve crop production while conserving water resources (De Souza et al., 2021).

Since broccoli is an important vegetable crop in the area under study and contributes a considerable area of cultivation under closed and open farming, controlled application of water is essential for improving this crop and other vegetable and fruit crops. However, to our knowledge, only few studies have investigated RDI in the study area. Therefore, the objective of the current study involved:

1) To know the effect of drip and responsive drip irrigation systems on broccoli yield.
2) To know the efficiency of drip and responsive drip irrigation systems.
3) To know the volume of water, we need to how many broccolis are in a dunam for both drip irrigation systems.

1. Brief Historical Review of Drip and (RDI) Irrigation Systems.

The history of drip irrigation dates back thousands of years, with early civilizations implementing rudimentary techniques to deliver water directly to plant roots. Ancient cultures such as the Egyptians, Chinese, and Mesopotamians utilized porous clay pots buried in the ground to slowly release water to crops, marking the inception of drip irrigation principles (FAO, 1984).

However, modern drip irrigation as we know it today began to take shape in the mid-20th century. In the 1960s, the invention of plastic tubing revolutionized irrigation practices, enabling the development of more efficient and affordable drip systems. Simcha Blass, an Israeli engineer, is credited with pioneering modern drip irrigation technology. Working with kibbutz farmers in Israel, Blass developed the first practical drip irrigation system using plastic tubing and emitters to deliver precise amounts of water directly to plant roots (Chapin, 1971 and Davis,. 1983).

Oram, (2012) throughout the latter half of the 20th century, drip irrigation gained traction worldwide, particularly in arid and semi-arid regions where water scarcity posed significant challenges to agriculture. The benefits of drip irrigation, including water conservation, improved crop yields, and reduced labor and fertilizer requirements, contributed to its widespread adoption across diverse agricultural landscapes.

As technological advancements continued, researchers and engineers sought ways to enhance the efficiency and precision of drip irrigation systems. This led to the development of Responsive Drip Irrigation (RDI) systems, which represent the next evolution in irrigation technology (Oram, 2012).

Responsive Drip Irrigation (RDI) systems integrate sensors, data analytics, and automation to dynamically adjust water delivery based on real-time environmental conditions and plant needs. The concept of responsive irrigation emerged in response to the limitations of conventional drip systems, which often relied on fixed schedules or manual adjustments that did not account for fluctuations in soil moisture, weather patterns, or crop water requirements (Hossain et al., 2024).

The development of RDI systems has been fueled by advances in sensor technology, wireless communication, and data processing capabilities. These systems incorporate various sensors, such as soil moisture sensors, weather stations, and plant-based sensors, to continuously monitor relevant parameters and provide feedback for precise irrigation management (Hossain et al., 2024).

The adoption of RDI systems offers several potential advantages over traditional drip irrigation, including improved water use efficiency, enhanced crop yield and quality, reduced environmental impact, and increased resilience to climate variability (Chai et al., 2016).

While RDI systems are still relatively new compared to traditional drip irrigation, ongoing research and innovation continue to refine and optimize these technologies. As agricultural water management becomes increasingly critical in the face of climate change and growing water scarcity, RDI systems hold promise for helping farmers achieve sustainable and productive irrigation practices in the years to come.

2. Subsurface irrigation

Subsurface irrigation was a new type method in recent years. Most of the traditional water-saving irrigation was carried out by laying drip irrigation pipes on the ground, while subsurface irrigation directly irrigates the root system by laying the pipes underground. The traditional RDI method was to infiltrate the soil around the underground roots from the surface, and then plant roots absorbed water from the soil. These methods had a low construction cost, but there would still be some ineffective irrigation to a certain extent. Subsurface irrigation ensure that water was absorbed and utilized by plants to the maximum extent, but the disadvantage was the high construction cost. Its fundamental principle and effect on plants were different from the traditional RDI methods. Subsur face irrigation could induce plant hardening, cause mild water stress response, and then lead to plant morphological strengthening, epidermis thickening and producing more waxy layer. On tomato, compared with the traditional RDI methods, subsurface irrigation could not only improve the fruit quality, but also enhance the photo synthetic activity and appropriately increased the fruit yield (Xu et al. 2011b). Summarily, this irrigation method could be used for field production in some areas to cope with low soil temperature in early spring and induce plants to improve yield and quality while saving water (Gan et al. 2013).

3. Advantages and Disadvantages of Drip Irrigation

3.1. Advantages of Drip Irrigation

Drip Irrigation is characterized by having several advantages like water conservation and increased productivity (Askri, 1999). Dasberg and Or (1999) report that drip irrigation has a high potential in reducing energy use, losses of water and nutrients besides increasing efficiencies. Keshtgar (2012) stated that the drip system can be regarded as the most water saving irrigation method and suitable for use in regions with limited water resources. Additionally, under system both fertilizer and pesticide can be injected into water. Furthermore, saline water can apply with drip irrigation system. Other benefits of this system include reduced infections from insects, disease and fungi due to minimized fraction of wetted surface area (Hensen et al., 1980).

3.2. Disadvantages of Drip Irrigation

The disadvantages include the lack of physical description of water distribution in the soil. The spatial variability in soil properties brings variation in pattern of water distribution around emitters (El-Hafedh et al., 2001). Furthermore, Bouwer (2000) revealed that water losses outside the root zone generate low efficiency of irrigation systems.

An ideal system is one with emitters of equal discharges, but variation in pressure will change the emitter’s discharges along the laterals. This may be due to the fact the low operating pressure is highly affected by the land slope and friction inside the laterals (Keshtgar, 2012).

Clogging of emitters by solid particles like sand, silt and clay particle, debris, chemical precipitants and organic growth can be considered as a serious problem of drip system. The gradual clogging of emitters gives rise to block flows and consequently cause unfavorable water distribution (Keshtgar, 2012).

4. Advantages and Disadvantages of RDI Irrigation System

RDI (Responsive drip Irrigation) is a method of irrigation that intentionally applies less water to crops than they need at full potential. This approach is typically used strategically during certain growth stages to optimize water use efficiency and improve crop quality. Here are some advantages and disadvantages of RDI irrigation ((Mehmet et al 2017), (Chavez et al. 2010), (Nemali and van Iersel 2006),(Abouelenein et al., 2009):

4.1. Advantages RDI Irrigation System:

1. Water Conservation: RDI helps in conserving water resources by applying water only when necessary and optimizing its use during critical growth stages.
2. Increased Water-Use Efficiency: By applying water strategically, RDI can improve the efficiency of water use, ensuring that crops receive adequate moisture while minimizing wastage.
3. Improved Crop Quality: Controlled stress induced by RDI can lead to better fruit quality, such as increased sugar content in fruits like grapes and tomatoes, and improved flavor profiles.
4. Reduced Disease Pressure: Controlled water stress can help in reducing the incidence of certain diseases that thrive in moist conditions, thus potentially reducing the need for chemical treatments.
5. Reduced Soil Erosion: By applying water in controlled amounts, RDI can help in reducing soil erosion compared to conventional irrigation methods where excess water can lead to runoff.

5.2. Disadvantages RDI Irrigation System:

1. Crop Yield Reduction: Excessive or mistimed application of RDI can lead to reduced crop yields due to inadequate water supply during critical growth stages.
2. Complex Management: Implementing RDI requires careful monitoring of soil moisture levels, crop water requirements, and environmental conditions. This can be complex and may require advanced technology or expertise.
3. Risk of Over-Stressing Plants: If not implemented properly, RDI can lead to excessive stress on plants, resulting in stunted growth, reduced yields, or even crop failure.

4. Initial Investment: Implementing RDI may require investment in infrastructure such as soil moisture sensors, irrigation systems, and management software, which can be costly for some farmers.
5. Crop Sensitivity: Not all crops respond positively to deficit irrigation. Some may be more sensitive to water stress than others, and implementing RDI for such crops may result in significant yield losses.
6. Knowledge and Skill Requirement: Farmers need to have a good understanding of crop water requirements, soil moisture dynamics, and irrigation scheduling to effectively implement RDI, which may pose a challenge for some.

Overall, while RDI offers potential benefits in terms of water conservation and improved crop quality, its successful implementation requires careful management and consideration of various factors to mitigate potential drawbacks.

6. Drip and (RDI) Irrigation System Components

The system is composed of emitters, laterals, manifold and mainline. Emitters are of various types such as, orifices, nozzles, microtubes, porous pipes, etc. to dissipate the water pressure and the reduced pressure allows a discharge with a few liters per hour. Laterals are usually made of polyethylene with diameters varying from 10 to 16 mm (Hensen et al., 1980). But in the RDI system the laterals contain tubes of billions of “smart micropores” in the tubes, by other meaning it is smart tube using for lateral (Yang et al, 2022).

On the other hand, manifold and mainline are made from polyethylene or rigid PVC with diameters varying from 20 to 100 mm. The main components of a drip and RDI irrigation system are the drip polyethylene tubes with emitters attached to the inside wall and equally spaced 0.3 to 0.6 meters apart along the lateral lengths, pump, filtration system, mail lines, manifold pressure regulators, air release valves, fertigation equipment. A pump is needed to provide the necessary pressure for emission of water (Dutta, 2010). Also, the RDI system has the same component of drip but with out the emitters and fertigation equipment (Yang et al, 2022).

7. Factors affecting the soil wetting pattern under drip irrigation

7.1. Soil Texture

It was noticed that the dynamic changes and water distribution of wetting patterns are affected by a host of factors, including soil physical properties (texture, bulk density and initial water content) and emitter parameters (discharge rate, line source length and buried depth) demonstrated that the factors affecting the spread of water from drip sources include various soil physical properties such as texture and structure (Naglic et al., 2014).

The findings of Khoshravesh-Miangoleh and Kiani (2014) have revealed that soil texture is an important factor for determining irrigation design parameters because it has a great influence on infiltration. Therefore, the design of the subsurface irrigation system should involve consideration of soil texture.

Khattak et al. (2017) reported that sandy soil showed greater (40-50%) vertical infiltration when compared to clayey soil. Conversely, the lateral infiltration was identified larger (5-10%) for clay soil than sandy. On the other hand, studied the impact of the individual soil particles (silt, sand and clay separates) on soil surface wetting area, under different application rates using point source trickle irrigation and their results indicated that the wetted areas in a loamy and a silty loam soils were 1.5 and 2.8 times the wetted area of a sandy loam soil, respectively.

7.2. Soil Bulk Density or Soil Porosity

Water enters the soil profile through the process of infiltration, and then moves through the soil profile via percolation. These processes are soil properties dependent that range from soil porosity to the shape and arrangement of soil peds (Schoonover and Crim, 2015). The percentages of micropores, mesopores, and macropores can also influence how quickly water enters into and moves through the soil profile. Water movement in the macro pores is gravity driven and rapid.

vertical movement of water is highly affected by the total porosity, while the lateral water movement is affected by micro pores. Bulk density affects total porosity and soil compaction gives rise to loss of total pore volume with a preferential loss of the big pores (Richard et al., 2001).

7.3. Initial Soil water content

The distribution of the water in the soil occurs along the hydraulic gradient between the wet and the dry soil, laterally by means of capillary action and vertically due to gravitation. Liu and Xu (2018) observed that the maximum wetted depth appeared in the minimum initial water content at the same irrigation time. They attributed this phenomenon to the greater gradient of matric suction with lower initial water content.

Skaggs et al. (2010) have noticed that higher antecedent water content increases water spreading from drip irrigation systems. They also arrived at the conclusion that the increases in spreading in the vertical direction were greater than that in the horizontal direction. This increase was attributed to higher irrigation time but not with flow rates, higher initial soil moisture conditions caused larger wetting pattern in both horizontal and vertical directions in less time, but the increase was larger in the vertical direction.

7.4. Emitter Discharge

Wetting the entire area under drip irrigation is needed for row crops and other crops with limited root zones via overlapping the wetting area by each emitter. Under other cases, for instance, for orchards with young trees a dry zone may separate each tree from its neighbor. The required distances to meet the crop water requirement should be based on the emitter discharge and soil properties (Dasberg and Or, 1999). Li et al. (2006) revealed that selection of the proper discharge should be based on the relationship between dripper discharge and soil wetting pattern.

8. Methodology and Research Design

8.1. Site Description

The study was conducted on a clay loam soil at the experimental site of the college of Agricultural Engineering Sciences at Girdarasha, which is about 5 km to the southwest of Erbil city (Latitude: 36° 6' 45.054" N; Longitude: 44° 0' 44.2512" E; 410 m a.s.l).

8.2. Land Preparation

Before implementing the experiment, a rectangular plot measuring 9 meters by 20 meters was delineated within the confines of the greenhouse. The existing ground cover within the designated area was carefully removed from obstacles, followed by ploughing to a depth of approximately 0.30 meters. Subsequent operations included disking and harrowing to facilitate soil preparation. The plot was then subdivided into two distinct blocks, with each block meticulously raked to achieve a smooth and level surface for uniformity across treatments.

8.3. Experimental Layout

The experimental configuration comprised a factorial design featuring two factors implemented within a completely block framework with 4 row of plants. The primary factor entailed the utilization of a drip irrigation system, characterized by emitter discharge set at 2.5 $L.hr^{-1}$ under a pressure of 0.7 bar. Additionally, the secondary factor involved the application of a RDI employing smart lateral tubes. Figure1 Field experiment layout showing the distribution of the treatments.

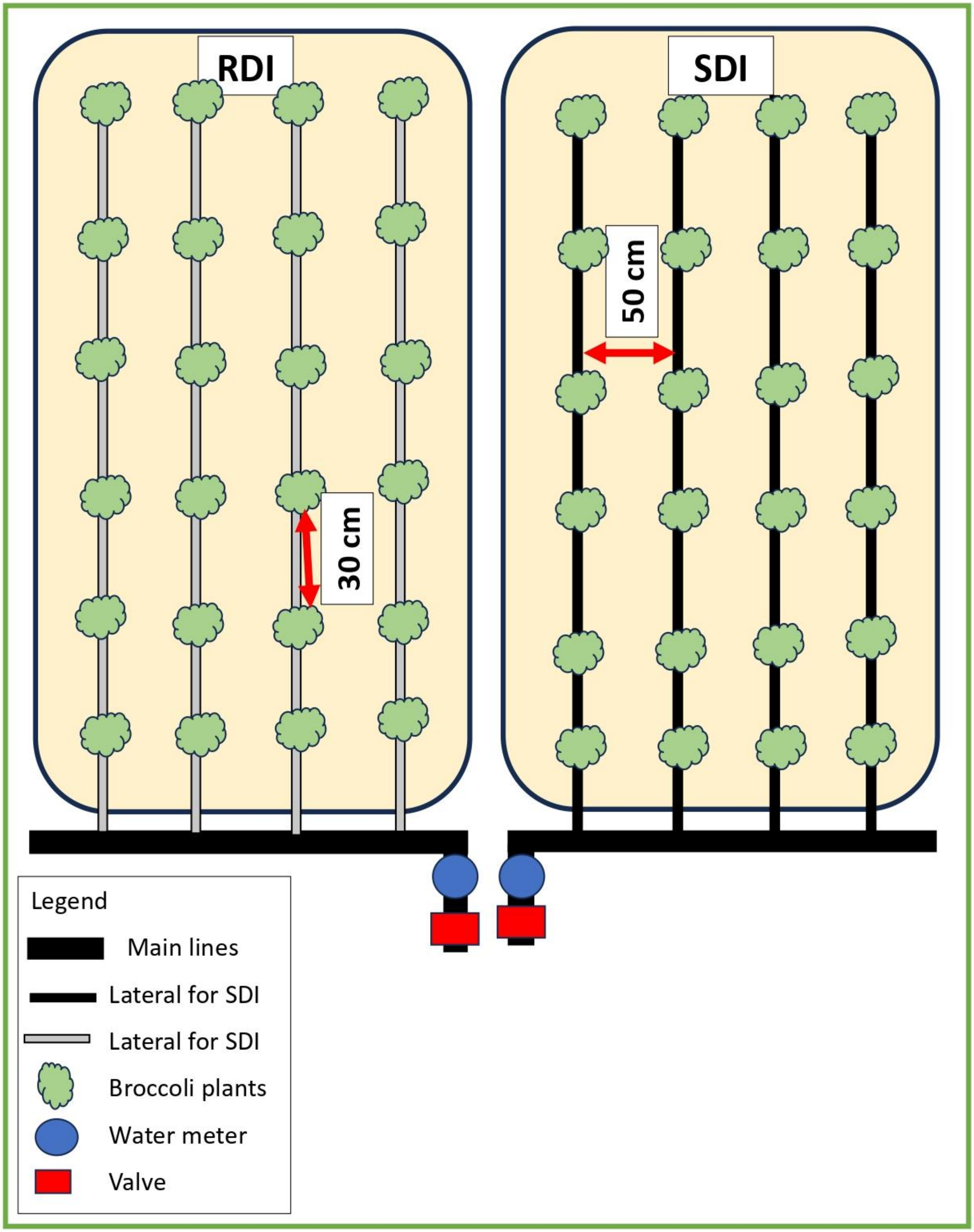

Fig. 1 Field experiment layout showing the distribution of the treatments

Four laterals were laid on the ground surface for drip irrigation system block along the lines of plants. Each lateral had a diameter of 16 mm with several emitters on the tubes. The drip system consists of 38 mm PVC pipe mainline which was connected to 16 mm lateral lines (Fig. 3.6).

Also, for the block of RDI system four laterals irrigation lines were carefully laid underground with the 10 cm depth near to the root zone of plants. Each lateral had a diameter of 16 mm with contain tubes of billions of “smart micropores. The RDI system consists of 38 mm PVC pipe mainline which was connected to 16 mm lateral lines. However, the mainline in start connected with valve, regulator pressure and water meter to calculate the volume of water applied to each shift of irrigation plants.

Fig. 2 Field experiment layout showing the distribution of the treatments

Fig. 3 show the RDI tube subsurface of soil and Drip irrigation tube on soil surface

8.4. Cultural Operation

Prior to transplanting, seeds of broccoli plant cultivar were sown in tray cells containing peat moss on 20th October in 2024. Subsequently, the seedlings were transplanted into the experimental site on 14th November in 2024. The distance between row to row and plant to plant was kept 0.5 m and 0.3 m, respectively. The crop received an application of NPK 12-12-17+MgO 0.5-to-0.75-ton ha^{-1} in form of three doses during the season from planting. Weeds were controlled periodically by hand especially in the drip system. Before seedling establishment, they were irrigated two times by conventional irrigation and each time the soil water content was brought to field capacity to a depth of 0.30 m.

8.5. Irrigation Schedule

8.5.1.Drip Irrigation System (SDI)

The required amount of water was applied under each treatment by operating the drip system for a predetermined time to compensate for the amount of water consumed during 2 or 3 times per week. The depth of applied water was based on the crop consumptive use (ET_c). The calculation of ET_c was based on:

$$ET_c = Kc\ ET_o \quad \text{..............................} (1)$$

Where ET_o = Potential evapotranspiration (mm day^{-1}) calculated according to Blenney-Criddle model for every month of the growing season, i.e., during the winter season of 2023 to 2024.

K_c = Crop coefficient.

The crop coefficient curve was constructed for broccoli following to the procedure described by (Allen et al., 1998) show in (Fig. 4).

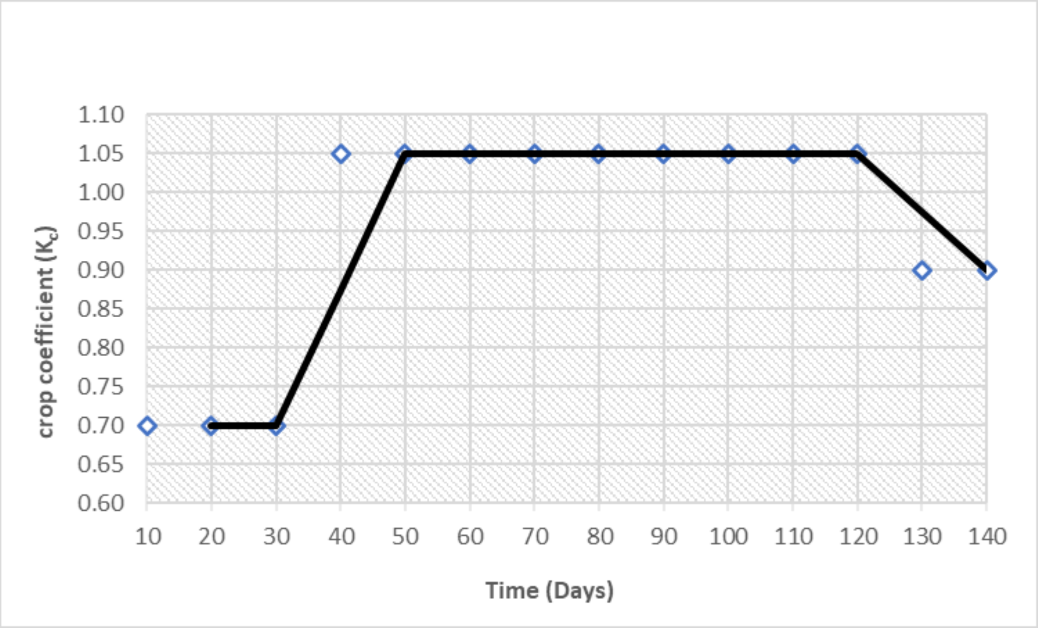

Fig. 4 Constructed crop coefficient (K_c) curve for Broccoli at Girdarasha site, Erbil, Iraqi Kurdistan region.

The gross depth of applied water (dg) was based on irrigation application efficiency (Ea) of 85% and as follows:

$$dg = \frac{dn}{Ea} \qquad (2)$$

Where dn = net depth of applied water (mm)

The volume of applied water per irrigation was computed from multiplication of dg and wetted area.

Irrigation water was delivered from a storage tank, 2 m high, placed 2.5 m above the ground level. Irrigation was scheduled at two-week interval during the early stage of growth and then increased to a three-week interval. Based on the proposed irrigation schedule the crop was irrigated 35 times during the growing season. Table 1 displays the depth of applied water during each irrigation. The source of irrigation water was a well nearby the experimental site. Water was pumped from the well to the storage. Table1 shows some chemical properties of the irrigation water (Ismael, 2020).

Soil Property		**Unit**	**Average value**
pH			7.51
Ece		dS m^{-1}	0.44
Soluble cations	Ca^{2+}	$mmole_c$ l^{-1}	2.58
	Mg^{2+}	$mmole_c$ l^{-1}	1.38
	Na^{+}	$mmole_c$ l^{-1}	0.46
	K^{+}	$mmole_c$ l^{-1}	0.03
Soluble anions	Cl^{-}	$Mmole_c$ l^{-1}	0.32
	SO_4^{2-}	$mmole_c$ l^{-1}	0.32
	CO_3^{-}	$mmole_c$ l^{-1}	0
	HCO_3^{-}	$mmole_c$ l^{-1}	3.01

Period	**Emitter discharge ($l\ hr^{-1}$)**	**ETo (mm/day)**	**Kc**	**ETc (mm/day)**	**Irrigation interval (days)**	**Time of application (hr)**	**Volume of applied water per event(l)**
14 -31 November	2.5	4.56	0.7	4.70	4	1.44	3.6
1 -15 December	2.5	4.28	0.85	7.37	4	1.41	3.52
16 - 31 December	2.5	4.00	1.05	8.23	4	1.81	4.53
01-15 January	2.5	3.86	1.05	8.98	4	1.72	4.29
16 - 31 January	2.5	4.7	1.05	9.13	4	1.72	4.29
01 -15 February	2.5	4.42	1.00	7.86	3	1.86	4.64
15 -29 February	2.5	4.2	1.00	7.86	3	1.74	4.35
29 -7 March	2.5	4.14	0.95	7.86	3	1.65	4.12

Table 3.2 Database showing the calculation of applied volume of irrigation water per event during the field experiment for SDI.

8.5.2.In Responsive drip irrigation (RDI)

Because in this system the lateral tube is smart tube when crops need water and nutrients, plant roots emit signals that allow them to uptake moisture and nutrients from the surrounding soil. RDI tubes which are installed near root zone interact and respond to these root signals and release water and nutrients out of the billions of "smart micropores" in the tubes.

These tubes provide a slow-release of water that matches the absorption capacity of the plant roots. When the plant is satiated, it stops producing the signals and the tubes stops releasing water. The system delivers what each plant needs, when they need it. By this reason we don't have calculate the volume of water applied per shift of irrigation, but we calculate the general of volume water took by plants at the end of the harvest by using the water meter equal to 2271 liter (2.271 m^3).

Fig. 5 Water meter for calculate volume of water in the RDI system.

Fig. 6 the RDI system with Drip Irrigation system

8.6. Soil Properties

Some selected soil physical and chemical properties of the soil of the experimental site, in Grdarasha field (Ismael, 2020).

Soil Property		**Unit**	**Average value**
Particle size distribution	Sand	g kg^{-1}	243
	Silt	g kg^{-1}	421
	Clay	g kg^{-1}	336
	Textural name		Clay loam
Bulk density		Mg m^{-3}	1.42
Infiltration rate		Cm hr^{-1}	1.9
pH			7.42
EC		dS m^{-1}	0.47
Organic matter		g kg^{-1}	9.6
Calcium carbonate equivalent		g kg^{-1}	306
Soluble cations	Ca^{2+}	mmole$_c$ l^{-1}	3
	Mg^{2+}	mmole$_c$ l^{-1}	1.5
	Na^{+}	mmole$_c$ l^{-1}	0.84
	K^{+}	mmole$_c$ l^{-1}	0.78
Soluble anions	Cl^{-}	mmole$_c$ l^{-1}	1.9
	SO_4^{2-}	mmole$_c$ l^{-1}	1.3
	HCO_3^{-}	mmole$_c$ l^{-1}	3.71
Cation exchange capacity		cmole$_c$ kg^{-1}	35
Total nitrogen		%	0.025
Available phosphorus		mg kg^{-1}	3.5

9. Results and Discussion

9.1. Crop production

This experiment was conducted to evaluate compare between drip irrigation (SDI) with Responsive drip irrigation (RDI) irrigation system in terms of marketable yield and water use efficiency of Broccoli at Girdarasha site. The results presented in Fig. 7 indicates that the marketable yield for SDI was 2.99 ton.ha^{-1} and for RDI was 4.59 ton.ha^{-1} depending on the yield combination. It is worth mentioning that the crop was harvested one time at the end of growing season.

RDI achieved a crop yield of 4.59 ton. ha^{-1} but in the conventional drip irrigation recorded the lower yield compare to RDI was equal to 2.99 tons per hectare. The results demonstrate the effectiveness of RDI in significantly enhancing crop yield compared to conventional drip irrigation. Achieving a 1.6-ton increase in yield per hectare highlights the potential of responsive irrigation systems to optimize water delivery and improve crop productivity (Yang et al, 2022).

Moreover, irrigation in the RDI system increase 20-50 percent yield compared to conventional drip irrigation (Ali et al, 2022), The crop yield in this study for RDI increased by 34.85% compared to drip. Another reason to increase crop yield in RDI are utilize sensors and real-time data to adjust water application according to plant needs, soil moisture levels, and environmental conditions. This adaptive approach ensures that crops receive the right amount of water at the right time, minimizing water stress and maximizing yield potential (Akbar et al., 2023 and De Souza et al., 2021).

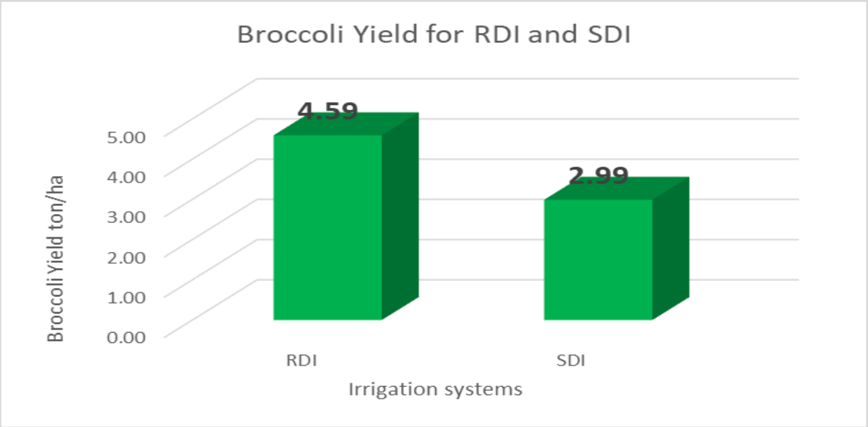

Fig.7 Broccoli yield as the different irrigation systems RDI and SDI

9.2. Water Use Efficiency

For broccoli vegetable crop, the water use efficiency differs considerably among various applied irrigation system. Fig.8 indicates that the irrigation water use efficiencies. In our experiment show us in the RDI system achieved a water use efficiency of 14.54 kg/m³ compared to SDI recorded a water use efficiency of 2.15 kg/m³.

The results illustrate a substantial improvement in water use efficiency with RDI compared to conventional drip irrigation. RDI achieve over six times higher efficiency in water utilization, indicating a more effective allocation of water resources (Arshad et al, 2023).

By delivering water directly to the root zone and minimizing surface runoff and evaporation losses, responsive drip irrigation reduces water wastage and maximizes the amount of water available to plants for uptake. This contributes to improved efficiency in water utilization (Kigalu et al, 2008 and Yang et al, 2022).

Irrigation water use efficiency (IWUE) can be an imperative factor when considering irrigation systems and water management and probably will become more important as access to water resource becomes more restricted (Shdeed, 2001).

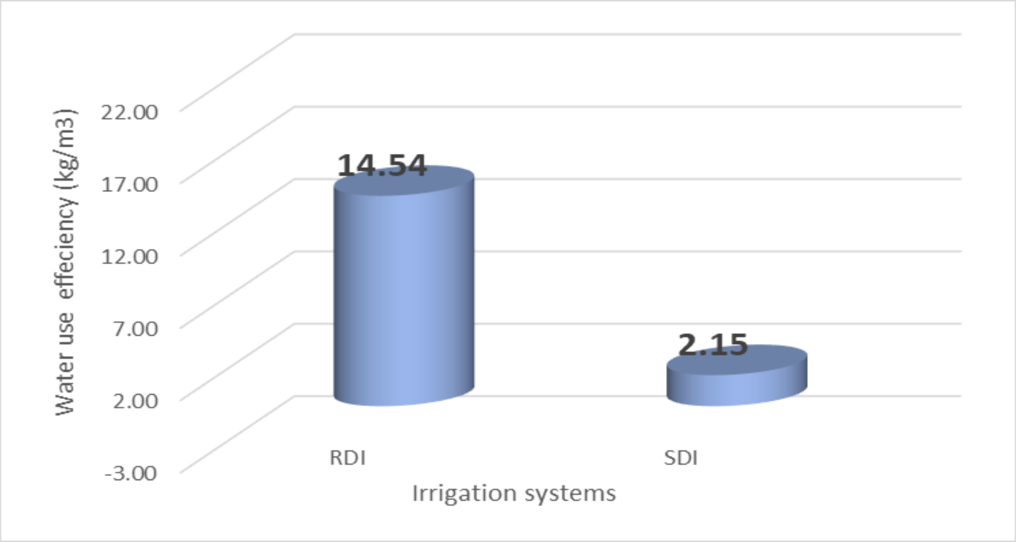

Fig. 8 Irrigation water use efficiency for Broccoli affected by the different RDI and SDI

10.1. Conclusions

The most outstanding conclusions that can be drawn from this study are:

1. It can be concluded from the above results that the RDI system is gave more product yield of broccoli compared to SDI system.
2. The crop yield and water use efficiency of broccoli affected by the RDI system because in this system water evaporation equal to zero.
3. The results show us a substantial improvement in water use efficiency in RDI system compared to conventional drip irrigation.
4. The findings underscore the RDI systems to boost crop yields significantly. Farmers and agricultural practitioners can benefit from adopting these advanced irrigation technologies.

10.2. Recommendations

In the light of the current study, it is recommended:

1. To repeat this experiment on the same site and other sites by using different vegetable.
2. To do the experiment on the how RDI system work under the subsurface of soil and shape of wetting.
3. Farmers and agricultural practitioners are encouraged to adopt responsive drip irrigation systems to optimize water use efficiency and enhance crop productivity.

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