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Water Productivity of Garlic (Allium sativum L.) under the Responsive Drip Irrigation (RDI) System Compared to the Drip and Furrow Irrigation Systems in Silty Loam Soil

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ABSTRACT

Rapid population growth and climate change-induced water scarcity are challenging food security. Therefore, growing more food with less water and energy is urgently needed. The innovative responsive drip irrigation (RDI) system recently introduced in Pakistan responds to plant demand for water and nutrients and may be helpful in achieving this goal. Therefore, the yield, irrigation input and water productivity of garlic **(***Allium sativum L.) were evaluated under the RDI in comparison with the drip irrigation (DI) and furrow irrigation (FI) system (control) under silty loam soil at Islamabad, Pakistan. The treatments were three times replicated in a randomized block design. The average results show a significant (94%, 48%) water saving for the RDI and DI respectively than the FI (443 mm). The average dry garlic yield was also higher (3%, 11%) for the RDI and DI treatments respectively than the FI (13.491 tons/ha). Consequently, reducing irrigation water input and increasing crop yield resulted in a significant (94%, 46%) increase in the water productivity of garlic for the RDI and DI systems respectively than the FI (1.536 kg/m^3). Thus, the newly introduced RDI system in Pakistan has indicated the prospects of increasing the yield and water productivity of garlic at the household level. Hence, promoting the concept and principles of the RDI system may be helpful in enhancing climate change resilience in water-scarce areas and vegetable production at household levels in urban areas, which may enhance local food and nutrition security in the country.*

Keywords: *Garlic Yield, Responsive Drip Irrigation, Furrow Irrigation, Water Productivity, Silty Loam*

1. Introduction

Pakistan is facing severe food security issues due to rapid population growth, climate change, and mismanagement of resources. The total cultivated area of the country is around 22 million ha comprising 23% rainfed and 67% irrigated. The majority (90%) of crop production comes from irrigated agriculture, where excessive use of the canal and groundwater is the norm [1]. Moreover, the irrigated production system is mainly focused on cereal crops whose yields are also far below the demonstrated achievable potential. Consequently, the water productivity of irrigated agriculture is below global average values [2]. On the other hand, the production from rainfed areas is negligible due to a lack of water conservation and mismanagement issues. We need to implement special water conservation strategies to tape the full potential of the varying rainfall patterns across the spatial and temporal boundaries of the country. The rainfall across the country's geographical area varies from 125 mm to 1500 mm and around 70% of the country receives less than 250 mm of rainfall, while 67% of the rainfall occurs during three monsoon months [3]. Areas suitable for cereal crops and vegetables need to be prioritized to fulfill the rising food demand. Vegetable production is extremely essential for local food and nutrient security. However, vegetables are grown in limited areas in Pakistan due to larger input costs, water scarcity and awareness issues. Vegetable productivity is generally very sensitive to water stress, diseases and pests. Moreover, Pakistan is facing climate change at the forefront. Consequently, climate change-induced frequent water scarcity, increased pests, diseases and heat or cold waves negatively impact vegetable productivity leading to reduced farmer interest and less productivity. Furthermore, vegetable production at the household level is negligible due to a lack of skills and awareness regarding new technologies.

Garlic **(***Allium sativum L.*) is an important vegetable due to its medicinal value, as the Allicin of garlic has anti-bacterial properties [4] and higher nutritive value (rich in phosphorus, calcium, and carbohydrates) than the other bulb crops [5]. Generally, garlic is used in sauces, soups, vinegar, and for seasoning foods. In Pakistan, garlic is marketed fresh in raw form as a fresh bulb, green garlic, or garlic scape, while the marketing of processed products like spreads and chopped garlic is negligible. The local garlic production in Pakistan is around 125000 tons [6], which is sufficient to meet 67% of the domestic needs, thus precious foreign exchange (US$ 69 to 102 million) is spent on garlic import to fulfill the local requirement. Although the garlic yield in Pakistan is higher than the major rice-exporting countries including India (the world's third largest garlic exporter) [7, 8] and Bangladesh (the world's second largest garlic exporter) [9] but still the total garlic production is relatively less in Pakistan. Lack of resources and awareness of new technologies and improved management practices are considered the main reasons for low garlic productivity in Pakistan.

The responsive drip irrigation (RDI) system is a novel irrigation method that allows plants to self-regulate their own water delivery. When crops and plants need water and nutrients, they emit root exudates that allow them to uptake what they need from the surrounding soil. The RDI system responds and interacts with these root exudates, allowing water and nutrients to be released out of the billions of "smart micropores" in the polymer tubing. It provides a slow-release delivery of water flow that matches the roots' absorption capacity. The RDI resembles in properties the Moistube which is an innovative irrigation method comprised of a flexible semi-permeable nano-porous membrane with around 100,000 nanopores per square centimetre and of 10 to 900 nm pore size [10] that facilitates

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moisture movement by soil water potential difference [11] and system pressure [12]. The soil water matric potential alone drives the flow in case of the absence of the system pressure [11] but both drive the flow, if the water head is available [12]. The Moistube irrigation system is highly efficient, low pressure, less power consuming, low maintenance cost, and ensures long steady plant-responsive irrigation [13]. It did not require technical skills in irrigation scheduling for the different crops and soil types, because it self-regulates the irrigation application. The farmers need to keep the water available in the feeding reservoir alone. This technique has been successfully used in the middle east, Africa, and water-stressed areas of China and Pakistan [14], thus may be very beneficial for revolutionizing farming in water-scarce areas in general and vegetable production at the household level in particular. The RDI system has been recently introduced by the Climate, Energy, and Water Research Institute (CEWRI) of the National Agricultural Research Centre (NARC) in Pakistan. The research and demonstration sites have been established at Islamabad, district Lasbella in Baluchistan, Umerkot in Sindh, Peshawar, and Lakki Marwat in Khyber Pakhtunkhwa provinces. However, the current main limitations of RDI are the high cost and convenient availability of its parts in remote areas, while its resistance to rodents and soil disturbance during mid-season operation, pressure drop in RDI lines and clogging are not yet known under the local conditions. The RDI technology may have wide scope for the rainfed and desert areas of Pakistan. Therefore, the main objective of this study is to evaluate the effectiveness of the innovative RDI system in comparison to the conventional drip and furrow irrigation systems for the garlic vegetable under silty loam soil of the NARC, Islamabad, Pakistan.

2. Materials and Methods

2.1 Site description

The study was conducted during the October 2021 to May 2022 period, at the field station of CEWRI, NARC located at 498 m above mean sea level and l33° 40’ 31” N, 73º 08’ 15” E, Chak Shahzad, Islamabad, Pakistan. The soil properties at the experimental site are given in Table 1. The weather data in Table 2 is from October 2021 to May 2022 and recorded during the garlic season.

2.2 Experimental treatments

The experimental treatments were comprised of three irrigation methods: (1) RDI, (2) (DI), and (3) (FI) Systems (control). The treatments were thrice replicated in a split-plot complete block design. The nine experimental blocks were laid in three columns and three rows. Each column and row were separated by 75 cm (2.5ft) compacted earthen ridge of 30 cm (1 ft) height as a buffer area to avoid mutual interference of treatments. The land preparation, furrow bed sizes, seed rate (spacing), and all inputs, except irrigation applications, were the same for all the treatments. The irrigation was managed through a pipe delivery network using digital flow meters for flow measurements in m^3 by maintaining 15 psi pressure for the DI, 2 m constant head for the RDI system, and free gravity flow for the FI system. Irrigation scheduling for the FI and DI was based on the local farmer practice. The Humayun Garlic 1 (HG1) variety developed by NARC was planted on October 5, 2021, and harvested on May 16, 2022.

Table 1: Key soil hydraulic, chemical, and physical properties of the experimental site

Parameter Description	Value
Soil Bulk density	1.42 ± 0.13*
Soil Type	Silty Loam
pH	7.84 ± 0.11
EC (dS m^{-1})	0.44 ± 0.05
N (mg kg^{-1})	1.23 ± 0.79
P (mg kg^{-1})	4.78 ± 1.34
K (mg kg^{-1})	78.75 ± 13.78
WP (%)	12.40
FC (%)	27.70
SAT (%)	46.70
AW (mm m^{-1})	150.00

**SD - standard deviation; WP - wilting point; FC - field capacity; SAT-saturation; AW - available water = FC – WP; Ksat - saturated hydraulic conductivity.*

Table 2: Key weather parameters recorded at the field site of CEWRI-NARC Islamabad during 2021 and 2022 seasons

Month	*T min (°C)	T max (°C)	Humidity (%)	Wind (km/day)	Rainfall (mm)
Oct 21	15.00	29.13	75.39	36.01	166
Nov 21	7.30	24.63	67.90	18.04	0
Dec 21	3.47	19.43	76.70	33.10	10
Jan 22	5.35	15.84	89.26	43.62	165
Feb 22	6.36	19.43	78.50	54.84	22
Mar 22	13.00	28.74	72.32	35.15	54
Apr 22	16.33	35.30	52.40	35.01	5
May 22	20.13	36.58	62.90	49.64	14

**T_{min} = Monthly average minimum temperature, T_{max} = Monthly average maximum temperature*

2.3 Data Collection and Analysis

The data collection was comprised of recording daily weather data, agronomic activities, fertilizers, and irrigation applications. The harvest samples were collected from the whole block by weighing the total green weight and the total dry weight of each block. Daily water use for the RDI treatment was recorded at 9:00 AM daily for consistency. However, the irrigation data of drip and furrow irrigation was recorded at the time of irrigation applications, while the local irrigation schedule was followed depending on the appearance and feel of the DI and FI systems. The Microsoft Excel spreadsheet 2007 was used for statistical analysis and mutual comparisons. All the data sets were checked for compliance with the ANOVA assumption. The Tukey’s (HSD) test at $p \leq 0.05$ was used to identify significant differences [15] among treatments. The standard deviation was used to show data variations from the mean. The root zone soil water balance and transpiration were assessed using the AquaCrop model of the Food and Agricultural Organization (FAO) according to guidelines given by [16]. The AquaCrop model simulates the soil-plant-atmosphere system by considering water and nutrients in the soil, growth, development, and yield in the plant and thermal regime, rainfall, evaporation, and carbon dioxide concentration in the atmosphere. The AquaCrop model has been widely used for simulating the water balance in the soil and atmosphere and the yield of vegetables [17, 18].

3. Results

3.1 Irrigation Applications

The analysis of irrigation applications is presented in Fig. 1. The results show 48% and 94% reduced irrigation applications to DI and RDI systems respectively than the FI system (443 mm). The average irrigation application per event were 1, 18 and 37 mm for the RDI, DI and FI systems respectively during the garlic season. The total irrigations event in excess of 1 mm per event were 21, 13 and 12 for the RDI, DI and FI treatments respectively.

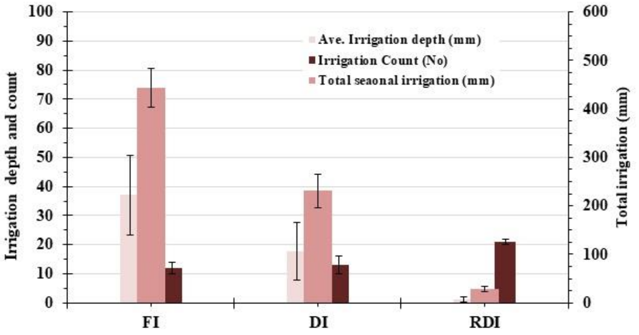

Fig. 1: Effect of FI, DI and RDI systems on average irrigation depth, irrigation count and total seasonal irrigation depth applications to garlic vegetable at NARC under silty loam soil *(vertical bars show standard deviations)*

3.2 Crop Yield

The crop yield results of garlic under the three irrigation methods are summarised in Fig. 2. The results show 1 and 3% higher dry garlic yield for the DI and RDI systems respectively than the FI (13.491 ton/ha) system.

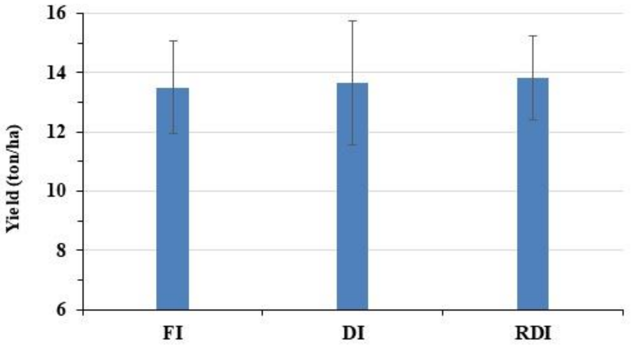

Fig. 2: Effect of DI and RDI systems compared to FI on yield of garlic (*vertical bars show standard deviations*)

3.3 Water Productivity of garlic

The water productivity of garlic under three irrigation methods is summarised in Fig. 3. The results show 34% and 88% higher water productivity for DI and RDI respectively than the FI (1.536 kg/m^3) system. The larger, water productivity of RDI than the FI is due to the relatively larger yield and significantly reduced irrigation applications to the RDI than the FI system.

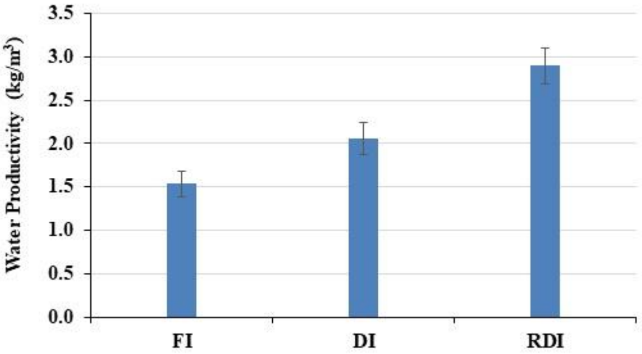

Fig. 3: Effect of FI, DI and RDI systems on the water productivity of garlic at NARC (*vertical bars show standard deviations*)

3.4 Rootzone Water Balance Analysis

The root zone profile (80 cm) moisture content variations for the three irrigation methods and rainfall events during the garlic season is presented in Fig. 4. The total rainfall of 435 mm was received in 31 rainfall events, with two major rainfall events including 96 mm on Oct 17, 2021 (early season) and 72 mm on January 7, 2022 (mid-season). The rainfall distribution and relatively less temperature during the season helped in keeping the rootzone above field capacity level, thus the water release from the RDI system was negligible to fulfil the soil moisture deficit in the rootzone during the crop season. However, irrigation in excess of demand was applied to FI and DI system. Consequently, the seasonal average profile moisture content in 80 cm rootzone profile was less (2%, 10%) for the DI and RDI systems respectively than the FI system (366 mm) system. The RDI system has shown a decreasing trend due to drainage and evapotranspiration in absence of rainfall, as the profile soil moisture content remained in excess of field capacity, except in the late season. However, the two daily rainfall in excess of 70 mm helped in equalizing the soil moisture content of all the irrigation treatments. The rootzone profile moisture content under the RDI system demonstrated larger rainwater conservation than the FI and DI systems, as the relatively dry rootzone profile of RDI allowed more rainfall runoff to store in the rootzone.

The water balance including details of all the water inputs and water outputs from the rootzone profile (80 cm) under the three irrigation methods using AquaCrop model is given in Fig. 5. The data shows maximum total infiltration, irrigation drainage and evapotranspiration for the FI system and minimum for the RDI system. Results shows 24 and 47% reduced infiltration, 28 and 55% reduced drainage, 29 and 35% reduced evaporation, 2% larger and 6% reduced transpiration and 9 and 17% reduced evapotranspiration for the DI and RDI systems respectively than the FI system.

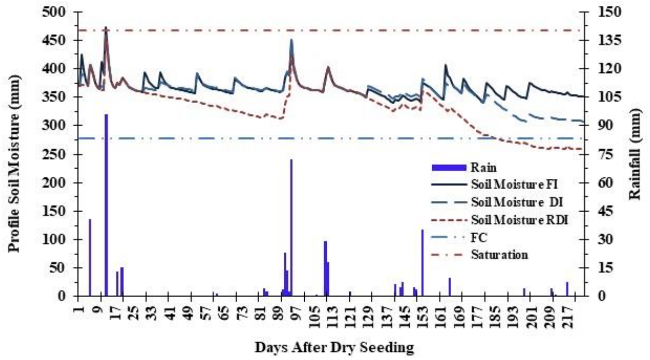

Fig. 4: Rainfall and rootzone profile moisture content variation relative to saturation and field capacity during the garlic season (Oct 5, 2021 to May 16, 2022) for the FI, DI and RDI systems

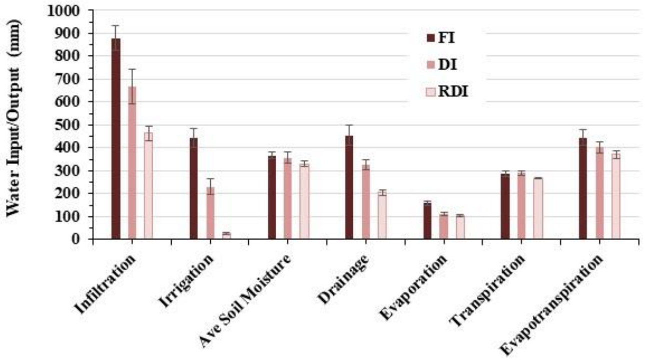

Fig. 5: Seasonal water input and output analysis in the rootzone profile (0-80 cm) for the FI, DI and RDI systems

4. Discussion

Vegetable production is important for the food security and healthy diet in Pakistan [19, 20]. However, despite being a short duration crop and generally grown on limited areas of farms [21], the demand for vegetables is rapidly increasing due to population growth, climate change induced water scarcity, diseases and pest infestation. Other reasons of less vegetable production and low quality are the less shelf life, market access issues, use of low quality water [22] and price variations due to supply and demand fluctuation. The unreliable water availability and less informed irrigation scheduling is further negatively impacting the vegetable productivity and quality [23]. Therefore, the use of innovative RDI technology used in the current study has elevated importance in using less water for growing more and healthy garlic. The 94% water saving indicates negligible irrigation application by the RDI than the FI system, which also helped in effectively using the available rainfall in the study area and fulfilling the water need without causing any water stress. These results also closely agree with the findings of RDI studies conducted at UAE showing water saving of 50% for date palm, 23% for cabbage and 33% for tomato than the DI system (personal communication). Therefore, the RDI system can be instrumental in enhancing crop yield and expanding vegetable grown areas in the water scarce regions. Moreover, vegetable production at household level or kitchen gardening can also be promoted in urban areas because the RDI system is less laborious, demands no frequent opening or closing of the valves and can irrigate vegetable using the available domestic water tanks and can ensure no vegetable damage in case the residents are away from home for several days. Although DI system also caused significant 48% saving in irrigation applications but still the water release was not according to the crop water requirement and is dependent on human decision of keeping the valve on or off, thus resulted over irrigation at the cost of more water, energy and labor.

The 1and 3% larger garlic fresh yield for the DI and RDI systems indicates that the garlic vegetable yield cannot be improved by increasing irrigation application but rather over irrigation make it more susceptible to weaker crop health, diseases and pest infestation due to increased humidity and submergence [24]. In contrast, other studies on RDI for tomato in Pothohar has shown up to 78% increase in yield and 41.5% overall benefit to the farmer than the conventional flood irrigation system [25]. Therefore, beside saving in irrigation water, the crop yield can also be increased by using the RDI system [14]. Hence, increasing crop yield and decreasing irrigation applications, the RDI and DI system showed 88 and 34% increase in water productivity of garlic crop respectively than the FI system [26], which can be helpful in producing more garlic with less water, especially in water scarce and urban areas of the country.

5. Conclusions

Growing garlic through RDI system can significantly decrease (94%) irrigation application and increase yield (3%), thus may lead to significant increase (88%) in water productivity than the furrow irrigation (FI) system. The use of DI system can also significantly increase water saving (48%) at no yield tradeoff, thus may lead to significant increase (34%) in water productivity of garlic than the conventional FI system. Producing more garlic yield with less water, less pumping energy, less labor and no technical knowledge regarding irrigation scheduling along with more rainwater conservation has indicated the prospects of larger vegetable production by adapting the RDI system in the water-scarce and urban areas of Pakistan. The concept of RDI system can be helpful in improving the climate change resilience and food security of vulnerable communities in the climate change-prone water-scarce areas of the country.

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