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Effect of deficit irrigation and nitrogen levels on water productivity and nitrogen use efficiency of wheat (*Triticum aestivum*) in a semi-arid environment

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Wheat (*Triticum aestivum* L.) is the second most important cereal crop in India after rice covering an area of about 28 m ha (http://eands.dacnet.nic.in/). Wheat is mostly grown in semiarid and arid tracts of India with dry winter season. Wheat, being highly sensitive to moisture stress, requires supplemental irrigation. However, now-a-days because of increased population and industrialization irrigated wheat of arid and semiarid tracts of India facing steep competition from other water users like domestic and industrial sectors, jeopardizing the future food security of the country. Therefore, there is an urgent need to increase crop water productivity of wheat, i e to produce more food with less water (Kijne *et al.* 2003). Higher crop water productivity is possible either by increasing production from same water resources or same production from less water resources. In either way it will benefit the other fresh water users (Zwart *et al.* 2004). Due to rising costs of irrigation pumping, inadequate irrigation system capacities and limited irrigation supplies, deliberate application of less water to wheat is a common practice (Panda *et al.* 2003) in the arid and semiarid areas of the country.

After irrigation, nitrogenous fertilizer is the second most important input (Lenka *et al.* 2009) for wheat crop growth and development. There are many reports that nitrogenous fertilizer enhances water productivity (Oweis *et al.* 2000 and Pandey *et al.* 2001), but the efficacy of nitrogenous fertilizer depends on the availability of soil moisture. Under limited soil moisture condition, the mineralization of nitrogenous fertilizer and its movements to plant roots is restricted and hence its utilization by plant. Similarly, under excessive soil moisture regime, leaching and volatilization losses of nitrogenous fertilizer hinder its efficiency. Keeping these in view, an experiment was planned to study the effect of deficit irrigation and nitrogen levels on water productivity and nitrogen use efficiency of wheat.

Field experiments were carried out during the years 2009-10 and 2010-11 at the research farm of the Indian Agricultural Research Institute, New Delhi (28°37' to 28°39' N latitude and 77°90' to 77°11' E longitude and at an altitude of 228.7 m above mean sea level). This region experiences extreme temperatures, the annual maximum temperature goes as high as 45°C in summer, whereas the minimum temperature dips to as low as 1°C in winter. The site has been characterized as semi-arid sub-tropical climate with mean annual rainfall of 750 mm, out of which a substantial amount (85%) is received during July to September. The soil is sandy loam (Typic Haplustept) with medium to angular blocky structure, non-calcareous and slightly alkaline in reaction. The soil (0–30 cm) has bulk density 1.56 Mg/m^3; hydraulic conductivity (saturated) 1.05 cm/h, saturated water content 0.42 m^3/m^3; pH (1:2.5 soil/ water suspension) 7.4; EC 0.34 dS/m; organic-C 3.0 g/kg; total N 0.031%; available (Olsen) P 6.9 kg/ha; available K 279.0 kg/ha; sand, silt and clay, 64.0, 16.8 and 19.2%, respectively. The soil moisture at 0.033 MPa suction ranged from 25–28% and at 1.5 MPa suction ranged from 8–10% in different layers of 0-120 cm soil depth. Wheat (cv HD 2932) was grown in a split plot design with four levels of irrigation, viz. control (rainfed) and irrigations to replenish 30% (30% SMD), 60% (60% SMD) and 100% (100% SMD) moisture deficit from field capacity in 0-120 cm depth, at critical growth stages as main plot factors and four level of N, viz. 0 (N0), 30 (N30), 60 (N60) and 120 (N120) kg N/ha as subplot factors. Nitrogen was applied in three equal splits at crown root initiation, maximum tillering and flowering stage. All the treatments received the recommended dose of P (60 kg P_2O_5 as SSP) and K (60 kg K_2O/ha as MOP). Irrigation was applied at critical crop growth stages in measured amount using Parshall flume.

Soil moisture content in the profile (0-120 cm) was determined gravimetrically at 15 days intervals during the crop growth period of 2009-10 and 2010-11 to study the

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distribution and redistribution of the soil water in the profile.

The water productivity (WP, kg/m^3) was computed using Eq 1 (Pereira 2005):

$$WP = \frac{Ya}{TWU} = \frac{Ya}{P + CR + \Delta SW + I} \quad (1)$$

where Ya is actual harvestable yield (kg/ha); TWU is the total water use (m^3/ha); P is precipitation (m^3/ha), CR is capillary rise (m^3/ha), ΔSW is the is the difference in soil water content between planting and harvest (m^3/ha) and I is the seasonal irrigation depth (m^3/ha). In the present condition, water table was below 4 m depth and therefore capillary rise (CR) was assumed to be negligible. The net sub-plot areas were harvested for grain yield.

The economic water productivity (EWP, ₹/m^3) was calculated by expressing the actual harvestable yield in rupees term. The price (Minimum Support Price of ₹ 1 080 per quintal in 2009-10 and ₹ 1 100 per quintal in 2010-11) of the actual harvestable yield or grain yield was taken from the Department of Food and Public Distribution, Government of India for the period considered.

The agronomic nitrogen use efficiency (ANUE, kg of grain/kg of N applied) was determined using Eq 2 (Jat *et al.* 2008):

$$ANUE = \frac{Y_N - Y_0}{F_N} \quad (2)$$

where Y_N is grain yield of N-fertilized plot (kg/ha); Y_0 is grain yield of control plot (kg/ha) and F_N is amount of fertilizer N (kg/ha applied).

The partial factor productivity of nitrogen (PFPN, kg of grain/kg of N applied) was determined using Eq 3 (Sharma and Banik 2012):

$$PFPN = \frac{Y_N}{F_N} \quad (3)$$

where Y_N is grain yield of N-fertilized plot (kg/ha) and F_N is amount of fertilizer N (kg/ha applied). The data were analyzed by analysis of variance as outlined by Gomez and Gomez (1984).

Soil moisture storage of wheat crop for both the years of study is presented in Fig 1. The peaks in the soil moisture storage in the profile corresponds to either irrigation or rainfall events. The soil moisture storage in all the treatments except the rainfed treatment remained well within the FC and PWP (the classical lower and upper limit suction for plant available water) throughout the crop growth period. The lowest soil moisture storage was observed in the treatments receiving 120 Kg N/ha followed by 60 kg N/ha, 30 kg N/ha and the 0 kg N/ha treatments (Fig 1 a and c), probably because of better crop growth and correspondingly higher uptake of water by the crop. Similar type of results were observed by Hati *et al.* (2001) for wheat and Bandyopadhyay *et al.* (2010) for soybean crop on Vertisol, while low soil moisture content in manured and fertilized plots than unfertilized plot because of better crop growth in the fertilized plots. However, among the irrigation treatments, highest soil moisture storage was observed in treatments receiving higher amount of irrigation (Fig 1b and d). The relation between water use (m^3/ha) and grain yield under various irrigation and nitrogen treatments combined for both the years of study are presented in Fig 2. It shows significant and positive linear relationship between grain yield and water use. The good correlation between grain yield and water use in this study also indicates that grain yield is strongly influenced by the pattern of water use during the crop season and emphasizes the importance of adequate water supply for higher yield. The seasonal water use could account for 58% variation in grain yield of wheat. Many workers have also reported linear relationships between water use and grain yield (Singh *et al.* 1979,

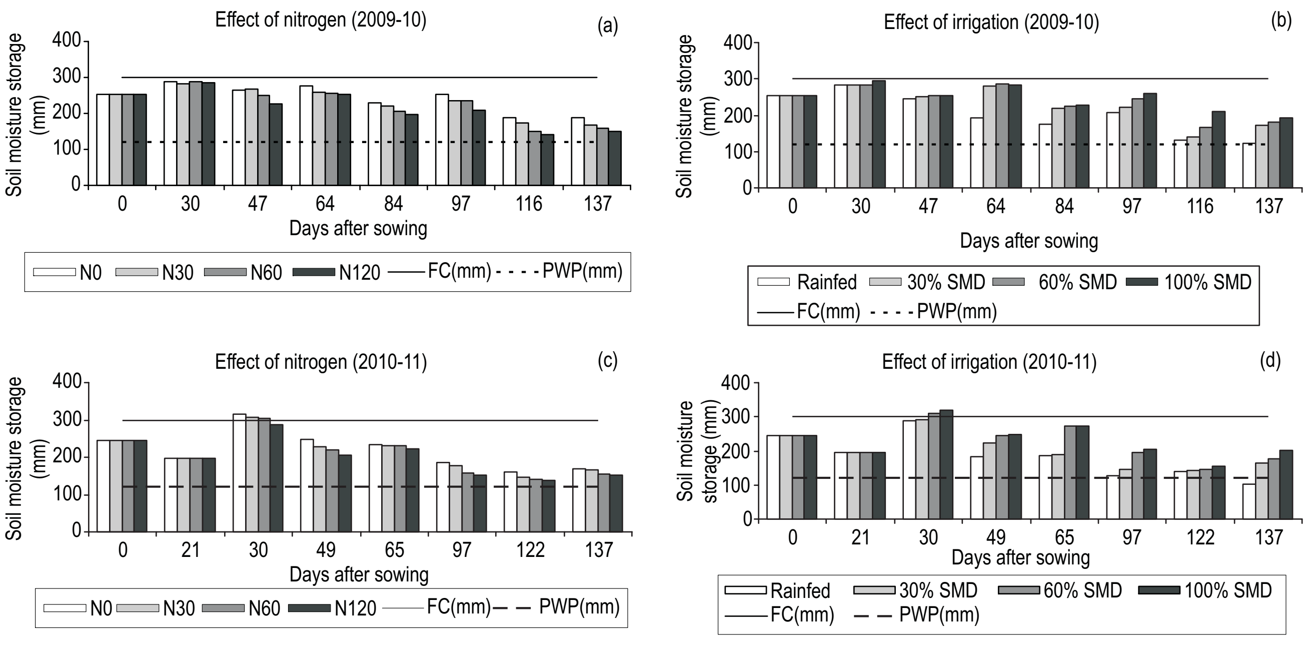

Fig 1 Temporal variation in the soil moisture storage in the profile (0-120 cm) during wheat 2009-10 and 2010-11.

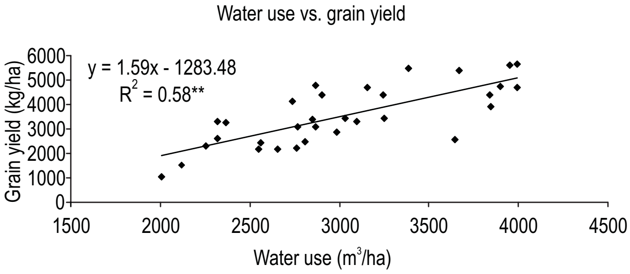

Fig 2 Relation between water use and wheat grain yield (combined for the years 2009-10 and 2010-11).

Steiner *et al.* 1985, Hati *et al.* 2001, Goswami and Sarkar 2008).

In both the years of study, grain yield increased significantly with the increased level of irrigation, being highest at 100% SMD treatment and lowest in rainfed treatment (Table 1). However, in the year 2010-11, 60% SMD treatment and 100% SMD treatment were statistically at par with respect to grain yield of wheat. It could be ascribed to the significantly higher rainfall (49.9 mm) received during the month of February 2011, which coincides with the booting, flowering and milk stage of wheat crop. Pooled over the years, the grain yield increased by 42, 80 and 90% over rainfed treatment in 30% SMD, 60% SMD and 100% SMD treatments, respectively. The higher yield with increasing levels of irrigation may be attributed to better water and nutrient availability, which gave rise to better plant growth and yield. Similar results have been reported in wheat by many workers (Singh *et al.* 1987, Gajri *et al.* 1993, Hati *et al.* 2001, Jat *et al.* 2008, Panday *et al.* 2008 and Bandyopadhyay *et al.* 2010). The grain yield also significantly increased with increasing nitrogen levels, highest being at N120 (4 755 kg/ha in 2009-10 and 4 627 kg/ha in 2010-11) and lowest in N0 (2 064 kg/ha in 2009-10 and 2 605 kg/ha in 2010-11). Pooled over the years, the grain yield increased by 41, 63 and 101% over N0 treatement in N30, N60 and N120 treatments, respectively. The interaction effect of irrigation and nitrogen on grain yield was significant and the highest grain yield was recorded in 100% SMD irrigation treatment with N120 levels of nitrogen, which was statistically at par with that at 60% SMD irrigation and N120 levels of nitrogen.

The effects of deficit irrigation and nitrogen levels on water productivity (WP) and economic water productivity (EWP) is presented in Table 2. Both the irrigation and

Table 1 Grain yield, Water productivity (WP) and Economic water productivity (EWP) of wheat for the year 2009-10 and 2010-11

	Grain yield (kg/ha)			WP (kg/m^3)			EWP (₹/m^3)		
	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled
				Effect of irrigation					
Rainfed	2307^{D*}	2311^{C}	2309^{D}	1.01^{C}	0.88^{C}	0.95^{C}	10.94^{C}	9.68^{C}	10.31^{C}
30% SMD	3302^{C}	3266^{B}	3284^{C}	1.10^{B}	1.16^{B}	1.13^{B}	11.83^{B}	12.78^{B}	12.30^{B}
60% SMD	3898^{B}	4398^{A}	4148^{B}	1.25^{A}	1.52^{A}	1.38^{A}	13.46^{A}	16.68^{A}	15.07^{A}
100% SMD	4312^{A}	4439^{A}	4376^{A}	1.11^{B}	1.18^{B}	1.14^{B}	11.99^{B}	12.95^{B}	12.47^{B}
				Effect of nitrogen					
N0	2064^{D}	2605^{D}	2334^{D}	0.74^{D}	1.00^{D}	0.87^{D}	8.05^{D}	11.03^{D}	9.54^{D}
N30	3228^{C}	3332^{C}	3280^{C}	1.05^{C}	1.13^{C}	1.09^{C}	11.36^{C}	12.38^{C}	11.87^{C}
N60	3773^{B}	3849^{B}	3811^{B}	1.19^{B}	1.24^{B}	1.22^{B}	12.89^{B}	13.63^{B}	13.26^{B}
N120	4755^{A}	4627^{A}	4691^{A}	1.47^{A}	1.37^{A}	1.42^{A}	15.93^{A}	15.04^{A}	15.46^{A}
				Effect of irrigation × nitrogen					
Rainfed N0	1051^{F}	1503^{G}	1277^{I}	0.52^{I}	0.71^{H}	0.62^{I}	5.66^{I}	7.80^{H}	6.73^{I}
Rainfed N30	2313^{E}	2179^{F}	2246^{H}	1.03^{EFG}	0.86^{G}	0.94^{FGH}	11.09^{EFG}	9.40^{GH}	10.25^{FGH}
Rainfed N60	2597DE	2473^{F}	2535^{GH}	1.12^{DE}	0.88^{FG}	1.00^{EFG}	12.09^{DE}	9.68^{FG}	10.89^{EFG}
Rainfed N120	3269^{C}	3089^{E}	3179^{EF}	1.38^{BC}	1.08^{CDE}	1.23^{B}	14.93^{BC}	11.84^{CDE}	13.39^{B}
30% SMD N0	2235^{E}	2174^{F}	2205^{H}	0.81^{H}	0.82^{GH}	0.81^{H}	8.75^{H}	9.02^{GH}	8.88^{H}
30% SMD N30	2871^{D}	3106^{E}	2989^{F}	0.96^{FG}	1.12^{CDE}	1.04^{DEF}	10.39^{FG}	12.34^{CDE}	11.36^{DEF}
30% SMD N60	3424^{C}	3413^{E}	3418DE	1.13^{DE}	1.20^{CD}	1.16^{BCD}	12.19^{DE}	13.18^{CD}	12.68^{BCD}
30% SMD N120	4678^{B}	4372^{BC}	4525^{BC}	1.48^{B}	1.51^{B}	1.50^{A}	16.01^{B}	16.57^{B}	16.29^{A}
60% SMD N0	2424^{E}	3312^{E}	2868^{FG}	0.94^{G}	1.43^{B}	1.19^{BC}	10.23^{G}	15.70^{B}	12.97^{BC}
60% SMD N30	3321^{C}	4131^{CD}	3726^{D}	1.07^{DEF}	1.51^{B}	1.29^{B}	11.58^{DEF}	16.59^{B}	14.09^{B}
60% SMD N60	4388^{B}	4765^{B}	4577^{B}	1.35^{C}	1.66^{A}	1.51^{A}	14.6^{C}	18.28^{A}	16.44^{A}
60% SMD N120	5460^{A}	5383^{A}	5422^{A}	1.61^{A}	1.47^{B}	1.54^{A}	17.43^{A}	16.14^{B}	16.78^{A}
100% SMD N120	2545DE	3431^{E}	2988^{F}	0.70^{H}	1.06^{DE}	0.88^{GH}	7.54^{H}	11.61^{DE}	9.58^{GH}
100% SMD N120	4406^{B}	3912^{D}	4159^{C}	1.15^{DE}	1.02^{EF}	1.08^{CDE}	12.39^{DE}	11.20^{EF}	11.79^{CDE}
100% SMD N120	4684^{B}	4746^{B}	4715^{B}	1.17^{D}	1.22^{C}	1.20^{BC}	12.67^{D}	13.39^{C}	13.03^{BC}
100% SMD N120	5615^{A}	5665^{A}	5640^{A}	1.42^{BC}	1.42^{B}	1.42^{A}	15.34^{BC}	15.61^{B}	15.48^{A}

Letters followed by same numbers are not significantly different at P=0.05 as per DMRT.

Table 2 Agronomic nitrogen use efficiency (ANUE) and partial factor productivity of nitrogen (PFPN) of wheat for the year 2009-10 and 2010-11

	ANUE (kg of grain /kg of nitrogen)			PFPN (kg of grain /kg of nitrogen)		
	2009-10	2010-11	Pooled	2009-10	2010-11	Pooled
			Effect of irrigation			
Rainfed	28.77^{B}	17.30^{A}	23.03^{B}	49.20^{D}	46.53^{C}	47.87^{D}
30% SMD	20.46^{B}	23.34^{A}	21.90^{B}	63.91^{C}	65.62^{B}	64.77^{C}
60% SMD	29.31^{B}	22.94^{A}	26.13^{AB}	76.44^{B}	87.33^{A}	81.89^{B}
100% SMD	41.09^{A}	18.87^{A}	29.98^{A}	90.57^{A}	85.58^{A}	88.07^{A}
			Effect of nitrogen			
N0						
N30	38.80^{A}	24.24^{A}	31.52^{A}	107.58^{A}	111.07^{A}	109.33^{A}
N60	28.49^{B}	20.74^{AB}	24.62^{B}	62.88^{B}	64.15^{B}	63.52^{B}
N120	22.43^{C}	16.85^{B}	19.64^{C}	39.63^{C}	38.56^{C}	39.1^{C}
			Effect of irrigation × nitrogen			
Rainfed N30	42.05^{B}	22.53^{ABC}	32.29^{AB}	77.09^{D}	72.64^{C}	74.86^{D}
Rainfed N60	25.78^{CDE}	16.16^{BC}	20.96^{BCD}	43.27^{F}	41.21^{EF}	42.24^{FG}
Rainfed N120	18.49^{E}	13.21^{C}	15.85^{D}	27.24^{G}	25.74^{G}	26.49^{H}
30% SMD N30	21.20^{DE}	31.05^{A}	26.13^{BCD}	95.70^{C}	103.54^{B}	99.62^{C}
30% SMD N60	19.81^{E}	20.64^{ABC}	20.23^{CD}	57.06^{E}	56.88^{D}	56.97^{E}
30% SMD N120	20.36^{E}	18.32^{BC}	19.34^{CD}	38.98^{F}	36.44^{F}	37.71^{G}
60% SMD N30	29.90^{CDE}	27.32^{AB}	28.61^{ABC}	110.70^{B}	137.7^{A}	124.2^{B}
60% SMD N60	32.73^{BCD}	24.23^{ABC}	28.48^{ABC}	73.13^{D}	79.42^{C}	76.28^{D}
60% SMD N120	25.30^{CDE}	17.27^{BC}	21.28^{BCD}	45.50^{F}	44.86^{EF}	45.18^{FG}
100% SMD N30	62.03^{A}	16.05^{BC}	39.04^{A}	146.85^{A}	130.41^{A}	138.63^{A}
100% SMD N60	35.66^{BC}	21.93^{ABC}	28.79^{ABC}	78.07^{D}	79.10^{C}	78.59^{D}
100% SMD N120	25.59^{CDE}	18.62^{BC}	22.10^{BCD}	46.79^{F}	47.21^{DE}	47.00^{F}

Letters followed by same numbers are not significantly different at P=0.05 as per DMRT.

nitrogen levels had significant effect on WP and EWP. The WP and EWP increased significantly with the increasing irrigation levels and highest WP was observed at 60% SMD but beyond that level it declined. Pooled over the years, the 30% SMD and 100% SMD irrigation levels were statistically at par with respect to WP and EWP. Goswami and Sarkar (2007) and Panday *et al.* (2008) and Jat *et al.* (2008) have also observed either decreased or nonsignificant change in water productivity at higher levels of irrigation. The WP and EWP was also significantly affected by nitrogen levels. The highest WP and EWP were found in N120 treatments followed by N60, N30 and N0 treatments. Pooled over the years, the WP was 63, 40 and 25% higher, respectively in N120 and N60 and N30 treatments compared to N0 treatment. Similarly, pooled over the years, the EWP was 62, 39 and 24% higher, respectively in N120 and N60 and N30 treatments compared to N0 treatment. The higher water productivity at higher nitrogen doses was mainly due to higher grain yield of crops with similar water use at higher nitrogen doses. These results are in agreement with the Oweis *et al.* (2000) and Pandey *et al.* (2001). The interaction effect of irrigation and nitrogen on water productivity was also significant (Table 1).

The nitrogen use efficiency of wheat expressed in terms of agronomic nitrogen use efficiency (ANUE) and partial factor productivity of nitrogen (PFPN) is presented in Table 2. Both ANUE and PFPN were significantly affected by irrigation and nitrogen levels. Pooled over the years, ANUE increased from 23.03 kg of grain/kg of N for rainfed treatment to 30 kg of grain/kg of nitrogen for 100% SMD irrigation treatment. Jat *et al.* (2008) and Bandyopadhyay *et al.* (2009) also observed higher nitrogen use efficiency at higher levels of irrigation, which they attributed to the better N mineralization and least nitrogen loss through leaching and volatilization at optimum soil moisture condition ultimately leading to better plant uptake of nitrogen and hence growth and yield. ANUE was highest in N30 treatment (31.52 kg of grain/kg of N) followed by N60 (24.62 kg of grain/kg of N) and N120 (16.85 kg of grain/kg of N) treatment. This may be attributed to losses of N at higher levels of N and to the fact that yield of wheat did not increase with the same proportion as the fertilizer application. The PFPN also showed trend similar to ANUE. Among irrigation treatments, it was highest for 100% SMD treatment (88.07 kg of grain/kg of N) followed by 60% SMD (81.89 kg of grain/kg of N), 30% SMD (64.77 kg of grain/kg of N) and rainfed treatments (47.87 kg of grain/kg of N). Among nitrogen treatments, N30 treatment (109.33 kg of grain/kg of N) showed highest PFPN followed by N60 (63.52 kg of grain/kg of N) and N120 (39.10 kg of grain/kg of N) treatments. The interaction effect of irrigation and nitrogen on ANUE and

PFPN were also significant (Table 2). Pooled over the years, irrigation at 100% SMD and N30 registered the highest ANUE and PFPN in wheat.

Thus from this study, it may be concluded that wheat may be grown with irrigation to replenish 60% SMD to field capacity and at 120 kg N/ha to achieve higher water productivity and nitrogen use efficiency without any significant reduction in crop yield in sandy loam soils of semiarid region of North India

SUMMARY

A field experiment was carried out during 2009-10 and 2010-11 on a sandy loam soil of IARI, New Delhi on wheat (*Triticum aestivum* L.) with four levels of irrigation (rainfed, irrigations to replenish 30, 60 and 100% moisture deficit from field capacity) as main plot factors and four levels of nitrogen (0, 30, 60 and 120 kg N/ha) as subplot factors in a split plot design. The soil moisture storage in the profile showed inverse relation with the nitrogen levels whereas direct relationship was observed with the irrigation levels. The water use vs. wheat yield relation was linear and significant. Regression analysis showed that 58% variation in grain yield of wheat could be explained by water use. The grain yield showed increasing trend with increase in irrigation and nitrogen levels. The WP and EWP increased with increase in irrigation level up to 60% SMD and thereafter it decreased. However, both WP and EWP showed increasing trend with increase in nitrogen levels. The ANUE and PFPN increased with increase in irrigation levels, but with increase in nitrogen levels both ANUE and PFPN decreased. Grain yield, water productivity and nitrogen use efficiency showed significant interaction effect of irrigation and nitrogen.

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