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RESEARCH ARTICLE

Drip fertigation improves seed cotton yield, water productivity and profitability of cotton raised under high density planting system in semi-arid environment

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ABSTRACT

The wasteful system of flood irrigation being widely practiced for cotton production in India needs replacement by efficient irrigation systems for conserving water. Cotton productivity can be boosted by optimizing the nutrient and water application through modern resource conservation techniques. Therefore, a field experiment has been conducted during summer (*Kharif*) season of year 2016 and 2017 to investigate consequence of surface drip irrigation along with N fertilization on the growth and seed cotton yield (SCY) under recently introduced high density planting system (HDPS) in India. The experiment having combinations of 3 drip irrigation {60, 80 and 100% of crop evapo-transpiration (ETc)} and 3 N fertigation levels {125 (94 kg N), 100 (75 kg N) and 75% (56 kg N) of recommended N dose (RDN)} along with control (i.e. conventional practice of irrigation through surface flood and soil broadcasting of urea as 100% RDN i.e., 75 kg N ha^{-1}) has been conducted in complete randomized block design replicated thrice. Drip irrigation scheduled at 0.8 ETc recorded 2.5 and 23.2% higher SCY (2509 kg ha^{-1}) than 1.0 ETc and 0.6 ETc, respectively. Among N levels, highest SCY (2452 kg) was observed with 75 kg N application, whereas 56 kg N ha^{-1} recorded least. A combination of drip fertigation at 0.8 ETc and 100% RDN elucidated 11.6, 61.5, 13.9 %, and 42.9 % higher SCY, water use efficiency, nitrogen use efficiency and benefit: cost than control, respectively. Drip fertigation at 1.0 ETc along with 100% RDN improved SCY by 7.3% over control.

Keywords: Fertigation, High density planting system, Nitrogen use efficiency, Seed cotton yield, Water productivity

INTRODUCTION

Though, India has largest cotton acreage (12.6 m ha) and constitutes 37.56 % of area with 24.26 % of world cotton production, but still a productivity rate of 494 kg ha^{-1} against world average of 764 kg ha^{-1} is extremely low (Anonymous 2019-20).Globally, lot of emphasis is sought for saving water and fertilizer by improvement in cultivation practices to sustain crop productivity. Resource conservation strategies like deficit irrigation can improve production levels in water scarce arid regions struggling with declining water availability and thus may contribute significantly in improving crop productivity (Singh et al. 2020). Cotton is a major cash crop in India and has great potential to perform better under limited water resources. Moreover, availability of quality irrigation water is declining at an alarming rate besides contamination of both surface and ground water resources. The impact could be particularly severe in the tropical areas of developing countries including India (Sathaye et al. 2005), where irrigation water is becoming increasingly scarce and expensive and thus it is very important to use it judiciously. To overcome such alarming situations owing to climate change that may arise in the future, farmers must be equipped with economic, effective and sustainable irrigation methods.

In north-western India, farmers are currently depleting ground water at a worrying rate of 0.4-0.9 m $annum^{-1}$ to fulfill the crop needs (Brar et al. 2012). Hence, special attention is sought after for framing techniques to minimize water losses besides improving cotton productivity through economic strategies (Singh et al. 2019). Among various methods of irrigation, drip irrigation has been found

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to be an effective and efficient technology as it retards soil evaporation besides countering weed issues (Kaur and Brar 2016). To avoid water wastage, drip irrigation method has been an effective way of supplying frequent and uniform application of water to cotton (Ibragimov et al. 2007). Fertigation in fact is an accurate delivery of chemical fertilizer through water to fulfill current plant requirements. It might be an encouraging practice for a crop like cotton whereby fertilizer and water losses can be significantly reduced besides higher N efficiency (Singh et al. 2018). Fertigation also facilitates elasticity in nutrient application timing in response to plant demand besides enhanced production and better water use efficiency (Radin et al. 1992).Fertigation, therefore could be of a greater utility in south-western Punjab, which constitutes the arid and semi-arid tracts of north-western India, facing acute shortage of good quality water besides having brackish underground water which is unsuitable for cultivation of crops (Jalota et al. 2008). Therefore, literature fairly elucidates that where quality water is a major constraint for raising crops, fertigation holds a great opportunity as an effective management tool for managing right amount, exact interval, and application of fertilizers and water at desired levels.

Another important agronomic aspect for higher yield is to deal with ideal plant population. Briggs et al. (1967) introduced concept of high density planting system (HDPS) in cotton. In addition to better SCY, other gains include better light interception and early canopy closure under HDPS to smother the weeds and reduce their competitiveness. Plant types tailored to accommodate planting densities varying from 100000-250000 plants ha^{-1} through narrow planting geometry is well adopted in developed nations like China, USA, Australia, Brazil, and Uzbekistan (Venugopalan et al. 2014). However, contrary to cotton grown in HDPS, conventional cotton in India is planted in rows 67.5 to 90 cm wider apart where plant stand rarely exceeds 16500-25000 plants ha^{-1}. Therefore, HDPS in Indian cotton is now sought after as an alternate production system having potential to improve both the productivity and profitability besides significant reduction in human drudgery through induction of machine picking, enhanced use efficiency of inputs and reduce the threats associated with the current cotton production systems (Gutierrez et al. 2015).

Area under drip irrigation is just 5% of the total net irrigated area of nation which is too low for a country like India where 17 percent of the world's population has to depend upon only 4 % of global fresh water available (Saxena et al. 2016; Moin and Kamil 2018). Although, drip fertigation (Wang et al. 2014; Dar et al. 2017; Sahoo et al. 2018; Singh et al. 2018) and HDPS is economically viable and resource conservative (Venugopalan et al. 2014; Desouza et al. 2020), however, at present hardly any documented work is specifically available on fertigation and HDPS of cotton in Indian context.

In present studies, we attempted to study the joint benefits of drip with deficit irrigation and N application through fertigation with an aim to realize possibility of conserving both resources without loss of seed cotton in recently introduced HDPS of cotton. The main objectives are to

(i) Compare growth, yield parameters and seed cotton yield of HDPS cotton raised with deficit and required irrigation through drip under varying levels of N and its comparison with surface flood method (Control)
(ii) Determine the best deficit irrigation and N level combination to achieve higher cotton productivity and
(iii) Calculate water and N use efficiency indices for cotton grown under HDPS with different water and N application rates and their economic evaluation.

MATERIALS AND METHODS

Experimental site description

The experiment has been carried at Regional farm of Punjab Agricultural University, Faridkot, India, during *Kharif* (summer) seasons of year 2016 and 2017. The regional farm is situated at 211 m above MS (mean sea) level, intersected with 30° 40' N latitudes and 74^0 44' E longitudes. Geographically, this agro-climatic zone belongs to Indo-Gangetic alluvial plains which comprise Indian Trans-Gangetic plain. The complete expansion of alluvial plains is constituted from variable monotony of Pleistocene along with recently accumulated deposits alluvium from Indo-Gangetic River, after complete shrouding of old ground surface. This area has been typically characterized to be semi-arid (dry) with mean annum precipitation of 401 mm, majority of whom (70-80 %) is usually received during monsoon rainfall during July up to September.

Weather and climate details

The weather parameters have been recorded at meteorological observatory established at Regional farm about 300 m from the experiment site. The range of mean monthly maximum air temperature, minimum air temperature, maximum and minimum relative humidity during crop seasons varied from 27.7-40.4°C, 9.9-27.6°C, 53-85% and 22-68%, respectively. During 2016 and 2017, total precipitation was 508.5 and 506.1 mm, respectively. A maximum temperature of 39.6ºC has been recorded on June 2016, while May (40.4ºC) remained the hottest during 2017. Thus, weather conditions generally remained similar during both study years (Fig. 1).

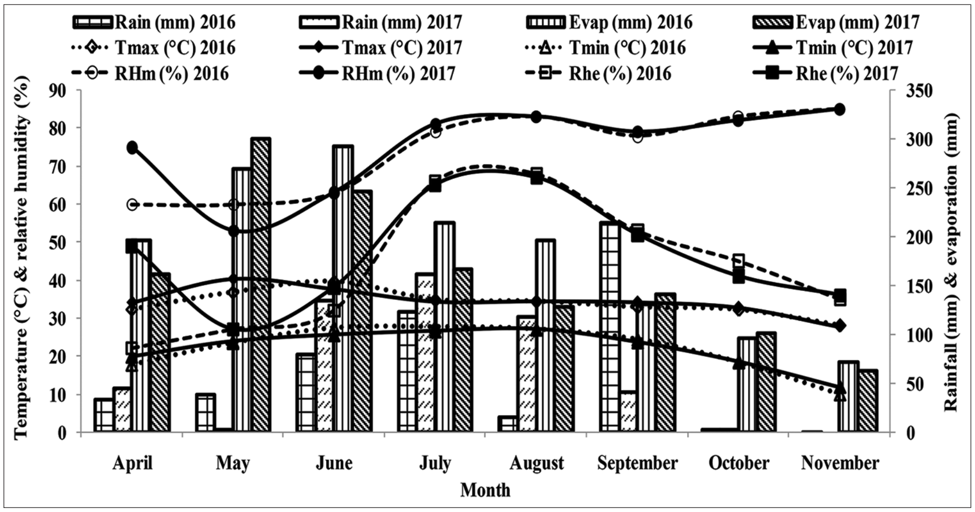

Fig 1. Prevailing weather conditions at the test site during crop growth period.

Soil type, treatments and crop management

The experimental field had a loamy sand texture with slightly alkaline pH (8.4), organic carbon (0.51%), normal electrical conductivity (0.20 ds m^{-1}), medium for available P (20.2 kg ha^{-1}) and high in K (750 kg ha^{-1}). The water table depth is over 21 feet deep and underground water is of brackish quality. The treatments comprised of 3 regimes of drip irrigation {60%, 80% and 100% ETc (crop evapo-transpiration)} and 3 nitrogen fertigation levels (94, 75 and 56 kg of N ha^{-1}) along with one control as surface flood method of irrigation and 75 kg of N ha^{-1} as soil application (100 % recommended N dose for conventional cultivation). The figurative layout plan of the experimental plots exhibiting planting geometry along with drip line placement has been given in Fig. 2. The cotton crop in north India is sown during hot summer month of May after harvesting of wheat crop. Therefore, to assure sufficient soil moisture at planting time, a pre-sowing irrigation of 75 mm had been given to ensure uniform emergence. The first irrigation to control was applied at 35 days after sowing (DAS) and thereafter each irrigation (75±5 mm depth) was applied at 2-3 weeks interval up to end of September. Here, 50 % of N (Urea) was applied 3 days after first post-sowing irrigation and rest 50 % was delivered at full bloom. The irrigation in drip system has been applied at 7 days intervals starting from 35 DAS for requisite duration to supply the calculated amount of water along with required quantity of N which has been fertigated (details in next headings). All plots received the recommended phosphorus (30 kg P_2O_5. ha^{-1}) as a basal dose during field preparation. Two sprays of mepiquat chloride @750 ml ha^{-1} have been given to regulate the crop growth at 60 and 75 DAS.

Quantification of water for different irrigation regimes and computation of water productivity functions

Drip irrigation has been applied at 7 days interval keeping irrigation depth equivalent to total of corresponding seven day crop evapo-transpiration (ETc) as per requirement of treatments. Daily ETc has been calculated by multiplication of daily reference evapo-transpiration (ETc) with respective crop coefficient (K_c) having value of 0.75 for May- June; 1.15 for July-August and 0.70 for September onwards. Daily ETc has been worked out from site specific meteorology data from various weather parameters using ETc calculator available on FAO website. Drip irrigation to each plot has been applied by a lateral PVC pipe fixed within crop rows (67.5 cm apart) through in-built drippers at every 8 inch distance having a discharge @ 2.2 lph (figure 2). Sufficient buffer (2.0 m) has been provided around each treatment plot to reduce any run-off and variability owing to water application. 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. Nitrogen fertigation to various drip irrigated plots initiated at 35 DAS and was accomplished within 110-120 days after sowing in ten uniform splits at 7 days interval as per treatment. In surface flood method of irrigation i.e control, ETc has been calculated from total soil moisture removed from soil profile (0-150 cm) before and after each irrigation by employing following equation of water balance.

$$ETc = (Re + I) - (R + D \pm \Delta S - Fx\ dt \qquad (1)$$

Here, ETc represents crop evapo-transpiration ($mm.day^{-1}$), Re indicates effective rainfall (mm), I indicates irrigation (mm), R is runoff, ΔS is soil moisture change in storage (mm), D is soil water drainage (mm), Fx indicates about vertical flux ($mm.day^{-1}$), and dt represent time interval. The upper flux is considered to be negligible since water table depth of the area was >21ft. Runoff is zero as limited irrigation has been applied and the plots remained bunded (30 cm)

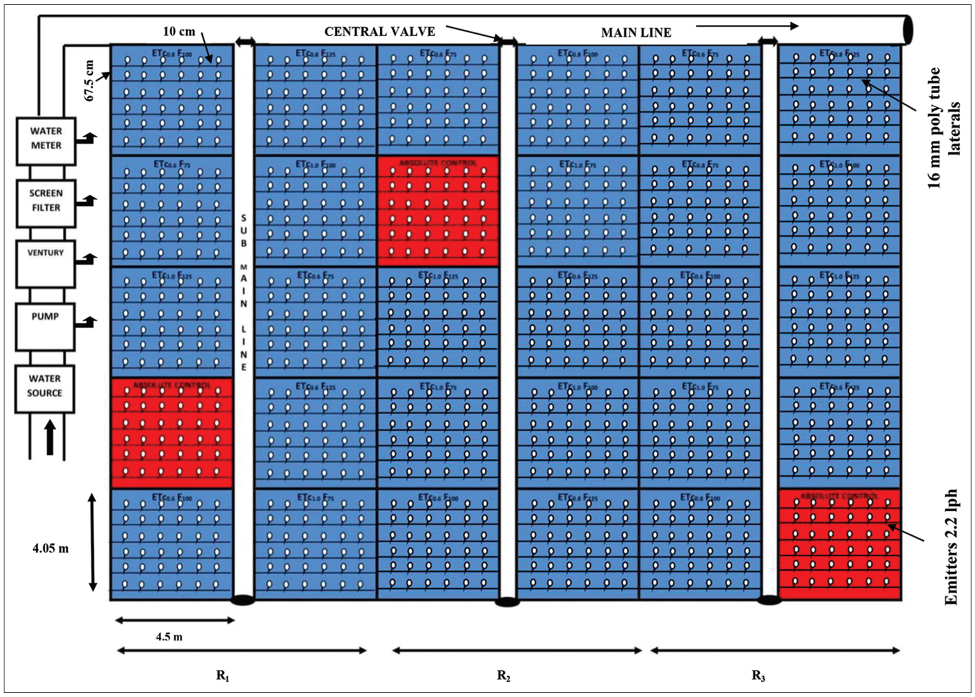

Fig 2. Layout of the experimental plots showing planting geometry (PG) and drip lines placement (for better view it is not to scale). F_{125}, F_{100} and F_{75} indicate a nitrogen level of 94,75 and 56 kg N ha^{-1}, respectively. Note: PG depicted is not to scale so as to provide easy understanding and avoid congestion. Each row had 46 plants instead of only 6 shown here.

along with sufficient buffers. Deep drainage has also been assumed zero as soil profile moisture storage has been lower than field capacity and whenever it surpassed field capacity storage (i.e. after rain or irrigation), it has been worked out to be difference within field capacity and soil moisture storage plus rain/irrigation (Dar et al. 2017). Soil moisture changes (ΔS), through profile (0-150 cm) for particular irrigation intervals were calculated by following formulae;

$$\Delta S = \frac{(M2 - M1) \times d \times d1}{100} \quad (2)$$

Where, M1 and M2 indicated soil moisture (%) measured on dry weight basis before and after irrigation; ρd indicates bulk density in g.cm^{-3}; d1 indicates sampling depth in mm. The dry mass based soil moisture has been calculated using Gravimetric technique up to a soil profile of 150 cm. Apparent water productivity (AWP) has been worked out in respect to irrigation water applied (Brar et al. 2012).

$$AWP(kg\ m^{-3}) = \frac{SCY}{IWA} \quad (3)$$

Where, AWP is apparent water productivity (kg.m^{-3}), SCY is seed cotton yield (kg.ha^{-1}) and IWA is irrigation water applied (m^{3}.ha^{-1})

Bio-physical water productivity (BPWP) and economic water productivity (EWP) have been worked by dividing seed cotton yield and net returns with actual crop evapotranspiration (Perry 2011)

$$BPWP = \frac{SCY}{ETa} \quad (4)$$

$$EWP = \frac{NR}{ETa} \quad (5)$$

Where, BPWP is Bio-physical water productivity (kg m^{-3}), SCY is seed cotton yield (kg.ha^{-1}) and ETa is actual evapo-transpiration (mm), EWP means Economic water productivity (\$ m^{-3}).

Water use efficiency has been worked out by dividing the actual evapo-transpiration with total irrigation water input as reported by Heydari (2014).

$$WUE = \frac{ETa}{I + Re \pm \Delta S} \quad (6)$$

Where, WUE is water use efficiency, ETa is Actual evapo-transpiration (mm), I indicates irrigation (mm), ΔS indicate soil moisture storage changes (mm) and NR is net returns (\$ ha^{-1}).

$$NUE = \frac{SCY}{N\ applied} \quad (7)$$

Where, NUE is nitrogen use efficiency, SCY is seed cotton yield (kg ha^{-1}) and N is nitrogen applied (kg ha^{-1}).

Cultivar and planting details

Recently released American cotton Cv. F2383 (Fig. 3) which is so far sole variety specifically suited for HDPS in north

India developed by Punjab Agricultural University, Regional farm, Faridkot, India has been planted on 30.5.2016 and 5.5.2017 at a planting geometry of 67.5 x 10 cm (1,48,000 plants ha^{-1}).

Growth, yield parameters and seed cotton yield

Final plant height, monopodial (vegetative branches plant^{-1}), sympodial (reproductive branches plant^{-1}) and fully mature open bolls plant^{-1} have been counted from ten plants plot^{-1} selected at random (Singh et al. 2020). Seed cotton yield (SCY) is presented in kg ha^{-1} by cumulating total of both manual pickings done on Oct.12 and Nov.15 during 2016 and Oct.7 and Nov.9 during 2017, respectively from whole plot (Fig.4). During second picking, fifty fully mature open bolls have been hand-picked from each plot to determine boll weight.

Economic analysis

The profitability of HDPS cotton cultivated under drip fertigation has been worked out by economic analysis (Sahoo et al. 2018).

Statistical analysis

Analysis of variance has been carried using SAS software 9.4 (SAS, 2017 Institute, Cary, NC,US) separately for individual seasons/environment and owing to similar trend of results for both study years, data has been pooled by keeping seasons/environment as a main plot factor to enhance the precision for drip irrigation and nitrogen fertigation. Fisher's LSD (p=0.05) has been employed to compare the difference among means.

Fig 3. A field view of the crop during peak bloom stage.

Fig 4. A field view of the crop during boll opening period.

RESULTS

Growth, yield parameters and seed cotton yield under irrigation regimes and N fertigation schedules

Pooled data revealed that growth parameters have been significantly affected by various drip irrigation regimes (Table 1). Cotton irrigated at 1.0ETc exhibited relatively taller plants (107.1cm), while 0.6 ETc recorded least plant height (95.1cm) due to relatively less availability of water for crop growth. Similarly, the higher monopodial (1.18) and sympodial branches (16.0) plant^{-1} have been observed at 100% ETc closely followed by 0.8 ETc (0.93 and 14.8) with the lowest under 0.6 ETc (0.79 and 13.3, respectively). However, plant stand among tested irrigation regimes remained at par. Bolls plant^{-1} and boll weight are most important yield contributing parameters of cotton. An irrigation regime of 0.8 ETc recorded the highest bolls plant^{-1} (17.6), while 0.6 ETc recorded least (13.9). However, boll weight continued to shrink with any of the deficit irrigation and irrigation at 1.0 ETc recorded the highest (2.77g). The seed cotton yield (SCY) was 2448, 2509 and 2035 kg ha^{-1} for an irrigation regime of 1.0, 0.8 and 0.6 ETc, respectively (Table 2).

Nitrogen fertigation exerted significant effect on most of growth parameters (Table 1). Among tested N levels, relatively taller plants (108.0 cm) have been observed under 94 kg N ha^{-1} followed by 75 kg N ha^{-1}, while 56 kg N ha^{-1} recorded least values not only for height (94.3 cm) but also for other attributes like monopodial, sympodial branches and bolls plant^{-1}. Sympodial branches plant^{-1} remained higher with 94 kg N (15.8), though at par with 75 kg N but significantly better than 56 kg N (12.9).Trivial differences for plant stand among tested irrigation and N levels indicated that results for different studies parameters truly represented the treatment effects. Higher bolls plant^{-1} (18.0) and boll weight (2.79 g) have been observed with 94 kg N while 56 kg N recorded least bolls (14.0) and boll weight (2.50 g). Consequently, application of 94 kg N (2415 kg) as well as 75 kg N (2452 kg), while being at par recorded higher SCY than 56 kg N ha^{-1} (Table 2). Seed cotton yield declined significantly, when N has been reduced to 56 kg (2125 kg) in all irrigation regimes, though quantum of reduction from 75 to 94 kg N ha^{-1} was comparatively low.

Table 1: Effect of irrigation regimes and N fertigation schedules on growth parameters of cotton. (Pooled mean of 2 years)

Nitrogen fertigation schedules (FS)	Irrigation regimes (IR)				Control#
	60% ETc	80% ETc	100% ETc	Mean	
		Plant height (cm)			
56 kg N ha^{-1}	90.6^{a}	94.4^{ab}	98.0^{bc}	94.3^{A}	
75 kg N ha^{-1}	95.9 ^{b}	101.5^{c}	108.9^{d}	102.1^{B}	
94 kg N ha^{-1}	98.7^{bc}	111.0^{de}	114.5^{e}	108.0^{C}	113.6^{cd}
Mean	95.1*	102.3$^{\$}$	107.1$^{\wedge}$		
LSD (p=0.05)	IR=4.1; FS=4.1; IR x FS=NS; IR x FS vs Control=5.36				
		Monopods plant^{-1}			
56 kg N ha^{-1}	0.50^{a}	0.72^{ab}	1.05^{c}	0.75A	
75 kg N ha^{-1}	0.91^{bc}	0.97^{c}	1.16^{cd}	1.01B	
94 kg N ha^{-1}	0.97^{c}	1.11^{cd}	1.33^{d}	1.13B	0.77^{b}
Mean	0.79*	0.93*	1.18$^{\$}$		
LSD (p=0.05)	IR=0.18; FS=0.18; IR x FS=NS; IR x FS vs Control=0.22				
		Sympods plant^{-1}			
56 kg N ha^{-1}	11.4^{a}	13.5^{b}	13.9^{bc}	12.9A	
75 kg N ha^{-1}	13.8^{b}	15.3^{c}	17.2^{de}	15.4B	
94 kg N ha^{-1}	14.8^{c}	15.7^{c}	16.8^{d}	15.8B	18.1^{e}
Mean	13.3*	14.8$^{\$}$	16.0$^{\wedge}$		
LSD (p=0.05)	IR=0.7; FS=0.7; IR x FS=NS; IR x FS vs Control=0.93				
		Biomass yield (Mg.ha^{-1})			
56 kg N ha^{-1}	6.62^{a}	8.46^{c}	10.47^{de}	8.51^{A}	
75 kg N ha^{-1}	7.54^{b}	9.96^{d}	11.58^{fg}	9.69^{B}	
94 kg N ha^{-1}	8.13^{bc}	11.07^{ef}	12.17^{g}	10.46^{C}	8.96^{c}
Mean	7.43*	9.83$^{\$}$	11.41$^{\wedge}$		
LSD (p=0.05)	IR=4.5; FS=4.5; IR x FS=NS; IR x FS vs Control=6.5				
		Plant stand ha^{-1}			
56 kg N ha^{-1}	143340^{a}	135582^{a}	132839^{a}	133312^{A}	
75 kg N ha^{-1}	128497^{a}	132291^{a}	131559^{a}	130782^{A}	
94 kg N ha^{-1}	131971^{a}	132108^{a}	135491^{a}	133190^{A}	
Mean	130660*	133327*	133296*		132457^{a}
LSD (p=0.05)	IR=NS; FS=NS; IR x FS=NS; IR x FS vs Control=NS				

Surface flood irrigation and soil application of 75 kg N ha^{-1}; 1 Mg=1000 kg.

- A, B, C. depict the significance between the fertigation schedules.
- Symbols (*,$,^) depict the significance between irrigation regimes.
- a, b, c.depict the significance of interaction between fertigation schedules and irrigation regimes versus absolute control.

Interaction effect of irrigation regimes and N fertigation schedules on seed cotton yield

The interaction effect among schedules of drip irrigation and N fertigation has remained non-significant for yield parameters and SCY. But, a comparison of surface flood (control) under a combination of drip irrigation and various fertigation schedules has been significant. Our findings indicated that each combination of drip irrigation and N fertigation resulted in statistically better or on par SCY than control except for a combination of 56/94 kg N ha^{-1} fertigation with 0.6 ETc (Table 2). Though, when amount of irrigation water through drip has been decreased to 60% for similar N level, then seed cotton (2174 kg ha^{-1}) declined by 8.2% over control. Significant reduction in yield has been observed only at drip irrigation of 0.6 ETc irrespective of N level over that of control, though the quantum of reduction was least at 75 kg N ha^{-1}. However, application of 75 and 94 kg N resulted in 3.6 and 2.0% higher SCY irrespective of drip irrigation levels, over surface flood (control).

Effect of N fertigation and drip irrigation regimes on nitrogen use efficiency, water productivity functions and monetary returns

Nitrogen use efficiency (NUE) is indicative of effective crop management techniques. In present investigation, each increase in applied N has been associated with a corresponding decline in NUE at every level of water application, though the impact has been highest at least level of applied irrigation water (Table 3). In present findings, NUE (4.07) remained higher at lower most level of nitrogen fertigation (56 kg) with 80% ET_C level of drip irrigation. Fertigation of 75 kg N at 0.8 ET_C drip regime recorded significantly better NUE (3.52) than control (3.09). Pooled data further revealed higher NUE (3.46) for 0.8 ET_C though at par with 1.0 ET_C (3.37) but significantly better than 0.6 ET_C (2.80). Highest NUE (3.78) has been observed under 56 kg N followed by 75 kg N (3.27), while 94 kg N ha^{-1} (2.57) recorded significantly least.

Water use efficiency (WUE) remained higher in all drip irrigation regimes over that of control (Table 3). Irrigation

Table 2: Effect of irrigation regimes and N fertigation schedules on yield attributes and seed cotton yield. (Pooled mean of 2 years)

Nitrogen fertigation schedules (FS)	Irrigation regimes (IR)				Control#
	60% ETc	80% ETc	100% ETc	Mean	
		Bolls plant^{-1}			
56 kg N ha^{-1}	12.6^{a}	14.8^{bc}	14.8^{bc}	14.0^{A}	
75 kg N ha^{-1}	13.6^{b}	18.8^{d}	18.3^{d}	17.0^{B}	
94 kg N ha^{-1}	15.6^{c}	19.1^{d}	19.2^{d}	18.0^{B}	18.2^{d}
Mean	13.9*	17.6$^{\$}$	17.4$^{\wedge}$		
LSD (p = 0.05)	IR = 1.0; FS = 1.0; IR x FS = NS; IR x FS vs Control = 1.9				
		Boll weight (g)			
56 kg N ha^{-1}	2.29^{a}	2.58^{b}	2.63^{bc}	2.50^{A}	
75 kg N ha^{-1}	2.59^{b}	2.83^{c}	2.85^{c}	2.76^{B}	
94 kg N ha^{-1}	2.74^{c}	2.80^{c}	2.84^{c}	2.79^{B}	2.72^{bc}
Mean	2.54*	2.74$^{\$}$	2.77$^{\wedge}$		
LSD (p = 0.05)	IR = 0.10; FS = 0.10; IR x FS = NS; IR x FS vs Control = 0.13				
		Seed cotton yield (kg ha^{-1})			
56 kg N ha^{-1}	1831^{a}	2291b^{c}	2253^{bc}	2125^{A}	
75 kg N ha^{-1}	2174^{bc}	2641^{d}	2540^{cd}	2452^{B}	
94 kg N ha^{-1}	2100^{b}	2595^{d}	2550^{cd}	2415^{B}	2367^{c}
Mean	2035*	2509$^{\$}$	2448$^{\wedge}$		
LSD (p = 0.05)	IR = 144; FS = 144; IR x FS = NS; IR x FS vs Control = 198				

Surface flood irrigation and soil application of 75 kg N ha^{-1}.
• A, B, C. depict the significance between the fertigation schedules.
• Symbols (*, $, ^) depict the significance between irrigation regimes.
• a, b, c.depict the significance of interaction between fertigation schedules and irrigation regimes versus absolute control.

Table 3: Effect of irrigation regimes and N fertigation schedules on various efficiency indices of cotton. (Pooled mean of 2 years)

Nitrogen fertigation schedules (FS)	Irrigation regimes (IR)				Control#
	60% ETc	80% ETc	100% ETc	Mean	
		Nitrogen use efficiency (kg SCY kg^{-1} N ha^{-1})			
56 kg N ha^{-1}	3.26^{bc}	4.07^{c}	4.01^{c}	3.78^{B}	
75 kg N ha^{-1}	2.90^{ab}	3.52^{bc}	3.39^{bc}	3.27^{B}	
94 kg N ha^{-1}	2.24^{a}	2.77^{ab}	2.72^{ab}	2.57^{A}	
Mean	2.80*	3.46$^{\$}$	3.37$^{\$}$		3.09^{b}
LSD (p=0.05)	IR=0.21; FS=0.21; IR x FS=NS; IR x FS vs Control=0.83				
		Actual crop evapotranspiration (mm)			
56 kg N ha^{-1}	473.4	504.8	533.5	503.9	
75 kg N ha^{-1}	485.6	528.2	544.2	519.9	
94 kg N ha^{-1}	497.5	532.0	556.7	528.7	
Mean	485.5	521.7	544.8		466.0
		Bio-physical water productivity (kg m^{-3})			
56 kg N ha^{-1}	0.387^{a}	0.453^{bc}	0.422^{ab}	0.420^{A}	
75 kg N ha^{-1}	0.447^{bc}	0.498^{d}	0.466^{c}	0.471^{B}	
94 kg N ha^{-1}	0.422^{ab}	0.487^{cd}	0.458^{bc}	0.456^{B}	
Mean	0.418*	0.479$^{\$}$	0.449$^{\wedge}$		0.508^{c}
LSD (p=0.05)	IR=0.028; FS=0.028; IR x FS=NS; IR x FS vs Control=0.040				
		Apparent water productivity (kg m^{-3})			
56 kg N ha^{-1}	0.882^{c}	0.915^{c}	0.762^{b}	0.853^{A}	
75 kg N ha^{-1}	1.049^{d}	1.053^{d}	0.859^{c}	0.987^{B}	
94 kg N ha^{-1}	1.012^{d}	1.034^{d}	0.860^{c}	0.969^{B}	
Mean	0.981*	1.001*	0.827$^{\$}$		0.357^{a}
LSD (p=0.05)	IR=0.060; FS=0.060; IR x FS=NS; IR x FS vs Control=0.075				
		Water use efficiency (%)			
56 kg N ha^{-1}	77.8	77.9	77.9	77.9	
75 kg N ha^{-1}	79.2	80.6	78.9	79.6	
94 kg N ha^{-1}	80.6	80.4	80.3	80.4	
Mean	79.2	79.6	79.1		49.9

Surface flood irrigation and soil application of 75 kg N ha^{-1}; 1 Mg=1000 kg.
• A, B, C. depict the significance between the fertigation schedules.
• Symbols (*, $, ^) depict the significance between irrigation regimes.
a, b, c.depict the significance of interaction between fertigation schedules and irrigation regimes versus absolute control.

at 0.8ET$_C$ (1.001 kg m^{-3}) exhibited higher apparent water productivity (AWP) while the least has been observed for surface flood (0.357 kg m^{-3}).The values of ETc remained higher for 1.0ET$_C$ (544.8 mm) followed by 0.8 ET$_C$ (521.2 mm) whereas the least has been recorded for 0.6 ET$_C$ (485.5 mm).Similarly, bio-physical water productivity (BPWP), and AWP have been statistically at par within 75 and 94 kg N but significantly better than 56 kg N ha^{-1}. In our study, drainage was 362.1 & 318.2, 361.2 & 307.4 and 349.6 & 296.9 mm lesser under drip irrigation at 0.6, 0.8 and 1.0 ETc than surface flooding during 2016 and 2017, respectively (Table 4). BPWP and AWP indices have been significantly affected with N levels with highest value for 75 kg N application (0.471 & 0.987) followed by 94 kg N application (0.456 & 0.969) while the statistically least (0.420 & 0.853) has been exhibited under 56 kg N ha^{-1}, respectively. During 2016 and 2017, 165% and 113.5% higher irrigation water has been consumed in control over drip at 0.8 ETc owing to over-irrigation under surface flood (Table 4).

Among drip irrigation regimes, higher net returns have been revealed under 0.8 ETc ($1067.9) though at par with 100% ETc, but significantly better than 60% ETc which recorded least. Cotton drip irrigated at 0.8 ETc clearly elucidated its financial advantages by exhibiting higher gross returns (23.2 & 24.3%), net returns (33.5 & 3.5%) and cost: benefit ratio (26.1 & 1.8%) over that of 0.6 and 1.0 ETc, respectively (Table 5). Cultivation cost remained highest ($728.7) for surface flood (control) due to huge consumption of irrigation water (higher by 165% and 113.5% during 2016 and 2017, respectively). Among studied levels of N, cultivation cost has been statistically higher for 94 kg N ($653.9), while 56 kg N incurred the least (Table 5). However, net returns under 75 kg N ($1033.9) remained on par with 94 kg N ($993.1) but significantly higher over 56 kg N ($860.4).

DISCUSSION

Growth, yield parameters and seed cotton yield under irrigation regimes and N fertigation schedules

Pooled data revealed significant influence of studied drip irrigation regimes on various cotton parameters (Table 1). Our findings indicated that treatments receiving more quantity of water had higher vegetative growth as revealed by higher plant height and enhanced monopodial and sympodial branches plant^{-1} under 1.0 ETc followed by 0.8 ETc (0.93 and 14.8) with the least value for 0.6 ETc (0.79 and 13.3, respectively) in line with Rao et al. (2016). Consequently, biomass accumulation remained maximum (11.41 Mg ha^{-1}) at 1.0 ETc in agreement with Shareef et al. (2018a) who reported excessive vegetative growth of cotton with over-irrigation. Drip irrigation at 0.8 ETc elucidated the highest bolls plant^{-1} (17.6), while 0.6 ETc recorded least (13.9) and gets support from Shareef et al. (2018b). However, boll weight was higher under an irrigation level of 1.0 ETc (2.77g) in accordance with Bednarz et al.(2000) and Dai et al. (2015) who could achieve stable SCY across wide range of plant densities by manipulating the boll number and boll weight through favorable changes in dry matter accumulation and partitioning. At par yield, among irrigation regimes of 1.0 ETc and 0.8 ETc clearly established the advantage of deficit irrigation level while significantly least yield under 0.6 ETc revealed that any decrease in water beyond 0.8 ETc could not retain higher productivity (Table 2) possibly owing to the difference in application of requisite irrigation water to crop under different levels of evapo-transpiration. Current findings are supported by Basal et al. (2009) who observed 20-30% lower yield with 50% less water over crop raised with full irrigation. Our results further elucidated an increased yield (7.3%) for drip fertigation combination of 1.0 ETc and

Table 4: Irrigation water input (IWI), changes in soil profile moisture (ΔS), drainage (D) and crop evapotranspiration (ETa) of cotton under different irrigation regimes and N fertigation schedules during 2016 and 2017

Irrigation regimes (IR)	N fertigation schedules (FS)	2016					2017				
		IWI (mm)	Rainfall (mm)	D (mm)	ΔS (mm)	ETa (mm)	IWI (mm)	Rainfall (mm)	D (mm)	ΔS (mm)	ETa (mm)
60% ETc	56 kg N ha^{-1}	198.1	426.5	117.3	20.0	487.3	219.5	459.0	153.4	65.7	459.4
	75 kg N ha^{-1}	198.1	426.5	112.5	14.0	498.1	219.5	459.0	142.8	62.6	473.1
	94 kg N ha^{-1}	198.1	426.5	102.0	12.0	510.6	219.5	459.0	138.6	55.5	484.4
	Mean	198.1	426.5	110.6	15.3	498.7	219.5	459.0	144.9	61.3	472.3
80% ETc	56 kg N ha^{-1}	239.1	426.5	124.1	25.0	516.5	267.7	459.0	162.8	70.8	493.1
	75 kg N ha^{-1}	239.1	426.5	102.2	18.0	545.4	267.7	459.0	153.3	62.4	511.0
	94 kg N ha^{-1}	239.1	426.5	108.3	10.0	547.3	267.7	459.0	150.9	59.2	516.6
	Mean	239.1	426.5	111.5	17.7	536.4	267.7	459.0	155.7	64.1	506.9
100% ETc	56 kg N ha^{-1}	280.1	426.5	130.1	32.0	544.5	315.9	459.0	172.5	79.9	522.5
	75 kg N ha^{-1}	280.1	426.5	123.6	28.0	555.0	315.9	459.0	167.9	73.6	533.4
	94 kg N ha^{-1}	280.1	426.5	115.7	23.0	567.9	315.9	459.0	158.1	71.4	545.4
	Mean	280.1	426.5	123.1	27.7	555.8	315.9	459.0	166.2	75.0	533.7
Control#	RDF 100%	700.0	426.5	472.7	165.0	488.8	625.0	459.0	463.1	177.7	443.2

Surface flood irrigation and soil application of 75 kg N ha^{-1}

Table 5: Effect of irrigation regimes and N fertigation schedules on monetary parameters (Pooled mean of 2 years)

Nitrogen fertigation schedules (FS)	Irrigation regimes (IR)				Control#
	60% ETc	80% ETc	100% ETc	Mean	
	Cost of cultivation ($ ha^{-1})				
56 kg N ha^{-1}	562.1^{a}	604.0^{b}	600.5^{b}	588.8^{A}	
75 kg N ha^{-1}	612.6^{b}	655.0^{cd}	645.9^{c}	637.8^{B}	
94 kg N ha^{-1}	625.3^{bc}	670.3^{d}	666.2^{cd}	653.9^{C}	
Mean	600.0*	643.1$^{\$}$	637.5$^{\$}$		728.7^{e}
LSD (p=0.05)	IR=15.8; FS=13.3;IR x FS vs Control=25.2				
	Gross returns ($ ha^{-1})				
56 kg N ha^{-1}	1248.5^{a}	1562.7^{bc}	1536.5^{b}	1449.2^{A}	
75 kg N ha^{-1}	1482.3^{ab}	1800.8^{c}	1732.2^{bc}	1671.8^{B}	
94 kg N ha^{-1}	1432.4^{ab}	1769.6^{bc}	1739.1^{bc}	1647.0^{B}	
Mean	1387.8*	1711.0$^{\$}$	1669.3$^{\$}$		1614.3^{bc}
LSD (p=0.05)	IR=118.9; FS=99.8; IR x FS vs Control=251.1				
	Net returns ($ ha^{-1})				
56 kg N ha^{-1}	686.4^{a}	958.7^{bc}	936.0^{ab}	860.4^{A}	
75 kg N ha^{-1}	869.6^{ab}	1145.7^{bc}	1086.3^{bc}	1033.9^{B}	
94 kg N ha^{-1}	807.1^{ab}	1099.3^{bc}	1072.9^{bc}	993.1^{B}	
Mean	787.7*	1067.9$^{\$}$	1031.7$^{\$}$		885.6^{ab}
LSD (p=0.05)	IR=103.0; FS=86.6;IR x FS vs Control=271.7				
	Cost : Benefit ratio				
56 kg N ha^{-1}	1.21^{a}	1.56^{abc}	1.55^{abc}	1.44^{A}	
75 kg N ha^{-1}	1.41a^{bc}	1.73^{c}	1.67^{bc}	1.60^{B}	
94 kg N ha^{-1}	1.28^{ab}	1.63^{bc}	1.60^{abc}	1.50^{AB}	
Mean	1.30*	1.64$^{\$}$	1.61$^{\wedge}$		1.21^{a}
LSD (p=0.05)	IR=0.12; FS=0.10; IR x FS vs Control=0.40				
	Economic water productivity ($ m^{-3})				
56 kg N ha^{-1}	0.146^{a}	0.191^{bc}	0.176^{b}	0.171^{A}	
75 kg N ha^{-1}	0.180^{bc}	0.218^{c}	0.200^{c}	0.199^{B}	
94 kg N ha^{-1}	0.163^{a}	0.208^{c}	0.193^{bc}	0.188^{AB}	
Mean	0.163*	0.206$^{\$}$	0.190$^{*\$}$		0.189^{bc}
LSD (p=0.05)	IR= 0.017; FS=0.017; IR x FS vs Control = 0.022				

Surface flood irrigation and soil application of 75 kg N ha^{-1}; 1 US$ = 66 INR.
• A, B, C. depict the significance between the fertigation schedules.
• Symbols (*, $, ^) depict the significance between irrigation regimes.
• a, b, c.depict the significance of interaction between fertigation schedules and irrigation regimes versus absolute control.

100% RDN in comparison to surface flood in line with Aujla et al. (2005) who reported 32% higher SCY for drip irrigated cotton as compared to surface flood. However, reducing it further to 0.8 ETc, increased the SCY by 11.5% in line with Mateos et al. (1991) who explained drip irrigation to be highly beneficial in water scarce areas owing to optimal water availability which resulted in higher dry matter diversion to various yield parameters. Contrarily, reducing water through drip to 0.6 ETc, resulted in 8.8% lesser yield than control. Our findings established the fact that for optimum growth and development, water requirement of cotton is specific and excessive and/or too less water inhibited the plant growth and yield attributes leading to decreased crop productivity. These results also get support from Basal et al. (2009) who reported that when amount of water to be delivered through drip was lowered by 25%, yield decreased by 7.5%, however when amount of water is further reduced by 50%, greater reductions (20-30% lower yield) are evident over crop growing with full irrigation. Highest SCY at drip irrigation regime of 0.8 ETc might be due to efficient utilization of applied water which closely matched the water required and minimized moisture stress as compared to 0.6 ETc, where significant reduction in yield parameters such as boll weight and bolls plant^{-1} due to water stress has been observed (Table 2). Our findings get support of Radin et al. (1992) who reported higher SCY because of enhanced yield attributing parameters in drip irrigation.

Data clearly revealed that SCY improved linearly with each increment in N levels at all intervals of drip irrigation only up to 0.8 ETc but decreased thereafter (Table 2). Fertigation at 75 kg N resulted 15.3% higher SCY than 56 kg N but only 1.5% higher than 94 kg N ha^{-1} (Tekale et al. 2000). Nitrogen fertigation lead to improvement in growth and biomass accumulation as revealed by values of 8.51, 9.69 and 10.46 Mg ha^{-1} for 56, 75 and 94 kg N, respectively, in accordance with Aujla et al. (2005) who reported higher biomass when same amount of water and N has been delivered through drip as compared to surface flood, whereas reducing supply of water by 75% through drip resulted significant reduction. Higher yield under 75 kg N fertigation in present findings has been outcome of optimum and continuous N supply for proper growth and development of cotton plants as is evident from 21.4% higher bolls plant^{-1} and 10.4% higher boll weight as compared to 56 kg N ha^{-1}. In present studies, decreased supply of N below and above 75 kg N ha^{-1} through fertigation reduced yield across all the levels of water. Our findings, therefore, could established 75 N kg ha^{-1} to be an optimum level for HDPS cotton grown under drip fertigation. Furthermore, it is also a well documented fact that that cotton being an indeterminate perennial plant usually exhibits excessive vegetative growth at supra optimal N doses without any yield increments and this could be one of the reasons that SCY failed to improve beyond a level of 75 kg N in conformity with Aujla et al. (2005).

Interaction effect of irrigation regimes and N fertigation schedules on seed cotton yield

Drip irrigation (0.8 ET_C and 1.0 ET_C) along with 75 or 94 kg N produced either at par or significantly better SCY than surface flood irrigation in conformity with Aujla et al. (2005) who reported significant reduction in SCY from 2144 kg ha^{-1} to 1819 kg ha^{-1} (15%) and 1689 kg ha^{-1} (21%), when N has been reduced to 75 and 50% of recommended rates in all watering regimes through drip. Our data could elucidate that water application at 1.0 ETc and 75 kg N applied through drip resulted in 7.3% higher yield as compared to Control. Furthermore, when amount of irrigation water through drip has been decreased to 80% for same N level, seed cotton increased marginally over 1.0 ETc, but still it was 11.5% higher than control in close agreement with Shareef et al. (2018a). Better SCY (2641 kg ha^{-1}) realization under combination of 0.8 ETc and 75 kg N ha^{-1} fertigation could be attributed to frequent and adequate water and nitrogen supply which could ensure better assimilation and translocation of applied fertilizer. In current investigations, when similar amount of water and nitrogen had been delivered through drip, it leads to enhanced SCY by 173 kg ha^{-1} than surface flood (Table 2). Moreover, drip irrigation under 0.8 ETc in combination with 75 kg N ha^{-1}, further improved the SCY by 274 kg ha^{-1} than surface flood (Thind et al. 2008), wherein reduced SCY with lowering of N to 50% as compared to 100% has been observed. Buttar et al. (2006) also supports present findings. Higher SCY under fertigation of 75 and 94 kg N ha^{-1} could be owing to improved uptake of nitrogen and proportion of nutrient directed from fertilizer in comparison to traditional application (Singh et al. 2018). These findings could clearly elucidate the yield benefits of drip over control besides saving of irrigation water. We could observe that the quantum of yield loss was higher at lowest water supply level, which declined with increasing water level.

Effect of N fertigation and drip irrigation regimes on nitrogen use efficiency, water productivity functions and monetary returns

Nitrogen has remained the most limiting element for crop cultivation across world and its efficient usage is indispensable for maintaining sustainability of agriculture. We could report higher NUE (4.07) for lowest N fertigation level (56 kg N ha^{-1}) along with 0.8 ET_C level of drip irrigation. Pooled data in Table 3 further revealed higher NUE (3.46) for 0.8 ET_C though at par with 1.0 ET_C (3.37) but better than 0.6 ET_C which exhibited lowest (2.80). Mohammad (2004) too observed better SCY for fertigated crop owing to improved uptake of N and enhanced NUE in comparison to soil broadcasting of fertilizer. Statistically least NUE (2.80) observed for 0.6 ETc could be because sub-optimal application of irrigation water application. Consequently, cotton remained vulnerable to water stress leading in significant decline of yield attributes like bolls plant^{-1} (13.9) and boll weight (2.54g). Low water availability could not only affect the N uptake drastically but also its utilization contributing towards significant reduction of yield. Highest NUE (3.78) under 56 kg N, while significantly least for 75 kg N ha^{-1} (2.57) is in line with Bharambe et al. (1997), who observed better NUE in low nitrogen fertigation. Improvised distribution of applied N fertilizer along with least leaching beyond root zone and run-off in comparison to surface flood might be a probable reason of better response under 56 kg N ha^{-1}. However, Thind et al. (2008) observed that luxuriant nitrogen applications might shift the equilibrium between vegetative and reproductive phases towards abundant development of canopy, leading to delayed cotton maturity and poor seed cotton as evident from low NUE under 94 kg N ha^{-1} irrespective of irrigation regimes. Lower NUE values with higher level of N application in support with current findings are well documented (Singh et al. 2014).

Water use efficiency has been an indicator of seed cotton yield in response to quantity of water utilized through irrigation and rainfall. Water use efficiency remained higher in all drip irrigation regimes over control (Table 3). Such improvement in WUE of cotton under deficit drip irrigation could be owing to better ground water utilization by pants experiencing soil water deficit. Irrigation at 0.8 ET_C revealed better apparent water productivity (1.001 kg m^{-3}) over surface flood (0.357 kg m^{-3}). Drip application at 0.8 ETc revealed improved NUE, WUE, and AWP because of availability of optimal moisture regimes for improved nutrient uptake, better solar light interception, which has resulted in higher SCY and yield parameters (Shareef et al. 2018a). Higher bio-physical water productivity (BPWP) of 0.498 kg m^{-3} under 0.8 ET_C and 75 kg N ha^{-1} through drip fertigation gets support from Rao et al. (2016) who reported a range of 0.380-0.410 kg m^{-3} for cotton grown with deficit irrigation. Similarly, higher BPWP value for surface flood (0.508 kg m^{-3}) in our case matched closely with Ünlü et al. (2011) who reported a value of 0.590 kg m^{-3} for irrigated cotton. These results elucidate that irrigation of HDPS cotton with drip method at 0.8 ETc level has significant benefits by saving irrigation water without sacrificing cotton yield and better AWP and BPWP values are indicative of advantages of applying deficit irrigation under scenario of scarce water supply.

Higher BPWP and AWP values under 75 and 94 kg N over 56 kg N ha^{-1} might be primarily due to better yield attributes and higher yield realization from crop fertigated with higher N than 56 kg N ha^{-1} because of optimum supply as well as utilization of nitrogen. Better agronomic efficiency of nitrogen under drip over flood method (control), even when same N was applied is well reported (Thind et al. 2008). During 2016 and 2017, 165% and 113.5% higher irrigation water has been consumed in surface flood over drip at 0.8 ETc primarily owing to over irrigation (Table 4). Therefore, drip application at 0.8 ETc could save 409.1 mm of water apart from 11.5% higher seed cotton over control. Our results for WUE are well supported by Tekale et al. (2000) who reported low WUE under decreased N levels in cotton grown on heavy textured soils. Benefits of drip irrigation in terms of better efficiency indices and higher yield in various crops including cotton (Shareef et al. 2018a) and maize (El-Hendawy et al. 2008) also support current findings. Present studies clearly depicted that though at 0.6 ETc level, considerable irrigation water could be saved as compared to 1.0 ETc, but as evident from significant decrease in SCY leading to major loss, such kind of water saving has no monetary benefits (Table 5).

Cost of urea as N fertilizer and more picking charges in lieu of enhanced seed cotton yield in case of 75 and 94 kg N are two prime reasons for relatively higher cultivation cost in comparison to 56 kg N ha^{-1}. Least C: B ratio (1.44) for 56 kg N clearly revealed it to be less remunerative over the 75 kg N ha^{-1}. Overall, combination of 80% ETc and 75 kg N exhibited the highest value of gross returns ($1800.8), net returns ($1145.7), C: B ratio (1.73) and economic water productivity ($0.218 m^{-3}) than control (Table 5). Higher C: B ratio (1.64) clearly substantiated financial superiority of drip irrigated cotton at 0.8 ETc over other irrigation regimes in line with Wang et al. (2014) from northern Xinjiang, China who observed monetary benefits for deficit drip irrigated cotton. Thus, we could establish that applying drip irrigation at 0.8 ET_C has been economically feasible and water efficient schedule over 60% and 100% ETc in line with findings of various workers (Kaur and Brar 2016; Singh et al. 2018; Sahoo et al. 2018), who observed economic benefits of drip fertigation over surface flood. Thus current study envisages that application of fertilizer and water through drip fertigation has been remunerative practice in comparison to surface flood (Singh et al. 2010).

CONCLUSION

Cotton cultivation through surface flood method is leading to loss of limited available water for agriculture besides leaching of nutrients, pollution of underground water and undesirable vegetative growth. Drip fertigation not only utilized low water but also performed better in terms of enhanced yield over surface flood. The differences among applied irrigation water in fact reflect the scope for reduction in deeper percolation while shifting from traditional surface flood towards drip culture under semi-arid environments. Nevertheless, sub-optimal irrigation might reduce yield, the question about identification of an ideal moisture regime emerges out. Our findings could reveal that drip irrigation for cotton planted under HDPS at 0.8 ETc has distinct advantages in saving of precious irrigation water without sacrificing for seed cotton. Thus, drip fertigation at 0.8 ETc along with 75 kg N ha^{-1} RDN has been identified to be profitable, nitrogen and water saving schedule over surface flood for promoting HDPS cultivation of cotton. However, based on monetary evaluation we could interpret that, even if irrigation water is surplus then net profit cannot be maximized by adopting 1.0 ETc level of drip irrigation. While, replenishment at 0.8 ETc has been established as best optimum drip irrigation option under limited water availability over surface flood in semi-arid environments. Hence, present findings clearly endorse suitability of tested technology for HDPS cotton for a sustainable production system. This might lead to a remarkable improvement in Indian cotton area by substituting drip fertigation over existing traditional methods and net returns *per se* are sufficient enough to promote the mass adoption of technology. Therefore, owing to higher use efficiency indices, drip irrigation might be exploited for saving huge quantity of water and fertilizer for cotton cultivation. For 12.6 m ha of Indian cotton acreage, experiencing acute water scarcity, drip coupled with fertigation for HDPS cotton has potential to enhance the cotton productivity leading to improved farmer's profits. The findings of this study could be utilized to conserve water and N resources in similar arid cotton agro-ecosystems across the globe.

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AUTHOR CONTRIBUTIONS

Kulvir Singh; Conceptualization, Methodology, Formal analysis, Writing - Original Draft.
Pankaj Rathore; Writing - Review & Editing and Project administration.
Ajmer Singh Brar; Formal analysis,Writing - Review & Editing.
Sudhir Kumar Mishra; methodology, Software and Formal analysis.

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