Research Article

Evaluation of Yield, Quality and Water Productivity of Responsive Drip Irrigation and Furrow Irrigation in Bitter Gourd

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Abstract | Water scarcity is one of the major challenges faced by vegetable production, particularly in arid and semi-arid regions. The experiment was conducted on bitter gourd at Water Management Research Farm, Renala Khurd, Okara. Bitter gourd seeds were sown on both sides of 30 cm wide beds with a bed-to-bed distance were 45 cm and a plant-to-plant distance was 91 cm. The nursery was sown in trays and after 45 days it was transplanted to 30 cm wide beds in the field. Irrigation was applied through both responsive drip irrigation (RDI) and in furrows in between beds in separate blocks. Data was recorded regarding the volume of water applied and the number of irrigations, crop health, quality, yield, and water productivity (WP). It was revealed that the RDI system consumed less water as compared to flood irrigation. The 5.56 tons per hectare yield was obtained from conventional/furrow irrigation while 7.8 tons per hectare yield was obtained from responsive drip irrigation with polythene as mulch. When the plants were mulched with polythene, total water applied was 4105.26 m^3 per hectare in responsive drip irrigation with WP of 1.90 Kg/m^3, while 4920.35 m^3 per hectare water was applied in case of furrow irrigation with WP of 1.13 Kg/m^3 for full growing season. However, total water applied was 2760.23 m^3 per hectare in responsive drip irrigation with WP of 1.71 Kg/m^3, while 4366.34 m^3 per hectare water was applied in case of furrow irrigation with WP of 1.01 Kg/m^3 for full growing season when soil was without polythene mulch.

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Keywords | Micro-irrigation, Bitter gourd, Growth, Yield, Water productivity

Introduction

Water scarcity is intensifying owing to the mismanagement of water resources (Ali *et al.*, 2022). Subsurface irrigation is vital to vegetable production (Wang *et al.*, 2022). Responsive drip irrigation (RDI) is a type of surface drip irrigation (SSDI). The use of RDI without puddling offers a significant water-saving advantage of 76%. However, implementing RDI for rice cultivation, specifically for the PK-1121 variety, may reduce crop yield by 18% due to water stress. This is because the microporous tube has a limited water release capacity and can only moisturize the root zone up to 15% above the field capacity in silty loam soil. While this level of moisture may be suitable for most cereal crops, it is not ideal for rice. To address this issue, growing rice with RDI requires either enhancing the water release capacity through changes in the microporous tube design or utilizing more drought-tolerant rice varieties (Akbar *et al.*, 2023).

According to fruit, vegetables and condiments statistics of Pakistan, bitter gourd was grown on an area of 6,709 ha during 2021-22 and produced a yield of 120,220 tons (GOP, 2022). Current study introduces a software application that enables convenient and accurate preliminary studies for new drip irrigation installations. With its user-friendly interface, this application allows for in situ assessments to be conducted efficiently. A well-designed drip irrigation system, facilitated by this software, can lead to notable economic benefits. It helps minimize water usage and reduces the materials required by optimizing the size of the installed system (Sesma *et al.*, 2015).

The limitation of water supply during the vegetable growing season significantly affects vegetable production (De Pascale *et al.*, 2011). Regulated deficit irrigation by RDI was applied to reduce water usage. A pot experiment was conducted to assess the impact of different RDI levels on maize, lettuce, and garland chrysanthemum. Four irrigation levels were implemented: full irrigation as the control (RDI-100), 70% of full irrigation (RDI-70), 50% of full irrigation (RDI-50), and 30% of full irrigation (RDI-30). The water use efficiency (WUE), vegetable yields, yield components, and water consumption were evaluated. Results revealed that WUE values were significantly higher with RDI-30 compared to other treatments for maize and lettuce. However, garland chrysanthemum significantly reduced WUE compared to other treatments. In maize plants, there were significant correlations between WUEi (nondestructive estimator of WUE) and both WUE yield and WUE biomass, indicating their usefulness in estimating yields and biomass content. Similarly, a significant correlation between WUEi and WUE yield was observed in lettuce plants. This index proved to be relevant for assessing economic production, as well as fresh weights and the water content of the irrigated crops. These findings provide valuable non-destructive measurements to evaluate water deficits in vegetable plants, facilitating large-scale water management and conservation of scarce water resources (Chang *et al.*, 2021).

The irrigation scheduling tools and water management models for efficient on-farm watering of vegetable crops in open field conditions. By employing these tools, water losses due to drainage can be reduced, and the risk of underground water contamination can be minimized. The review emphasizes the use of commercial applications based on previous scientific findings to optimize on-farm water productivity.

2. Materials and Methods

2.1. Study design

The experiment was conducted on bitter gourd at Water Management Research Farm, Renala Khurd, Okara. RDI system (iPERL) was installed at WMRF (Figure 1). Bitter gourd hybrid (Gullu F10 was sown on small beds. Bed size was 30 cm with a bed-to-bed distance was 45 cm and plant-to-plant distance was 91 cm. The nursery was sown in trays in the Rabi season 2022-23 and after 45 days it was transplanted to beds. Crop Water requirement was executed based on actual ETo and Kc. Irrigation was applied through bother responsive drip irrigation (RDI) and furrow irrigation in separate blocks in comparison with flood irrigation in furrows. Cut throat flume was used to measure quantity of water applied in furrows. Polythene was used as mulch in comparison with without mulch on some beds. Plants were trained vertically on plastic nets. Yield related attributes i.e., number of fruits per plant, fruit length, fruit girth, fruit weight, fruit yield /plant, yield/acre, water applied, water productivity and quality related attributes i.e., TSS Brix, ascorbic acid, protein content, shelf life were observed.

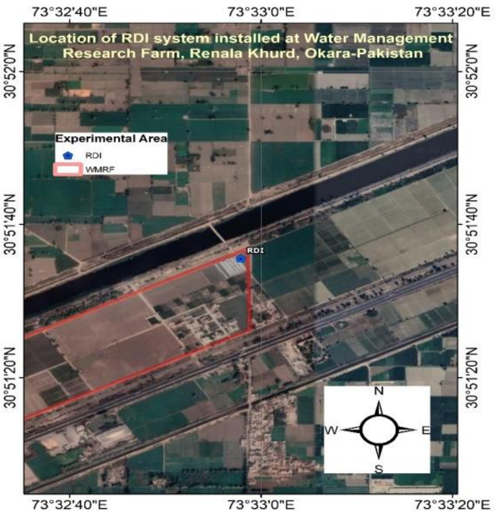


Figure 1: Location of RDI system installed at Water Management Research Farm, Renala Khurd, Okara (ARC GIS 10.7)

Table 1: Specifications of iPERL smart water meter of responsive drip irrigation installed at Water Management Research Farm, Renala Khurd, Okara.

Service	**Measurement of potable and reclaim water, and Residential Fire Service (UL 327b). 0-100% humidity. Fully submersible. IP68+ rated.**			
Starting Flow	5/8” (DN 15 mm) size: 0.03 gpm (0.007 m3/h)	5/8” x 3/4” (DN 15x20 mm) size: 0.03 gpm (0.007 m3/h)	3/4” (DN 20 mm) size: 0.03 gpm (0.007 m3/h)	1” (DN 25 mm) size: 0.11 gpm (0.025 m3/h)
Low Flow Range (±3%)	5/8” (DN 15 mm) size: >0.10 gpm (0.025 m3/hr) to <0.18 gpm (0.041 m3/hr)	5/8” x 3/4” (DN 15 mm) size: >0.10 gpm (0.025 m3/hr) to <0.18 gpm (0.041 m3/hr)	3/4” (DN 20 mm) size: >0.10 gpm (0.025 m3/hr) to <0.18 <0.4 gpm (0.041 m3/hr)	1” (DN 25 mm) size: >0.3 gpm (0.068 m3/hr) to gpm (0.09 m3/hr)
Normal Water Operating Flow Range (±1.5%)	5/8” (DN 15 mm) size: 0.18 to 25 gpm (0.04 to 5.7 m3/hr)	5/8” x 3/4” (DN 15x20 mm) size: 0.18 to 35 g 8.0 m3/hr)	3/4” (DN 20 mm) size: 0.18 to 35 gpm (0.04 to 8.0 m3/hr)	1” (DN 25 mm) size: 0.4 to 55 gpm (0.09 to 12.5 m3/hr)
Maximum Operating Pressure	5/8’’, 5/8” x 3/4”, and 3/4’’ size: 200 psi (13.8 bar) 1’’ size: 175 psi (12.1 bar)			
Measurement Technology	Solid state electromagnetic flow			
Register	Hermetically sealed, 9-digit programmable electronic register			
Capacity	10,000,000 gallons, 1,000,000 cubic feet or 100,000 m3 capacity			
Register Resolution	.01 gallons/imperial gallons, .001 cubic foot, or .0001 m3			
Conformance to Standards	Meets the requirements of NSF 61, Annex G and NSF 372. Exceeds the most current revision of AWWA Standard C-715.			
Materials	External housing – Thermal polymer Flowtube – Composite polymer or a bronze alloy flowtube with a composite polymer internal core		Electrode – Silver/silver chloride Register cover – Hermetically sealed glass	

2.2. Total Soluble Solids (TSS)

TSS of bitter gourd was measured extracting juice drop with the help of a Refractometer by leveraging the principle of light refraction (ATAGO, RX 5000, Japan).

2.3. Protein quantification

The Bradford assay, as described by Kruger (2009), was employed for the quantification of soluble proteins. The procedure commenced with the addition of 2 mL of Bradford reagent to a microcentrifuge tube, followed by the introduction of 50 µL of the protein sample. A blank was prepared using only the Bradford reagent. The absorbance of the sample was then measured at a wavelength of 595 nm. To quantify the protein content, a standard curve was constructed using various concentrations of bovine serum albumin (BSA).

2.4. Ascorbic acid quantification

The concentration of ascorbic acid (AA) in guava fruit juice was quantified following the method outlined by Razzaq *et al.* (2014) and reported in units of mg per 100 mL of fresh weight (FW). In this procedure, a 10 mL sample of the fruit juice was transferred to a 100 mL volumetric flask, and the remaining volume was filled with a 0.4% oxalic acid solution. The mixture was thoroughly homogenized and then filtered using Whatman® No. 1 filter paper. Subsequently, a 5 mL aliquot of the filtered solution was titrated against a blue dye, specifically 2,6-dichlorophenolindophenol, with gentle stirring until a persistent light pink color was observed.

$$Ascorbic\ Acid\ \left(100\frac{mg}{L}FW\right) = \mathrm{(D1xAx100)/(D2xXxY)}$$

Where; D1 = volume of dye (mL), D2 = Standard reading (3.63 mL), X = volume of cactus pear juice (mL), A = Solution volume made after addition of oxalic acid (100 mL), Y = Volume of aliquot (5 mL).

All the above experimental methods and field studies were carried out by relevant guidelines and legislations of institutional, national, and international criteria.

2.5. Statistical analysis

The mean values of each treatment were compared with the HSD test. Statistical analysis was done using STATISTIX version 10.0.

3. Results

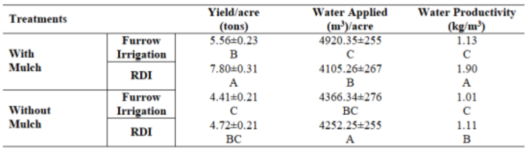
Regarding number of fruits per plant in furrow irrigation were16.8 and in RDI were 18.6 while without mulch with furrow irrigation were 15.4, while with RDI were 14.1. Regarding fruit length in furrow irrigation were11.4 cm and in RDI were 13.5 cm, while without mulch with furrow irrigation were 10.1 cm while with RDI were 10.1 cm. Regarding fruit girth in furrow irrigation were 45.3 mm and in RDI were 41.9 mm, while without mulch with furrow irrigation were 40.1 cm while with RDI were 40.2 cm. Regarding fruit weight in furrow irrigation were 70.2 g and in RDI were 72.5 g, while without mulch with furrow irrigation were 68.2 g, while with RDI were 67.5 g. Regarding fruit weight in furrow irrigation were 1.20 Kg and in RDI were 1.36 Kg (maximum), while without mulch with furrow irrigation were 1.00 Kg (minimum), while with RDI were 1.10 Kg (Table 2).

Table 2: Yield related attributes of bitter gourd grown on furrow irrigation and RDI irrigation.

Treatments		No. of fruits per plant	Fruit length (cm)	Fruit girth (mm)	Fruit weight (g)	Fruit yield /plant (kg)
With Mulch	Furrow Irrigation	16.8±0.88 AB	11.4±0.45 B	45.3±2.3 A	70.2±3.4 AB	1.20±0.06 AB
	RDI	18.6±0.76 A	13.5±0.54 A	41.9±2.1 B	72.5±3.3 A	1.36±0.07 A
Without Mulch	Furrow Irrigation	15.4±0.91 B	10.1±0.33 B	40.1±2.3 B	68.2±3.2 B	1.00±0.06 D
	RDI	14.1±0.67 C	10.1±0.45 B	40.2±2.1 B	67.5±3.5 B	1.10±0.05 C

On overall basis, 5.56 tons per hectare yield was obtained from conventional/furrow irrigation while 7.8 tons per hectare yield was obtained from responsive drip irrigation. Total water applied was 6,282 m^3 per hectare in responsive drip irrigation while 14,820 m^3 per hectare water was applied in case of responsive drip irrigation (RDI) for full growing season. So, water productivity (WP) of furrow irrigation was 1.13 Kg/m^3 while it was 1.90 Kg/m^3 (Table 3).

Table 3: Yield and water productivity of bitter gourd grown on furrow irrigation and RDI irrigation.



Treatments		Yield/acre (tons)	Water Applied (m^3)/acre	Water Productivity (kg/m^3)
With Mulch	Furrow Irrigation	5.56±0.23 B	4920.35±255 C	1.13 C
	RDI	7.80±0.31 A	4105.26±267 B	1.90 A
Without Mulch	Furrow Irrigation	4.41±0.21 C	4366.34±276 BC	1.01 C
	RDI	4.72±0.21 BC	4252.25±255 A	1.11 B

Regarding quality attributes maximum TSS was observed in plants on RDI with mulch was 2.91 Brix while minimum was observed in plants irrigated in furrows without mulches was 2.52 Brix (Figure 2). The maximum ascorbic acid (mg/100 g) was observed in plants on RDI with mulch was 73 mg/100 g, while ascorbic acid content was in plants irrigated in furrows without mulches was 63 mg/100 g (Figure 3). The maximum protein content (mg/100 g) was observed in plants on RDI with mulch 1.70 %, while protein content were minimum in plants irrigated in furrows without mulches were 1.43% (Figure 4). Maximum shelf life 5.5 days were observed in RDI with mulch, while protein content were minimum in plants irrigated in furrows without mulches were both in 4.10 days (Figure 5).

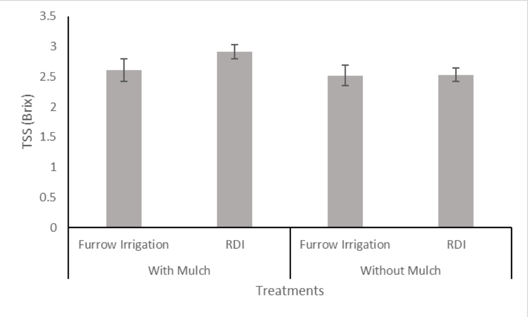


Figure 2: TSS of bitter gourd grown on furrow irrigation and RDI irrigation.

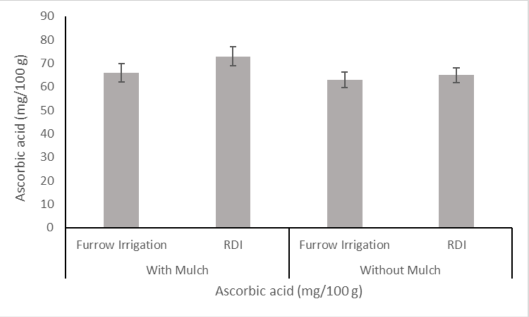


Figure 3: Ascorbic acid of bitter gourd grown on furrow irrigation and RDI irrigation.

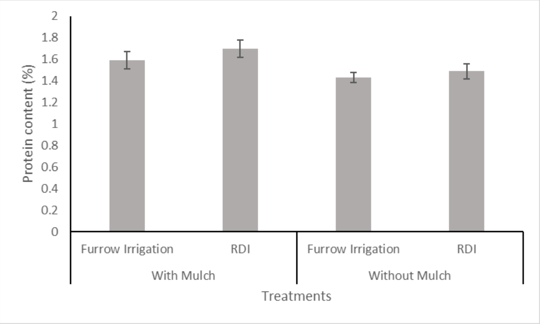


Figure 4: Protein content of bitter gourd grown on furrow irrigation and RDI irrigation.

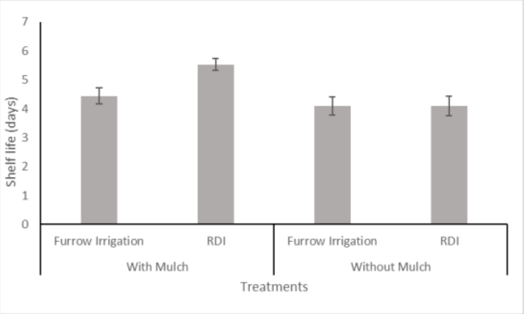


Figure 5: Shelf life of bitter gourd grown on furrow irrigation and RDI irrigation.

4. Discussion

Responsive drip irrigation is a kind of sub-surface irrigation. The results are in line with the findings of Thompson *et al.* (2002) who demonstrated that nitrogen uptake and yield of broccoli was higher in sub-surface drip irrigation. In terms of crop yield, RDI resulted in a 20% higher yield of bitter gourd compared to furrow irrigation. This result is consistent with the observations of Allen *et al.* (1998), who reported that drip irrigation enhances crop yields due to more precise water application and reduced water stress. The higher yield can be attributed to the more uniform water distribution and the reduction in water-related plant stress that RDI offers. Furthermore, mulching is very effective in water use efficiency enhancement and fruit dry matter (Singandhupe *et al*., 2000). Drip irrigation is most effective way for water use efficiency improvement in vegetables especially for bittergourd (Soomro *et al*., 2022).

Additionally, the quality of bitter gourd, measured in terms of fruit size and marketable yield, was superior under RDI. Improved water management through drip irrigation could enhance the quality of horticultural produce. The better quality and increased marketable yield could potentially result in higher economic returns for farmers, reinforcing the economic viability of RDI. Drip irrigation improves yield and quality of bitter gourd (Mali *et al*., 2017).

The study also highlights that RDI can lead to more efficient water usage, which is crucial in areas experiencing water shortages. The enhanced water productivity under RDI which emphasized that drip irrigation not only conserves water but also increases the productivity per unit of water used. This increased water productivity contributes to environmental sustainability by reducing the overall water footprint of agricultural activities (Abraham *et al*., 2018).

The quality of the bitter gourd was Improved in case of RDI system as the translocation of these nutrients to the fruiting nodes enhances fruit set, fruit development, and ultimately increases yield. Comparable effects of nitrogen and phosphorus on yield parameters have been documented by Pulak Bhunia Mandai (2009) and Thriveni *et al*. (2015) in bitter gourd, Saravaiya *et al*. (2012) in pointed gourd, and Kameswari and Narayanamma (2011). The improvement in quality of bitter gourd fruit (protein, ascorbic acid content, TSS, and shelf life etc.) is due to effective fertigation in case of RDI/conventional drip irrigation system (Hari *et al*., 2016).

5. Conclusion

Overall, the responsive drip irrigation system is an innovative and efficient way to manage water and nutrients in agriculture. Its precise and efficient water and nutrient management can increase crop yields, conserve water, reduce fertilizer usage, increase efficiency, and improve soil health. In conclusion, the comparison between responsive drip irrigation and furrow irrigation demonstrates that RDI is a more water-efficient and productive method for cultivating bitter gourd. The findings support the adoption of RDI for better water management and enhanced crop yields and nutritional value, although considerations related to cost and system implementation remain relevant. Further research and technological advancements could help in addressing these challenges, ultimately promoting more sustainable agricultural practices.

6. Acknowledgments

All authors are thankful to International Water Management Institute (IWMI) (Okara substation) for technical support of soil moisture measurement by Cameleon WiFi reader/sensor.

7. Author’s Contribution

All authors have contributed equally.

8. Conflict of Interest

No conflict.

9. Novelty Statement

Water scarcity is one of the major challenges faced by vegetable production, particularly in arid and semi-arid regions. Current study was conducted on bitter gourd. Irrigation was applied through both responsive drip irrigation and in furrows in between beds in separate blocks. Data was recorded regarding the volume of water applied and the number of irrigations, crop health, quality, yield, and water productivity. It was revealed that the RDI system consumed less water as compared to flood irrigation.

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