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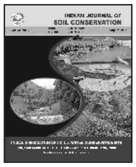

Resource conservation in wheat (*Triticum aestivum* L.) under different water and nitrogen stress levels

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ABSTRACT

A field experiment with four irrigation and four nitrogen treatments was carried out with wheat (*cv* HD 2932) for two *rabi* seasons, 2009-10 and 2010-11 at ICAR-Indian Agricultural Research Institute, New Delhi to quantify the water and nitrogen use efficiencies under differential water and nitrogen levels. Responses of water-use efficiency (WUE), nitrogen-use efficiency (NUE) and wheat yield to variable water and nitrogen levels were investigated. Yield and NUE are significantly affected ($P \leq 0.05$) by the different water and nitrogen levels. Under low water level condition along with no nitrogen stress resulted in only 5% decrease in yield compared to the highest yield but it had increased NUE from 34 to 38%. Therefore, low water stress can be allowed which can result in higher NUE and non-significant decrease in yield. The study revealed that the lower water stress resulted in higher NUE, however, higher water stress resulted in decline in NUE.

1. INTRODUCTION

In India, wheat is the second most important cereal crop after rice, which is cultivated in an area of about 30 m ha with a production of 95 m tonne and the average yield is 3.1 t ha^{-1} (http://www.indiaagristat.com). Inappropriate use of applied inputs and overexploitation of resources, principally water, is leading to secondary salinization in low-quality aquifer zones, groundwater table recession in fresh water aquifer zones, physical and chemical deterioration of the soil and water quality due to nutrient mining and pollution of ground water due to over application of nitrogenous fertilizers (Gupta *et al*., 2003).Water shortage is an important factor limiting grain production in many parts of the world (Khan *et al*., 2009; Dong *et al*., 2011). During the wheat growing season (from mid-November to mid-April of the following year), the mean precipitation is about 50 mm, while the evapo-transpiration of wheat can reach up to 400 mm. Therefore, irrigation is required to satisfy the consumptive use of the crop. Burgeoning population and industrialization has increased the gap of supply and demand of water which is leading to less availability for agricultural purposes. Therefore, it is an utmost need to enhance water-use efficiency (WUE) of the crop *i.e.*, to produce more grain per unit of water. There has been a tendency to apply higher amount of irrigation water and fertilizer for increasing the agricultural production (Hussain and Al-Jaloud, 1995) which reduces the efficiency to a great extent. Higher WUE can be attained by reducing percolation and runoff losses (Li *et al*., 2004). WUE can be managed by applying deficit irrigation practices (Abbate *et al*., 2004), by providing irrigation at critical crop growth stages and allows development of water stresses at non-critical stages of the crop and by applying efficient micro-irrigation systems in place of flood irrigation practices (Buttar *et al*., 2006; Rathore *et al*., 2014).

After irrigation, nitrogenous fertilizer is the second most important input (Lenka *et al*., 2009) for wheat crop growth and development.The indiscriminate use of nitrogenous fertilizer to increase yield reduces the NUE as well as increases the probability of ground water pollution. Hence, the efficient use of nitrogenous fertilizer is crucial for sustainable crop production. It has been reported by some researchers that the optimum nitrogenous fertilizer dose are required for maximum utilization of elemental N (Rathore and Singh, 2009; Rahimizadeh *et al*., 2010; and

Sharma *et al*., 2012). Worldwide, NUE for cereal crop production is approximately 33% (Mosier, 2002). The unaccounted 67% represents the loss of N which amounts to a \$16 billion annual loss of N fertilizer (Raun and Johnson, 1999). The losses of fertilizer N increase at higher rates of fertilizer N application (Timsina *et al*., 2001). Therefore, the present focus in crop production has shifted to increase input use efficiency for maximizing benefit. Thus, the study was undertaken to assess the impacts of water and N stress levels on WUE and NUE associated with changes in crop yield of wheat as a function of water and nitrogen stress factor. Based on this study a tool may be developed to optimize crop yield and NUE which will be helpful in predicting the individual and interactive effects of water and nitrogen levels on these variables.

2. MATERIALS AND METHODS

Experimental Site

The field experiment was conducted at experimental field of Indian Agricultural Research Institute, New Delhi, India (28°35' N latitude, 77°12' E longitude and 229 m above mean sea level) during the growing season of *rabi* (from November to April) in 2009-2010 and 2010-11 with wheat (*Triticuma estivum* L.) variety HD 2932. Delhi, located under Indo-Gangetic Plains (IGP) has semi-arid and sub-tropical climate with extreme hot summer and cool winter. June is the hottest month with 45°C mean monthly maximum temperature and January is the coldest month with 6 ^{o}C mean monthly minimum temperature. The mean annual rainfall is about 680 mm of which 75-80% is received during monsoon periods of July to September. The soil is yellowish to dark brown silty clay loam belongs to the major soil group of Indo-Gangetic alluvium, hyperthermic family of Typic Haplustepts. The soil is slightly alkaline having pH (1:2.5 soil: water suspension) of 7.23 to 7.75 and electrical conductivity (EC) of 0.11 to 0.31 dSm^{-1} has soil depth more than 1.20 m. The experimental site has bulk density (B.D) of 1.44 to 1.64 Mg m^{-3}; field capacity of 32 to 38% (v/v); wilting point of 6.7 to 9.0% (v/v); saturated hydraulic conductivity of 0.70 to 1.01 cm hr^{-1}; organic C 0.003%, total N of 0.03%; available (Olsen) P of 7.0 kg ha^{-1} and available K of 280.0 kg ha^{-1}.

Experimental Details

To generate a range of water and nitrogen stresses, wheat crop was grown in split plot design with four levels of irrigation *viz.* no irrigation (I_0), 30% (I_1), 60% (I_2) and 100% (I_3) replenishment of soil moisture depletion (SMD) from field capacity (FC) in 0-120 cm soil profile at critical growth stages and four levels of nitrogen *viz*., 0 (N_0), 30 (N_1), 60 (N_2) and 120 kg N ha^{-1} (N_3).The SMD for each soil layer (0-15, 15-30, 30-60, 60-90 and 90-120 cm) was calculated using the formula: SMD (cm) = $(\theta_{fc}-\theta_i)\times BD\times z$ where, θ_{fc} is mass water content at field capacity (%), θ_i is mass water content before irrigation (%), BD is the bulk density (g cm^{-3}) and z is the depth of soil layer (cm). The experiment was conducted in the plot size 5×4 m with three replications where irrigation levels were the main plot treatment and nitrogen levels were the sub-plot treatment. Nitrogen was applied in three equal splits at the time of first (21 days after sowing (DAS)), second (54 DAS) and third (84 DAS) irrigation. Except for the irrigation and N, all treatments received the same field management operations, including recommended dose of P (60 kg P_2O_5 ha^{-1} as single super phosphate) and K (60 kg K_2O ha^{-1} as muriate of potash).The crop received 14 and 56 mm of rainfall during 2009-10 and 2010-11, respectively. In addition to rainfall, measured amount of irrigation was applied at critical crop growth stages using parshall flume. The total water applied in different irrigation treatments was104, 219, 259 and 314 mm during 2009-10 and 156, 235, 256 and 296 mm during 2010-11 in I_0, I_1, I_2 and I_3, respectively. The wheat crop was sown on 25 and 24 November, during 2009 and 2010, respectively and was harvested on 11 April in both the years. The daily weather parameters of 2009-10 and 2010-11 are presented in Fig. 1.

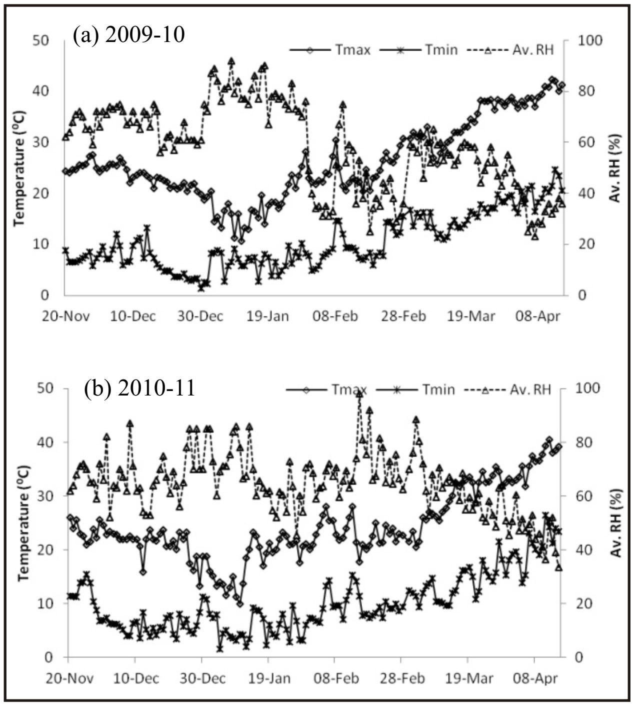


Fig. 1. Daily maximum, minimum temperature (°C) and average relative humidity (Av. RH, %) during (a) 2009-10 and (b) 2010-11

Measurements

The above ground biomass was determined at each growth stage (CRI, tillering, booting, flowering, milking and maturity) of the crop through destructive plant sampling. Plant and grain nitrogen content was estimated using Micro-Kjeldahl method (Guebel *et al*., 1991). The plant nitrogen uptake use efficiency (NUE, %) can be calculated as a ratio of the 'difference of nitrogen uptake from fertilized plot and from control' and 'total nitrogen applied' and is given as:

$$NUE = [N_f - N_c] / F \quad \ldots(1)$$

Where, N_f is nitrogen uptake from fertilized plot (kg ha^{-1}), N_c is nitrogen uptake from control (kg ha^{-1}) and F is the total N applied (kg ha^{-1}). Nitrogen uptake (kg ha^{-1}) from a plot was calculated by multiplying per cent N concentration in plant and weight of dry matter (kg ha^{-1}) and divided by 100 and is given as:

N uptake (kg ha^{-1}) = [N concentration in plant (%) x Dry matter of plant (kg ha^{-1})]/100 .. (2)

The water-use efficiency (WUE, kg ha^{-1} mm^{-1}) can be calculated as a ratio of 'grain yield attained by a treatment and the 'total evapo-transpiration occurred from sowing to harvest' and is given as:

WUE = [Grain yield (kg ha^{-1})] / [Seasonal evapo-transpiration (mm)] … (3)

Seasonal evapo-transpiration was computed using field water balance method (Hillel, 1998).

Water and Nitrogen Stress Factor

Differential nitrogen stresses in plants were due to four nitrogen treatments, were quantified by a nitrogen stress factor (NSF) which was defined as NSF = $[N_r - N_a] / N_r$ where, N_r and N_a are the recommended dose and actual dose of nitrogen (kg ha^{-1}), respectively during the crop duration. The recommended dose of N was the highest N application in N_3 treatment and decreased in other treatments to create increasing degree of N stresses. During the both years, the NSF values were 1, 0.50, 0.25 and 0 for nitrogen treatment N_0, N_1, N_2 and N_3, respectively. In order to quantify the water stress level under different irrigation treatment, a water stress factor (WSF) was calculated which was defined as WSF = $[W_r-W_a] / W_r$ where, W_r and W_a are recommended and actual water application (mm) during the crop duration. In this study, the maximum water applied was the recommended amount of water (I_3), when crop did not suffer a water stress. The WSF has a value zero for the treatment having recommended water application treatment and its value increases as the applied water decreases and hence water stress increases (Table 1).

Table: 1
Water stress factor (WSF) under different irrigation treatments during 2009-10 and 2010-11

Irrigation treatment	2009-10		2010-11	
	Rainfall+Water applied (mm)	WSF	Rainfall+Water applied (mm)	WSF
I_0	104	0.67	156	0.47
I_1	219	0.30	236	0.20
I_2	259	0.18	256	0.14
I_3	314	0	296	0

Statistical Analyses

All the statistical analysis was performed using the SAS 9.3. Standard deviations for each treatment were calculated. Mean values were compared using Duncan multiple range test (DMRT) for a probability level of $P \leq 0.05$.

3. RESULTS AND DISCUSSION

Effects of Water and Nitrogen Stresses on Grain Yield

Water and nitrogen stress affected wheat yield significantly ($P \leq 0.05$) in both the years. Impact of water stress showed that the grain yield under all the irrigation treatments was significantly different during the first year (Table 2).The highest grain yield (56.2 q ha^{-1}) was observed under no water and no N stress (I_3N_3) whereas the lowest grain yield (10.5 q ha^{-1}) was observed under maximum water and maximum N stress (I_0N_0). Similar observations were also recorded in second year (2010-11). However, yields were at par under I_3 (WSF= 0) and I_2 (WSF= 0.14) under all N treatments in both years except N_2 in first year. This indicated that reduction of water input by 14% does not reduce the mean yield significantly. The analysis also revealed that the water stress equal to or more than 0.18 (WSF $\geq$ 0.18) significantly decreased wheat yield. Sarma *et al.* (2007) have reported significantly higher yield of wheat under adequate irrigation at Hissar, Haryana. Increasing trend of wheat yield up to a certain irrigation level was also confirmed by several researchers (Gupta *et al.,* 2006; Ram and Mir, 2006; Nadeem *et al*., 2007).

As the nitrogen application rate was progressively increased, the grain yield of wheat increased significantly during both the years. The differences in yield were mainly attributed by an increase N uptake by wheat which leads to

Table: 2
Effect of water and nitrogen treatment on grain yield (q ha^{-1}) of wheat during 2009-10 and 2010-11

Treatment	2009-10				2010-11			
	N_0	N_1	N_2	N_3	N_0	N_1	N_2	N_3
I_0	10.5^C	23.1^D	26.0^C	32.7^C	15.0^C	21.8^C	24.7^C	30.9^C
I_1	22.4^B	28.7^C	34.2^B	46.8^B	21.7^B	31.1^B	34.1^B	43.7^B
I_2	24.2^A	33.2^B	43.9^A	54.6^A	33.1^A	41.3^A	47.7^A	53.8^A
I_3	25.4^A	44.1^A	46.8^A	56.2^A	34.3^A	39.1^A	47.5^A	56.7^A

Different letters following the values in column indicate significant differences at the level of $P \leq 0.05$, based on the DMRT.

improve the integrity of plant structure and key physiological processes such as light interception by chlorophyll, energy for carbohydrate build-up and enhanced the hydraulic conductivity of the root cortical cells, thereby improving the yield. These results are in agreement with those of Kumar *et al*. (2007); Sharma *et al.* (2011); Jat *et al*. (2014) and Pradhan *et al*. (2014) who reported the grain yield increased by increasing N level in wheat.

The interaction of water and nitrogen treatments also affected the yield significantly ($P \leq 0.05$) during the first year. The interaction was statistically at par during the second year, probably due to two reasons. First, the range of water stress among different treatments was much wider during first year (ΔWSF = 0.67) as compared to a narrow range during the second year (ΔWSF = 0.47). Second, the water stress values were much lower during second year, indicating wetter conditions in the soil profile. This led to non-significant interaction of N stress and water stress during the second year.

Effects of Water and Nitrogen Stresses on NUE

The nitrogen-use efficiency in terms of nitrogen uptake use efficiency was significantly higher in I_2 (60% water replenishment of SMD) than I_0 (rain-fed) and I_1 (30% water replenishment of SMD) under all N treatments (Table 3). Interestingly, NUE was not observed maximum under I_3 but I_2. As compared to zero WSF (I_3), the NUE increased under I_2 during both the years when water input reduced to create a WSF of 0.18 (2009-10) and 0.14 (2010-11) except under high nitrogen stress condition (N_1; NSF = 0.75). When the water stress was further increased, the NUE was found to reduce under all N stress treatments in both the year. Therefore, during both the years, the I_2 treatment showed maximum NUE compared to higher water stresses (I_0 and I_1) and lower water stress (I_3) in lower to no N stress conditions (N_2 and N_2). Bandyopadhyay *et al.* (2009) in cotton 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. There was no significant difference in NUE between N_3 (120 kg N ha^{-1}) and N_2 (60 kg N ha^{-1}), but was significantly higher NUE as compared to in N_1 (30 kg N ha^{-1}) during both the years. Rathore and Singh (2009) in tuberose and Pradhan *et al.* (2014) in wheat also observed decreased NUE at higher levels of nitrogen. Response surface plot (Fig. 2) between water and nitrogen applied *vs* NUE showed that under I_1 (219 and 236 mm water applied during 2009-10 and 2010-11, respectively) and I_2 (259 and 256 mm water applied during 2009-10 and 2010-11, respectively) treatments, NUE was the maximum under all N application levels. At a given water application level, NUE decreases with increased N application. This effect was more pronounced at higher water applications. Similar effect of N application on NUE was observed during second year also.

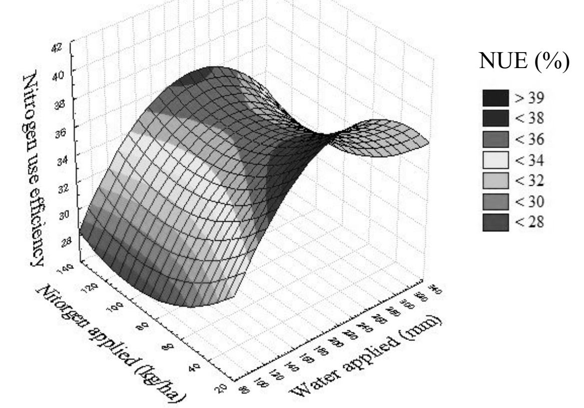
The NUE was very much affected by N stress and water stress. Although, in the present study, NUE was observed highest in I_3N_1 treatment during both the years, but it is not economical because yield loss was approximately 31%. There was negative effect of N on NUE at a given water level. Ammonification of N fertilizer occurs in plots

Table: 3
Effect of water and nitrogen treatment on nitrogen-use efficiency (%) of wheat during 2009-10 and 2010-11

Treatment	2009-10			2010-11		
	N_1	N_2	N_3	N_1	N_2	N_3
I_0	33.6^D	30.8^C	30.0^C	35.0^C	31.3^C	29.0^C
I_1	37.6^C	34.7^B	34.0^B	39.0^B	36.0^B	35.9A^B
I_2	40.6^B	37.7^A	37.3^A	41.6^B	38.6^A	37.9^A
I_3	42.1^A	36.7^A	35.4^B	44.0^A	37.3A^B	34.1^B

Different letters following the values in column indicate significant differences at the level of $P \leq 0.05$, based on the DMRT.

(a) 2009-10



(b) 2010-11

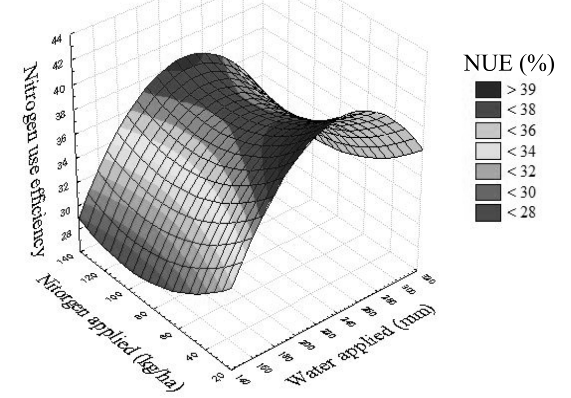


Fig. 2. Response surface plot of nitrogen-use efficiency (NUE) under different water and nitrogen application levels during (a) first year (2009-10) and (b) second year (2010-11) of wheat

fertilized with high N and ammonia is liberated in the atmosphere in the form of gas. This results in lower NUE. The NUE was significantly affected by soil water stress. As the water stress increased from I_2 to I_1, NUE deceased by almost 3%. Under excess water condition, leaching losses of N fertilizer occur in the form of nitrate (very labile) to the deeper soil depths causing soil water pollution, whereas, under excess water stress condition, volatilization of N fertilizer occurs. Thus, at both the extremes, NUE decreases. Based on such interactive effects, it can be inferred that low water stress up to I_2 (0.18 WSF) was beneficial for improvement in NUE with associated insignificant reduction in yield.

In treatment I_2N_1 as well as I_1N_1 NUE was also high, but percentage decrease in yield was also significantly high (27 and 45%, respectively). The application of low stress of water along with no stress of nitrogen resulted in only 5% decrease in yield compared to the highest yield (I_3N_3) but it had increased NUE from 34% to 38%. The results also indicated that if low water stress condition prevailed in a given situation and the growers were ready to accept 16% decrease in yield, then low stress of N could also be allowed. This will increase NUE from 34 to 38% and require less expenditure on N fertilizer. The implication of this result is that under marginal drought conditions, it is not wise to apply full recommended dose of N fertilizer.

Effect of Water and Nitrogen Stresses on WUE

Water-use efficiency is a function of water and nitrogen stresses experienced by the crop. The WUE under different water and nitrogen treatments is presented in Table 4 for both the two years. Effect of different water stress levels on water-use efficiency was not very much significant under different N levels. However, in both the years, WUE was found to increase with increase in water applied (decreasing water stress) upto I_2 level of irrigation in almost all N levels. The finding indicated that I_2 (60% water replenishment of SMD) treatment was the optimum water supply to wheat crop for maximum utilization of water. These results are in consonance with Dutta and Mondal (2006), Nadeem *et al.* (2007) and Sarkar *et al.* (2010) who observed either decreased or non-significant change in WUE at higher levels of irrigation. Increase in levels of N enhances the WUE. The WUE was observed significant higher in N_3 (120 kg N ha^{-1}) than the other N treatment in both the years. The increase in water-use efficiency with increase in N level might be due to greater grain yield. These results also corroborate the findings of Rathore *et al.* (2014) and Pradhan *et al.* (2014).

In both years, the WUE was found maximum in I_2N_3 treatment (16.43 and 15.95 kg ha^{-1} mm^{-1}, respectively). Response surface plot showed the trend of variation of WUE with changes in water and nitrogen applied (Fig. 3).

Table: 4
Effect of water and nitrogen treatment on Water-use efficiency (kg ha^{-1} mm^{-1}) of wheat during 2009-10 and 2010-11

Treatment	2009-10				2010-11			
	N_0	N^1	N_2	N_3	N_0	N_1	N_2	N_3
I_0	5.24^B	10.27^A	11.2^{0B}	15.52^{AB}	5.98^C	8.53^C	10.28^C	13.34^C
I_1	8.10^A	10.29^A	11.29^B	15.45^B	8.12^B	11.23^B	12.12^B	14.65^B
I_2	9.47^A	10.72^A	13.52^A	16.43^A	10.24^A	12.73^A	14.37^A	15.95^A
I_3	6.99^B	11.99^A	11.73^B	14.21^C	8.95^B	11.39^B	11.91^B	14.15^B

Different letters following the values in column indicate significant differences at the level of $P \leq 0.05$, based on the DMRT.

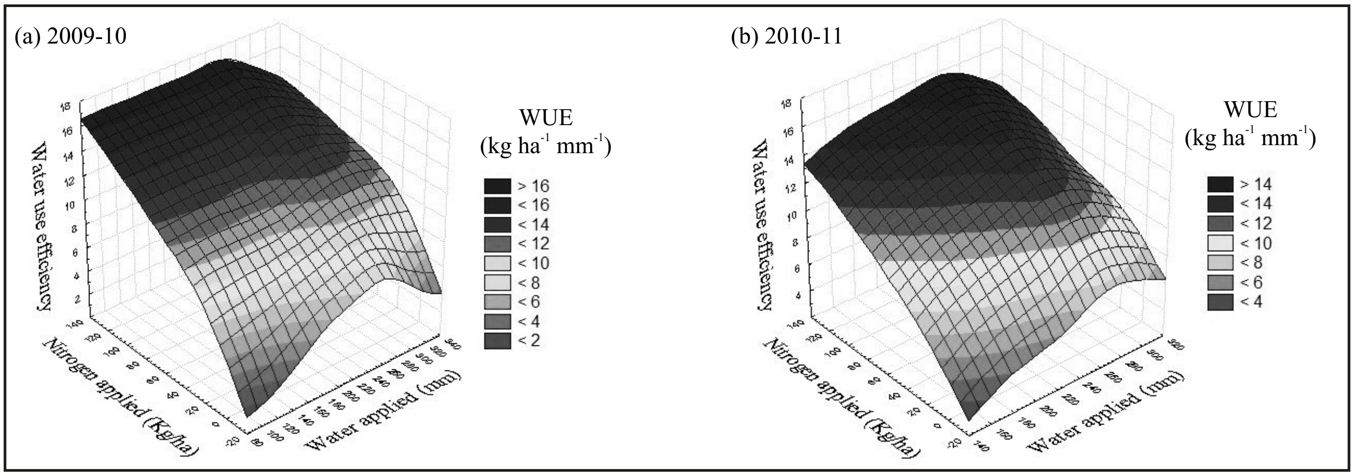


Fig. 3. Response surface plot of water-use efficiency (WUE) under different water and nitrogen application during (a) first year (2009-10) (b) second year (2010-11) of wheat

This graph showed that full recommended amount of water does not result in highest WUE but it is a low water stress condition where the plants use water most efficiently. The primary reason for this is that total water requirement of crop includes the water losses also which get reduced in low water stress conditions. Therefore, as long as yield does not get affected significantly, low water stress can be allowed to save water as a depleting resource.

The yield reduction was observed very high of the tune of 40-60% under moderate N stress treatments. The study concluded that the strategy of applying recommended amount of water and N do not result in the highest WUE and NUE although it produced highest yield. Under situations of less availability of water and N, a better strategy is required to improve WUE and NUE at the cost of non-significant reduction in yield. The best strategy for wheat in such situation would be low stress of water with no N stress for wheat cultivation which can increase NUE (34 to 38%) with non-significant decrease in yield.

4. CONCLUSIONS

It is concluded that wheat yield and NUE are significantly affected by the irrigation and nitrogen stresses level. The yield increases with the increase in irrigation and nitrogen upto a certain limit. Although, application of recommended levels of water and nitrogen to the crop, yield will be high but the input use efficiency remain low. The impact of water stress on NUE varies with the magnitude of the stress. The lower water stress increased the NUE, whereas, higher water stress decreased NUE. The application of low stress of water (60% replenishment of SMD from FC) along with no N stress resulted in only 5% decrease in yield compared to highest yield (I_3N_3) but it had increased NUE from 34% to 38%. Therefore, low water stress can be allowed which can result in higher NUE and non-significant decrease in yield. However, more experimentation is required to quantify the values of low water stress on different soil type for wide acceptance.

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