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Enhancing crop and water productivity of *Bt* cotton (*Gossypium hirsutum*) through drip irrigation and fertigation in semi-arid environments of south-western Punjab

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ABSTRACT

The experiment was conducted during 2019 and 2020 at Regional Research Station (Punjab Agricultural University, Ludhiana, Punjab), Faridkot, Punjab to evaluate the impact of different drip irrigation and fertigation regimes on *Bt* cotton (*Gossypium hirsutum* L.) (cv. RCH 773 BGII). The experiment was conducted in a randomized complete block design (RCBD) comprised of 3 drip irrigation levels (60%, 80%, and 100% of ETc); 2 fertigation doses (75% and 100% of recommended nitrogen dose), along with two extra control treatments (surface flood irrigation with 105 kg N/ha and subsurface flood irrigation with 112.5 kg N/ha). Results revealed that surface drip irrigation significantly reduced water usage by 13.9–32.3% as compared to conventional surface flood irrigation, while seed cotton yield increased by 18.2–25.2%. Notably, subsurface drip fertigation (SSDF) (100% recommended level of nitrogen applied at 80% ETc) exhibited the potential to conserve about 8.9–25.7% of total water applied, besides boosting crop yield by 37.2%. In conclusion, this study elucidated better crop and water productivity with subsurface drip followed by surface drip irrigation as compared to traditional surface flood irrigation and manual fertilizer application. Therefore, adoption of drip irrigation systems for water and nitrogen application needs to be advocated for sustainable cotton cultivation.

Keywords: *Bt* cotton, Drip irrigation, Fertigation, Seed cotton yield, Water productivity

Cotton (*Gossypium hirsutum* L.) is a vital cash crop with a global presence, cultivated in over 77 countries. Among these, India, China, and the United States stand out as the top cotton-producing nations (AICRP 2021–22). In south-western region of Indian Punjab, cotton is second major crop of the *kharif* (summer) season, following rice. During 2021–22, area under cotton cultivation in Punjab was 2.48 lakh hectares which produced 10.14 lakh bales with 694 kg lint/ha average yield (Anonymous 2021–22). Cotton production in India has recorded a decrease of 5.22%, compared to last year (ICAC 2021–22) due to unfavourable edapho-hydro-climatic conditions, and heavy attack of insect-pests and diseases (Kaur *et al*. 2022).

Water is precious natural resource but, its availability is gradually decreasing in north-western India at a worrying rate of 0.4–0.9 m/annum (Brar *et al.* 2012). For optimal plant growth and productivity, a cotton crop requires 400–800 mm water during its long-life cycle which is supplied either through rainfall or irrigation (Singh *et al.* 2023). However, the quantity, timing and method of irrigation play significant role in crop growth and development. The conventional irrigation and fertilizer application methods in cotton lead to considerable loss of water and nutrients resulting in lower productivity (Singh *et al.* 2023). Shortage of quality irrigation water and faulty irrigation scheduling with brackish water contribute to lower cotton productivity (Singh *et al.* 2020). So, the effective way to save shrinking water resources is to use resource conservation methods like a drip irrigation as it provides precise site-specific moisture and nutrients to the root zone of the crop (Singh *et al.* 2018, 2020 and Sujatha *et al.* 2023). It also eliminates runoff, deep percolation, evaporation, and minimizes weed growth (Kaur and Brar 2016), and helps to achieve higher crop and water productivities (Singh *et al.* 2022). Hence, the present study aimed to evaluate the impact of water and nitrogen schedule for higher crop and water productivity of cotton.

MATERIALS AND METHODS

Study area weather and climatic details: The experiment was conducted during 2019 and 2020 at Regional Research Station (Punjab Agricultural University, Ludhiana, Punjab), Faridkot (longitude 74°44’E, latitude 30°40’N and altitude

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of 200 m amsl), Punjab. The daily meteorological data were recorded at meteorological observatory located near the experimental site at Regional Research Station, Faridkot, Punjab. During both crop seasons, mean monthly maximum temperature lied between 25.2–40.5°C and 25.8–38.0°C during 2019 and 2020, respectively. Likewise, range of minimum temperature during 2019 and 2020 was 12.1–27.5°C and 8.6–27.2°C, respectively. During 2019 and 2020, the morning time relative humidity was 56–90% and 59–89%, while in the afternoon it was 28–63% and 27–67%. The total rainfall during the crop season was 358.3 mm (during 2019) and 561.0 mm (during 2020). The annual normal rainfall of Faridkot, Punjab is about 420 mm, more than 70% of which is met with south-west monsoon (June–September) months (Mishra *et al.* 2021)

Soil type, crop management and treatment: The experimental site had sandy loam soil texture which contained 76.2% sand, 14.0% silt and 9.8% clay and have organic carbon of (0.31–0.61%), available nitrogen (125.44–263.40 kg/ha), phosphorus (20.83–38.10 kg/ha), potassium (73.92–230.72 kg/ha), iron (8.7–9.55 ppm), manganese (13.48–14.38 ppm), zinc (2.78–2.89 ppm), copper (0.12–0.15 ppm), bulk density (1.53–1.68 g/cm³), cation exchange capacity (8.04–8.44 Cmol/kg) and field capacity (20–23 cm/cm³). The cotton genotypes (RCH773) selected in this investigation was sown with 67.5 cm apart in rows and plant spacing of 75 cm at depth of 4–5 cm by manual dibbling of 2–3 seeds/hill. Experiment was conducted in randomized complete block design (RCBD) comprised of 3 irrigation regimes i.e. 60% ETc (I_1), 80% ETc (I_2) and 100% ETc (I_3) and drip fertigation of two N doses i.e. 75% of RDN (F_1), 100% RDN of drip fertigation (F_2) i.e. (RDN for drip as 112.5 kg N/ha) along with two control treatments [Control 1: Surface flood irrigation with 100% RDN i.e. 105 kg N/ha (C_1); Control 2: Surface flood irrigation with 100% RDN i.e. 112.5 kg N/ha (C_1)], replicated thrice. In drip treatments, irrigation was provided initially at 30 DAS and further at 7 days interval. Amount of irrigation water was applied equal to crop evapo-transpiration and fertigation of N has been provided as per treatment. The first irrigation to control plots was applied at 35 days after sowing and thereafter irrigation was applied at 2–3 weeks interval up to end of September and N was delivered in two splits, viz. 50% of N (urea) at 3 days after first post-sowing irrigation and remaining 50 % was supplied at full bloom stage. Phosphorus was applied @30 kg/ha as a basal dose to all treatments.

Soil moisture and water balance calculation: To compute various indices soil profile moisture was measured up to four depths (0–10, 10–20, 20–30, and 30–40 cm) with the help of a soil moisture meter before and after each irrigation and also at 7–10 days' interval for non-irrigation days.

Estimation of amount of irrigation water: Drip irrigation was provided to each treatment plot through inbuilt drippers placed at 67.5 cm apart having discharge rate of 2.2 litre/h. A water meter was installed on PVC pipe to record amount of water delivered for drip irrigation plots as well as control. Gross amount of water applied for irrigation during cotton growth period has been worked out by accumulating total volume of water delivered during every irrigation (Singh *et al.* 2022). However, for surface flood treatment, crop evapo-transpiration was calculated by using soil water balance equation described by Dar *et al.* (2017), Singh *et al.* (2023). Irrigation was given based on crop evapotranspiration (ETc) to each treatment. Daily ETc was calculated with the help of FAO CropWat8.0 Software. In order to estimate daily ETc values, the reference evapotranspiration (ETo) was multiplied with the corresponding value of the crop coefficient (Kc). The crop coefficient value varied for different months, viz. 0.75 for May–June; 1.15 for July–August and 0.70 for September onwards (Singh *et al.* 2019).

Efficiency indices: Apparent water productivity, bio-physical water productivity and crop water use efficiency (WUE) were computed using formula described by Brar *et al.* (2012). However, the nitrogen use efficiency (NUE) has been worked out by dividing the seed cotton yield with dose of nitrogen applied (Singh *et al.* 2023b).

Statistical analysis: Analysis of variance (ANOVA) was performed using CPCS1 Software to evaluate the effect of drip irrigation and fertigation schedules ongrowth, yield and water productivity of cotton. Comparison of difference between the means was studied using critical difference at P=0.05. Since similar trends in results were recorded during both the years, the data was pooled to increase the precision for the treatments.

RESULTS AND DISCUSSION

Growth parameters of cotton: Pooled analysis revealed that the plant population in different treatments non-significantly varied between 18042–18947 plants/ha (Table 1). Crop supplied with 100% ETc and 100% RDN (I_3F_2) exhibited taller plants (168.6 cm) while, the lowest plant height (133.0 cm) was recorded under 60% ETc with 75% RDN due to limited water and fertilizer availability. However, among the controls, surface drip (C_2) with 164.5 cm plant height performed better than 147.8 cm under surface flood (C_1). The results indicated that increased water and fertilizers improved plant height. The subsurface drip system was better than the surface drip and conventional methods. Anusree *et al.* (2020) also reported increased plant height in cotton with higher fertigation levels. Highest monopods/plant (2.1) and sympods/plant (27.4) were observed at 100% ETc along 100% RDN. Similar results were reported by Singh *et al.* (2018), where in significantly higher monopods and sympods were observed at 100% ETc as compared to 80% ETc and 60% ETc. The leaf area index under different treatments ranged from 3.29–3.62.

Effect of irrigation and fertigation regimes on yield and quality attributes of cotton: Results showed significant effect of different treatments on cotton yield and quality parameters (Table 2). A fertigation of 100% RDN with 100% ETc produced maximum bolls/plant (72.7). However, irrigation regime of 60% ETc with 75 and 100% RDN significantly lowered bolls/plant to be 47.3 and 50.3,

Table 1 Effect of irrigation and fertigation regimes on growth parameters of cotton

Treatment	Plant stand/ha	Plant height (cm)	Monopods/plant	Sympods/plant	Leaf area index
C_1	18327	147.8	1.3	19.6	3.33
C_2	18947	164.5	1.7	26.2	3.43
I_1F_1	18660	133.0	1.0	16.2	3.22
I_1F_2	18042	139.4	1.4	20.0	3.29
I_2F_1	18289	157.8	1.6	23.8	3.42
I_2F_2	18136	163.1	1.3	23.3	3.46
I_3F_1	18383	163.6	1.8	25.9	3.58
I_3F_2	18580	168.6	2.1	27.4	3.62
CD (P=0.05)	NS	11.9	0.2	2.80	0.24

C_1, Surface flood irrigation with 100% recommended dose of nitrogen (RDN); C_2, Surface drip irrigation with 100% RDN; I_1F_1, Irrigation at 60% crop evapotranspiration (ETc) with fertigation of 75% RDN; I_1F_2, Irrigation at 60% ETc with fertigation of 100% RDN; I_2F_1, Irrigation at 80% ETc with fertigation of 75% RDN; I_2F_2, Irrigation at 80% ETc with fertigation of 100% RDN; I_3F_1, Irrigation at 100% ETc with fertigation of 75% RDN; I_3F_2, Irrigation at 100% ETc with fertigation of 100% RDN.

Table 2 Effect of irrigation and fertigation regimes on yield and quality parameters of cotton

Treatment	Boll weight (g)	Bolls/plant	Biomass (kg/ha)	SCY (kg/ha)	GOT (%)	Halo length (mm)
C_1	3.77	52.0	1708	2558	31.9	25.5
C_2	4.06	65.5	2037	3114	33.0	26.3
I_1F_1	3.37	47.3	1490	2257	32.6	24.3
I_1F_2	3.47	50.3	1710	2473	32.9	24.8
I_2F_1	3.95	62.5	2087	2995	33.2	26.5
I_2F_2	4.09	69.4	2184	3411	33.5	26.4
I_3F_1	4.13	69.9	2346	3147	32.3	26.4
I_3F_2	4.10	72.7	2410	3387	33.0	26.3
CD (P=0.05)	0.21	5.2	41.6	333	1.05	2.80

C_1, Surface flood irrigation with 100% recommended dose of nitrogen (RDN); C_1, Surface drip irrigation with 100% RDN; I_1F_1, Irrigation at 60% crop evapotranspiration (ETc) with fertigation of 75% RDN; I_1F_2, Irrigation at 60% ETc with fertigation of 100% RDN; I_2F_1, Irrigation at 80% ETc with fertigation of 75% RDN; I_2F_2, Irrigation at 80% ETc with fertigation of 100% RDN; I_3F_1, Irrigation at 100% ETc with fertigation of 75% RDN; I_3F_2, Irrigation at 100% ETc with fertigation of 100% RDN. SCY, Seed cotton yield; GOT, Ginning out turn.

respectively. Likewise, Sampathkumar *et al.* (2012) also observed that under water stressed treatments, abscisic acid production increased in leaves which acted as a growth inhibitor that subsequently affected the floral production and boll formation. Gladston *et al.* (2016) also reported higher bolls/plant with irrigation given at 80% ETc along with recommended dose of fertilizer than at 60% ETc. However, boll weight continued to shrink with any of the deficit irrigation and irrigation at 100% ETc recorded the highest (4.13 g). A combination of 80% ETc and 100% RDN resulted maximum yield (3411 kg/ha) and it was at par with I_3F_1 (3147 kg/ha) and I_3F_2 (3387 kg/ha). Treatment C_2 (surface drip) recorded higher yield (3114 kg/ha) as compared to C_1 (surface flood) having a SCY of 2558 kg/ha. Decreased SCY by 3.3% and 11.8%, respectively has been recorded from 60% ETc with 100 and 75% RDN than surface flood (2558 kg/ha) (Table 2). Singh *et al.* (2018) also recorded higher yield under drip irrigation at 80% ETc and highest decline in seed cotton yield was found under 60% ETc. Likewise, biomass accumulation was also highest (2410 kg/ha) under 100% ETc combined with 100% RDN and least (1490 kg/ha) under combination of 60% ETc with 75% RDN relatively because of lesser availability of water and fertilizers. Bhalerao *et al.* (2011) also reported that fertigation in various splits helped to attain more dry matter. However, among the controls, surface drip was able to produce more biomass (2037 kg/ha) as compared to surface flood (1708 kg/ha). This might be owing to the fact that drip fertigation enabled the crop for effective uptake of water as well as nutrients resulting into superior canopy, leaf expansion and more dry matter accumulation.

Ginning out turn (GOT) represents the amount of lint present in the seed cotton. Data pertaining to GOT revealed that fertigation of 100% RDN with 80% ETc depicted highest value (33.5%). Among control treatments, surface drip exhibited better GOT (33.0%) than surface

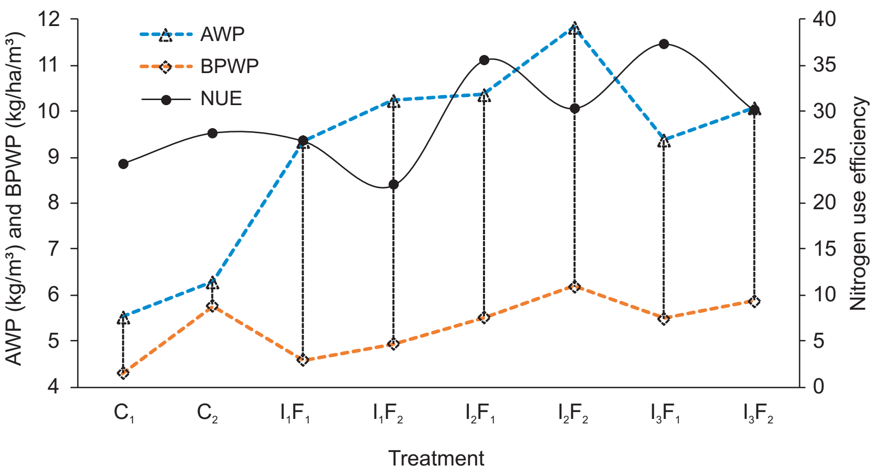

Fig. 1 Effect of irrigation and fertigation regimes on apparent water productivity (AWP), bio-physical water productivity (BPWP) and nitrogen use efficiency (NUE). C_1, Surface flood irrigation with 100% recommended dose of nitrogen (RDN); C_2, Surface drip irrigation with 100% RDN; I_1F_1, Irrigation at 60% crop evapotranspiration (ETc) with fertigation of 75% RDN; I_1F_2, Irrigation at 60% ETc with fertigation of 100% RDN; I_2F_1, Irrigation at 80% ETc with fertigation of 75% RDN; I_2F_2, Irrigation at 80% ETc with fertigation of 100% RDN; I_3F_1, Irrigation at 100% ETc with fertigation of 75% RDN; I_3F_2, Irrigation at 100% ETc with fertigation of 100% RDN.

flood (31.9%) (Table 2). Sahito *et al.* (2015) also found improved GOT (33.86%), when 6 irrigations were given at 21 days interval followed by 5 irrigations at 28 days interval (32.69%), and 4 irrigations at 35 days interval (31.28%). Likewise, the halo length was also significantly affected by different treatments. It was highest under I_2F_1 (26.5 mm) and lowest under I_1F_1 (24.3 mm) in accordance with Magare *et al.* (2018) who observed halo length of 26.40 mm under drip fertigation treatments as compared to soil application of nutrients through conventional method (27.08 mm).

Water productivity functions and nitrogen use efficiency: Among the subsurface fertigation regimes, the bio-physical water productivity (BPWP) was better (6.19 kg/m^3) under 80% ETc with 100% RDN (I_2F_2) leading to higher crop yield (3411 kg/ha) than remaining treatments. Contrarily, reduced irrigation and fertilizer delivery (I_1F_1) not only resulted minimum bio-physical water productivity (BPWP) (4.58 kg/m^3) but also produced lowest yield (2557 kg/ha). Surface drip recorded more BPWP (5.76 kg/m^3) compared to surface flood (4.29 kg/m^3) (Fig. 1). Thus, these results confirmed that the drip fertigation has been a better option than surface flood. Overall, results revealed that crop WUE was heavily affected by method of application of water and fertilizers. Nalque *et al.* (2007) also reported a WUE of 1.606 kg/ha under rainfed and 2.092 kg/ha under well irrigated conditions. The apparent water use efficiency (AWUE) of 11.82 kg/ha/m^3 remained higher at 80% ETc with 100% RDN but, was reduced to 9.35 kg/ha/m^3 under I_1F_1 (75% RDN with 60% ETc). Surface flood (C_1) recorded lowest AWUE 5.52 kg/ha/m^3. Singh *et al.* (2018) also reported higher AWUE (9.554 kg/ha/m^3) under 60% ETc in south-western Punjab. The nitrogen use efficiency was highest (37.33) under 100% ETc combined with 75% RDN while, it was lowest under reduced application of irrigation along with 100% RDN (21.98).

Relationship between total water applied and seed cotton yield: Crop water productivity refers to the total quantity of water used for the crop production. In present study, the subsurface drip fertigation (SSDF) treatment I_2F_2 consumed 522 mm and 763 mm of total water (i.e. irrigation water + effective rainfall) for producing maximum seed cotton yield (i.e. 3430 kg/ha and 3393 kg/ha during 2019 and 2020, respectively). Though, maximum amount of water (i.e. 770 and 886.3 mm during 2019 and 2020 respectively was supplied in surface flood irrigation), but it recorded lower SCY than I_2F_2 during both the years. Because in comparison of the SSDF, surface flood irrigation was associated with high evaporation losses and uneven water supply and caused poor production. These results are in line with Aujla *et al.* (2005) who reported 32% higher SCY through drip irrigation (2144 kg/ha) as compared to 1624 kg/ha under surface flood. A second order polynomial equation $Y = -0.0494 X^2 + 61.60 X - 15592$, $R^2 = 0.81$ (for 2019) and $Y = -0.1136 X^2 + 183.29 X - 70640$, $R^2 = 0.85$ (for 2020) fairly depicted the relationship of amount of total water applied with SCY (Fig. 2). Along with this, the linear regression models $Y = 12.734 X - 3953.1$, $R^2 = 0.82$ (for 2019) and $Y = 9.652 X - 2445.9$, $R^2 = 0.72$ (for 2020) predicted a close relationship between actual crop evapotranspiration and seed cotton yield (Fig. 3). Likewise, Jalota *et al.* (2006)

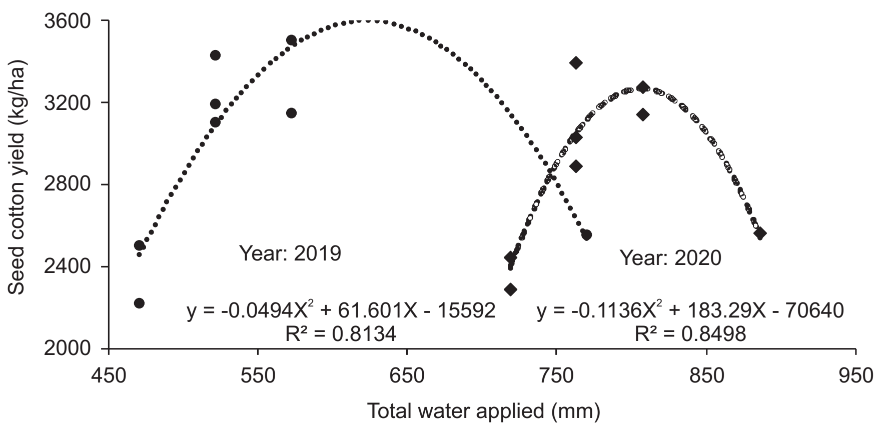

Fig. 2 Relationship between seed cotton yield and total water applied during 2019 and 2020.

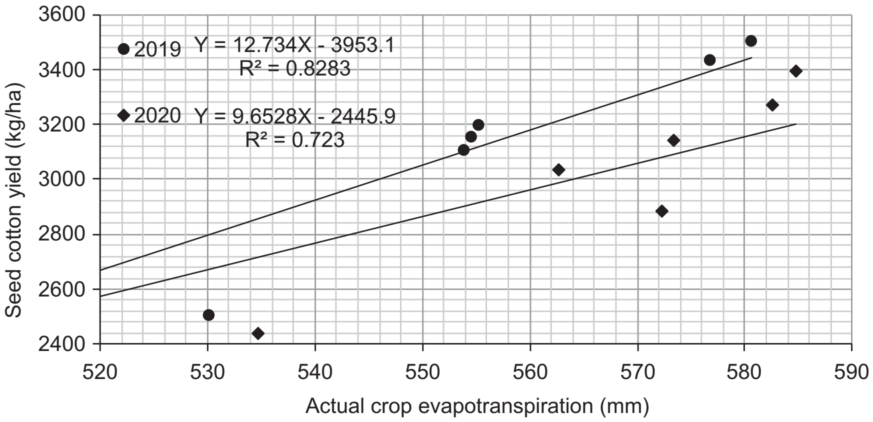

Fig. 3 Relationship between seed cotton yield and actual crop evapotranspiration during 2019 and 2020.

reported strong relationship between ETc and yield of cotton under silt loam, sandy loam and loamy conditions with R^2 values of 0.84, 0.97 and 0.97, respectively.

Cultivation of cotton through conventional method i.e. surface flood irrigation is causing the excessive loss of water and nutrients, pollution of underground water and undesirable vegetative growth. Contrarily, drip fertigation is able to perform better in terms of yield by utilizing lesser amount of water as compared to surface flood. Our findings conclude that sub-surface drip irrigation schedules had exerted significant effect on plant height, biomass accumulation, and most of yield attributing parameters besides a pronounced effect on seed cotton yield. Subsurface fertigation of 100% RDN along with irrigation applied at 80% ETc (I_2F_2) resulted in highest seed cotton yield (3411 kg/ha). Conversely, due to least water and fertilizer input under I_1F_1 (75% RDN with irrigation at 60% ETc), yield was lowered by 11.8% as compared to surface flood (C_1). Owing to high water use efficiency, drip irrigation must be exploited for saving huge quantity of water and fertilizer for cotton cultivation. Thus, for better seed cotton yield, subsurface irrigation at 80% ETc along with 100% RDN (112.5 kg N/ha) in 10 equal splits should be applied at 7 days interval starting from 30–35 days after sowing.

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