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Deficit irrigation and nitrogen rate co limitation enhanced wheat crop growth and phenology

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Wheat production is dependent on irrigation water, nutrients availability in the rhizosphere and occurrence of rainfall in Pakistan. Water availability is decreasing with time and severe water scarcity is expected as the per capita per annum water availability in Pakistan is less than 1000 m3. Proper irrigation management at right time with optimum water application and nutrient management keeping in view the efficient uptake and reducing the production cost is the need of time. This study was conducted at Agronomy Research Farm, The University of Agriculture Peshawar during 2018-19 and 2019-20 to economize nitrogen rates for wheat growth and phenology under water regimes. Reduction in irrigation volume affects the nitrogen availability. Water stress comprised of control with 0 MAD, 25% MAD, 50% MAD and 75% MAD and nitrogen (N) rates of 120, 90, 60 and 30 kg N ha^{-1} with control treatment having no nitrogen application. A Randomized complete block design with split plot arrangement was used to assess the irrigation and nitrogen effect on wheat with water stress allocated as main plot factor and nitrogen rates as sub plot factor. Results revealed that days to tillering, anthesis and maturity were delayed by optimum water application (0 MAD) and increment in water stress accelerated phenological days to complete early. Similarly, with increment in N rate decrease the phenological days with lower days for control with no N application. Canopy height, leaf area and chlorophyll contents were affected by the degree of water stress with maximum canopy height (cm), leaf area (cm^2) and chlorophyll contents were observed under 25 % MAD and 90 kg N ha which did not vary from 120 kg N ha^{-1}. Solutes i.e. proline are accumulated at high water stress with maximum at 75 % MAD and 120 kg N ha^{-1}. Grain yield was observed maximum at 25 % MAD with N application of 90 kg N ha^{-1} with no significant differences from 120 kg N ha^{-1}. It is concluded that reduction in irrigation water with nitrogen rate not decreasing the wheat phenology, growth and yield and is better to save water and nitrogen thereby decreasing production cost.

Keywords: nitrogen rates, water deficit, crop growth, phenology, co limitation

INTRODUCTION

Water stress is considered as the major yield limiting factor, where it is difficult to apply irrigation water according to the crop full requirement for the optimum growth, development and yield well (Eissa et al. 2018). Therefore, under water stress conditions it is necessary to know that how to achieve optimum crop growth and yield. For enhancing irrigation and water use efficiencies it is necessary to adopt regulated water deficit irrigation strategies. Wheat productivity is mainly influenced by the adverse effects of climate changes. Food requirement of the overwhelming population is attained by the wheat yield and its quality through the influence of changing climate of the area which change with unpredictable variations in the moisture availability and temperature (Goswami et al. 2006). After sowing of wheat, crop growth and productivity is increased by temperature and together with moisture it increases the risk of rust attack, which decrease wheat production. Due to prevailing climate change, it is expected that by year 2025, about 1.8 million population come up with water scarcity and about 65% population of the world will be living under water stress environments (Nezhadahmadi et al. 2013). This is because of excessive use of irrigation water levels resulting in greater evapotranspiration through the shoots than the water uptake by root (Reynolds et al. 2005). Therefore, water stress is the major threat, which severely affects wheat crop morphological, physiological, biochemical, and molecular characteristics and results in severe loss in overall production (Nezhadahmadi et al. 2013 and Bilal et al. 2015).

Under different degrees of water deficit, the physiology and the metabolic processes of the plants which are stomatal conductance, photosynthetic rate and transpiration rate are affected differently (Hongbo et al. 2005). Spikeletes and grain numbers are reduced significantly by stress imposition at stem elongation stage of the crop (Shpiler et al. 1991). The translocation of the assimilates towards the grains from the leaves are negatively associated with water stress at flowering stage of the crop (Garcia et al. 2003 and Ilker et al. 2011). Drought stress reduced wheat yield significantly (Ma et al. 2014). Irrigation water applied affected the water status, water productivity and yield of wheat crop (Kirda et al. 2007). Furthermore, excess amount of irrigation water application is not associated with optimum grain yield and economics. Hence, the need of proper irrigation scheduling is therefore necessary (Sun et al. 2007). Cereal crops resulted in less radiation and water use efficiency when water stress was applied at tillering stage of the crop (Liu et al. 2002). Under drought stress, minimum or deficit irrigation is therefore accepted as suitable practice which comprised of other practices like potential soil moisture deficit approach (difference amongst irrigation plus rainfall and potential evapotranspiration) in which reduced amount of water is applied to crop without having any adverse effects on crop yield (Bashir et al. 2016). The main aim of the soil moisture depletion is to improve water productivity (Hou et al. 2012). Compared to the establishment and early stages of the wheat crop the stages after anthesis are mostly affected by water stress (Kang et al. 2012).Nevertheless, this effect is overwhelming with lower nitrogen application in the early stages of the crop growth and development (Gevrek and Atasoy. 2012).

Nitrogen is considered as an important nutrient required for optimal plant growth and development (Vitousek. 1994), grain quality and productivity was reduced when nitrogen was applied in deficit because of its unavailability to plants (Passioura et al. 2002). Nitrogen uptake and nutritional status of the soil is severely affected by the water availability (Rezadost and Roshdi. 2006). Crop total dry matter accumulation and leaf area with duration was increased through the application of optimum nitrogen application (Yang et al. 2001, Basso and Ritchie 2005). Nitrogen also increases the size and number of cells, improves the radiation absorption efficiency and enhances plant’s leaf area index (Marbet et al. 2000). Wheat productivity is greatly influenced by the nitrogen application in arid and semiarid areas (Ghani et al. 2000 and Semenov et al. 2007). Various factors are used for the determination of nitrogen and its utilization by plants are comprised of the activity and length of the root system, the nitrate uptake intensity, reductase activity of nitrate, grains sink, nitrogen loss due to soil characteristics and leaching and carbohydrate production (Fathi et al. 1997). Leaves nitrogen amount and contents determines the photosynthetic capability, strength and the metabolism of carbohydrate (Tranaviciene et al. 2007) and amount of estimated nitrogen uptake can be measured by chlorophyll contents of the leaves (Brown 2000 and Shangguan et al. 2000).

Irrigation and nitrogen are considered as the main reasons which affects the roots distributions and productivity of wheat crop and finally influences the soil water use (Zhang et al. 2009 and Wang et al. 2014) and nitrate content of the soil (Xu et al. 2016). Generally, water deficit and nitrogen reduction caused increase in vertical root penetration, growth and hence cause reduction in the root densities in the shallow layers of the soil and thereby increasing the root length density In general, slight water shortages and nitrogen deficiency during vegetative growth of wheat cause an increase in vertical root penetration, reduction in root length density in the top soil layer and increasing the root length density in deeper layers (Li et al. 2010, Wang et al. 2014 and Xu et al. 2016). Crop roots in the deep soil layers (>0.8m) are therefore necessary for nutrient and moisture absorption and, therefore, growth and final yield of wheat (Dai et al. 2014 and Xu et al. 2016). Therefore, this research was designed to investigate the effect of water deficit levels and nitrogen rates on growth and phenology of wheat crop.

MATERIALS AND METHODS

Experimental site

Experiments were conducted at Agronomy Research Farm (ARF), The University of Agriculture Peshawar, Pakistan during Rabi season 2018-19 and 2019-20. The coordinates of the experimental site are 34.01 °N and 71.35 °E with an altitude of 350 meter above sea level. Peshawar is semi-arid with hot summer and short winter with mild cool season. Daily mean temperature ranges 25-40 °C in summer while 4-18 °C in winter season with annual rainfall (Fig. 1). Field soil is silty loam, Tarnab soil series of the soil survey of Pakistan. Soil physiochemical properties of the experimental soil is shown in Table 1.

Experimental design and treatments

The experiments were conducted in Randomized Complete Block Design (RCBD) with split plot arrangement. Deficit irrigations were allocated to main plot till anthesis stage of the crop and nitrogen rates as subplot factor to assess their simultaneous co limitation effect on growth and phenology of wheat crop. Water stress levels based on Maximum Allowable Depletion (MAD) i.e. 25%, 50% and 75% along with control treatment where full irrigation water were applied as per crop need and Nitrogen (N) rates i.e. 120, 90, 60 and 30 kg N ha^{-1} were applied from Urea along with control treatment with no N application. Main plots were bifurcated with 2m buffer to avoid water lateral moment in the soil layers. Commutative irrigation and rainfall is shown in Fig. 2. Field capacity, bulk density and permanent welting point of the soil were calculated prior to sowing and amount of water needed for a treatment to attain field capacity were calculated thereafter. Each experimental unit was fertilized with 80 and 60 kg ha^{-1} from single super phosphate (SSP) and murate of potash (MOP) as source of Phosphorous and Potassium respectively. Uniform seed rate of 100 kg ha^{-1} was used for sowing wheat with hand hoe at 30 cm apart in rows. Seedbed was prepared through rotavator followed by twice cultivator and planking. Sub plot with of 2.4 m width accommodating 8 rows of wheat and having 3m length with 0.3m row to row distance. Rest of the agronomic practices for wheat production were kept uniform for all treatments.

Irrigation water calculation

Available soil water (depth) is the amount of water present between field capacity and permanent wilting point and was calculated through the following formula

$$\mathrm{AW} = \frac{\mathrm{Drz(FC - PWP)}}{100}$$

Where, AW is available water (mm), Drz is depth of root zone (mm), FC is the field capacity (%) on volume basis and PWP is permanent welting point (%) on volume basis. The Maximum allowable depletion or deficit (MAD) is the percentage of plant available water that can be removed from the soil without seriously affecting crop growth and development. In simpler terms, the MAD of any crop is the allowable percentage of water that can be withdrawn from the soil between irrigation events without stressing the crop to the point where significant reductions in crop yield or quality are experienced. The MAD for wheat crop is 56%. Based on this MAD, different water levels were applied to the crop. Where Readily Available Water (RAW) for the crop was calculated through the product of available soil water (AW) and MAD of that crop.

$$\mathrm{RAW\ (mm) = AW\ (mm)\ x\ MAD\ (\%)}$$

Soil moisture was monitored through FDR (DIVINER 2000; Australia) and irrigation water were applied when the soil moisture content reached the desired depletion level. Volume of water (V) for attaining the respective MAD was applied and calculated through area (A) of the plot to the required water depth (Dw) by formula

V (m^3) = A (m^2) x Dw (mm)

The time needed for the application of the required volume of water was calculated by dividing volume (V) of water on discharge (Q).

T = V/Q

Hence, the respective volume of water was applied to maintain the respective MAD in main plots.

Sampling and measurements

Days taken till emergence, tillering, anthesis, and maturity were calculated by counting the number of days till the day when 50 % of the experimental unit reached the respective stages. At anthesis stage of the crop, about 10 plants were randomly selected for leaf area measurement. Leaf length (cm) and maximum leaf width (cm) were measured for each leaf. Leaf area was calculated by the product of leaf length, width, and factor (0.75) for each leaf and averaged for leaf area (cm^2) per plant.

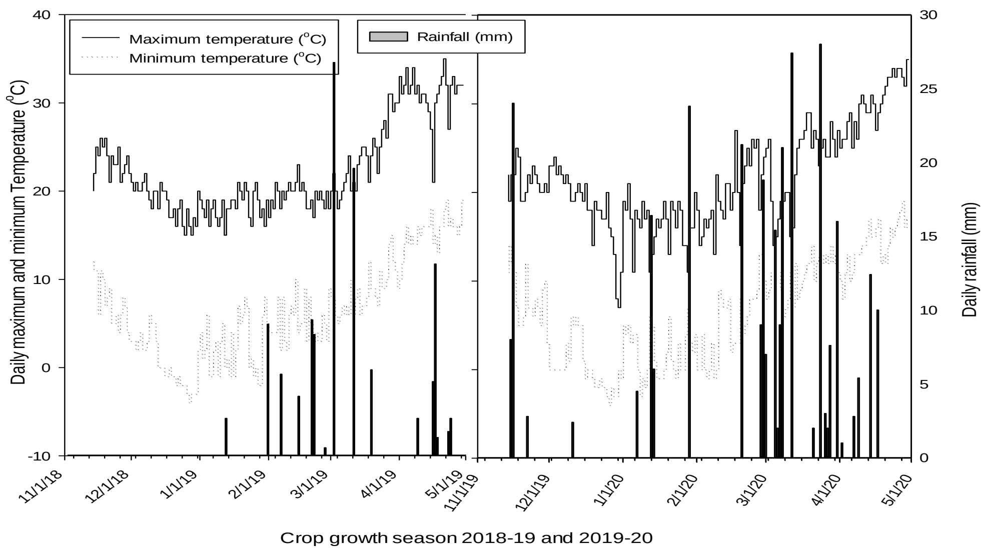

Figure 1: Mean maximum and minimum daily temperature and rainfall of experimental farm during wheat growth season 2018-19 and 2019-20

Table 1: Days to emergence and days to tillering of wheat crop as affected by economizing nitrogen rate (NR) under water stress (WS) conditions

Water stress (WS)	**Days to emergence**			**Days to tillering**		
	2018-19	**2019-20**	**Mean**	**2018-19**	**2019-20**	**Mean**
0 MAD	10	13	12	46	49	48 a
25 % MAD	10	13	12	46	50	48 a
50 % MAD	10	14	13	44	46	45 b
75 % MAD	10	13	13	42	46	44 b
LSD for WS	NS	NS	NS	2	3	2
Nitrogen rates (NR)						
120 kg ha^{-1}	10	14	12	47	50	49 a
90 kg ha^{-1}	11	14	12	46	49	48 ab
60 kg ha^{-1}	10	15	12	44	48	46 bc
30 kg ha^{-1}	11	13	12	44	46	45 cd
Control	10	14	12	41	45	43 d
LSD for NR	NS	NS	NS	2	3	2
Year						
2018-19			10			45
2019-20			14			48
Significance			***			***
Interaction	Significance			Significance		
Y x WS	NS			***		
WS x NR	*			NS		
Y x NR	NS			NS		
Y x WS x NR	NS			NS		

Grain fill duration was also calculated by subtracting the days to anthesis from days to physiological maturity. Digital SPAD meter was used for leaves SPAD values at anthesis stage. Leaves were collected from each treatment and homogenized and placed in 10 ml C7H6O6S 3% w/v solution overnight at 4˚C. Thereafter glacial acetic acid and acid ninhydrin was added in tube for 1 hour at 100 ˚C and tube was placed in bath after reaction. About 4ml toluene as added and stirred for 20 seconds. Sample extracted and analysed through UV spectrophotometer at 520 nm. Proline concentration was expressed in mg per gram. Plant height (cm) was measured in each respective plot through measuring tape from soil surface till the tip of the spike. Grain yield was measured by harvesting the central rows and weighed for harvested area for each treatment and was converted to g m^{-2}.

Statistical analysis

Data collected during this study was statistically analysed using Fishers analysis of variance technique and significant means was separated using least significant difference test (LSD) at 5% probability level (Steel et al. 1997).

RESULTS

Days to emergence and days to tillering

Emergence days were non significantly affected by water stress and nitrogen rates (Table 1). Days to tillering stage of wheat crop were significantly affected by both water stress and nitrogen rate are shown in table 1. Averaged across water stress and nitrogen rates, maximum days to tillering stage were observed for 2019-20 than 2018-19. While mean across nitrogen rates, results indicated that maximum days to tillering were observed for no water stress (0 MAD) which was statistically similar to 25 % MAD. The minimum days to tillering were measured for 50 % MAD which did not differ with 75 % MAD. Among nitrogen rates, maximum days till tillering stage of the wheat crop were measured in plots treated with 120 kg N ha^{-1} which did not differ statistically from 90 kg N ha^{-1}. This followed by 60 and 30 kg N ha-1 while minimum days to tillering were observes for control treatment where no nitrogen was applied. The interactive effect of WS x NR was found significant for days to emergence of wheat crop while all the interaction were found non-significant except Y x WS.

Days to anthesis and maturity

Table 2 shows days taken till anthesis and maturity stage of wheat crop as affected by economizing nitrogen rates under water stress conditions. Statistical analysis of the data revealed that days to anthesis were significantly affected by year, water stress and nitrogen rates. Maximum days to anthesis were observed in 2019-20 than 2018-19. The maximum days to anthesis were observed for no water stress (0 MAD) followed by 25 % MAD. Days to anthesis did not vary significantly for 50 % and 75 % MAD. Averaged across years and water stress, nitrogen rate 120 kg ha^{-1} resulted in maximum days to anthesis which were statistically at par with the 90 and 60 kg N ha^{-1}. This followed by 30 kg N ha^{-1} wile minimum days to anthesis were measured for control (no nitrogen application). The interaction WS x NR and Y x WS X NR were found significant for days to anthesis. Days to maturity did not differ for both the experimental years but varied for water stress and nitrogen rates with maximum maturity days were observed for no water stress followed by 25 % MAD. Maturity days did not differ statistically for 50 % MAD and 75 % MAD. Mean across year and water stress, 120 kg N ha^{-1} delayed crop maturity and lower N rates application caused early maturity with minimum days for control where no nitrogen was applied.

Grain fill duration and plant height (cm)

Grain fill duration varied significantly for both the growing seasons with maximum for season 2018-19 as shown in Table 3. Statistical analysis showed that nitrogen rates significantly affected the grain fill duration with maximum for higher N rate and decrease in N rates decreased the grain fill duration. The interaction of WS x NR and Y x NR were significant for grain fill duration of wheat crop. Similarly, maximum canopy height was measured for growing season 2018-19 than 2019-20. Averaged across years and N rates, maximum plant height was observed for the wheat crop where no water stress was imposed followed by the increment in waster stress treatment and minimum canopy height was observed for 75 % MAD. Nitrogen application at higher rates increased the canopy height and decrease in nitrogen rate cause reduction in canopy height with minimum for control treatment where no nitrogen was applied. Interactive effect of WS x NR was found significant for plant height of wheat crop.

Chlorophyll contents (SPAD values) and proline contents

Growing seasons, water stress and nitrogen rates significantly affected the chlorophyll and proline contents of wheat crop as shown in Table 4. Statistical analysis indicated that maximum chlorophyll contents were measured for growing season 2018-19 than 2019-20. Water stress decreased the chlorophyll contents of wheat. Increment in N rate increased the chlorophyll contents with maximum for 120 kg N ha^{-1} which did not differ from 90 kg N followed by other rate and minimum for control with no N application. Similarly, proline contents were enhanced with water stress and nitrogen application decreased the proline contents by mitigating the water stress effect wheat crop.

Grain yield and leaf area

Grain yield of wheat crop was significantly affected by growing season with maximum for 2019-20 as shown in Table 5. Mean across the growing seasons, statistical analysis of the data revealed that both the water stress and nitrogen rates significantly affected the grain yield of wheat with maximum for 25 % MAD which is statistically at par with no water stress followed by 50 % Mad and 75 % Mad resulted in lower grain yield. Averaged across water stress and years, reduction in nitrogen decreased the grain yield with maximum for 120 kg N ha^{-1} followed by 90 kg N ha^{-1} and further decrease in N rate decreased the grain yield with minimum for no nitrogen applied treatments. The grain yield did not differ for 30 and 60 kg N ha^{-1}. The WS x NR interaction was found significant for grain yield of wheat. Leaf area (Table 5) was also significantly affected by water stress and nitrogen rates. Water stress decreased the leaf area of the wheat. Maximum leaf area was measured for no water stress imposition. Increment in water stress decreased leaf area with minimum for 75 % MAD. The nitrogen rates 90 kg ha^{-1} resulted in maximum leaf area which did not differ statistically with 120 kg N but differ from 60 kg N application and minimum leaf area was observed for control treatment where no nitrogen was applied. Interactive effect was found non-significant for leaf area of wheat crop.

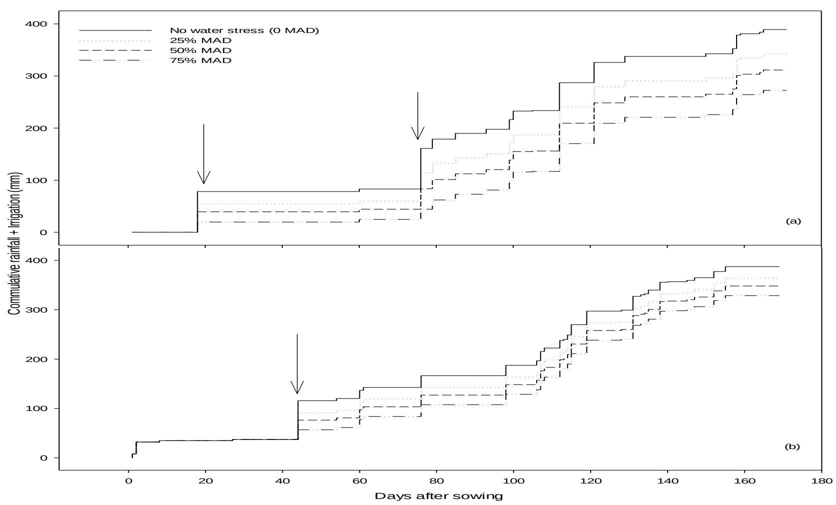

Figure 2: Cumulative rainfall and irrigation water (mm) with arrow showing irrigation application for different water regimes in each window at experimental farm during wheat growth season 2018-19 (a) and 2019-20 (b).

Table 2: Days to anthesis and days to maturity of wheat crop as affected by economizing nitrogen rate (NR) under water stress (WS) conditions

Water stress (WS)	Days to anthesis			Days to maturity		
	2018-19	2019-20	Mean	2018-19	2019-20	Mean
0 MAD	137	141	139 a	162	161	162 a
25 % MAD	135	139	137 b	160	160	160 b
50 % MAD	132	136	134 c	156	158	157 c
75 % MAD	132	133	132 c	154	157	155 c
LSD for WS	2	2	2	2	2	1
Nitrogen rates (NR)						
120 kg ha-1	137	140	138 a	163	163	163 a
90 kg ha-1	136	140	138 a	159	160	159 b
60 kg ha-1	134	139	137 a	159	158	159 b
30 kg ha-1	132	136	134 b	157	158	158 b
Control	131	130	131 c	152	155	154 c
LSD for NR	2	4	2	2	3	2
Year						
2018-19			134			158
2019-20			137			159
Significance			**			NS
Interaction	Significance			Significance		
Y x WS	NS			*		
WS x NR	***			NS		
Y x NR	NS			NS		
Y x WS x NR	**			NS		

Table 3: Grain fill duration and plant height (cm) of wheat crop as affected by economizing nitrogen rate (NR) under water stress (WS) conditions

Water stress (WS)	Grain fill duration			Plant height (cm)		
	2018-19	2019-20	Mean	2018-19	2019-20	Mean
0 MAD	25	19	22	102.46	94.03	98.25 a
25 % MAD	25	21	23	96.13	89.01	92.57 b
50 % MAD	24	22	23	92.87	86.67	89.77 c
75 % MAD	22	24	23	89.69	83.89	86.79 d
LSD for WS	NS	NS	NS	4.17	3.24	2.23
Nitrogen rates (NR)						
120 kg ha-1	26	23	24 a	102.59	93.74	98.17 a
90 kg ha-1	23	19	21 ab	99.48	89.88	94.68 b
60 kg ha-1	25	19	22 ab	96.16	89.79	92.98 b
30 kg ha-1	25	22	24 ab	93.04	86.30	89.67 c
Control	21	25	23 b	85.15	82.30	83.73 d
LSD for NR	NS	NS	NS	3.24	3.40	2.30
Year						
2018-19			24			95.29
2019-20			22			88.40
Significance			**			***
Interaction	Significance			Significance		
Y x WS	NS			NS		
WS x NR	**			***		
Y x NR	*			*		
Y x WS x NR	NS			***		

Table 4: Chlorophyll contents (SPAD values) and proline contents (%) of wheat crop as affected by economizing nitrogen rate (NR) under water stress (WS) conditions

Water stress (WS)	Chlorophyll contents			Proline contents		
	2018-19	2019-20	Mean	2018-19	2019-20	Mean
0 MAD	61.03	53.44	57.24 a	33.95	38.57	36.26 c
25 % MAD	56.01	50.61	53.31 b	37.12	41.35	39.23 b
50 % MAD	53.67	56.04	54.86 b	42.34	47.21	44.78 a
75 % MAD	42.89	37.03	39.96 c	44.45	47.33	45.89 a
LSD for WS	2.77	3.40	2.14	3.35	3.60	2.29
Nitrogen rates (NR)						
120 kg ha-1	58.74	52.72	55.73 a	34.98	39.03	37.00 c
90 kg ha-1	54.88	51.88	53.38 ab	36.62	41.19	38.90 c
60 kg ha-1	54.79	50.60	52.70 b	40.68	44.38	42.53 b
30 kg ha-1	51.30	48.80	50.05 c	40.53	45.03	42.78 b
Control	47.30	42.40	44.85 d	44.53	48.45	46.49 a
LSD for NR	3.40	3.61	2.43	3.60	3.65	2.52
Year						
2018-19			53.40			39.47
2019-20			49.28			43.61
Significance			**			**
Interaction	Significance			Significance		
Y x WS	**			***		
WS x NR	***			***		
Y x NR	NS			***		
Y x WS x NR	***			***		

Table 5: Grain yield (g m^{-2}) and leaf area (cm^2) of wheat crop as affected by economizing nitrogen rate (NR) under water stress (WS) conditions

Water stress (WS)	Grain yield (g m^{-2})			Leaf area (cm^2)		
	2018-19	2019-20	Mean	2018-19	2019-20	Mean
0 MAD	260.4	369.0	314.7 a	85.0	89.5	87.3 b
25 % MAD	296.7	340.2	318.4 a	94.0	99.3	96.7 a
50 % MAD	265.3	284.9	275.1 b	78.8	78.2	78.5 c
75 % MAD	247.3	235.6	241.5 c	60.8	64.7	62.8 d
LSD for WS	27.1	29.4	23.9	12.4	15.7	8.2
Nitrogen rates (NR)						
120 kg ha-1	344.0	404.2	374.1 a	91.0	94.8	92.9 a
90 kg ha-1	316.3	351.4	333.9 b	99.7	104.2	102.0 a
60 kg ha-1	232.4	290.3	261.3 c	76.6	81.3	79.0 b
30 kg ha-1	225.3	262.1	243.7 c	72.8	77.0	74.9 b
Control	219.0	229.2	224.1 d	58.2	57.3	57.7 c
LSD for NR	29.4	24.1	18.6	15.7	16.3	11.1
Year						
2018-19			267.4			79.7
2019-20			307.4			82.9
Significance			**			NS
Interaction	Significance			Significance		
Y x WS	***			***		
WS x NR	***			NS		
Y x NR	NS			NS		
Y x WS x NR	***			NS		

DISCUSSION

Water stress is the major limiting factor affecting crop growth and yield (Vadez et al. 2013; Seleiman et al. 2021). Water stress also affects the crop life cycle by altering the phenological stages during vegetative growth of the crop (Ali et al. 2020). Emergence days were observed not affected by water stress because of prior irrigation to sowing that did not affected the emergence days. The effect of nitrogen was also not observed on days to emergence of wheat crop as nitrogen is necessary for the vegetative growth of the plants (Qiao et al. 2019; Ali et al 2020). Differences in days to tillering were observed for both the years because the of the temperature variation in the growing seasons. Temperature influences the growth and phenology of the plants (Ihsan et al. 2016). Water stress imposition shorten the plant life cycle because under water stress condition plant avoids the drought spell and thereby completing life cycle early (Hasanuzzaman et al 2018; Brito et al. 2019). Early tillering was observed in the treatments subjected to water stress indicated that water stress shortens plant phenological developmental stages. Similar results were also observed by Abid et al. (2016). Nitrogen enhances the vegetative growth of the plants thereby delays plant phenological stages. Ali et al. (2019) reported that higher N application delays the crop growth by enhancement in vegetative period. Early flowering is initiated in plant subjected to water stress for completing its life cycle. Abid et al. (2018) reported that drought stress-imposed treatments flowers early than the treatments under optimum water supply. Increment in nitrogen rate enhances the vegetative period of the crop and thereby delays flowering compared to control with no N application. Similar results were also reported by Ma et al. (2018) that increment in nitrogen application rates at delays days to flowering of wheat crop. Similarly, water deficit shortens the overall life cycle of the plants by early commencement of maturity thereby plants initiate fruit setting under drought stress conditions. Zeng et al. (2009) reported that under optimum irrigation water supply, plants grow well. Decrease in water availability during vegetative stages, early maturity is expected in crop for completing its life cycle. Maturity of the crop is also delayed by higher nitrogen application (Tian et al. 2012) as nitrogen enhances the vegetative growth of the plants (Ali et al. 2020). Biomass of the crop plants is of great importance and it is adversely affected by the water deficit at vegetative growth of the crop (Jaleel et al. 2009). Under optimum irrigation water supply, plant grows well with better canopy height and leaf area. The canopy height and leaf area is adversely affected by the drought stress imposition (Anosheh et al. 2012). Plant vegetative growth varies with the degrees of water stress. More water stress severely affected the leaf area and canopy height and resulted in decrease of the plant height and leaf area thereby favouring early maturity as reported by Hendriks et al. (2016). Similar results were also obtained by Izanlo et al. (2008) that water stress imposition decreases the plant height of the crop which finally decrease the total biomass. The biomass is the function of optimum nitrogen supply to the crop. Optimum nitrogen application favours vegetative growth thereby increasing the photosynthetic capacity by increment in photosynthetic area. Srivastava et al. (2018) observed that nitrogen application in higher rate increasing the biomass of the plant. Optimum irrigation water supply favours better uptakes of the nutrients, and hence plants containing maximum chlorophyll contents than the plants which are subjected to water stress (Seleiman et al. 2021). Water is necessary for the proper physiological processes of the plants. Photosynthesis is also affected by the water stress as water stress decreases the chlorophyll contents of the plants. Waraich et al. (2011) reported that plant physiological processes are affected by the water stress and decrease in chlorophyll contents is also observed in plants subjected to water stress. Nitrogen is the basic constituent of the chlorophyll and optimum nitrogen supply enhances the chlorophyll contents of plants (Fageria and Balegar, 2005). Decrease in chlorophyll contents observed with decrease in nitrogen rates. Similar results were also reported by Hafiz and Gharib, (2016) that nitrogen application increases the chlorophyll contents of leaves. Water stress affected the grain yield of the wheat crop adversely and it depends on the severity of the water stress and its imposition stages.Water stress at both the vegetative and reproductive stages of the crop decrease the grain yield of the crop (Mi et al. 2018). Water stress during vegetative stage decreases the rate of photosynthesis and thereby affecting final yield (Akram, 2011). At anthesis stage, water stress decreases the grain setting. Decrease in grain number and grain size is resulted under water deficit condition which finally affects the grain yield. Grain yield is also influenced by Nitrogen rates. Optimum nitrogen application resulting in maximum yield and quality (Abedi et al. 2011). Grain number and size is adversely affected by the nitrogen application rates which results in lower final grain yield.

CONCLUSION

Based on the results obtained from the experiments it is concluded that reduced volume of irrigation water decreased grain yield and affects the growth and phenology, but this reduction is non-significant. The optimum water application ensures the efficient nitrogen uptake at reduced rates of nitrogen thereby decreasing leaching losses and increasing water productivity. Increment in water stress caused early maturity affects the growth and grain yield of the wheat crop. Similarly decrease in N rates adversely affects the wheat productivity but simultaneous reduction in nitrogen with water stress favours the nitrogen uptake and enhanced whet productivity. Therefore, 90 kg N ha^{-1} with synchronized reduction in water is considered as the best strategy for wheat production.

CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest.

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AUTHOR CONTRIBUTIONS

NA and MA designed experiment. NA conducted experiment, collected and analysed data, wrote draft. MA reviewed draft.

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