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# EFFECT OF IRRIGATION SYSTEMS ON RICE PRODUCTIVITY

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## SUMMARY

In light of the scarcity of irrigation water, extreme wastage of water, saline soils, and the dominance of traditional water management methods, the presented research transpired in 2020 in the Directorate of Agriculture, ALHashimiya area, Hilla City, Iraq. The latest study aimed to investigate the effects of subsurface drip irrigation system (SDIS) and flood irrigation system (FIS), with three drip irrigation distances of 18, 20, and 22 cm on two rice (*Oryza sativa* L.) cultivars, i.e., 'Tarm Hashemi' (TH) and 'Daillman Mazandarani' (DM). The irrigation systems (SDIS and FIS) significantly impacted the growth and productivity traits of the rice crop. The SDIS ensures the addition of an appropriate amount of water to the plants by keeping wet the root zone without wasting water compared with the flood irrigation system. The interaction of rice cultivar Tarm Hashemi, SDIS, and drip irrigation distance (DID of 18 cm) resulted in the best performance for root growth traits, i.e., root length and root fresh and dry weight (17.66 cm and 1.80 and 0.85 g, respectively). It also provided the highest plant vigor index (PVI), biological, and grain yield (71.15 cm, 1,747.23, and 608.26 g.m$^{-2}$, respectively). Cultivar Tarm Hashemi proved superior to cultivar Daillman Mazandarani in managing the morpho-yield traits. The subsurface drip irrigation system during the growing season helped increase the productivity of the rice crop compared with the traditional irrigation system. Compared with FIS, the SDIS not only improved and enhanced the growth and grain yield, but also saved abundant water and nutrients.

**Keywords:** Rice (*Oryza sativa* L.), cultivars Tarm Hashemi (TH) and Daillman Mazandarani (DM), subsurface drip irrigation system (SDIS), flood irrigation system (FIS), drip irrigation distance (DID)

**Key findings:** The study focused on achieving the best growth results for the rice (*Oryza sativa* L.) crop, with the highest productivity emerging with the subsurface drip irrigation system and the planting distance of 18 cm. The reaction of rice cultivar Tarm Hashemi (TH) to the subsurface drip irrigation system gave the highest studied characteristics compared with the rice cultivar Daillman Mazandarani (DM).

**Abbreviations used**

TH: Tarm Hashemi, DM: Daillman Mazandarani, C: Cultivars, 1Mon: One Month, 2Mon: Two Months, GSE: Growth Season End, SDIS: Subsurface Drip Irrigation System, IS: Irrigation System, FIS: Flood Irrigation System, DID: Drip Irrigation Distance, SBD: Soil Bulk Density, TSP: Total Soil Porosity, RL: Root Length, RFW: Root Fresh Weight, RDW: Root Dry Weight, PVI: Plant Vigor Index, BY: Biological Yield, GY: Grain Yield, HI: Harvest Index

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## INTRODUCTION

Rice (*Oryza sativa* L.) is the essential staple food crop consumed by more than 41 million people in Iraq. Rice is grown in large areas of Iraq; however, the concentration of its cultivation is in Najaf, Karbala, Wasit, Babil, and Baghdad (Mohammed and Farhood, 2020). The Ministry of Agriculture, Iraq, also supports the farming community through fertilizers, equipment, and other materials to combat the abundance of water for planting rice and to increase its production (Alsharifi *et al*., 2017a, b; Alaamer and Alsharifi, 2020b). The humidity distribution within the soil trough gets directly affected by the dripper drainage, the distance between the drippers, and the design efficiency for humidity distribution in the soil around the roots of crop plants (Kang and Zhang, 2004; Shtewy *et al*., 2020a; Wening *et al*., 2020). Drip irrigation achieves the precise application of water and its movement within the soil to obtain the best hydration (Juan *et al*., 2016; Ebeed *et al*., 2019).

The rice crop development through drip irrigation creates better soil evaporation, improving crop productivity (Adekoya *et al*., 2014). Past studies on improving rice productivity depend upon the methods of adding water to the soil, which ensures the availability of adequate moisture for germination and crop growth (Matsuo and Mochizuki, 2009; Kannan and Venkataramanan, 2010; Malarvizhi *et al*., 2011). Drip irrigation is adding water to the soil slowly and at frequent intervals to maintain the humidity content in the ground, close to the field capacity (Lampayan *et al*., 2015; Sujariya *et al*., 2019), and in a way that ensures high growth and plant productivity (Abu-Awwad *et al*., 2017; Alaamer *et al*., 2021). Therefore, it is possible to spread a working principle that doubly increases in rice productivity under drip irrigation by using groundwater and encourages the farming community to change their cultivation system, which leads to greater rice yields (He *et al*., 2014).

During the growing season, the crop plants need moisture content to ensure their better growth in a country like Iraq, where the temperature rises to more than 50 °C in the summer, causing plant death without the appropriate moisture for the development and mitigation of the heat wave. The highest moisture content was closer to the drip source and gradually decreased as the distance gets further away from the drip source; thus, it mainly depends upon the drainage and distance between the drips and crop types (Shtewy *et al*., 2020b). Rice is typically grown under flooded conditions, but can also be grown in unsaturated soils to reduce freshwater use. Drip irrigation gives 50% water, with a 29% increase in rice yield compared with conventional dry land cultivation (Suriyan *et al*., 2010). The drip irrigation system definition is the addition of water through point and line sources above and beneath the soil surface at a little operative compression and a faint emptying rate, resulting in part-time moistening of the soil surface (Hanson and May, 2007; Hamoud *et al*., 2018). Therefore, it is crucial to develop agronomic practices that potentially minimize water use without reducing planting distance (Sangsoo *et al*., 2021). This system can apply water precisely and uniformly at a high irrigation frequency compared with furrow and sprinkler irrigation, potentially increasing yield, reducing subsurface drainage, and providing better salinity control (Irmak *et al*., 2014).

The growth and spread of plant roots depend on the availability and distribution of moisture content, according to the type of soil, its porosity, and its ability to conserve water for a longer period for plant growth (Luo, 2010; Guo *et al*., 2018). Keeping the soil dry until hairline cracks are visible, the decrease in the soil water potential does not cause significant crop stress. Drip irrigation consider the thermoregulatory effect of the water to avoid compromising production in the most critical stages of the crop, such as, panicle differentiation, flowering, and early ripening, to ensure weed control and the protective effect against gusty winds (Balaine *et al*., 2019). The characteristics of growth and plant productivity gain impact from the distance between the dots, which have a role that contributes to an increase in area and the wetness size, which in turn increases the spread of the plant root system, the vegetative growth and its productivity, using the subsurface irrigation system (Malash *et al*., 2008; Heba *et al*., 2019). The traditional method of cultivating the rice crop is still prevalent in many countries, which is the immersion method. This method leads to the wastage of large quantities of water, in contrast to the modern and approved scientific methods for cultivating rice crops. In addition, water scarcity requires a challenge and an intensive study to reduce wasting large quantities of irrigation water (José *et al*., 2021).

Drip irrigation takes advantage of the great potential, in terms of automation and fertigation and water savings, allowing the expansion of rice cultivation to highland areas with promising results (Parthasarathi *et al*., 2013; Gonçalves *et al*., 2020). Application competence of various drip irrigation and surface irrigation methods varies and depends on the design and running processes (Suriyan *et al*., 2010). Through the study carried out by Douh and Boujelben (2011) and Saito *et al*. (2018), they concluded that spaced planting and the drip irrigation method achieved the best yield, water abundance, and other physiological parameters as compared with traditional irrigation. The water function is the relationship between crop productivity and the water consumption by the crop during its life cycle (Mahmoudzadeh, 2016). Water consumption depends mainly on the crop type, location, climatic conditions, and farming techniques (Kato *et al*., 2009; Wang *et al*., 2011).

The drip irrigation system depicts providing water exclusively in the root zone, limiting the spread of harmful messes that impede the growth of the plant. In addition, the use of subsurface irrigation determined the water amount added in the root zone and the latest fertilizer optimization added in the root zone, meaning that the plant benefits completely from fertilizers without competition, reflecting positive plant growth and productivity (Tingwu *et al*., 2003; Belhaj-Mguidiche *et al*., 2014). The studies on the relationship between water consumption and crop productivity confirmed that crop yield mainly depends on irrigation water (Miyazaki and Arita, 2020). The main goal of the present research was to study the effects of subsurface drip and flood irrigation systems on rice (*Oryza sativa* L.) cultivars, i.e., Tarm Hashemi (TH) and Daillman Mazandarani (DM) with different distances between drippers.

## MATERIALS AND METHODS

### Plant material and procedure

The research, started in 2020 in the ALHashimiya area, Hilla City, Iraq, consisted of two irrigation systems (IM), i.e., subsurface drip irrigation system (SDIS) and flood irrigation system (FIS) used on two rice (*O. sativa* L.) cultivars Tarm Hashemi (TH) and Daillman Mazandarani (DM), with drip irrigation distances (DID) of 18, 20, and 22 cm (Figure 1). The experiment comprised a randomized complete block design in a split-split plot arrangement with three replications. Adopting renewable energy operated the pumping units. Using a moldboard plow stirred the soil to a depth of 25 cm, then pulled by a tractor (MSF-285s type), with the extension of subsurface drip irrigation used to a depth of 15 cm (Figure 2). The analysis of the physical and chemical properties of the soil appears in Table 1. Planting a rice crop proceeded on the first of July in lines using the dry farming method.

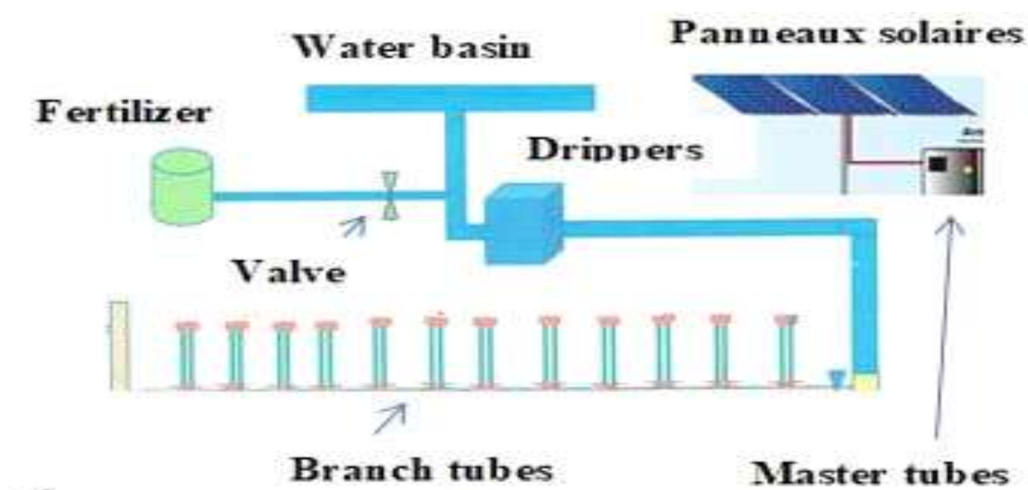


**Figure 1.** Drip irrigation system.

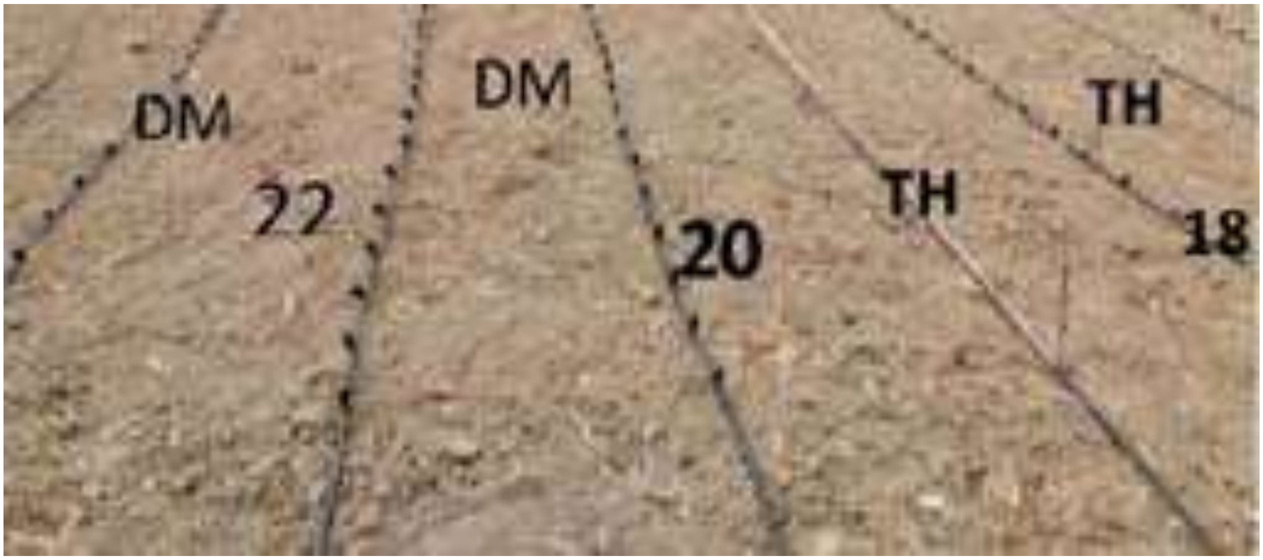


**Figure 2.** Subsurface drip irrigation pipe distribution and drippers before covering.

**Table 1.** Physical and chemical properties of the soil.

| Depth | Texture (%) | | | |
|---|---|---|---|---|
| 0-25 (cm) | Clay | Silt | Sand | |
| | 46 | 21 | 33 | Silt Clay loam |
| | Soil physical properties | | | |
| | SBD (Mg $m^{-3}$) | TSP (%) | Soil penetration resistance (Kpa ) | |
| | 1.42 | 46.41 | 1453.23 | |
| | 1.44 | 45.66 | 1486.78 | |
| | 1.43 | 46.03 | 1478.12 | |
| VA | 1.46 | 44.91 | 1472.7 | |
| 0-25 (cm) | Soil chemical properties | | | |
| | E.C (ds\cm$^3$) | HP | | |
| | 1.48 | 6.78 | | |
| | Soluble cation meq\I | | | |
| | Na | K | Ca + Mg | |
| | 12.42 | 13.45 | 56.82 | |
| | O.C (%) | CEC (Meq\100g) | CaCo3 (%) | O.M (%) |
| | 0.45 | 32.91 | 4 | 0.54 |

**Soil properties**

Six samples, taken randomly from the field soil with three tillage depths, determined the properties by following past research methods (Irmak *et al*., 2014; Hamoud *et al*., 2018). Soil samples collected through the pipette method measured soil moisture, bulk density, and the total porosity of the soil during the growing season after one month, two months, and at the growing season end (GSE). The collected samples were immediately put in plastic bags to conserve moisture during transferring to the laboratory, then weighed and dried at 105 °C for 48 h, with the averages calculated (Hu *et al*., 2012). The field underwent division of 12 experimental units and they contained two adjacent field pipes. A distance of one meter existed between the experimental units, strike-through, in which the pipe under the main and the carrier of the field pipes interspersed. The installed drip irrigation system has the dripper discharge controlled in 8 l $hr^{-1}$, by controlling the operating pressure using transparent piezometers placed at the end of each under-main tube at a height of 150 cm.

**Irrigation water**

Collecting used water samples took place, which used a concrete basin prepared for this purpose, with the PH measured. The pumping unit consists of pulling and pushing pipe, where the diameters of the pulling and pushing pipes are 3 and 2 in, respectively, where drawing water from the sump used a centrifugal pump with a capacity of 30 Hp. The drip irrigation system consists of the main pipe, manifold pipes, field pipes, and spiral drippers. Using a device PH-Meter, measuring the EC used an EC- Meter, type WTW, during the growing season, with the following formula:

$$w = \frac{W_W}{W_S} \times 100 \qquad (1)$$

Where:
$W$ : The soil humidity ratio (%)
$W_w$ : The mass of wet soil (kg)
$W_s$ : The mass of dry soil (kg)

$$S_{BD} = \frac{M_S}{V_T} \qquad (2)$$

Where:
$S_{BD}$ : (mg. m$^{-3}$)
$M_S$ : The dried soil weight (mg)
$V_T$ : Total soil volume (m$^{3}$)

$$T_{SP} = (1 - \frac{S_{BD}}{P_S}) \times 100 \qquad (3)$$

Where:
$T_{SP}$ : (%)
$S_{BD}$ : (mg.m$^{-3}$)
$P_S$ : Partial density (2.65 mg.m$^{-3}$)

**Soil moisture distribution**

Soil moisture distribution calculation ensued a month after planting and at the end of the growing season, with a soil sample taken from a depth of 25 cm, then proceeded to dry in an oven at 105 °C for 24 h following Alaamer *et al*. (2021).

**Root length**

Approximately at the full maturity stage, 10 randomly selected plants at three replications were uprooted, cleaned with water at 50 cm depth, and measured using a measuring ruler (Alttiya and Wuhaib, 1982; Hou *et al*., 2015). The traits, viz., root dry weight, root fresh weight, and plant vigor index (PVI) calculations followed the formula (Shtewy and Alsharifi, 2020):

$$P_{VI} = \frac{P_L \times C_P}{100} \qquad (4)$$

Where:
PVI: Plant vigor index (cm)
$P_L$ : Plant length (cm)
$G_P$ : Germination ratio

**Biological yield**

Plants cut from the ground level got dried in the oven at 70 °C and then weighed with a sensitive scale with three replicates for each experimental unit, using the calculations as follows:

$$B_Y = \mathrm{RP} + \mathrm{AG} \qquad (5)$$

Where:
$B_Y$ : Biological yield (g.m$^{-2}$)
$RP$ : Rate dry weight of the plant (kg)
$AG$ : Area grains (g.m$^{-2}$)

**Grain yield**

Grain yield was calculated after threshing for an area of 0.4 m$^{2}$ in each experimental unit (Malarvizhi *et al*., 2011).

**Harvest index**

The harvest index calculation followed the formula below (Shahani *et al*., 2016; Asmamaw *et al*., 2021).

$$H_I = \frac{G_Y}{B_Y} \times 100 \qquad (6)$$

Where:
$H_I$ : Harvest index (%)
$B_Y$ : Biological yield (g.m$^{-2}$)
$GY$ : Seed weight (g.m$^{-2}$)

The experiments progressed as per the Nested design, using the Gestate V.12 program with a randomized complete block design (RCBD) and three replications. The least significant difference ($LSD_{0.05}$) test compared and separated the treatment means (Oehlent, 2010).

## RESULTS

### Soil characteristics

The results revealed that the soil density values were inversely proportional to the porosity values. The SDIS decreased the SBD values after one and two months, and at the GSE, with values of 1.27, 1.30, and 1.32 Mg.m$^{-3}$, respectively. An increase in the TSP resulted in 52.07%, 50.44%, and 50.18%, respectively (Table 2). However, after one and two months, GSE, with the same conditions for the FIS, achieved the lowest values of the soil's physical properties (bulk density and soil porosity). The SDIS created a non-solid surface layer (fragile soil) compared with the FIS, causing the soil destruction composition and revealing poor soil physical properties during the growing season (Hanson and May, 2007; Alsharifi *et al*., 2017a).

A decrease in the DID of 18 cm led to a decline in the values of the SBD, i.e., 1.28, 1.31, and 1.35 Mg.m$^{-3}$, respectively, but it increased TSP with rates of 51.69%, 50.56%, and 49.05% after one and two months and GSE, versus the distances of the subsurface, DID of 20 and 22 cm. The same effects also indicated an increase in the soil moisture distribution ratios during the growing season. It has also appeared that the main cause of providing the best ratios for the physical properties of the soil (bulk density and soil porosity) co-related with a decrease in the distance between drippers (Hu *et al*., 2012). The rice cultivar TH achieved the best SBD values of 1.29, 1.31, and 1.34 Mg.m$^{-3}$, with the increase in ratios of soil porosity at 51.32%, 50.56%, and 49.43%, given the same conditions for the rice cultivar DM.

**Table 2.** Effect of irrigation systems (IS), rice cultivars, and drip irrigation distance (DID) on soil properties.

| TSP | | | SBD | | | DID | Cultivars | IS |
|---|---|---|---|---|---|---|---|---|
| GSE | 2Mon | 1Mon | GSE | 2Mon | 1Mon | | | |
| 50.94 | 51.69 | 52.54 | 1.30 | 1.28 | 1.26 | 18 | TH | SDIS |
| 50.56 | 51.32 | 52.07 | 1.31 | 1.29 | 1.27 | 20 | | |
| 49.81 | 50.94 | 51.32 | 1.33 | 1.30 | 1.29 | 22 | | |
| 50.18 | 50.56 | 52.07 | 1.32 | 1.31 | 1.27 | 18 | DM | |
| 49.43 | 50.18 | 51.69 | 1.34 | 1.32 | 1.28 | 20 | | |
| 48.67 | 49.81 | 50.94 | 1.36 | 1.33 | 1.30 | 22 | | |
| 48.67 | 50.56 | 50.94 | 1.36 | 1.31 | 1.30 | 18 | TH | FIS |
| 47.98 | 50.18 | 50.56 | 1.38 | 1.32 | 1.31 | 20 | | |
| 47.16 | 49.43 | 50.56 | 1.40 | 1.34 | 1.31 | 22 | | |
| 47.97 | 50.94 | 50.18 | 1.41 | 1.33 | 1.32 | 18 | DM | |
| 46.41 | 49.34 | 50.18 | 1.42 | 1.34 | 1.32 | 20 | | |
| 46.03 | 49.05 | 49.81 | 1.43 | 1.35 | 1.33 | 22 | | |
| 50.18 | 50.94 | 52.07 | 1.32 | 1.30 | 1.27 | SDIS | Average of IS | |
| 47.16 | 49.81 | 50.56 | 1.40 | 1.33 | 1.31 | FI | | |
| 49.43 | 50.56 | 51.32 | 1.34 | 1.31 | 1.29 | TH | Average of cultivars | |
| 47.92 | 49.43 | 50.94 | 1.38 | 1.34 | 1.30 | DM | | |
| 49.05 | 50.56 | 51.69 | 1.35 | 1.31 | 1.28 | 18 | Average of DID | |
| 48.67 | 50.18 | 50.94 | 1.36 | 1.32 | 1.30 | 20 | | |
| 47.92 | 49.81 | 50.56 | 1.38 | 1.33 | 1.31 | 22 | | |
| 0.187 | 0.183 | 0.172 | 0.004 | 0.002 | 0.003 | IS | | $LSD_{0.05}$ |
| 0.189 | 0.188 | 0.186 | 0.006 | 0.003 | 0.005 | DID | | |
| 0.187 | 0.183 | 0.172 | 0.004 | 0.002 | 0.003 | Cultivars | | |
| 0.231 | 0.203 | 0.194 | 0.007 | 0.006 | 0.004 | IS*C | | |
| 0.259 | 0.244 | 0.213 | 0.18 | 0. 13 | 0.16 | IS*DID | | |
| 0.259 | 0.244 | 0.213 | 0.18 | 0.13 | 0.16 | C*DID | | |
| 0.372 | 0.319 | 0.261 | 0.26 | 0.22 | 0.24 | C*DID*IS | | |

Irrigation systems (IS), Tarm Hashemi (TH), Daillman Mazandarani (DM), subsurface drip irrigation system (SDIS), flood irrigation system (FIS), drip irrigation distance (DID), soil bulk density (SBD), total soil porosity (TSP), one month (1Mon), two months (2Mon), and growth season end (GSE).

**Root growth parameters**

The effects of three relevant factors, i.e., irrigation system, rice cultivars, and DID, on root growth parameters, viz., RL, RFW, and RDW, emerged in Table 3. The results showed that the SDIS had the highest averages of root growth parameters, i.e., 15.49 cm, 1.68 g, and 0.64 g, compared with FIS having the lowest values at 12.23 cm, 1.49 g, and 0.52 g, respectively. It can be due to SDIS, which ensures the addition of an appropriate amount of water to the plants (to keep the root area wet to the required depth) without wasting water compared with the FIS. These results were consistent with past studies. which authenticated that DID significantly influenced root growth parameters in *Oryza sativa* L. (Adekoya *et al*., 2014). The distance of 18 cm provided the highest average values of 14.95 cm, 1.66 g, and 0.69 g compared with DID at 20 and 22 cm, which revealed a significant decrease in the root's growth characteristics during the growing season. The fewer distances between drippers provide a greater wet area in the root zone (Shtewy *et al*., 2020a), with the root growth ratio increased by 14.81 cm, 1.64 g, and 0.68, respectively, for cultivar TH, while a decrease in root growth ratio by 12.92 cm, 1.48 g, and 0.48 g, for the rice cultivar DM with the same conditions. However, the interaction among irrigation system IS, DID of 18 cm, and the rice cultivar TH showed the best among all the interactions (17.66 cm, 1.80 g, and 0.85 g).

**Yield and growth parameters**

The increase in DID achieved a decrease in the rice plant vigor index (PVI) at 59.24, 57.13, and 54.22 cm, respectively. The reduction in the distance between the drippers caused the regular water distribution in the root area following the conditions of water conservation and the environment suitable for plant growth, as compared with the increased distance between the drippers for the drip irrigation system (Matsuo and Mochizuki, 2009; He *et al*., 2014). The cultivar TH resulted in the highest PVI (59.81 cm), whereas the cultivar DM indicated the lowest PVI (53.92 cm) (Table 4). However, the SDIS (62.60 cm) was significantly better than the FIS (51.12 cm) because of the regular distribution of water in

**Table 3.** Effect of irrigation systems (IS), rice cultivars, and drip irrigation distance (DID) on root growth traits.

| RDW (g) | RFW (g) | RL (cm) | DID | Cultivars | IS |
|---|---|---|---|---|---|
| 0.85 | 1.80 | 17.66 | 18 | TH | SDIS |
| 0.71 | 1.72 | 16.19 | 20 | | |
| 0.63 | 1.69 | 15.41 | 22 | | |
| 0.69 | 1.61 | 15.81 | 18 | DM | |
| 0.56 | 1.52 | 14.56 | 20 | | |
| 0.41 | 1.46 | 13.34 | 22 | | |
| 0.68 | 1.68 | 14.09 | 18 | TH | FIS |
| 0.63 | 1.53 | 13.41 | 20 | | |
| 0.55 | 1.42 | 12.05 | 22 | | |
| 0.52 | 1.55 | 12.22 | 18 | DM | |
| 0.41 | 1.41 | 11.38 | 20 | | |
| 0.33 | 1.38 | 10.22 | 22 | | |
| 0.64 | 1.63 | 15.49 | SDIS | Average of IS | |
| 0.52 | 1.49 | 12.23 | FI | | |
| 0.68 | 1.64 | 14.81 | TH | Average of cultivars | |
| 0.48 | 1.48 | 12.92 | DM | | |
| 0.69 | 1.66 | 14.95 | 18 | Average of DID | |
| 0.57 | 1.55 | 13.88 | 20 | | |
| 0.49 | 1.47 | 12.76 | 22 | | |
| 0.101 | 0.102 | 0.143 | IS | | $LSD_{0.05}$ |
| 0.121 | 0.208 | 0.296 | DID | | |
| 0.101 | 0.102 | 0.143 | Cultivars | | |
| 0.142 | 0.214 | 0.301 | IS*C | | |
| 0.155 | 0.283 | 0.455 | IS*DID | | |
| 0.155 | 0.283 | 0.455 | C*DID | | |
| 0.218 | 0.331 | 0.533 | C*DID*IS | | |

Irrigation systems (IS), Tarm Hashemi (TH), Daillman Mazandarani (DM), subsurface drip irrigation system (SDIS), flood irrigation system (FIS), drip irrigation distance (DID), root length (RL), root fresh weight (RFW), and root dry weight (RDW).

**Table 4.** Effect of irrigation systems (IS), rice cultivars, and drip irrigation distance (DID) on rice growth and yield-related traits.

| HI (%) | GY (g.m$^{-2}$) | BY (g.m$^{-2}$) | PVI (cm) | DID | Cultivars | IS |
|---|---|---|---|---|---|---|
| 34.81 | 608.26 | 1747.23 | 71.15 | 18 | | |
| 34.33 | 559.81 | 1630.61 | 65.83 | 20 | TH | |
| 31.74 | 500.16 | 1576.15 | 63.71 | 22 | | SDIS |
| 33.72 | 541.66 | 1606.21 | 60.34 | 18 | | |
| 31.73 | 488.14 | 1538.19 | 59.45 | 20 | DM | |
| 27.20 | 404.96 | 1489.05 | 55.13 | 22 | | |
| 30.33 | 513.18 | 1691.71 | 54.09 | 18 | | |
| 30.87 | 484.02 | 1567.93 | 52.31 | 20 | TH | |
| 26.91 | 400.18 | 1486.77 | 51.69 | 22 | | FI |
| 31.70 | 501.01 | 1580.09 | 51.38 | 18 | | |
| 27.73 | 410.44 | 1479.96 | 50.93 | 20 | DM | |
| 30.35 | 391.08 | 1288.17 | 46.34 | 22 | | |
| 32.36 | 517.16 | 1597.90 | 62.60 | SDIS | Average of IM | |
| 29.68 | 449.98 | 1515.77 | 51.12 | FI | | |
| 31.60 | 510.93 | 1616.73 | 59.81 | TH | Average of cultivars | |
| 29.53 | 456.21 | 1544.48 | 53.92 | DM | | |
| 32.66 | 541.02 | 1656.31 | 59.24 | 18 | Average of DID | |
| 32.06 | 485.60 | 1554.17 | 57.13 | 20 | | |
| 29.09 | 424.09 | 1460.03 | 54.22 | 22 | | |
| 0.381 | 0.122 | 0.213 | 0.416 | Irrigation system | | |
| 0.493 | 0.201 | 0.364 | 0.623 | DID | | |
| 0.381 | 0.122 | 0.213 | 0.416 | Cultivars | | |
| 0.513 | N.S | 0.386 | 0.508 | IM*C | | $LSD_{0.05}$ |
| 0.692 | N.S | 0.418 | 0.643 | IM*DID | | |
| 0.692 | N.S | 0.418 | 0.643 | C*DID | | |
| 0.758 | 0.415 | 0.512 | 0.815 | C*DID*IM | | |

Irrigation systems (IS), Tarm Hashemi (TH), Daillman Mazandarani (DM), subsurface drip irrigation system (SDIS), flood irrigation system (FIS), drip irrigation distance (DID), plant vigor index (PVI), biological yield (BY), grain yield (GY), and harvest index (HI).

the root zone for better propagation and root growth. These results were also in analogy with the findings of Hamoud *et al*. (2018) by studying the effects of irrigation water regimes, soil clay content, and their interaction on the rice's growth, yield, and water use efficiency. The interaction of cultivar TH, DID (18 cm), and the SDIS provided the best PVI value (71.15 cm). Results further illustrated that the increased DID achieved the lowest harvest index at 32.66%, 32.06%, and 29.09%, respectively (Sangsoo *et al*., 2021).

The rice cultivar TH resulted in the highest harvest index (31.60%), and the cultivar DM indicated the lowest (29.53%) (Table 4). However, the SDIS was significantly better than the FIS, with harvest index values of 32.36% and 29.68%, respectively. Maintaining moisture in the root area due to SDIS positively affects crop growth and increases crop yield (Suriyan *et al*., 2010). The interaction among rice cultivar TH, DID (18 cm), and the SDIS provided the highest harvest index (34.81%). The DID of 18 cm achieved increased biological (BY) and grain yield (GY) parameters at 1,656.31 and 541.02 g.m$^{-2}$, respectively. The technique of the distance between the drippers gives water in small quantities and sustained manner (permanent moistening of the root area); however, as the distance between the drippers increased, the hydration area decreased and exposed the plants to drought, affecting the growth, biological yield, and, eventually, the grain yield (Alsharifi *et al*., 2017a). The cultivar TH resulted in the highest parameters of biological and grain yield (1,616.73 and 510.93 g.m$^{-2}$, respectively), while the cultivar DM gave the lowest values for the said traits (1,544.48 and 456.21 g.m$^{-2}$, respectively). Overall, the SDIS proved significantly better than the FIS, with values of 1,597.90, 1,515.77, 517.16, and 449.98 g.m$^{-2}$, respectively. The interaction among rice cultivar TH, DID (18 cm), and the SDIS displayed the highest values of biological and grain yields (1,747.23 and 608.26 g.m$^{-2}$, respectively).

## DISCUSSION

The use of a subsurface drip irrigation system (SDIS) during the entire growing season led to an increase in the productivity of the rice (*O. sativa* L.) crop compared with the yield obtained from the traditional irrigation system, i.e., FIS (Dass and Chandra, 2013). The SDIS increases water productivity compared with traditional irrigation systems (FIS). The reason for the decrease in the water percentage and the increase in soil moisture at the root zone by adopting the subsurface drip irrigation system is to improve the growth and productivity of the rice crop, linked to the distribution of water within the roots zone (Uphoff *et al*., 2013). Reducing water use during the plant growth stages may enable farmers to save more water without decreasing the rice grain yield and is desirable because of the drought periods in countries like Iraq.

Improvement in the rice yield due to the increase in soil fertility along with the abundance of water, the decreased distance between the planted plants with planting distance (PD) of 18 cm, achieved the highest values for rice growth and grain yield. That promising performance of the rice genotypes might be due to the abundance of sufficient moisture in the root zone of the rice crop. Drought and high temperatures during the growing season, with good soil conditions and equal distribution of water continuously, soil evaporation decreased at the PD of 18 cm compared with the PD of 20 cm and 22 cm, at which evaporation rates increased, resulting in the deterioration of rice crop growth (Alaamet *et al*., 2021).

The SDIS adoption to grow the rice cultivars Tarm Hashemi (TH) and Daillman Mazandarani (DM), with planting distances of 18, 20, and 22 cm, was compared with the FIS. The SDIS achieved water in abundance as reflected in the improvement of all the studied characteristics of crop growth, i.e., RL (15.49 cm), RFW (1.63 g), RDW (0.64 g), and PVI (62.60 cm), and increased grain yield (517.16 $g.m^{-2}$) and harvest index (32.36%) for both rice cultivars. It can refer to an increase in moisture content by increasing the volume of added water and the role of disintegration and non-compact soil, increasing its permeability and thus increasing its ability to retain irrigation water at the root zone, making it less vulnerable to environmental conditions, such as sunlight and wind, as well as, an increase in water movement at the root zone and an increase in the volumetric distribution of soil pores, which in turn increases the soil ability to hold water and retain moisture.

The presented study focused on the abundance of water and increasing the area cultivated with rice crops. The results showed the extent of the response of the rice cultivar Tarm Hashemi, with a planting distance of 18 cm, by giving the best performance as compared with cultivar Daillman Mazandarani. As far as the FIS is concerned, it gave unrewarding results for all the studied traits of both rice cultivars, in addition to large amounts of water wasted, as compared with SDIS, which not only improved and enhanced the growth and grain yield-related traits, but also save abundant water and nutrients. The SDIS facilitates the continuous availability of water; thus, the plant is in a state of sustained growth to maintain moist soil (Alsharifi *et al*., 2017b).

The irrigation systems (SDIS and FIS) had a significant impact on the growth and productivity characteristics of the rice crop, with the SDIS being found more suitable by improving plant population with the planting distance of 18 cm, which gave a regular distribution of water to the rice plants (Liu *et al*., 2013). The recent results indicated that adopting water-saving irrigation (WSI), with amplified water-use efficiency, caused significantly higher rice yield (Tables 3 and 4). A substantial decline in water application may adversely impact rice yield due to sensitivity to non-saturated soil environments (Kadiyala *et al*., 2015). In other crops, adopting SDIS also helps lower the irrigation dose and the growing season to reduce crop losses due to drought.

## CONCLUSIONS

The subsurface drip irrigation system (SDIS) proved significantly better than the flood irrigation system (FIS). The rice (*O. sativa* L.) cultivar Tarm Hashemi showed significant superiority over Daillman Mazandarani. Further, the drip irrigation distance (DID - 18 cm) also provided a significantly better response than other distances, i.e., 20 and 22 cm in the studied parameters. The interaction of rice cultivar Tarm Hashemi, SDIS, and DID (18 cm) displayed remarkable performance versus other interactions.

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