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Effect of fertilizer application on nutrient and water use efficiency of wheat under limited irrigation

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Abstract
A field experiment entitled "Effect of fertilizer application on water and nutrient use efficiency of wheat under limited irrigation" was conducted during *Rabi* 2019-20 at Soil Research Farm, CCS Haryana Agricultural University and Hisar. The study includes three irrigation levels in the main plot *viz.*, one (CRI), two (CRI and flowering stage) and three irrigations (CRI, late jointing and dough stage) and four fertilizer levels in the subplots (control, 75, 100, 125 per cent RDF). The results indicate that the three irrigations and 125 per cent RDF under fertilizer treatment resulted in higher N, P and K content and uptake both in grain and straw, agronomic efficiency, apparent recovery. The water use efficiency was highest under two irrigations followed by three and one irrigation, but in case of fertilizer levels, it was found to be highest under 125 percent RDF followed by lower fertilizer levels.

Keywords: Wheat, limited irrigation, fertilizer, apparent recovery, water use efficiency, agronomic efficiency

Introduction
Agriculture is the most vulnerable of all sectors of the economy to water scarcity. It accounts for 70% of global freshwater and more than 90% of consumptive use in the domestic and industrial sectors (FAO, 2009) [12]. Presently, the agricultural sector accounts for about 83 percent of all water uses. Other sectors like domestic, industrial and energy sectors and other consumers use 5, 3, 6 and 3 per cent, respectively. Increasing competition with other water users in the future would limit the water availability for expanding irrigated areas, further climate change aggravates this crisis. It will become a challenging problem for the farming industry to feed the rising world population with little available irrigation water.

In India, the irrigated area consists of about 36 percent of the net sown area. The proportion of irrigated wheat in Punjab, Haryana and Rajasthan is over 97 percent. The declining groundwater table necessitates a move to limited irrigation in regions of Haryana, intending to increase output per unit of water applied rather than maximizing production per unit of land. Recent advancements in dry land agriculture have increased yield stability by limited irrigation, along with scheduling of irrigation at the proper stage of crop to assess the production potential of various cropping systems (Hergert *et.al.*, 1993) [13]. In North India, wheat is grown as *Rabi* crop. During this period crop weather remains relatively dry, except a few light showers which may be achieved occasionally. The water scarcity is increasing especially in arid and semi-arid regions and due to this yield is significantly reduced because of limited availability of water.

To improve fertilizer use efficiency, nutrients should be applied at the right place, at the right time, at the right rate and from right source. Soil fertility management is important for increasing and preserving agronomic and biomass productivity. Intensive agricultural agro ecosystems can only be long-term sustainable practice, if the outputs of all generated components are balanced by sufficient inputs in order to maintain the inherent nutrient capacity of soil. The use of adequate fertilizer has a significant impact on wheat yield. Nitrogen promotes early plant growth, improves seed quality, enhances the growth of leafy vegetables and increases the protein content of grains (Bloom, 2015) [11]. Furthermore, when nitrogen and phosphorus are combined, the overall productivity of crop is also enhanced (Stoeva and Tonev, 2003) [16].

Materials and Methods

The experiment was conducted at Soil Research Farm, CCS Haryana Agricultural University and Hisar during *Rabi* season, 2019–20. Hisar is situated in in the western region of Haryana comes under the great Indo-Gangetic plains, with Latitude 29' 10A" N, Longitude 75'46A" E and Altitude 215.2 m. The region has a subtropical semi-arid climate, with hot and dry summers, extremely cold winters, and humid warm monsoon months with average rainfall of 450 mm. The mean weekly maximum and minimum temperature ranges were 35.1–11.9 °C and 17.7–2.6 °C, respectively recorded during the crop season. Mean morning relative humidity was between 100 and 71 percent, while evening relative humidity was between 24 and 82 percent. The crop season's weekly mean wind velocity range was 1.5-6.4 km hr^{-1}, with the range nearly rising in magnitude as the crop season progressed. The highest evaporative demand was 4.9 mm per day during the 15th standard week, while the lowest open pan evaporation was recorded during the 3rd standard week with 0.5 mm per day (Fig. 1). The soil of experimental field was silty loam texture with low available N (134.4 kg ha^{-1}), medium in available P (17.5 kg ha^{-1}) and high available K (318.5 kg ha^{-1}). The experiment was laid out in split plot design with three replications.

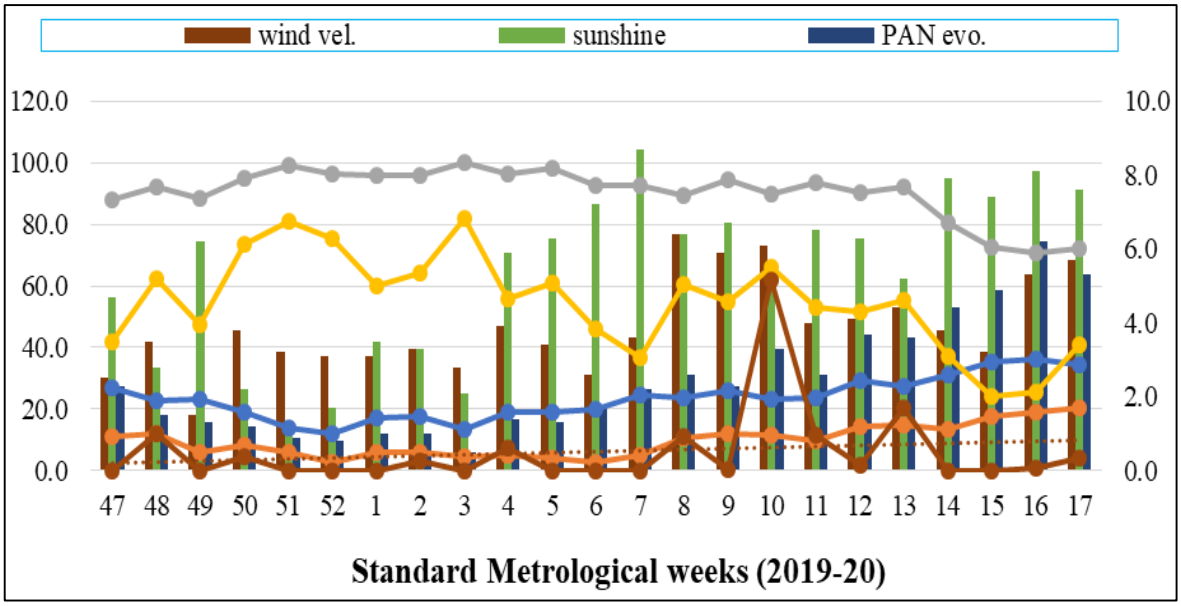

Fig 1: Mean weekly meteorological data during crop growing season 2019-20

The experimental treatments consisted of combination of three irrigation levels *viz.*, one (CRI), two (CRI and flowering stage) and three irrigations (CRI, late jointing and dough stage) in main plots and four fertilizer levels (control, 75, 100 and 125% RDF) in sub-plots. The recommended doses of fertilizers, *i.e.*, 60:40:40 N, P_2O_5 and K_2O kg ha^{-1} was applied to wheat (*cv.* WH1142) as per the treatment. Application of fertilizer was same for all the treatments *i.e.*, 60 kg N ha^{-1} applied in 2 splits, 40 kg P_2O_5 ha^{-1} and 40 kg K_2O ha^{-1}, applied basal as urea, diammonium phosphate and muriate of potash, respectively. Other crop-management practices were as per the local package of practices of the HAU (Package of Practices). The data recorded for different parameters were analysed with the help of analysis of variance (ANOVA) technique for a split plot design. The results are presented at 5% level of significance (p = 0.05).

N, P and K content

For analysis of N, P and K oven dried plant material (grain and straw at harvest) from each plot were ground separately with grinder. The methods used for analysis were Nessler's reagent method for nitrogen, Vanadomolybdo-phosphoric acid yellow colour method (Jackson, 1973) [14] for phosphorus and Flame photometer method (Richards, 1954) [15] for potassium contents.

Protein content

Protein content in grain was calculated by following formula:

$$\text{Protein content} = \text{N content (\%) in grain} \times 6.25.$$

Nutrient uptake (%)

Uptake of each nutrient was computed as follows:

$$\text{Nutrient uptake} = \frac{\text{Percent nutrient content in grain or straw} \times \text{yield}}{100}$$

Periodic soil moisture depletion

To monitor the profile soil moisture status of the active root zone gravimetrically at sowing, before and after each irrigation and at harvest, soil samples were taken from 0-15, 15-30, 30-60, 60-90 and 90-120 cm depth, weighed to record the wet weight and kept in a hot air oven at 105°C till a constant weight was obtained. The moisture content in entire root zone (cm) was calculated by using the following formula:

$$M = \sum \frac{Mi \times Dbi \times Di}{100}$$

Where,
M = Amount of moisture in 0-120 cm in soil profile in cm
Mi = Moisture per cent of i^{th} layer
DBI = Bulk density of i^{th} layer
Di = Depth of i^{th} layer

For calculating total water use, soil moisture depleted, irrigation water and effective rainfall was summed up. The effective rainfall was calculated by using Cropwat software.

Water productivity (kg ha^{-1} mm)

$$WP = \frac{\text{Grain yield(kg/ha)}}{\text{Total water use (mm)}}$$

Economic optimum dose

The agronomic efficiency, physiological efficiency, apparent recovery efficiency and nitrogen use efficiency were calculated by following formula.

$$\text{Agronomic efficiency} = \frac{\text{Grain yield of fertilized crop in kg} - \text{Grain yield of unfertilized crop in kg}}{\text{Quantity of fertilizer applied in kg}}$$

$$\text{Physiological efficiency} = \frac{\text{Total DM in yield of fertilized crop in kg} - \text{Total DM of unfertilized crop on kg}}{\text{Nutrient uptake by fertilized crop in kg} - \text{Nutrient uptake by unfertilized crop in kg}}$$

$$\text{Apparent recovery eficiency} = \frac{\text{Nutrient uptake by fertilized crop in kg} - \text{Nutrient uptake of unfertilized crop on kg}}{\text{Quantity of fertilizer applied in kg}} \times 100$$

Results

Nutrient content

With the increasing levels of irrigation, nitrogen, phosphorus and potassium contents in grain and straw was increasing (Table 1). Because adequate moisture supply gives better root growth and density which helps in better accumulation of nutrients in the plants (Bindraban *et al.*, 2015) [10]. Xu *et al.* (2005) [19] also reported decrement in nitrogen translocation amount and efficiency with a decline in irrigation or by excessive irrigation.

Among fertilizer levels, application of 125 percent RDF recorded highest content of nitrogen, phosphorus and potassium in grain and straw and the lowest nitrogen, phosphorus and potassium contents in grain and straw were recorded in unfertilized plot. It may happen because of high nutrient availability to plant throughout the crop's life cycle.

Table 1: Effect of irrigation and fertilizer levels on nutrient content in grain and straw of wheat

Treatments	N content (%)		Protein (%)	P content (%)		K content (%)	
	Grain	Straw		Grain	Straw	Grain	Straw
Irrigation levels							
CRI	1.75	0.24	10.91	0.43	0.038	0.24	1.35
CRI + Flowering	1.77	0.27	11.04	0.44	0.052	0.28	1.38
CRI+ Late jointing + Dough	1.80	0.28	11.22	0.45	0.066	0.29	1.43
SE m ±	0.02	0.003	0.14	0.01	0.001	0.002	0.01
CD (p = 0.05)	NS	0.01	NS	NS	0.002	0.01	0.06
Fertilizer levels							
Control	1.57	0.21	9.80	0.34	0.031	0.22	1.22
75% RDF	1.74	0.24	10.87	0.37	0.046	0.25	1.39
100% RDF	1.87	0.30	11.68	0.49	0.058	0.31	1.46
125% RDF	1.90	0.31	11.88	0.56	0.073	0.31	1.48
SE m ±	0.03	0.005	0.16	0.01	0.001	0.005	0.02
CD (p = 0.05)	0.08	0.01	0.48	0.02	0.003	0.01	0.07

Protein content

From the table 1, it has been observed that the protein content increased with increase in irrigation levels but not significantly. However, numerically three irrigations showed the highest protein as compared to two and one irrigation. Also, with the increment in the fertilizer doses, protein content significantly increased, the highest grain protein was found under 125 per cent RDF while lowest was found in control. This might be due to more available nitrogen in the soil due to high fertilization practices which leads to more accumulation of nutrient in the plant. The same findings were also observed by other researchers like Wu *et al.* (2019) [18] and Stupar *et al.* (2021) [17].

Nutrient uptake

From table 2, it has been observed that the N, P and K uptake by grain and straw was more under three irrigations as compare to one irrigation, because optimum moisture in soil increased the availability of nutrients to plant through high transpiration that leads to mass flow of nutrient, hence better uptake of nutrients was observed by Kumar *et al.* (2015) [8].

In case of fertilizer level, nutrient uptake was highest in 125 percent RDF in comparison to control plot. This might be due to higher amount of readily available nitrogen, phosphorus and potassium under higher fertilizer doses may have helped the crop to uptake and accumulate higher amount of nutrients. The other reason is that nutrient uptake was calculated by multiplying nutrient content in grain and straw with their respective yields which was more under 125 per cent RDF, consequently result into high nutrient uptake.

Table 2: Effect of irrigation and fertilizer levels on wheat nutrient uptake

Treatments	N uptake (kg ha^{-1})			P uptake (kg ha^{-1})			K uptake (kg ha^{-1})		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
Irrigation levels									
CRI	48.8	10.7	59.5	12.2	1.7	13.9	6.9	58.6	65.4
CRI + Flowering	76.4	16.5	92.9	19.6	3.2	22.8	12.2	82.8	95.0
CRI + Late jointing + Dough	86.1	18.9	105	21.9	4.5	26.4	14.2	93.8	107.9
SE m ±	2.7	0.4	3.0	0.8	0.1	0.9	0.4	2.0	2.3
CD (p = 0.05)	11.0	1.8	12.3	3.3	0.3	3.4	1.6	8.1	9.3
Fertilizer levels									
Control	45.2	9.2	54.4	9.9	1.4	11.3	6.3	53.0	59.2
75% RDF	65.3	13.2	78.5	13.8	2.6	16.3	9.3	76.2	85.5
100% RDF	79.3	18.3	97.6	20.9	3.7	24.6	13.2	88.9	102.2
125% RDF	91.9	20.6	112.6	27.0	4.9	31.9	15.4	95.4	110.9
SEM ±	1.8	0.4	2.1	0.6	0.1	0.7	0.3	2.0	2.1
CD (p = 0.05)	5.4	1.3	6.2	1.8	0.3	2.0	0.9	6.1	6.3

Nutrient use efficiency

From the table 3, it is observed that with increase in irrigation level, all the fertilizer use efficiency (*i.e.*, agronomic efficiency, apparent recovery and nutrient use efficiency) increased. This is due to the reason that with increasing the number of irrigation, the nutrient uptake and yield also increased. The adequate moisture provided in higher irrigation levels will increase the efficient utilization of nutrients, hence the apparent recovery also increased. Supported findings are Kumar and Pannu (2012) [7] and Bandyopadhyay *et al.* (2010) [5]. The increase in the level of fertilizer resulted in increased value of nutrient use efficiency, agronomic efficiency and apparent recovery. This might be due to increased nutrient uptake by wheat even under higher fertilizer doses, that's why the recovery of applied fertilizer increase, so is the nutrient use efficiency, as, in this experiment wheat shows positive response with the increment in fertilizer dose even beyond RDF. However, 75 per cent RDF resulted in higher physiological efficiency, while lower value was obtained under 125 per cent RDF. This might be due to the higher uptake of nutrients with the application of increased fertility levels.

Table 3: Effect of irrigation and fertilizer levels on agronomic efficiency, physiological efficiency and apparent recovery of wheat

Treatments	Agronomic Efficiency (kg grain per kg N)	Physiological Efficiency (kg grain per kg uptake)	Apparent Recovery (%)
Irrigation levels			
CRI	2.11	27.93	17.14
CRI + Flowering	5.86	23.71	38.82
CRI + Late jointing + Dough	7.95	25.58	51.54
SE m ±	0.78	1.40	2.88
CD (p = 0.05)	3.13	NS	11.63
Fertilizer levels			
75% RDF	5.93	35.96	38.84
100% RDF	7.12	33.25	51.00
125% RDF	8.18	32.42	53.49
SEM ±	0.47	2.32	2.55
CD (p = 0.05)	1.40	6.94	7.63

Water productivity (WP)

From the table 4, it is clearly shown that the water productivity was higher under two irrigations as compared to three irrigations. The lowest water productivity was observed with one irrigation only. Supported findings are Ram *et al.* (2013) [3] and Singh *et al.* (2010) [4].

Among the fertilizer levels, the highest water efficiency was recorded with 125 per cent RDF and lowest under control. Application of more nitrogen favored the growth of plants, thereby consumed more amount of water for their metabolic processes and transpiration which in term led to higher water productivity (Chen *et. al.* 2014) [2]. This might be due to the fact that increasing nutrient level increase the grain yield which consequently resulted into higher water productivity. Tiwari *et al.* (2016) [1] also found that the WUE was increasing with increasing nutrient proportion.

Table 4: Effect of irrigation and fertilizer levels on total water use and water productivity of wheat

Treatments	Soil moisture depletion (mm)	Effective Rainfall (mm)	Irrigation Water (mm)	Total Water (mm)	Water Productivity (kg ha^{-1} mm)
Irrigation levels					
CRI	129.8	94.3	60.2	284.3	9.2
CRI + Flowering	104.7	94.3	120.8	319.8	13.3
CRI + Late jointing + Dough	82.4	94.3	181.1	357.8	13.2
Fertilizer levels					
Control	96.7	94.3	120.6	311.6	9.3
75% RDF	101.4	94.3	120.6	316.3	11.8
100% RDF	107.1	94.3	120.6	322.0	13.2
125% RDF	117.3	94.3	120.6	332.2	14.5

Conclusion

From the above study, it may be concluded that in case of irrigation level, with increase in irrigation level, all the fertilizer use efficiency (*i.e.*, agronomic efficiency, apparent recovery and nutrient use efficiency) increased, except, physiological efficiency which decreased with increase in irrigation level but, the water productivity was higher under two irrigation as compared to three irrigations. Among the fertilizer levels, the highest water efficiency was recorded with 125 per cent RDF and lowest under control.

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