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Research Articles

Impact of drip irrigation and N-fertigation scheduling on wheat (*Triticum aestivum*) under semi-arid tropical environment

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ABSTRACT

The efficient use of water by modern irrigation systems is becoming increasingly important in arid and semi-arid regions with limited water resources. A field experiment was conducted at Jain Hi-Tech. Agri. Institute, Jalgaon, Maharashtra during *rabi* season of 2012-13 and 2013-14, to study the impact of drip irrigation and N-fertigation scheduling on growth and yield of winter wheat (*Triticum aestivum* L.). The results revealed that all growth traits, yield components, grain and straw yield of wheat increased significantly at each higher levels of drip irrigation up to DI - 1.0 Epan with water application of 511 and 446 mm and fertigation of 120 kg N/ha in both the years. The highest water productivity was recorded with 0.8 Epan and N_{160} in both the years of study. The predicted maximum grain yield was 4838 kg/ha in the 2012-13 with an input level of 171.1 kg N/ha, 4451 kg/ha in the 2013-14 with an input level of 154.7 kg N/ha and 4642 kg/ha on pooled basis with an input level of 162.6 kg N/ha, respectively beyond which the yield decrease. However, the maximum grain yield (Y_{max}) in 2012-13 and on pooled basis was not bracketed within the tested range of nitrogen levels (0 to 160 kg/ha). The economic optima of N level that will maximize the net return under prevailing prices considered above worked out to be 156.8 kg N/ha with the resultant grain yield of 4640 kg/ha.

Key words: Drip irrigation, Fertigation, Fertilizer production functions, Water productivity, Wheat, Yield

At global level, wheat is the leading cereal crop cultivated in 226.45 million ha with a production of 707.2 million tonnes (CMIE 2014). In India, wheat production is about 95.91 million tonnes from an area of 30.61 million ha (CMIE 2014). Out of total cultivated wheat area in India, 92% area is under irrigation. Irrigation and fertilization are two most important crop management factors through which farmers can control crop development, yield and quality. Of late due to erratic behavior of monsoon and uncontrolled exploitation of ground water (1 m per year over the last 20 years) caused scarcity of water resources (Perveen *et al.* 2012). The scarce water resources in the country necessitate its economic use which will be possible only by efficient water management practices by adopting advanced technology of irrigation like micro-irrigation. Micro-irrigation is a high frequency irrigation method of supplying water directly to the plant root zone. Adoption of micro-irrigation might help in raising the irrigated area, productivity of crops and water-use efficiency (Sivanappan 2004). A number of previous studies have shown considerable advantages of drip irrigation compared with other irrigation methods (Singh *et al.* 2003). Although its benefits are numerous, drip irrigation in India has been applied mainly to fruit trees, flowers and vegetables. At present, with the increasing shortage of water resources, drip irrigation is also slowly being applied on sparse row crops, such as cotton and sugarcane. However, application on dense field row crops such as wheat is not common in India, due to high installation costs.

Among the chemical fertilizer, nitrogen is also considered one of the most important factors affecting crop morphology, physiological traits and grain yield (Khan *et al.* 2008). The main role of N in the plant is its presence in the structure of protein, the most important building substances from which the living material or protoplasm of every cell is made. In addition, nitrogen is also found in chlorophyll, the green colouring matter of leaves. Chlorophyll enables the plant to transfer energy from sunlight by photosynthesis. Therefore, the nitrogen supply to the plant will influence the amount of protein, protoplasm and chlorophyll formed. In turn, this influences cell size, leaf area and photosynthetic activity. Wheat is very sensitive to insufficient nitrogen and very responsive to nitrogen fertilization. Insufficient N availability to wheat plants results in low yields and significantly reduced profits compared to a properly fertilized crop (Singh *et al.* 2003). Application of nitrogen fertilizer through irrigation systems, i.e. fertigation through which

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nutrients were applied directly into the root zone of plant along with water. The introduction of simultaneous micro-irrigation and fertilizer application (drip irrigation) opens new possibility for controlling the water and nutrient supplies to crop and besides maintaining the desired concentration and distribution of nutrient and water into the soils. When the fertilizer is applied through drip, it is observed that the yield increased and about 30% of the fertilizer could be saved with improved efficiency of fertilizers (Patil *et al.* 2011).

Research works on drip irrigation and N-fertigation scheduling optimization in row crops is very meager. Input information on optimal schedules for micro-irrigation and N-fertigation to wheat will have to be generated. Therefore, the present investigation was conducted to study the impact of drip irrigation and N-fertigation scheduling on wheat under semi-arid tropical region of India.

MATERIALS AND METHODS

A field experiment was carried out during winter (*rabi*) season of 2012-13 and 2013-14 at Jain Hi-Tech Agri. Institute, Jalgaon, Maharashtra. The site is geographically situated at 21° 01' 52" N-Latitude, 75° 56' 38" E-Longitude and at an altitude of 292 m above mean sea level. The region is characterized by tropical and semi-arid with dry winter (November-February). The pan evaporation was 513 mm and 406 mm during the crop season 2012-13 and 2013-14, respectively. Soils in the experimental plot is sandy clay loam texture at the surface layer and sandy loam in the remaining lower layer, neutral in reaction and non-saline. Mechanical analysis of the soil at different depths revealed sand percentage increased with increase in soil depth from 0-15 cm to 45-60 cm. The available nitrogen content was low at all depths and ranged from 164.6 to 276.6 kg N/ha. The available phosphorous content was high in second layer (68.97 kg P_2O_5/ha), medium in 0-15 cm depth and low in 30-45 cm and 45-60 cm depth. The available potassium content was medium in all layers ranging from 222.7 to 297.9 kg K_2O/ha. The soil moisture retention capacity at field capacity and at permanent wilting point of the experimental site was 22.40% and 10.30% (0-60 cm) estimated by the standard procedures (Dastane 1967). The total plant available soil water, i.e. the difference between field capacity and permanent wilting point from 0 to 60 cm soil depth amounted to 89.83 mm. Hydraulic conductivity of soil was found to be moderate (1.34 to 2.50 cm/h) and bulk density was found to be affect the root growth (1.475 g/cm).

LOK-1 wheat variety @ 125 kg/ha was sown on 6 November in 2012-13 and 1 November in 2013-14 and the recommended dose of fertilizers was 120:60:60 NPK kg/ha. The experiment was laid out in a split plot design with twenty treatment combinations and replicated four times. The main treatment comprised five irrigation levels involving four irrigations through drip (DI - 0.6, 0.8, 1.0, 1.2 Epan and one control [SI- surface check basin irrigation at IW/CPE=1] as main treatments along with four N-fertigation schedule, viz. control, 80, 120 and 160 kg/ha through drip. Drip irrigation was scheduled once in two days and N-fertigation scheduled once in a week up to 65 days mentioned in Table 1. Full dose of phosphorus was applied as basal dose and potassium applied through fertigation at weekly intervals up to 65 days.

Inline dripper line laid out on the ground surface along the crop rows at 0.90 m apart with emitters spaced at 0.30 m apart delivering 4 l/h. Both the drip and surface irrigation treatment plots were separated by buffer channels of 1.0 m width to avoid seepage into the adjoining drip irrigated plots. Gross plot size was 9.0 m × 3.6 m and net plot size was 8.0 m × 2.7 m.

Irrigation scheduling was based on daily evaporation data recorded in Agro-meteorological station R and D Farm Jain Hi–Tech Agri. Institute, Jain Irrigation Systems Ltd, Jalgaon. Scheduling of irrigation for 0.6 to 1.2 pan evaporation replenishment (Epan) treatments were fixed for alternate day. Application rate and irrigation time of

Table 1 Nitrogen and potassium fertigation scheduling program for wheat

DAS	Nitrogen (kg/ha)							Potassium (kg/ha)		
	N %	Nitrogen @ 80 kg/ha		Nitrogen @ 120 kg/ha		Nitrogen @ 160 kg/ha		K_2O %	Potassium @ 60 kg/ha	
		N (kg/ha)	Urea (kg/ha)	N (kg/ha)	Urea (kg/ha)	N (kg/ha)	Urea (kg/ha)		K_2O (kg/ha)	MOP (kg/ha)
Basal	10	8	17.39	12	26.09	16	34.78	25	15	25.00
15 DAS	15	12	26.09	18	39.13	24	52.17	10	6	10.00
16 – 22	15	12	26.09	18	39.13	24	52.17	15	9	15.00
23 – 29	15	12	26.09	18	39.13	24	52.17	15	9	15.00
30 – 36	15	12	26.09	18	39.13	24	52.17	10	6	10.00
37 – 43	10	8	17.39	12	26.09	16	34.78	10	6	10.00
44 – 50	10	8	17.39	12	26.09	16	34.78	5	3	5.00
51 – 57	5	4	8.69	6	13.04	8	17.39	5	3	5.00
58 – 64	5	4	8.69	6	13.04	8	17.39	5	3	5.00
Total	100	80	173.9	120	260.9	160	347.8	100	60	100.0

the drip system was calculated by the following formulae.

$$\text{Application rate (mm/h)} = \frac{Q}{D_L \times D_E}$$

where, Q = Dripper discharge (per hour), D_L= Distance between laterals (m), D_E = Distance between drippers (m).

$$\text{Irrigation time (min)} = \frac{\text{Epan} \times \text{Treatment} \times 60}{\text{Application rate (mm/h)}}$$

Epan = Pan evaporation (mm/day).
or

$$\text{Time of application (h)} = \frac{\text{Volume of water (L)}}{\text{Emitter discharge (L/ha)} \times \text{No. of emitters/plot}}$$

In surface check basin irrigation treatment, plots were leveled by manual labour. Irrigation was scheduled based on climatological approach and it was given at IW/CPE=1 with 50 mm depth throughout the experiment. First irrigation was given immediately after sowing.

The volume of water required was calculated in case of 50 mm water is to be applied by the following formulae.

$$W = A \times d \times 1000$$

where, W = Quantity of water (l/ha), A =Plot area in m^2, d = Depth (m) of irrigation water in meters.

Periodical soil samples were collected from 0-15 cm, 15-30 cm, 30-45 cm and 45-60 cm soil depth increments from sowing to harvest at weekly interval in drip irrigation treatment and before and after irrigation in surface check basin irrigation plot.

The amount of soil moisture (SM) in terms of mass water percentage was estimated by gravimetric method as given by Black (1965) as follows:

$$\text{Wet weight (g)} = \frac{\text{Wet weight (g) - Dry weight (g)}}{\text{Dry weight (g)}} \times 100$$

Water productivity is the economic yield per unit of irrigation water consumed by the crop and expressed in kg/m^3.

$$WP = \frac{Y}{IR}$$

where, WP = Water productivity in kg/m^3, Y = Marketable crop yield in kg/ha, IR = Applied irrigation water in m^3.

Crop yield (dependent variable) was assumed as a function of various growth traits, yield components and nutrient uptake (independent variables) and the following straight line model was established by least square technique (Gomez and Gomez 1984) as follows:

$$Y = a + b\ (x)$$

where, Y = Grain yield of wheat (g/m^2), a = Y–axis intercept, b = Régression coefficient, x = Growth and yield components.

The functional relationship between crop yield and applied N is defined as crop production function. The fertilizer production functions evaluated in the present study for wheat were as follows:

Linear Fertilizer Production Function:

$$Y = a + b\ (N)$$

where in: Y = Crop yield (kg/ha), N = Applied nitrogen (kg/ha), a = Y-axis intercept, b = Regression coefficients reflecting the yield variation per unit change in nitrogen.

Quadratic Fertilizer Production Function:

$$Y = a + b\ (N) + c\ (N^2)$$

where in: Y = Crop yield (kg/ha), N = Applied nitrogen (kg/ha), a = Y – axis intercept, b and c = Regression coefficients reflecting the yield variation per unit change in nitrogen.

The data obtained on the different growth and yield components and yield were analyzed statistically by the method of analysis of variance as per the procedure outlined for split plot design given by Gomez and Gomez (1984). Statistical significance was tested by P–value at 0.05 level of probability and critical difference was worked out wherever the effects were significant.

RESULTS AND DISCUSSION

Growth parameters

It is evident from the data presented in Table 2 that each higher level of pan evaporation replenishment from DI - 0.6 to 1.2 Epan produced significantly higher growth parameters, i.e. plant height, leaf area index, number of tillers/m^2 and dry matter production over its lower level except that the difference between DI - 1.0 and 1.2 Epan was statistically non-significant in 2012-13 and 2013-14, respectively. These results can be ascribed to the maintenance of higher soil water potential contributing favourable plant water balance as compared to other treatments (Mahdi *et al.* 1997; Vijaykumar 2009). Better performance of crop in terms of growth traits could also be traced to effective absorption and utilization of available nutrients and better proliferation of roots resulting in quick canopy growth (Sivanappan 2004). Dilip and Madakini (1993) while working with drip irrigated corn observed improved plant height and higher LAI as compared to surface check basin irrigation.

Among the nitrogen levels, increase in nitrogen levels from N_0 to N_{120} significantly increased all growth traits over its lower level. Application of nitrogen beyond 120 kg N/ha, i.e. 160 kg N/ha did not prove to be statistically beneficial in both the years (Table 2). Islam (1997) and Mukherjee (2008) also reported that the maximum number of tillers/plant and dry matter production with 120 kg N/ha and the minimum in control. Adequate supply of N (>120 kg/ha) might have stimulated increased activity of nucleotide, protein, chlorophyll formation, meristematic cells and cell division, cell elongation of internodes and enzymes involve in various metabolic process which have direct impact on vegetative phase (Lockhart and Wiseman 1988). Interaction between drip irrigation and N-fertigation scheduling did not show significant effect on growth parameters.

Yield components

Yield components, viz. ear/m^2, ear length, number of

Table 2 Growth parameters and yield components of wheat as influenced by irrigation (drip and surface check basin) and nitrogen levels.

Treatment	Plant height (cm)		Leaf area index		Number of tillers/m^2		Dry matter production (g/m^2)		No. of ears/m^2		Ear length (cm)		No. of fertile spikelets/ear		No. of grains/ ear		1000 grain weight (g)	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Irrigation levels (I)																		
DI - 0.6 Epan	76.60	74.35	3.91	3.50	305.6	326.8	705.2	672.2	295.6	320.8	5.36	5.12	13.63	12.56	27.87	25.41	37.33	35.10
DI - 0.8 Epan	81.83	77.43	4.79	4.28	343.8	343.7	1078	1039	324.8	337.7	5.78	5.60	15.41	14.53	34.29	31.49	40.10	38.15
DI - 1.0 Epan	83.04	78.83	5.45	5.15	363.9	364.2	1352	1308	338.8	353.2	6.18	5.90	16.58	15.64	36.32	33.92	41.80	40.19
DI - 1.2 Epan	84.38	80.10	5.47	5.30	370.4	368.5	1444	1393	343.4	355.5	6.30	6.04	16.88	16.01	37.08	34.99	43.06	41.31
IW/CPE=1	79.83	76.12	4.67	3.96	326.6	335.3	918.1	904.9	312.5	328.3	5.57	5.35	14.11	13.81	31.23	29.60	39.46	37.43
SEm+	0.86	0.74	0.09	0.07	3.81	4.23	38.58	51.42	3.81	4.23	0.11	0.085	0.16	0.26	0.52	0.44	0.39	0.43
CD (P=0.05)	2.66	2.28	0.29	0.21	11.75	13.04	118.9	158.4	11.75	13.03	0.34	0.26	0.51	0.81	1.61	1.36	1.26	1.34
Nitrogen levels (N)																		
N0 - 0 kg/ha	77.94	74.38	4.01	3.65	276.4	290.5	700.2	658.8	257.4	281.9	5.16	4.87	13.79	12.88	28.23	27.81	35.84	34.18
N80 - 80 kg/ha	81.06	77.20	4.91	4.50	348.1	354.4	1026	999.6	329.0	345.8	5.85	5.64	15.22	14.48	32.82	30.19	40.78	38.72
N120 -120 kg/ha	82.52	78.62	5.19	4.78	370.7	370.5	1301	1257	351.7	361.9	6.13	5.90	16.07	15.26	35.77	32.87	42.14	40.11
N160 -160 kg/ha	83.03	79.27	5.31	4.83	372.9	375.5	1371	1338	353.9	366.8	6.22	6.01	16.23	15.42	36.60	33.45	42.65	40.64
SEm+	0.56	0.53	0.08	0.07	5.59	3.83	32.37	34.00	5.59	3.83	0.08	0.09	0.13	0.20	0.47	0.38	0.36	0.48
CD (P=0.05)	1.60	1.53	0.25	0.21	15.95	10.92	92.24	96.88	15.95	10.92	0.25	0.25	0.38	0.57	1.36	1.10	1.02	1.37
Interaction (I × N)																		
Nitrogen at same level of irrigation																		
SEm+	1.72	1.48	0.19	0.14	7.63	8.46	78.65	102.9	7.63	8.46	0.22	0.171	0.33	0.52	1.05	0.88	0.75	0.87
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Irrigation at same or different levels of nitrogen																		
SEm+	1.39	1.28	0.19	0.16	11.49	8.54	73.65	83.55	11.49	8.54	0.20	0.194	0.30	0.46	1.06	0.87	0.79	1.03
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
General mean	81.1	77.4	4.86	4.44	342.0	347.7	1099	1063	323.0	339.1	5.84	5.60	15.32	14.51	33.36	31.08	40.35	38.44

fertile spikelets/ear, number of grains/ear and test weight were significantly higher with DI - 1.0 Epan over the lower levels but it was statistically on par with higher level of irrigation level (DI - 1.2 Epan) in 2012-13 and 2013-14, respectively (Table 2). These findings are corroborated with the observations by Mahdi *et al.* (1997) with drip irrigation at 1.0 ET compared to deficit irrigation (0.33 and 0.67 ET). Better yield components of wheat under drip irrigation due to favourable soil water balance and effective absorption and utilization of available nutrients without wide fluctuations under DI - 1.0 and 1.2 Epan treatments resulting in higher growth rate of wheat. Among the nitrogen levels, each higher level of N significantly increased the yield components over its lower level up to 120 kg N/ha in 2012-13 and 2013-14, respectively (Table 2). Use of higher level of N 160 kg N/ha did not prove to be advantageous in improving yield components over N_{120}. Similar beneficial effects of nitrogen response at 120 kg N/ha on yield components of wheat were also reported by Behera and Ghosh (2009). Adequate nitrogen level enhanced vegetative growth in terms of plant height, leaf area index, number of tillers and dry matter production consequently increased the number of ear bearing tiller, ear length, fertile spikelets/ear, grains/ear and test weight due to greater carbohydrate translocation from vegetative plant parts to reproductive parts.

Grain and straw yield

Average wheat grain and straw yield was greater (4760.5 and 5425 kg/ha) when irrigation was scheduled by DI - 1.2 Epan but it was statistically on par with DI - 1.0 Epan and significantly superior to DI - 0.6 and 0.8 Epan in both the years (2012-13 and 2013-14; Table 3). Similarly Mahdi *et al*. (1997) also reported similar results with drip irrigation at 1.0 ET compared to deficit irrigation. However, harvest index showed no response in relation to irrigation levels (drip and surface check basin). On an average the crop in DI - 1.0 Epan treatment registered 44.28% and 10.26% more yield over DI - 0.6 and 0.8 Epan. Wheat grain yield under surface check basin irrigation at IW/CPE=1 (3589.2 kg/ha) was also statistically inferior in comparison to drip irrigation treatments (DI - 0.8, 1.0 and 1.2 Epan) except DI - 0.6 Epan. The above trends in grain and straw yield registered under DI - 1.0 and 1.2pan evaporation (Epan) in comparison to other treatments could be traced to the

Table 3 Grain yield, straw yield, harvest index, consumption use of water and water productivity of wheat as influenced by irrigation (drip and surface check basin) and nitrogen levels

Treatment	Grain yield (kg/ha)		Straw yield (kg/ha)		Harvest index (%)		Total seasonal consumptive use of water (mm)		Water productivity (kg/m3)	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Irrigation Scheduling (I)										
DI - 0.6 Epan	3357	3056	3634	3337	48.11	47.80	348.8	292.4	0.96	1.05
DI - 0.8 Epan	4402	3990	4817	4402	47.95	47.70	431.2	359.1	1.02	1.11
DI - 1.0 Epan	4707	4546	5366	5023	46.80	47.66	513.6	411.5	0.92	1.10
DI - 1.2 Epan	4863	4658	5582	5268	46.63	47.02	596.0	475.4	0.82	0.98
IW/CPE=1	3679	3500	3979	3872	48.01	47.51	570.0	440.0	0.65	0.80
SEm+	98.50	124.7	113.7	82.49	0.57	0.75				
CD (P=0.05)	303.4	384.3	350.2	254.1	NS	NS				
Nitrogen levels (N)										
N0 - 0 kg/ha	2987	2886	3234	3018	48.12	48.74	481.9	391.7	0.62	0.74
N80 - 80 kg/ha	4307	4103	4745	4443	47.61	48.09	481.9	391.7	0.89	1.05
N120 -120 kg/ha	4686	4353	5278	4940	47.16	46.84	481.9	391.7	0.97	1.11
N160 -160 kg/ha	4826	4458	5446	5121	47.11	46.55	481.9	391.7	1.00	1.14
SEm+	88.52	83.24	94.2	87.33	0.41	0.46				
CD (P=0.05)	252.2	237.2	268.3	248.8	N.S.	1.31				
Interaction (I × N)										
Nitrogen at same level of irrigation										
SEm+	197.0	249.4	227.4	164.9	1.14	1.51				
CD (P=0.05)	NS	NS	NS	NS	NS	NS				
Irrigation at same or different levels of nitrogen										
SEm+	197.7	203.8	214.9	188.2	0.97	1.17				
CD (P=0.05)	NS	NS	NS	NS	NS	NS				
General Mean	4202	3950	4676	4380	47.50	47.55				

favourable soil water balance near to field capacity (applied water) as observed by variation in soil moisture during the crop growing season (Bar-Yosef 1999). Thus, favourable soil water balance under DI - 1.0 and 1.2 Epan aided the plants to put forth improved performance over other treatments, since water plays a vital role in carbohydrate metabolism, protein synthesis, cell wall synthesis, cell enlargement and partitioning of photosynthates to sink for improved development of growth traits (Gardner *et al.*1985). Therefore, crop plants in DI - 1.0 and 1.2 Epan treatments had the crop growth, development and yield contributing characters resulting in higher yields.

In case of nitrogen levels, fertigation of N_{120} recorded significantly higher grain and straw yield of wheat over N_0 and N_{80} and it was on par with N_{160} in both the years of study. These results are in conformity with Behera and Ghosh (2009) reported from Indore, Madhya Pradesh. However, harvest index showed inverse relationship with each higher level of N. Higher grain yield of wheat under higher N levels (N_{120}) could be traced to adequately nitrogen nutrition that might have resulted into a more vigorous and extensive root system of crop leading to increased vegetative growth. Wheat crop fertilized with N_{120} (120 kg N/ha) had more plant height, which in turn helped the plants to put forth more number of tillers contributing to higher leaf area index, as leaves continued to grow and persist (LAD) until an optimal leaf area index (leaf area index = ≥4.0) is achieved, that maximizes canopy photosynthesis with higher photosynthetic efficiency, i.e. net assimilation rate (NAR) resulting in greater crop growth rates contributing to higher dry matter production (Table 2).

Regression of growth traits and yield components on grain yield of wheat

Table 4 presents the empirical results of all the linear best fits established between grain yield (as dependent variable) of wheat versus growth traits and yield components as independent variables. All the independent variables showed a significant positive and linear relationship with grain yield (Table 4) suggesting an increment in grain yield of wheat with increase in given growth trait and yield component. However, the magnitude of this reinforcement varied with the independent variable, viz. growth trait and yield component and their units. The explained total variation as indicated by coefficient of determination (R^2) in grain yield by various growth traits (plant height, tiller production, leaf area index and dry matter production) and yield components (ears/m^2, grains/ear and test weight) chosen as independent variables individually ranged from 82.11 to 93.77% and 80.87 to 96.69%. The variance ratio for testing R^2 was highly significant ($P < 0.01$) in all the relationships. This suggests that the grain yield of wheat can be adequately predicted using the tested independent variables, viz. growth traits and yield components.

Consumptive use of water and water productivity

Among all irrigation levels (drip and surface check basin), the lowest consumptive use of water was recorded with DI - 0.6 Epan (348.8 and 292.4 mm) followed by 0.8 Epan (431.2 and 359.1 mm) and highest with DI - 1.2 Epan (596 and 475.4) and surface check basin irrigation (570 and 440 mm) in 2013-13 and 2013-14 respectively (Table 3). Drip irrigation recorded highest water productivity over surface check basin irrigation method. Application of water through drip at DI - 0.8 Epan registered highest water productivity (1.02 and 1.11 kg/m^3) which was superior over 0.6, 1.0 and 1.2 Epan in 2012-13 and 2013-14, respectively (Table 3). These findings are in agreement with (Mahdi *et al.* 1997, Clinton *et al.* 2005). Generally water productivity decreases with increases in irrigation as yield gain is less than proportional increase in ET. Arora *et al.* (2007) also highlighted water productivity of wheat decreases with increase in irrigation at high initial soil water (75% EW), while at low initial soil water (25% EW), water productivity increase from no irrigation to partial irrigation regime, and decrease thereafter with more irrigation.

In case of nitrogen levels, each increment of N level from N_0 to N_{160} increased water productivity but at a diminishing rate in 2012-13 and 2013-14, respectively. Application of N @ 160 kg/ha (N_{160}) registered highest water productivity (1.00 and 1.14 kg/m^3) which was superior over N_0, N_{80} and N_{120} (Table 3). Similar results were reported by Sundrapandiyan (2012) and Singh *et al.* (2003). The mean percent increase in water productivity under N_{160}

Table 4 Empirical estimates for the regression of growth traits and yield components on grain yield of wheat (Pooled basis)

Relationship	Regression constant		Coefficients	Test statistics
	a	b	R^2	F value for testing R^2
Yield – Plant height (cm)	-1859.35	28.603	0.935**	259.2
Yield – No. of tillers/m^2	-313.636	2.0786	0.821**	82.60
Yield – LAI	-114.141	111.30	0.898**	158.1
Yield – Dry matter (g/m^2)	158.696	0.2301	0.938**	271.3
Yield – No. of ears/m^2	-24..647	1.9700	0.809**	76.10
Yield – Ear length (cm)	-501.761	158.82	0.956**	395.6
Yield – Fertile spikelet/ear	-403.652	54.366	0.939**	276.0
Yield – No. of grains/ear	-223.314	19.578	0.911**	184.4
Yield – Test weight (g)	-638.2179	26.54399	0.967**	527.3

was 57.71%, 10.22% and 2.68% over N_0, N_{80} and N_{120} respectively. Significantly lowest water productivity was recorded in control treatment (N_0) in both years.

Soil water content

Different drip and surface irrigation levels markedly influenced the average soil moisture content at 0-60 cm depth during 2012-13 and 2013-14 depicted in Fig 1. Drip irrigation levels exhibited uniform soil moisture depletion pattern as compared to surface check basin irrigation method which showed higher fluctuation between irrigation events during both years. The soil moisture content in drip irrigation treatment, viz. 1.2 and 1.0 pan evaporation replenishment (Epan) was higher throughout the crop life as compared to other treatments (0.6, 0.8 Epan and at IW/CPE=1). Likewise, the irrigation scheduled at IW/CPE=1 though had higher fluctuation between irrigation events maintained higher soil moisture contents over drip irrigation at 0.6 and 0.8 Epan beyond 50 DAS during 2012-13. However, same trend was not observed during second year in this treatment.

Fertilizer Production Function

Optimization of nitrogen

The relation between wheat grain yield (Y) under each nitrogen levels (N) was established following quadratic production function. The resultant function and test statistics are as follows.

$Y = 2985.4 + 21.727\ N – 0.0637\ N^2$

t(b1) = 52.77 *t(b2) = -25.013* $R^2 = 0.999$ *F value = 0.0099*……….(2012-13)

$Y = 2888.5 + 20.216\ N – 0.0654\ \mathbf{N^2}$

t(b1) = 26.675 *t(b2) = -13.932* $R^2 = 0.999$ *F value = 0.0212*………(2013-14)

$Y = 2937.0 + 20.972\ N – 0.0645\ N^2$

t(b1) = 121.147 *t(b2) = -60.239* $R^2 = 0.999$ *F value = 0.0044*………..(Pooled)

The test statistic (R^2 and F – value) of fitted quadratic production function in 2012-13, 2013-14 and pooled basis were highly significant. The explained total variation (R^2) in grain yield with nitrogen levels was 99.99%, 99.96% and 99.99% during 2012-13, 2013-14 and pooled basis, respectively suggesting that in the present study the best fit for the data was obtained with quadratic form as fertilizer production function. Likewise, the sign of intercept (a) and regression coefficient of linear (N) and quadratic (N^2) were alike in all the equation.

The yield – nitrogen production function did not emerge through the origin and the value of regression constant (intercept 'a') was positive indicating that some minimum grain yield of 2987, 2886 and 2936 kg/ha during 2012-13, 2013-14 and polled basis, respectively can be realized based on the native fertility of the experimental soil. The positive linear coefficient for N term denoted that grain yield increased linearly from the addition of initial N levels. On the other hand, the negative second power (quadratic) regression coefficient (N^2) suggested that the increase in grain yield from each increment of N diminished at higher levels.

The predicted maximum grain yield was 4838 kg/ha in the 2012-13 with an input level of 171.1 kg N/ha, 4451 kg/ha in the 2013-14 with an input level of 154.7 kg N/ha and 4642 kg/ha on pooled basis with an input level of 162.6 kg N/ha, respectively beyond which the yield decreased (Fig 2). However, the maximum grain yield (Y_{max}) in 2012-13 and on pooled basis was not bracketed within the tested range of nitrogen levels (0 to 160 kg/ha).

The ultimate objective of this type of analysis is to predict the N rate that will result in maximum profit. These levels were accomplished by solving the following equations:

$$2012–13 : d_y/d_N = 21.727–0.1274N = P_N/P_Y$$

$$2013–14 : d_y/d_N = 20.216–0.6448N = P_N/P_Y$$

$$\text{Pooled} : d_y/d_N = 20.972–0.1290N = P_N/P_Y$$

where, P_Y is the price of grain yield/kg (₹ 20.0 grain/kg) and P_N is the unit price of N (₹ 15.65 N/kg).

The economic optima of N level that will maximize the net return under prevailing prices considered above worked out to be 156.8 kg N/ha with the resultant grain yield of 4640 kg/ha (Table 4). The optimum N level represents one point on the derived demand curve (Fig 2). Thus economic

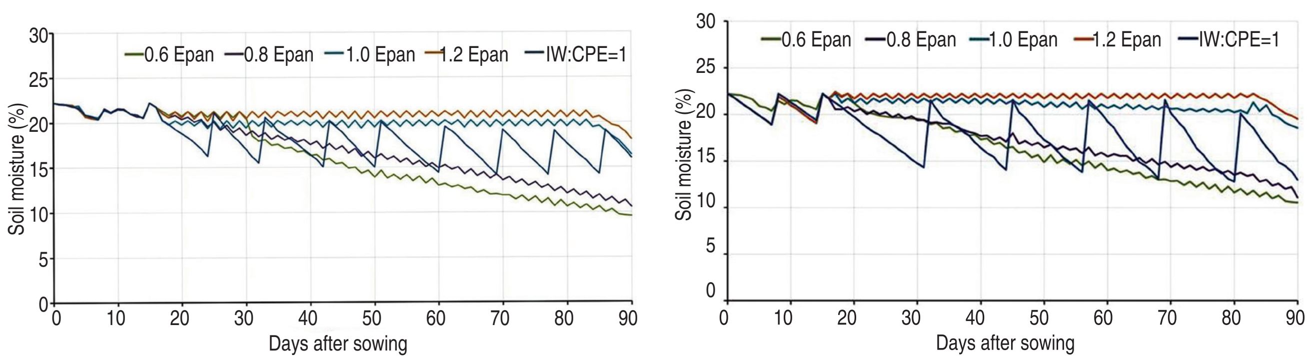

Fig 1 Soil moisture content (0-60 cm) at different crop growth stages as influenced by irrigation levels (drip and surface check basin).

Table 5　Economic return of wheat at optimum levels of nitrogen under different appraised prices

Unit price of N (₹/kg)	Price of produce (₹/kg)	Price ratio (Pr =Pw/ Py)	Optimum nitrogen (kg/ha)	Yield (kg/ha)	Total returns (₹/ha)	Cost of nitrogen (₹/ha)	Cost of cultivation* (₹/ha)	Net returns (₹/ha)	Net returns/₹ invested
15.0	15	1.00	154.8	4638	69567	2322	23699	43546	1.67
	20	0.75	156.8	4640	92800	2351	23699	66750	2.56
	25	0.60	157.9	4640	116000	2369	23699	89932	3.45
	30	0.50	158.7	4641	139230	2380	23699	113151	4.34
17.5	15	1.17	153.5	4635	69525	2687	23699	43139	1.63
	20	0.88	155.8	4638	92760	2726	23699	66335	2.51
	25	0.70	157.1	4639	115975	2750	23699	89526	3.38
	30	0.58	158.1	4640	139200	2766	23699	112735	4.26
20.0	15	1.33	152.2	4631	69465	3045	23699	42721	1.60
	20	1.00	154.8	4636	92720	3096	23699	65925	2.46
	25	0.80	156.4	4638	115950	3127	23699	89124	3.32
	30	0.67	157.4	4639	139170	3148	23699	112323	4.18
22.5	15	1.50	150.9	4626	69390	3396	23699	42295	1.56
	20	1.13	153.9	4633	92660	3462	23699	65499	2.41
	25	0.90	155.6	4636	115900	3501	23699	88700	3.26
	30	0.75	156.8	4638	139140	3527	23699	111914	4.11

*Cost of cultivation excluding cost of water and fertilizer (urea)

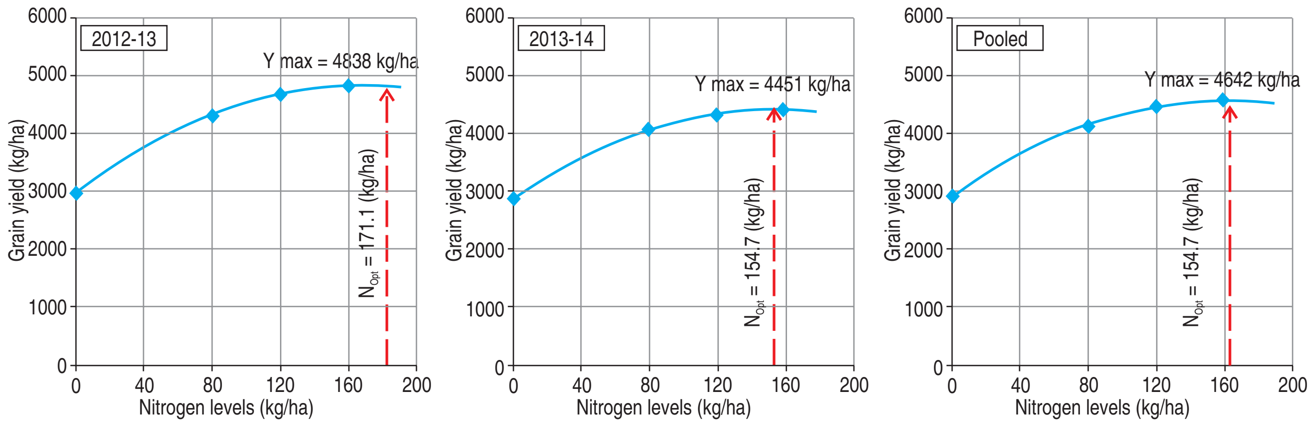

Fig 2　Yield - nitrogen production function during 2012-13, 2013-14 and on pooled basis

optimum levels of nitrogen under different appraised prices of output and input show that the optimum level of nitrogen was inversely related to increase in unit price of nitrogen (P_N), whereas it (N_{opt}) had a direct positive and relationship with the price of grain yield (Table 5).

It indicates that an increase in cost of fertilizer, keeping the prices of yield constant, require the use of less nitrogen to derive maximum profit. But if the prices of produce increase, greater amount of nitrogen can be used profitably. Similar trend were noted with net return and net return per rupee invested. The increase in unit price of nitrogen from ₹ 15 to 22.5 N/kg under given price of the produce, say ₹ 15 kg/ha, is associated with only 3.9 kg decreased in demand of nitrogen. This low decrease in demand was due partly to fixed level of all inputs other than nitrogen and high value of marginal physical product of nitrogen, and hence the price of nitrogen did not substantially affect the quantity of nitrogen demanded.

CONCLUSION

Drip irrigation with N-fertigation is an advantageous technique for getting higher yield of winter wheat in tropical region of India. DI - 1.0 Epan and fertigation of nitrogen at 120 kg N/ha (N_{120}) gave significantly superior performance in terms of growth traits, yield components and yield. The water productivity was found to be highest with drip irrigation at 0.8 Epan and 120 kg N/ha in both the years. The predicted maximum grain yield was recorded with 171.1 kg N/ha in 2012-13, 154.7 kg N/ha in 2013-14 and 162.6 kg N/ha on pooled basis respectively, beyond which the yield decrease. However, the maximum grain yield (Y_{max}) in 2012-13 and on pooled basis was not bracketed within the tested range of nitrogen levels (0 to 160 kg/ha). The economic optima of N level that will maximize the net return under prevailing prices considered above worked out to be 156.8 kg N/ha with the resultant grain yield of 4640 kg/ha. We recommend drip irrigation along with N-fertigation for wheat crops grown in water scare regions in India. The results of this study provide useful information to farmers to make drip irrigation and fertigation decisions for profit maximization and resource conservation.

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