



Performance of Wheat with Deficit and Full Sub-Surface Drip Irrigation versus Surface Flood Irrigation

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Abstract: Subsurface drip irrigation (SDI) is an emerging micro-irrigation technique, particularly promising for close-spaced crops like wheat. SDI minimizes evaporation losses by delivering water directly to the root zone, potentially enhancing yield with reduced water consumption. This field study, conducted at Punjab Agricultural University's Regional Research Stations in Abohar and Faridkot, investigated fertigation scheduling and wheat performance under deficit SDI regimes. Treatments included three SDI levels (60, 80, and 100% of crop evapotranspiration, ET_c) combined with two fertigation levels (60 and 80% of the recommended nitrogen dose, RDN), alongside a surface flood irrigation control (100% RDN). SDI at 80 and 100% ET_c significantly increased grain yield by 9.3 and 12.1%, respectively, compared to the control, with corresponding increases of 10.1 and 12.9% over 60% ET_c. Both fertigation levels yielded higher grain yields (5.5-8.3% increase over control), but no significant difference was observed between them. SDI improved nitrogen use efficiency (NUE), peaking at 80% and 100% ET_c. Water savings with SDI ranged from 54.5-66.0% in Abohar to 27.9-46.8% in Faridkot, compared to the control. The 60% ET_c treatment, with the least water application, achieved the highest apparent water productivity (AWP), followed by 80% and 100% ET_c under SDI. Surface flood irrigation resulted in the lowest AWP due to lower yield and higher water use. This study indicates that SDI at 80% ET_c, coupled with fertigation at 60% RDN, optimizes wheat yield and AWP.

Keywords: Wheat, Drip irrigation, Fertigation, Grain yield, Irrigation water applied, Nitrogen use efficiency

Wheat (*Triticum aestivum* L.), a staple food worldwide, holds particular significance in India, where it ranks as the primary cereal crop. The nation leads globally in wheat acreage, spanning 30.79 million hectares, and stands second only to China in production, with 98.51 million tonnes. In Punjab, wheat dominates the winter cropping season, covering 3.53 million hectares and yielding 17.19 million tonnes (Anonymous 2022).

Despite its importance, wheat cultivation in Punjab, like many field crops, heavily relies on surface flood irrigation. This method, while prevalent due to historically accessible canal water and subsidized electricity for tubewells, leads to substantial water wastage (Singh and Singh 2013). The unsustainable nature of flood irrigation necessitates its replacement with more efficient systems to conserve this precious resource (Singh et al. 2018). The global freshwater supply faces increasing strain from a burgeoning population and the agricultural sector's substantial water demand (Gleick and Palaniappan 2010, Hoekstra and Mekonnen 2012). In Punjab, over-extraction of groundwater has resulted in a concerning decline in aquifer levels, with 80% of the area experiencing depletion at a rate of 0.4 meters per year (Brar et al 2012). Addressing this critical issue demands innovative irrigation strategies that reduce water use without compromising crop yield.

Subsurface drip irrigation (SDI), traditionally employed for high-value, widely spaced crops, offers a potential solution for field crops like wheat. In SDI, drip lines are buried near the root zone, minimizing evaporation, facilitating field operations, and optimizing nutrient uptake while reducing weed growth and labor costs (Camp 2018). Research suggests SDI promotes deeper root development and improves water use efficiency compared to surface drip irrigation (Patra et al 2023, Yang et al 2019). This field study aimed to evaluate SDI's potential for wheat cultivation in Punjab, specifically focusing on optimizing irrigation scheduling under SDI in a wheat-cotton rotation system.

MATERIAL AND METHODS

Site description: Field experiments were conducted during the 2019-2020 winter season at two research stations of Punjab Agricultural University: Regional Research Station in Abohar (30.80°N, 74.12°E) and the Regional Research Station in Faridkot (30.40°N, 74.44°E). This southwestern region of Punjab is characterized by a predominantly cotton-wheat cropping rotation. The mean maximum and minimum temperatures during the experimental period were 23.2°C and 9.6°C in Abohar, and 22.9°C and 12.8°C in Faridkot, respectively (Table 1). The soil texture was loamy sand in Abohar and sandy loam in Faridkot. Soil moisture holding

capacity and bulk density for each location are presented in Tables 2 and 3.

Drip layout: In the summer of 2018, prior to cotton sowing, drip laterals were installed 20 cm beneath the soil surface at both locations using a tractor-mounted lateral laying machine. The laterals were spaced 67.5 cm apart and equipped with in-line drippers spaced 20 cm apart, each with a discharge rate of 2.2 liters per hour. Both cotton and wheat crops were sown parallel to the subsurface drip laterals. This arrangement allowed each lateral to serve one row of cotton (67.5 cm row spacing) in the summer and three rows of wheat (22.5 cm row spacing) in the winter.

Field preparation and crop management: The pre-sowing flood irrigation was applied to ensure adequate moisture for wheat germination. Following cotton harvest, the field was prepared with a single pass of a tractor-operated rotavator and one pass with a planker to create a firm seedbed. Wheat was sown on November 6, 2019, in Faridkot and November 11, 2019, in Abohar, with a row spacing of 22.5 cm. Each treatment plot had a gross size of 12 rows x 18 m. Standard agronomic practices, except for irrigation and nitrogen management, were followed as per Punjab Agricultural University recommendations for wheat (Anonymous 2022). The crop was harvested on April 15, 2020, in Abohar and April 23, 2020, in Faridkot.

Experimental treatments and design: The experiment followed a randomized complete block design with three replications. Treatments consisted of combinations of three subsurface drip irrigation regimes (60, 80% and 100% ETc) and two nitrogen fertigation levels (60 and 80% RDN). These six SDI treatments were compared to a control treatment of flood irrigation with 100% RDN.

Irrigation/Fertigation Scheduling

Control: The first flood irrigation was applied 25 days after sowing, with subsequent irrigations at 3-4 week intervals, depending on rainfall. The final irrigation was applied in the last week of March at both locations. The recommended

nitrogen dose of 125 kg N/ha was applied as urea in two equal splits: the first at the first irrigation and the second after the second irrigation.

SDI: The first irrigation was applied 21 days after sowing. Subsequent irrigations were applied every 5 days, with varying water amounts based on the three irrigation regimes and the reference crop evapotranspiration (ETc) calculated using the FAO Penman-Monteith equation for each 5-day period. Irrigation duration was calculated considering emitter discharge rate and the number of emitters per plot using the following formula:

$$\text{Time (minutes)} = \frac{\text{Amount of water required (mm)} \times \text{Plot area (sq.m.)} \times 60}{\text{Discharge rate of emitter (litres/hour)} \times \text{Number of emitters in plot}}$$

Table 2. Moisture retention capacity of soil at experimental fields

Soil depth (cm)	Moisture content (%) at field capacity		Moisture content (%) at permanent wilting point (PWP)	
	Faridkot	Abohar	Faridkot	Abohar
0-15	21.0	19.8	12.5	8.9
15-30	16.7	14.3	10.1	10.3
30-45	16.0	15.0	9.9	10.0
45-60	18.2	16.4	10.9	10.1
60-90	17.6	16.6	10.1	8.2
90-120	16.2	15.0	9.9	9.1
120-150	18.3	16.7	12.1	10.7

Table 3. Bulk density of soil at experimental fields

Soil depth (cm)	Bulk density (g cm ⁻³)	
	Faridkot	Abohar
0-15	1.55	1.59
15-30	1.53	1.69
30-60	1.67	1.71

Table 1. Mean monthly meteorological data of experimental sites during crop season

Month	Abohar				Faridkot			
	Temperature (°C)		Total rainfall (mm)	Rainy days (no.)	Temperature (°C)		Total rainfall (mm)	Rainy days (no.)
	Maximum	Minimum			Maximum	Minimum		
November	25.6	12.6	33.8	4	25.2	12.1	26.8	4
December	16.6	5.4	22.4	1	15.6	5.9	15.3	2
January	16.3	5.2	39.2	3	15.8	5.5	38.6	3
February	22.6	7.4	1.8	0	22.3	8.2	1.2	1
March	24.8	12.4	80.4	7	24.7	12.9	57.2	5
April	33.2	16.8	8.4	4	33.6	18.1	7.0	3

Nitrogen fertigation under SDI was applied in five splits, with the first dose at the first irrigation and the remaining four doses applied with every alternate irrigation, according to the treatment.

Data recording: Grain yield was recorded from the net plot area (2.25 m x 18 m) after manual harvesting and threshing and converted to kg/ha. Nitrogen use efficiency (NUE) was calculated by dividing grain yield (kg/ha) by nitrogen uptake (kg/ha). Apparent water productivity (AWP) was calculated as:

$$\text{AWP (kg m}^{-3}\text{)} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Irrigation water applied (mm)} \times 10}$$

Statistical analysis: Data were analyzed using ANOVA (GLM procedure in SAS 9.3), and means were separated using LSD at $p < 0.05$.

RESULTS AND DISCUSSION

Grain yield: Subsurface drip irrigation (SDI) consistently improved grain yield compared to surface flood irrigation (control) at both experimental sites (Table 4). In Abohar, the yield under surface flood (3644 kg/ha) was lower than even the 60% ETc SDI treatment (4100 kg/ha). Although SDI treatments did not show statistically significant yield differences at this location, the overall yield increase compared to flood irrigation can be attributed to the precise water delivery near the root zone, minimizing evaporative losses. This efficient water use likely enabled the 60% ETc treatment to achieve yields comparable to higher SDI levels. In Faridkot, the 100% ETc SDI treatment produced the highest yield (6319 kg/ha), statistically similar to the 80% ETc treatment (6205 kg/ha). The deficit irrigation treatment (60%

ETc) resulted in a lower yield than the control, possibly due to insufficient water application. Compared to 60% ETc, the 100% and 80% ETc treatments increased yield by 15.0 and 15.8% in Faridkot, and 6.0 and 2.4% in Abohar, respectively. Sinha et al (2017) also reported higher yields with SDI and fertigation compared to the control, except for SDI at 60 and 80% ETc with 60% RDN. Pooled data analysis confirmed that 100 and 80% ETc SDI treatments significantly outperformed 60% ETc, with the latter being comparable to flood irrigation. The 100 and 80% ETc SDI treatments yielded 12.1 and 9.3% more grain than the control, respectively. This yield advantage can be attributed to improved crop growth due to consistent soil moisture and nutrient availability under SDI, leading to enhanced yield components. Rao et al (2016) similarly observed comparable seed cotton yields at 100 and 80% ETc SDI, both superior to 60% ETc. The interaction between irrigation and fertigation was non-significant, the comparison between SDI treatments and the control remained significant at both locations.

Nitrogen use efficiency (NUE): Irrigation levels influenced NUE only in Faridkot, while fertigation levels significantly impacted NUE at both locations (Table 5). In Faridkot, the highest NUE was observed at 100% ETc (89.0), statistically similar to 80% ETc (87.4) but significantly higher than 60% ETc (75.3). Regarding fertigation, 80% RDN through SDI resulted in lower NUE than 60% RDN at both sites. Pooled data analysis confirmed the significance of both irrigation and fertigation levels in influencing NUE, with trends similar to those observed in Faridkot. SDI consistently outperformed flood irrigation in terms of NUE, likely due to the targeted nitrogen application minimizing losses through leaching and volatilization. These results highlight SDI's advantage over

Table 4. Influence of different levels of fertigation and irrigation on grain yield of SSDI wheat

Treatment	Abohar				Faridkot				Pooled				
	60% ETc	80% ETc	100% ETc	Mean	60% ETc	80% ETc	100% ETc	Mean	60% ETc	80% ETc	100% ETc	Mean	
Grain yield (kg ha ⁻¹)													
60% RDN	4027	4088	4316	4144	5253	6167	6297	5907	4640	5128	5307	5025	
80% RDN	4173	4316	4407	4299	5460	6243	6340	6014	4817	5280	5374	5157	
Mean	4100	4202	4362		5357	6205	6319		4728	5204	5340		
Surface flood (Control)													
	Abohar				Faridkot				Pooled				
	3644				5880				4762				
LSD (p=0.05)													
Irrigation					NS				534				282
Fertigation					NS				NS				NS
Irrigation X Fertigation					NS				NS				NS
Irrigation X Fertigation v/s Control					284				577				305

flood irrigation in improving nutrient use efficiency, consistent with findings by Bharat et al. (2015) and Singh et al (2018). The 60% RDN fertigation level under SDI demonstrated significantly higher NUE than the control, further supported by pooled data analysis. This suggests that lower nitrogen application rates can lead to improved NUE, as also reported by Jayakumar et al (2015).

Apparent water productivity (AWP): AWP, representing grain yield per unit of irrigation water applied, was significantly influenced by irrigation levels (Table 6). At both locations, the highest AWP was achieved with 60% ETc SDI (2.68 and 3.35 kg/m³ in Abohar and Faridkot, respectively), followed by 80 and 100% ETc. In Abohar, 60% ETc was significantly superior to the other SDI levels, while in Faridkot,

60 and 80% ETc were statistically similar but higher than 100% ETc. Pooled analysis confirmed these trends, with the highest AWP at 60% ETc and the lowest at 100% ETc. Fertigation levels did not significantly affect AWP, nor did the interaction between irrigation and fertigation. However, all SDI treatments significantly outperformed flood irrigation, which had the lowest AWP at both locations (0.81 kg/m³ in Abohar and 1.96 kg/m³ in Faridkot). Although non-significant, 80% RDN fertigation tended to produce higher AWP than 60% RDN, suggesting a potential benefit of slightly higher nitrogen application.

The superior AWP at 60% ETc, despite lower yield, highlights the efficient water use under deficit irrigation. In contrast, flood irrigation's high water application did not

Table 5. Influence of different levels of fertigation and irrigation on nitrogen use efficiency (NUE) of SSDI wheat

Treatment	Abohar				Faridkot				Pooled			
	60% ETc	80% ETc	100% ETc	Mean	60% ETc	80% ETc	100% ETc	Mean	60% ETc	80% ETc	100% ETc	Mean
Nitrogen use efficiency (NUE)												
60% RDN	53.1	53.9	56.9	54.6	84.6	99.3	101.4	95.1	68.9	76.6	79.2	74.9
80% RDN	41.2	42.6	43.6	42.5	65.9	75.4	76.6	72.6	53.6	59.0	60.1	57.6
Mean	47.2	48.3	50.3		75.3	87.4	89.0		61.2	67.8	69.9	
	Abohar				Faridkot				Pooled			
Surface flood (Control)	26.8				56.8				42.8			
LSD (p=0.05)												
Irrigation				NS				6.8				3.5
Fertigation				2.4				5.6				2.8
Irrigation X Fertigation				NS				NS				NS
Irrigation X Fertigation v/s Control				284				7.4				3.8

Table 6. Influence of different levels of fertigation and irrigation on apparent water productivity (kg m⁻³) of SSDI wheat

Treatment	Abohar				Faridkot				Pooled			
	60% ETc	80% ETc	100% ETc	Mean	60% ETc	80% ETc	100% ETc	Mean	60% ETc	80% ETc	100% ETc	Mean
Apparent water productivity												
60% RDN	2.64	2.29	2.11	2.34	3.29	3.28	2.91	3.16	2.96	2.78	2.51	2.75
80% RDN	2.73	2.42	2.15	2.43	3.42	3.32	2.93	3.22	3.08	2.87	2.54	2.83
Mean	2.68	2.35	2.13		3.35	3.30	2.92		3.02	2.83	2.53	
	Abohar				Faridkot				Pooled			
Surface flood (Control)	0.81				1.96				1.39			
LSD (p=0.05)												
Irrigation				0.13				0.29				0.15
Fertigation				NS				NS				NS
Irrigation X Fertigation				NS				NS				NS
Irrigation X Fertigation v/s Control				0.15				0.32				0.16

translate into a proportional yield increase, resulting in the lowest AWP. This underscores the inefficiency of flood irrigation in terms of water use. Sinha et al (2017) reported the highest AWP at 100% RDN. This discrepancy may be attributed to differences in experimental conditions, crop responses, or the specific metrics used to evaluate AWP. In their study, the higher AWP at 100% RDN was likely influenced by the increased yield, as water application remained constant across fertigation levels. However, other factors, such as crop water use efficiency and nutrient uptake, might have also played a role in determining AWP.

The study demonstrates the potential of SDI to improve wheat yield, NUE, and AWP compared to conventional flood irrigation in Punjab. The 80% ETc irrigation level, coupled with 60% RDN fertigation, appears to be a promising strategy for optimizing water and nitrogen use efficiency while maintaining satisfactory yields. Further research is warranted to refine SDI management practices and explore its applicability in diverse agro-climatic conditions.

CONCLUSIONS

The 100% ETc resulted in the highest grain yield and was statistically comparable to 80% ETc. Both of these SDI irrigation levels outperformed surface flood irrigation and the 60% ETc SDI treatment. Although fertigation levels did not significantly affect grain yield under SDI, both 60 and 80% RDN applied through SDI resulted in improved grain yield and NUE compared to the 100% RDN applied via surface flood irrigation. Apparent water productivity (AWP) was significantly higher at 60% ETc in both Abohar and Faridkot, although it was comparable to 80% ETc in Faridkot. SDI achieved substantial water savings. Surface flood irrigation exhibited the lowest AWP. On the basis of this study recommended irrigating wheat with 80% ETc and applying 60% RDN through subsurface drip irrigation. This offers a promising strategy to enhance grain yield, AWP, and NUE, contributing to sustainable water and nutrient management practices in wheat production.

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