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Growth Dynamics and Yield of Cotton-Wheat in Relation to Nutrient Use and Irrigation Regimes under Sub-Surface Drip Irrigation System

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***Abstract*:** The present study was conducted to evaluate growth dynamics and yield of cotton-wheat cropping system under sub-surface drip irrigation at Punjab Agricultural University, Ludhiana during 2019-2020 and 2020-2021. The experiment was conducted with the combination of 3 irrigation regimes (60 80,100% ET_c), 2 fertility levels (80% recommended dose of nitrogen (RDN),100 % RDN) and 3 methods of application of nutrients (M_{foliar} i.e. foliar application of nutrients, M_{soil} i.e. soil application of nutrients). These 12 combinations were compared with further three controls; control1: surface drip + 100% RDN + M_{foliar}; control 2: surface drip + 100% RDN+ M_{soil}; control 3: Flood irrigation + soil RDN + M_{foliar}. The highest growth, seed cotton, grain yieldwere recorded at 100% ET_c which was at par with 80% ET_c but significantly higher than 60% ET_c. Among N levels, 100% RDN remained at par with 80% RDN in both the crops. Further, M_{foliar} resulted in higher growthand yield in cotton over M_{soil}, however, residual effect of M_{soil} was more in wheat. Both The control 1 and 2 were better over control 3, in terms of growthand yield. Therefore, foreseeing the impeding water resources, sub-surface drip at 80% ET_c, 80% RDN and M_{foliar}seems to be a better preposition in terms of water and fertilizer saving than conventional practice of cultivation.

Keywords: ET_c, Foliar feeding, Nutrients, Residual, Water productivity

Irrigation has been a key factor behind intensifying agricultural production to fulfill the world's growing demand for food, fiber and fuel. Under the pressure of increasing population and economic development, the available resources of water are being exploited at a faster rate. Cotton-wheat cropping system is the major cash and grain cropping system occupies an area of about 4.5 M ha in South-Asia and 2.6 M ha in India (Rajpoot et al 2021). Cotton is sown April-May under north Indian conditions when evaporative demand of atmosphere from April to June remains very high due to high temperature & low relative humidity (Rajpoot et al 2021). Early phase of the cotton and later phases of wheat both coincides with high evaporative demand atmosphere. The maintenance of sufficient moisture in soil through irrigation is an essential requirement to ensure rich harvest of any crop. Hence, it becomes important to investigate the different methods of irrigation to emphasize the efficient water resources utilization to attain higher water productivity.

Adoption of micro-irrigation systems like surface and sub-surface drip irrigation over wasteful method i.e. flood irrigation, embark a promising proposition as we look to the future, where water availability would become more scarcer (Singh et al 2021 and Rao et al 2016). These modern strategies, contributes immensely by site-specific water and nutrients utilization through the root zone of the crop plant (Hanson and May 2004). However, in surface drip, removal of laterals during harvesting and sowing of crop, make it labor intensive (Enciso-Medina et al 2011). Therefore, a more efficient form of precision irrigation would be sub-surface drip irrigation (SSDI), which supplies water through buried plastic tubes with embedded emitters spaced at regular intervals in the soil at some depth. In sub-surface drip, soil surface remains dry which minimizes evaporation (Valentin et al 2020), infiltration, weed problem and also it creates no hinderance in sowing and harvesting of crop. Therefore, this system improves labour intensity and increases lifespan of system. Fertigation is necessary for utilizing micro-irrigation to its greatest capacity. In addition to lowering the amount of fertilizer applied, fertigation may prove beneficial for Indian agriculture (Sivanappan and Ranghaswami 2005) and may open the door to the effective use of expensive fertilizers. Therefore, foreseeing the impeding water constraints, cropping systems in water-scarce regions must be redesigned to increase water productivity and growers' profitability.

MATERIAL AND METHODS

The present study was conducted at Punjab Agricultural University, Ludhiana for two consecutive years 2019-2020 and 2020-2021. The experiment was conducted in factorial randomized complete block design with combination of 2

nitrogen fertigation levels (F_{80}: 80% and F_{100}: 100% of recommended dose of nitrogen (RDN), 3 sub-surface drip irrigation levels based on crop evapo-transpiration (ET_c) (I_{60}: 60%; I_{80}: 80% & I_{100}: 100% ET_c) and two methods of nutrient application i.e. M_{foliar} (foliar spray of 2% KNO_3 & 1% $MgSO_4$) and M_{soil} (soil application of KNO_3@ 20 kg ha^{-1} & $MgSO_4$@ 5 kg ha^{-1}. These 12 combinations further compared with three controls i.e. control 1 (surface drip irrigation with 100% RDN and M_{foliar}), control 2 (surface drip with 100% RDN and M_{soil}) and control 3 (flood irrigation with 100% RDN and M_{foliar}). Application of KNO_3 & $MgSO_4$, was done to cotton crop at flower initiation and boll opening stages and its residual effect was observed on succeeding wheat crop. Cotton crop was sown on well-prepared seed bed by keeping row to row spacing of 67.5 cm and plant to plant spacing 75 cm whereas wheat was sown keeping row to row distance of 22.5 cm. Fertilizer and irrigation was applied to both the crops according to treatment. Thinning of the cotton was done on 30 days after sowing to obtain the optimum plant population.

Irrigations on the basis of crop evapo-transpiration were applied through polyethylene drip pipes placed at depth of 20 cm with 30 cm emitter spacing and 67.5 cm between the laterals such that one row of cotton and three rows of wheat at 22.5 cm spacing could be irrigated. Daily reference evapotranspiration (ET_o) was calculated from weather data using ET_o calculator available on the website of the Food and Agriculture Organization. This ET_o, further multiplied with crop coefficient to calculate crop evapotranspiration (ET_c). Fertigation of N in cotton was done @ 112 kg ha^{-1} in 10 splits from 35 days after sowing onwards. Whereas, in wheat, $1/5^{th}$ RDN i.e. 125 kg ha^{-1} was applied at sowing whereas remaining was fertigated in 8 splits starting from crown root initiation. In flood control 3, 50% RDN was applied at sowing, whereas remaining was applied at flower initiation. In wheat, RDN was applied in three splits, first at time of sowing and second & third with first and second irrigation. Data on growth attributes like leaf area index, dry matter accumulation, crop growth rate & relative growth rate and yield were recorded at different stages in both cotton and wheat. Crop growth rate was calculated using formula: $CGR = \frac{W_2 - W_1}{T_2 - T_1} \times \frac{1}{P}$; Where, W_1 = Dry weight (g) at time T_1 (days), W_2 = Dry weights (g) at time T_2 (days), P= Ground area (m^2). Relative growth rate was calculated by formula: $RGR = \frac{\ln W_2 - \ln W_1}{T_2 - T_1}$; W_1 = dry weight at time T_1 (days); W_2 = dry weight at time T_2 (days); ln = Natural log

Statistical analysis: Data recorded were subjected to analysis of variance using Proc GLM procedure of SAS version 9.4.

RESULTS AND DISCUSSION

Periodic leaf area index: Interception of solar radiation, photosynthesis and finally the yield is directly related to leaf area index. Rate of increase in leaf area index was slow up to 45 DAS in both cotton and wheat. Thereafter, a rapid increase was observed and later on, it decreased towards maturity (Tables 1 to 4). Leaf area index (LAI) decreased with increase in moisture stress from I_{100} to I_{60}, at all stages of growth of cotton, except at 45 DAS. The effect of irrigation and fertilization remained non significant at 45 DAS, as the treatments were imposed at 35 DAS in cotton. However, at 90, 135 DAS and maturity, significantly higher LAI (5.62, 7.55 and 3.99) was observed under I_{100} over I_{60}, while I_{80} remained at par with both the levels, during 2019. During 2020, difference due to I_{100} and I_{80} was not significant, but it was significantly lowest at I_{60}, at all stages of growth. In wheat, LAI was not significantly influenced by irrigation regimes as well as fertilization levels (Tables 3 and 4) at 45 and 90 DAS due to sufficient rainfall, leading to non application of irrigation at these stages, during 2019-2020. During 2020-2021, LAI was significantly affected by irrigation regimes at all stages. Higher LAI of 1.26, 4.84 and 3.92 were observed under I_{100}, which was statistically at par with 1.22, 4.79 and 3.82 under I_{80} and both these levels were significantly better than 1.10, 4.57 and 3.68 under I_{60} at 45, 90 and 135 DAS, respectively. The higher LAI might be due to due to better availability of water for longer period (Ihsan et al 2016 and Asif et al 2010).

Graded doses of fertilizer didn't show any pronounced variation in LAI at all stages in both cotton and wheat. However, higher dose of N resulted in more growth components and yield which is in agreement with the findings of Wassie et al (2022). Further, significant difference due to method of application of nutrients at all stages except at 45 DAS in cotton. From 90 DAS upto maturity, significantly more leaf area index was recorded with M_{foliar} over M_{soil}. Increase in LAI due to readily availability of nutrients through foliar application resulted in increase in LAI (Channakeshava et al 2013). Among various controls, control 1 and 2 being at par with each other were significantly superior than control 3 at all stages except at 45 DAS during both the years in cotton and at all stages in wheat, during 2020-2021. Singh et al (2018) also found better crop growth under surface drip over flood irrigation in cotton.

Interaction among different irrigation, fertigation levels and KNO_3 & $MgSO_4$ application methods was non-significant in both cotton and wheat. Comparison of different irrigation with fertigation regimes and controls were also non significant at 45 DAS, however, it became significant afterwards in cotton. However, in wheat, comparison of controls with various combinations of irrigation regimes and fertilization levels were significant at135 DAS, during 2019-2020 and at all stages during 2020-2021.

Table 1. Leaf area index of cotton as affected under irrigation regimes, varied N levels and method of application of KNO_3 & $MgSO_4$ (2019)

Leaf area index DAS**										
	45**					90**				
Irrigation regimes (I)	Fertilization levels				Mean	Fertilization levels				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	2.67	2.66	2.67	2.57	2.64	5.03	4.63	5.12	4.90	4.92
I_{80}=80% ET_c	2.90	2.78	2.63	2.75	2.76	5.60	5.15	5.78	5.22	5.43
I_{100}=100% ET_c	2.62	2.87	2.94	2.80	2.80	5.92	5.27	5.97	5.33	5.62
Mean	2.72		2.74		2.73	5.26		5.38		5.32
	M_{foliar}=2.73; M_{soil}=2.75					M_{foliar}=5.58; M_{soil}=5.07				
	Control 1=2.74; Control 2=2.78; Control 3=2.72				Mean of all controls=2.74	Control 1= 5.56; Control 2=5.42; Control 3=4.67				Mean of all controls=5.21
LSD (p=0.05)	I =NS; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = NS; Among control = NS					I =0.54; F = NS ; M =0.45; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 0.67; Among control = 0.72				
	135**					Maturity**				
Irrigation regimes (I)	Fertilization levels				Mean	Fertilization levels				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	6.93	6.50	6.99	6.77	6.79	3.33	2.93	3.49	3.20	3.23
I_{80}=80% ET_c	7.55	7.04	7.71	7.09	7.34	3.97	3.57	4.18	3.50	3.79
I_{100}=100% ET_c	7.85	7.16	7.93	7.21	7.55	4.34	3.54	4.42	3.66	3.99
Mean	7.17		7.28		7.22	3.61		3.74		3.67
	M_{foliar}=7.50; M_{soil}=6.94					M_{foliar}=3.96; M_{soil}=3.40				
	Control 1=7.51; Control 2=7.33; Control 3=6.57				Mean of all controls=7.13	Control 1=3.92; Control 2=3.75; Control 3=2.97				Mean of all controls=3.54
LSD (p=0.05)	I =0.56; F = NS ; M =0.48; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control =0.61; Among control = 0.65					I =0.58 ; F = NS ; M =0.45; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 0.69; Among control = 0.71				

Table 2. Leaf area index of cotton as affected under irrigation regimes, N levels and method of application of KNO_3 & $MgSO_4$ during 2020

Leaf area index DAS**										
	45**					90**				
Irrigation regimes (I)	Fertilization levels				Mean	Fertilization levels				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	2.23	2.24	2.28	2.22	2.24	4.17	3.70	4.25	4.10	4.05
I_{80}=80% ET_c	2.50	2.38	2.23	2.36	2.36	4.93	4.42	5.04	4.54	4.76
I_{100}=100% ET_c	2.22	2.46	2.53	2.43	2.40	5.25	4.64	5.32	4.79	5.01
Mean	2.33		2.35		2.33	4.52		4.69		4.60
	M_{foliar}=2.33; M_{soil}=2.32					M_{foliar}=4.85; M_{soil}=4.36				
	Control 1=2.33; Control 2=2.38; Control 3=2.32				Mean of all controls=2.34	Control 1= 4.63; Control 2=4.49; Control 3=3.73				Mean of all controls=4.28
LSD (p=0.05)	I =NS; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = NS; Among control = NS					I =0.51; F = NS ; M =0.40; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 0.55; Among control = 0.61				
	135**					Maturity**				
Irrigation regimes (I)	Fertilization levels				Mean	Fertilization levels				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	6.03	5.37	6.12	5.77	5.82	3.23	2.57	3.29	2.67	2.94
I_{80}=80% ET_c	6.80	6.12	6.94	6.25	6.53	3.97	3.39	4.03	3.40	3.67
I_{100}=100% ET_c	7.05	6.39	7.13	6.61	6.79	4.10	3.72	4.23	3.82	3.96
Mean	6.29		6.48		6.38	3.47		3.59		3.52
	M_{foliar}=6.69; M_{soil}=6.07					M_{foliar}=3.84; M_{soil}=3.23				
	Control 1=6.49; Control 2=6.37; Control 3=5.40				Mean of all controls =6.08	Control 1=3.67; Control 2=3.52; Control 3=2.73				Mean of all controls =3.30
LSD (p=0.05)	I =0.61; F = NS ; M =0.49; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control =0.57; Among control = 0.63					I =0.52; F = NS ; M =0.42; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 0.54; Among control = 0.58				

Table 3. Effect of irrigation regimes, fertilizer levels and residual effect of KNO_3 & $MgSO_4$ applied to cotton on periodic leaf area index of wheat (2019-2020)

Leaf area index (DAS**)										
	45**					90*				
Irrigation regimes (I)	Fertilization regimes				Mean	Fertilization regimes				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	Applied to cotton					Applied to cotton				
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	1.27	1.29	1.32	1.36	1.31	4.80	4.82	4.89	5.07	4.89
I_{80}=80% ET_c	1.30	1.33	1.33	1.43	1.34	4.83	4.93	4.97	5.18	4.97
I_{100}=100% ET_c	1.31	1.35	1.40	1.42	1.37	4.87	5.04	5.06	5.09	5.01
Mean	1.30		1.37		1.34	4.89		5.03		4.95
	M_{foliar}=1.32; M_{soil}=1.36					M_{foliar}=4.90; M_{soil}=5.02				
	Control 1=1.35; Control 2=1.37; Control 3=1.31			Mean of all controls=1.34		Control 1= 4.92; Control 2=4.97; Control 3=4.87			Mean of all controls=4.92	
LSD (p=0.05)	I =NS; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = NS; Among control = NS					I =NS ; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS;I*F*M = NS; Treatment v/s control = NS; Among control = NS				

135**					
Irrigation regimes (I)	Fertilization regimes				Mean
	F_{80}		F_{100}		
	Applied to cotton				
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	3.53	3.56	3.57	3.68	3.58
I_{80}=80% ET_c	3.77	3.80	3.83	3.87	3.81
I_{100}=100% ET_c	3.82	3.83	3.91	3.97	3.88
Mean	3.72		3.80		3.76
	M_{foliar}=3.73; M_{soil}=3.78				
	Control 1= 3.77; Control 2= 3.83; Control 3= 3.54			Mean of all controls=3.71	
LSD (p=0.05)	I =0.14 ; F = NS ; M =; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 0.07; Among control = 0.08				

Table 4. Effect of irrigation regimes, fertilizer levels and residual effect of KNO_3 & $MgSO_4$ applied to cotton on periodic leaf area index of wheat (2020-2021)

Leaf area index (DAS**)										
	45**					90**				
Irrigation regimes (I)	Fertilization regimes				Mean	Fertilization regimes				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	Applied to cotton					Applied to cotton				
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	1.05	1.12	1.08	1.15	1.10	4.53	4.57	4.58	4.62	4.57
I_{80}=80% ET_c	1.18	1.22	1.23	1.26	1.22	4.74	4.76	4.81	4.85	4.79
I_{100}=100% ET_c	1.23	1.25	1.27	1.29	1.26	4.79	4.83	4.87	4.89	4.84
Mean	1.17		1.21		1.19	4.70		4.76		4.73
	M_{foliar}=1.17; M_{soil}=1.22					M_{foliar}=4.72 M_{soil}=4.75				
	Control 1=1.21; Control 2=1.26; Control 3=1.11			Mean of all controls=1.19		Control 1= 4.77; Control 2=4.82; Control 3=4.56			Mean of all controls=4.71	
LSD (p=0.05)	I =0.07; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 0.04; Among control = 0.07					I =0.08; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 0.13; Among control = 0.18				

135**					
Irrigation regimes (I)	Fertilization regimes				Mean
	F_{80}		F_{100}		
	Applied to cotton				
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	3.60	3.71	3.64	3.74	3.68
I_{80}=80% ET_c	3.76	3.86	3.79	3.88	3.82
I_{100}=100% ET_c	3.89	3.91	3.93	3.95	3.92
Mean	3.78		3.85		3.80
	M_{foliar}=3.75; M_{soil}=3.84				
	Control 1= 3.84; Control 2= 3.88; Control 3= 3.70			Mean of all controls=3.80	
LSD (p=0.05)	I =0.12 ; F = NS ; M =; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 0.08; Among control = 0.10				

Table 5. Periodic dry matter of cotton as influenced by irrigation regimes, N levels and method of application of KNO_3 & $MgSO_4$ during 2019

Dry matter (g plant^{-1}) DAS**										
	45**					90**				
Irrigation regimes (I)	Fertilization levels				Mean	Fertilization levels				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	85.28	83.14	86.07	83.50	84.49	297.0	290.0	302.0	295.3	296.1
I_{80}=80% ET_c	83.26	85.10	84.79	85.47	84.65	319.0	299.0	323.3	303.3	311.1
I_{100}=100% ET_c	84.19	85.19	86.47	86.27	85.53	329.3	309.3	335.6	315.6	322.5
Mean	84.35		85.43		84.89	307.2		312.5		309.9
	M_{foliar} =85.00; M_{soil} =84.77					M_{foliar} =317.7; M_{soil} =302.1				
	Control 1=84.90; Control 2=83.63; Control 3=83.50 Mean of all controls=84.01					Control 1= 317.6; Control 2=311.0; Control 3=292.0 Mean of all controls=306.8				
LSD (p=0.05)	I =NS; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = NS; Among control = NS					I =15.5; F = NS ; M =11.1; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 16.75; Among control = 18.2				
	135**					Maturity**				
Irrigation regimes (I)	Fertilization levels				Mean	Fertilization levels				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	844.3	818.3	850.3	823.3	834.0	1029	1021	1032	1026	1027
I_{80}=80% ET_c	862.3	833.3	865.0	838.3	850.2	1051	1034	1060	1038	1046
I_{100}=100% ET_c	873.6	846.0	879.0	852.3	862.7	1067	1044	1072	1047	1057
Mean	846.3		851.7		848.9	1041		1046		1043
	M_{foliar} =862.7; M_{soil} =835.2					M_{foliar} =1052; M_{soil} =1035				
	Control 1=853.3; Control 2=844.3; Control 3=820.0 Mean of all controls=839.2					Control 1=1050; Control 2=1044; Control 3=1023 Mean of all controls=1039				
LSD (p=0.05)	I =15.66; F = NS ; M =12.76; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 21.90; Among control = 23.52					I =17.35 ; F = NS ; M =14.16; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 19.31; Among control = 20.98				

Table 6. Periodic dry matter of cotton as influenced by irrigation regimes, N levels and method of application of KNO_3 & $MgSO_4$ during 2020

Dry matter (g plant^{-1}) DAS**										
	45**					90**				
Irrigation regimes (I)	Fertilization levels				Mean	Fertilization levels				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	77.62	75.16	78.40	75.83	76.75	235.0	218.3	242.0	227.0	230.5
I_{80}=80% ET_c	75.27	77.10	77.12	77.47	76.73	269.0	246.6	276.0	251.6	260.3
I_{100}=100% ET_c	76.53	77.54	77.82	78.27	77.53	279.3	257.6	285.6	264.6	271.8
Mean	76.54		77.47		77.00	251.0		257.5		254.2
	M_{foliar} =77.12; M_{soil} =76.89					M_{foliar} =264.1; M_{soil} =244.3				
	Control 1=76.90; Control 2=75.96; Control 3=75.49 Mean of all controls =76.11					Control 1= 257.6; Control 2=249.8; Control 3=228.6 Mean of all controls =245.3				
LSD (p=0.05)	I =NS; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = NS; Among control = NS					I =13.16; F = NS ; M =10.75; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 17.65; Among control = 19.50				
	135**					Maturity**				
Irrigation regimes (I)	Fertilization levels				Mean	Fertilization levels				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	715.0	695.0	721.6	708.3	710.0	910.6	898.3	916.6	903.6	907.3
I_{80}=80% ET_c	762.6	736.6	766.0	742.3	752.1	958.6	931.6	969.0	937.6	949.2
I_{100}=100% ET_c	770.3	748.6	776.6	755.6	763.0	975.3	944.3	982.3	949.0	962.7
Mean	738.0		745.1		741.7	936.5		943.1		939.7
	M_{foliar} =752.0; M_{soil} =731.1					M_{foliar} =952.1; M_{soil} =927.4				
	Control 1=731.0; Control 2=724.3; Control 3=703.3 Mean of all controls =719.5					Control 1=929.0; Control 2=922.6; Control 3=900.0 Mean of all controls =917.2				
LSD (p=0.05)	I =15.72; F = NS ; M =12.83; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control =14.72; Among control = 15.78					I =16.79 ; F = NS ; M =13.71; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 16.04; Among control = 17.58				

Table 7. Effect of irrigation regimes, fertilizer levels and residual effect of KNO_3& $MgSO_4$applied to cotton on periodic dry matter of wheat (2019-2020)

Dry matter (g m^{-2}) DAS**										
	45**					90**				
Irrigation regimes (I)	Fertilization regimes				Mean	Fertilization regimes				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	Applied to cotton					Applied to cotton				
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	167.3	168.3	169.3	172.0	169.2	465.0	466.3	475.0	488.3	473.6
I_{60}=80% ET_c	169.3	171.6	172.0	173.67	171.6	468.3	478.3	479.6	495.6	480.5
I_{60}=100% ET_c	168.6	173.3	173.6	173.0	172.1	472.3	483.3	491.0	493.3	485.0
Mean	172.2		170.7		170.9	472.2		487.1		479.1
	M_{foliar} =170.1; M_{soil} =172.0					M_{foliar} =475.2; M_{soil} =484.2				
	Control 1=168.6; Control 2=170.3; Control 3=168.3 Mean of all controls=169.0					Control 1= 478.3; Control 2=481.6; Control 3=465.6 Mean of all controls=475.2				
LSD (p=0.05)	I =NS; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = NS; Among control = NS					I =NS ; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = NS; Among control = NS				

	135**				
Irrigation regimes (I)	Fertilization regimes				Mean
	F_{80}		F_{100}		
	Applied to cotton				
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	745.0	758.3	763.3	768.3	758.7
I_{60}=80% ET_c	753.3	783.3	775.0	798.3	777.5
I_{60}=100% ET_c	786.6	795.0	802.6	808.3	798.2
Mean	770.2		786.0		778.1
	M_{foliar}=771.0; M_{soil} =785.2				
	Control 1= 780.0; Control 2= 791.6; Control 3= 693.3 Mean of all controls=754.9				
LSD (p=0.05)	I =23.93 ; F = NS ; M =; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 25.0; Among control = 54.61				

Table 8. Effect of irrigation regimes, fertilizer levels and residual effect of KNO_3& $MgSO_4$ applied to cotton on periodic dry matter of wheat (2020-2021)

Dry matter (g m^{-2}) DAS**										
	45**					90**				
Irrigation regimes (I)	Fertilization regimes				Mean	Fertilization regimes				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	Applied to cotton					Applied to cotton				
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	115.0	117.0	118.3	121.3	117.9	420.0	423.3	425.0	434.0	425.5
I_{80}=80% ET_c	135.3	136.0	136.6	138.6	136.4	440.3	443.6	450.0	454.6	447.1
I_{100}=100% ET_c	138.0	139.6	141.6	143.3	140.6	446.0	448.3	458.0	461.3	453.4
Mean	130.0		133.3		131.6	436.9		447.1		442.0
	M_{foliar}=130.6; M_{soil}=132.6					M_{foliar}=439.8; M_{soil}=444.2				
	Control 1=130.6; Control 2=134.6; Control 3=120.0 Mean of all controls=128.4					Control 1= 442.6; Control 2=449.0; Control 3=430.3 Mean of all controls=440.6				
LSD (p=0.05)	I =4.33; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 4.11; Among control = 5.44					I =16.41 ; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 14.3; Among control = 12.2				

	135**				
Irrigation regimes (I)	Fertilization regimes				Mean
	F_{80}		F_{100}		
	Applied to cotton				
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	707.0	710.0	712.3	714.6	711.0
I_{80}=80% ET_c	723.0	727.0	738.0	740.6	732.1
I_{100}=100% ET_c	738.0	740.3	742.3	745.3	741.5
Mean	724.2		732.2		728.2
	M_{foliar}=726.7; M_{soil}=729.6				
	Control 1= 728.0; Control 2= 734.0; Control 3= 709.0 Mean of all controls=723.6				
LSD (p=0.05)	I =11.02 ; F = NS ; M =; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 15.80; Among control = 18.60				

Periodic dry matter accumulation: Dry matter accumulation (DMA) is directly associated with crop yield. DMA rapidly and progressively increased from 45 DAS up to maturity and was significantly affected by different treatments in both the crops. DMA at 45 DAS did not differ significantly due to irrigation regimes as well as fertilization levels during both the years in cotton, as the treatments were imposed at 35 DAS (Table 5 & 6). However, it increased with increase in water regime from I_{60} to I_{100} at 90, 135 DAS and at maturity during both the years. I_{100} combinations exhibited significant increase over I_{60}in cotton. Fertilizer levels didn't cause variation in DMA at all stages during both the years. Among controls, control 1 & 2, produced significantly higher DMA at all stages except 45 DAS, during both the years, over control 3. Further in wheat, effect of various treatments was not significant at 45 and 90 DAS during 2019-2020 (Table 7 & 8). However, DMA significantly increased with increase in irrigation regimes at all the stages during 2020-2021. Reduced water availability, limits the cellular expansion and elongation, causes stomatal closure, raises the leaf temperature and reduces the net assimilation rate of photosynthates which decreased DMA (Ihsan et al 2016).Fertilization levels and method of application of nutrients didn't cause variation in DMA during both the years. Among controls, higher dry matter (accumulated under control 2, was at par with control 1 and significantly better than control 3 at 45, 90 and 135 DAS, during 2020-2021. Higher dry matter accumulation under surface drip irrigated crop might be due to favorable moisture conditions because of light and frequent irrigation applied to the root zone of crop.

Crop growth rate: The higher CGR of cotton between 90-135 DAS and wheat during 45-90 DAS was due to more expansion of the plant at this stage during both the years (Fig. 1 & 2). Well irrigated and fertilizer regimes coupled with congenial environment resulted in higher crop growth rate during both the years. Maximum CGR in cotton was observed under $I_{100}F_{100}M_{foliar}$ during 2019 and 2020 between 45 and 90 as well as 90 and 135 DAS, respectively over other treatments. However in wheat, maximum CGR was observed under $I_{100}F_{100}M_{soil}$ between 45-90 and 90-135 DAS, respectively over other treatments. Water deficit during early growth (45 to 90 DAS) stage causes more reduction in CGR

Table 9. Effect of irrigation regimes, N levels and method of application of KNO_3 & $MgSO_4$ on seed cotton yield during 2019 and 2020

Seed cotton yield (q ha^{-1})										
	2019					2020				
Irrigation regimes (I)	Fertilization levels				Mean	Fertilization levels				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	29.18	28.84	29.46	28.89	29.10	29.57	28.00	30.38	28.76	29.17
I_{80}=80% ET_c	30.90	29.53	31.29	30.18	30.46	33.21	31.07	33.71	31.67	32.41
I_{100}=100% ET_c	32.74	30.25	33.02	30.72	31.68	34.14	32.15	34.62	32.76	33.41
Mean	30.23		30.59			31.35		31.98		
	M_{foliar}=31.09; M_{soil}=29.73					M_{foliar}=32.60; M_{soil}=30.73				
	Control 1=30.86; Control 2=30.15; Control 3=28.91					Control 1= 32.76; Control 2=31.84; Control 3=28.23				
LSD (p=0.05)	I =1.38; F = NS ; M =0.97; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control =0.93; Among control = 1.12					I =1.21; F = NS ; M =0.99; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 1.50; Among control = 2.33				

Table 10. Grain yield of wheat as influenced by irrigation regimes, fertilizer levels and residual effect of KNO_3 & $MgSO_4$ applied to cotton during 2019-2020 and 2020-2021

	2019-2020					2020-2021				
Irrigation regimes (I)	Fertilization regimes				Mean	Fertilization regimes				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	Applied to cotton					Applied to cotton				
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	48.93	49.85	49.89	50.03	49.67	45.54	45.85	45.95	46.27	45.90
I_{80}=80% ET_c	50.66	51.43	51.12	51.84	51.26	48.22	48.51	49.28	49.42	48.85
I_{100}=100% ET_c	51.61	51.79	52.20	52.78	52.09	48.96	49.18	50.08	50.31	49.63
Mean	50.71		51.31			47.70		48.55		
	M_{foliar}=50.73; M_{soil}=51.28					M_{foliar} =48.00; M_{soil} =48.28				
	Control 1=51.31; Control 2=51.72; Control 3=49.12					Control 1= 47.94; Control 2=48.60; Control 3=46.72				
LSD (p=0.05)	I =1.57; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 1.65; Among control = 1.94					I =1.36; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 1.21; Among control = 1.23				

in both the crops during both the years. The, control 3, resulted in lower crop growth rate over all other treatments, between 45-90 and 90-135 DAS, during both the years in both the crops. Increase in crop growth rate with irrigation levels were also observed by Saleem et al (2010).

Relative growth rate: RGR is expressed as gram of dry matter produced by a gram of existing dry matter in a day. Relative growth rate from 45 to 90 DAS was higher than that between 90 and 135 DAS, during both the yearsin both the crops (Fig. 3 and 4). Between 45 and 90 DAS, maximum RGR was observed under I_{100} combinations with fertilization followed by I_{80} and I_{60} during both the years in cotton and 2019-2020 in wheat. Whereas, from 90 to 135 DAS in cotton, trend of RGR reversed in favor of I_{60} with its higher value compared to well watered and fertilized conditions. This was because of slower growth of crop under treatment I_{60} combination with fertilization, due to water stress up to 80-90 DAS and growth was accelerated with start of rains at the end of July and resulted in higher RGR, during both the years in cotton.

Seed cotton and grain yield: Seed cotton and grain yield increased with increasing level of irrigation from 60% to 100% ET_c during both the years (Tables 9, 10). Effect of consecutive levels of irrigation was not statistically different, during 2019-2020. However, during 2020-2021, highest seed cotton and grain yield of 33.41 q ha^{-1} & 49.63 q ha^{-1} was under I_{100} which was statistically at par with I_{80} and significantly better than I_{60}. This might have resulted from the difference in

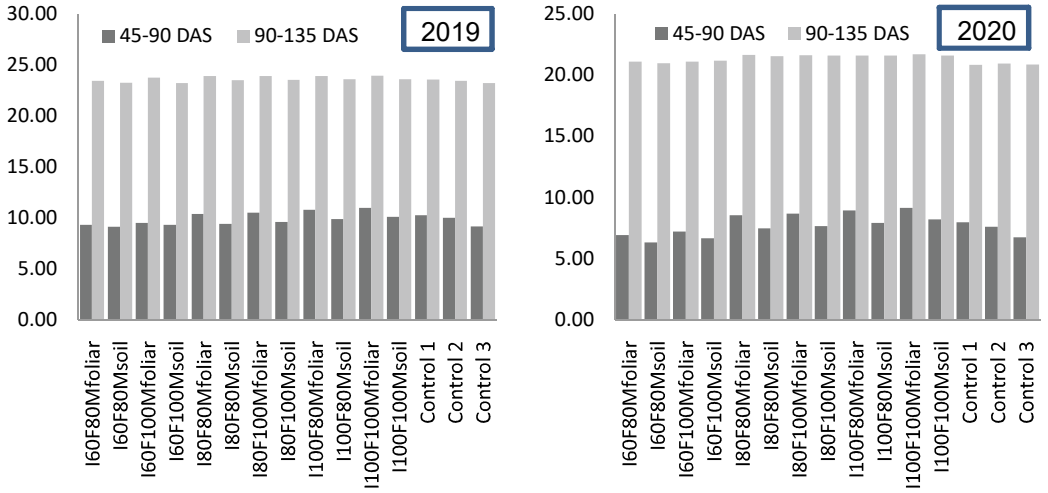

Fig 1. Effect of irrigation regimes, N levels and method of application of KNO_3 & $MgSO_4$ on crop growth rate (g $m^{-2}day^{-1}$) of cotton during 2019 and 2020

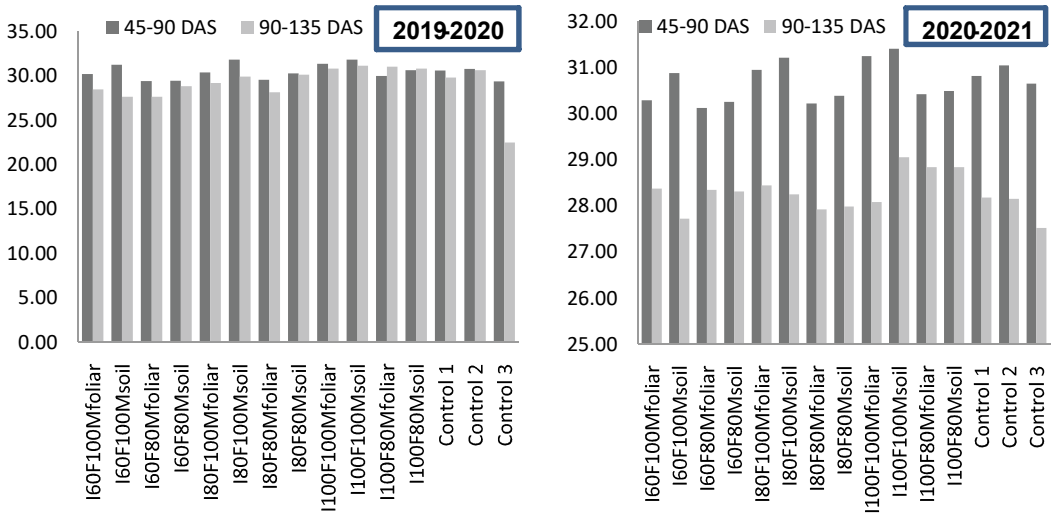

Fig. 2. Effect of irrigation regimes, fertilizer levels and residual effect of KNO_3 & $MgSO_4$ applied to cotton on crop growth rate (g $m^{-2}day^{-1}$) of wheat during 2019-2020 and 2020-2021

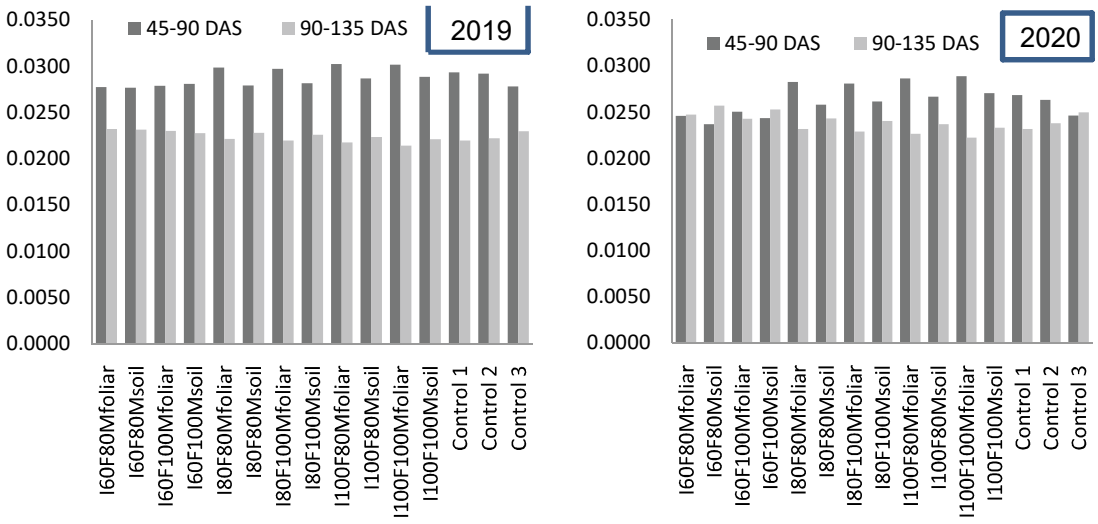

Fig. 3. Effect of irrigation regimes, N levels and method of application of KNO_3 & $MgSO_4$ on relative growth rate (g g^{-1} day^{-1}) of cotton during 2019 and 2020

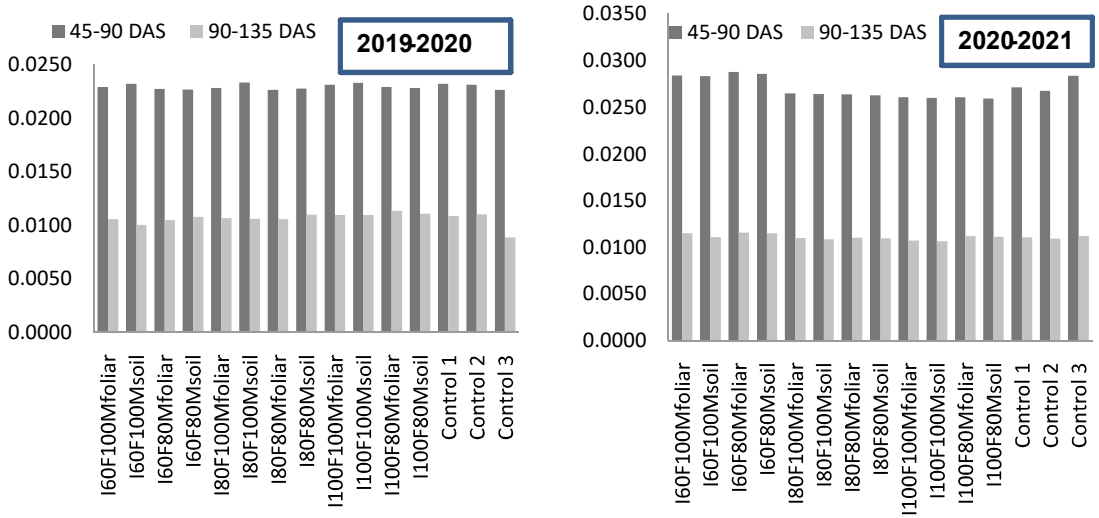

Fig. 4. Effect of irrigation regimes, fertilizer levels and residual effect of KNO_3 & $MgSO_4$ applied to cotton on relative growth rate (g g^{-1} day^{-1}) of wheat during 2019-2020 and 2020-2021

application of desired amount of water applied under different ET_c levels (Singh et al 2018). Level of fertilizer failed to cause significant variation in seed cotton as well as grain yield during both the years. M_{foliar} produced significantly higher seed cotton (31.09 and 32.60 q ha^{-1}) whereas M_{soil} resulted higher grain yield in wheat (51.28 and 48.28 q ha^{-1}) during both the years. Furthermore, among controls, seed cotton and grain yield was significantly improved under control 1 & 2 over control 3. Surface drip system supplies water and fertilizer to root zone, thereby avoids the application of water and nutrients to non target area, leading to improvement in yield over flood irrigation (Aujla et al 2005, Nuti et al 2006). The interaction between irrigation regimes and fertilization were non-significant, however, comparison of controls with combination of sub-surface drip irrigation regimes and fertilization were found to be significant in both the crops.

CONCLUSIONS

Production of crops through surface flood leads to loss of limited water resources besides leaching of nutrients, undesirable vegetative crop growth and underground water pollution. This study investigated water and nutrient management in 'cotton-wheat' cropping system and provided scientific evidence, revealing that sub-surface drip and fertigation technique leads to saving of irrigation water as well as fertilizer. Sub-surface drip irrigated at 80% ET_c has distinct advantages of saving water upto 20% without sacrificing yield and adverse effect on growth components. Fertigation

of 80% RDN, resulted similar growth attributes and yield over 100% RDN, therefore saves 20% fertilizer dose. Foliar application of KNO_3 & $MgSO_4$ proved superior in cotton while residual effect of KNO_3 & $MgSO_4$ was observed in wheat. Therefore, sub-surface drip at 80% ET_c and F_{80}, proved to be valuable option over surface drip under water scarcity conditions.

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