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Phenology, Growth, Yield and Nitrogen Uptake of Wheat in Response to Nitrogen, Potassium and Their Application Methods

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Abstract. Application of macronutrients in less amount along with improper application method(s) are the major factors for low yield. Experiments were designed with the objectives to determine the optimum rate of nitrogen (N) and potassium (K) along with suitable application method to minimize nutrients losses. The experimental site was New Developmental Farm of the University of Agriculture Peshawar and experiments were conducted for two consecutive years *i.e*. 2010-11 and 2011-12. After analysis, the results indicated that both N and K significantly affected days to phenology (anthesis and maturity). Days to phenology increased linearly with increase in rate of N and K and more days to phenology were recorded when both were at their highest rates. Similarly plant height, leaf area/tiller, flag leaf area, leaf area index, leaf area duration, grain yield, N uptake by grains and straw were increased with increasing level of N and K and attained maximum value when N and K was applied at the rate of 180 and 90 Kg/ha, respectively. Nutrients application method significantly affected plant height, leaf area/tiller, flag leaf area, grain yield and N uptake by straw and grains with maximum values for these traits were recorded when nutrients (N and K) were applied in such a combination that 15% nutrients were supplied through foliar and 85% through soil application. Application methods had a non-significant effect on days to phenology, leaf area index and leaf area duration. It is concluded from the results that application of N and K at the rate of 180 and 90 Kg/ha respectively in such a way that 15% is applied through foliar spray and 85% through soil application improved growth, yield and N uptake of wheat crop under the semi-arid climate.

Keywords: *Triticum aestivum* L., foliar application, days to maturity, plant height, leaf area index, grain yield, N uptake by grains

Introduction

Wheat (*Triticum aestivum* L.), an important cereal crop grown all over the world to feed the masses. Pakistan is 8th largest wheat producer and its contribution to the World's wheat production is about 3.2%. In agriculture sector of Pakistan wheat is the most important staple crop and holds central position among other cereals. Fertilizers are applied to promote growth, yield, quality, shelf life and to develop resistance against insect pests and diseases in crops. Besides its use, nitrogen (N) is still the most limited plant nutrient and wheat is very sensitive to its deficiency and very responsive to N fertilization (Bakht *et al*., 2010). It is the building block of protein and chlorophyll molecules. Therefore, amount of protein and chlorophyll formed inside the plant depend on N supply. Adequate application of N ensures quick and economic growth of the plant (Gab-Allah, 2003). Non-judicious use of N causes tender growth, resulting in lodging, delayed maturity and increase susceptibility to insect pests. In the list of reasons responsible for lower wheat yield, inappropriate use of fertilizers come in the top of list. Time is demanding to develop such strategies to minimize nutrients losses and provide optimum nutrients to crop for better yield and to feed masses.

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Plants need huge amount of potassium (K), because it plays an important role photosynthesis, enzyme action, protein and carbohydrates production and enables the plant to resist against diseases and pests (El-Shal, 2016). Potassium influences photosynthesis by helping Adenosine Triphosphate (ATP) formation, keeping water and carbon dioxide movement in balance through stomata as an osmo-regulator, helps in protein manufacturing by activating enzyme (nitrate reductase) and sends sugars to seeds (Wallace, 2001). K application increases K^+ and proline content and enhances soluble sugar in leaf. Seed size is reduced in wheat due to short supply of K and negatively affects GFD (Grain Filling

Duration) in wheat. It has a well-built interaction with N and increases the uptake of N. In Pakistan, most soils contain relatively large amount of total K as component of insoluble minerals. A small fraction of K when present as a component of insoluble mineral is available to plants (Feng *et al*., 2014). Potassium increases plant tolerance to drought, enhances the resistance to diseases, different pests, and keeps anion balance in plants (Wang *et al*., 2013). Potassium usage as a mineral fertilizer is very low in Pakistan due to socio economic status of the farmers. Most of the farmers of Pakistan are poor and hold small farms. They completely depend on chemical fertilizers and have no alternate choice except balanced use of nutrients for good yield. K application in Pakistan for agronomic crops is very low because farmers give less attention to its application (Adnan *et al*., 2016). Application of K has primitive effect on growth, development and grain yield in maize (Bukhsh *et al*., 2012) Cereal crops removed about 4 Kg/ha of K and about the same amount are lost due to leaching with artificial and rain water (Wallace, 2001).

Most of the fertilizers are usually applied directly to soil. In case of N, loss of fertilizers take place through volatilization and leaching, while in case of K, soluble portion leaches down. Foliar application of N and K may reduce their losses to some extent. Foliar application ensures rapid availability of fertilizers to plant with less chance of losses. Foliar application of N causes a greater increase in yield of crops (Amanullah *et al*., 2013). Gab-Allah *et al*. (2003) reported that spraying 10 Kg/ha of urea at anthesis stage increased seed protein from 10.2 to 11.8%. Spraying 10 Kg/ha urea at milk stage in wheat increased seed protein from 9.9 to 10.8% with no effect on yield (Johnson and Prince, 2002). Application method of N greatly affects its use efficiency and poor application method can decrease yield up to 50% (Nisar and Rashid, 2003). Soil application of N in combination with foliar application has been documented as an economical and effective method of N application (Mahajan *et al*., 2004). N when applied as a foliar improve yield, quality and is a cost-effective strategy (Siuliauskas *et al*., 2001). Foliar application of N significantly increased growth, yield and yield attributes of wheat than soil application (Wagan *et al*., 2017). K applied as a foliar increases leaf area duration and leaf chlorophyll content which finally results in improved yield and quality of wheat crop (Hongbo *et al*., 2006). The present research was designed to determine the impact of N and K (when completely applied on soil and in integration with foliar application at different percentages) on phenology, growth and quality attributes of wheat.

Materials and Methods

Experimental area description. Two field experiments were conducted at Agronomy Research Farm of the University of Agriculture Peshawar, Pakistan. The experimental site is located at 340°1″ N latitude and 71°35″ E longitude with an altitude of 359 m (1178 feet) above sea level and at a distance of about 1400 km towards north of the Arabian sea. The environmental condition of the research farm is warm to hot having semi-arid subtropical continental climate (Khan *et al*., 2015). Metrological data of the experimental site during the conduction of experiment are given in Fig. 1. Soil is silt clay loam. The nature of soil is alkaline with pH 7.5-7.8. The soil was deficient in total N (≤ 0.5 g/Kg of soil) and K (≤ 105 mg/Kg) of soil (Asad *et al*., 2015). Pre-sowing soil tests were carried out for determining total N, available phosphorus (P) and K, organic matter and soil pH, results of which are given in Table 1.

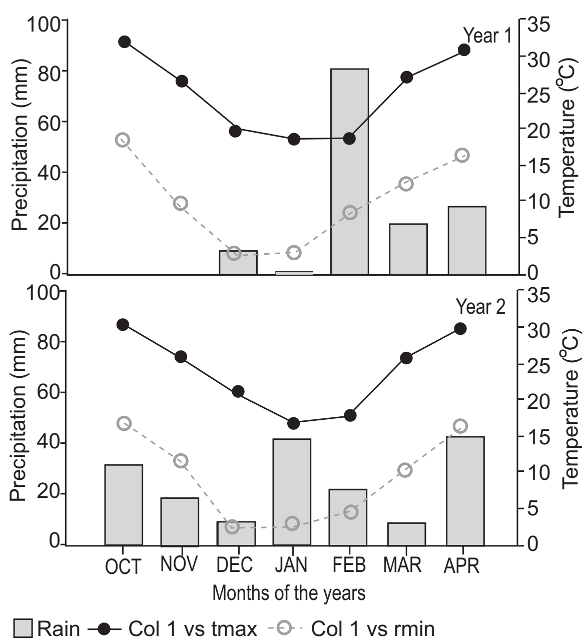

Fig. 1. Data of rainfall (mm) are shown in bar graph while mean maximum temperature (°C) are shown in continuous lines and minimum temperature (°C) in dotted lines for the crop growth season (2010-12).

Table 1. Soil physico-chemical analysis (on dry weight basis)

Determination	Year	
Mechanical analysis	2010	2011
Sand g/Kg	180	180
Silt g/Kg	620	630
Clay g/Kg	200	190
Soil Texture	Silty clay loam	
Chemical analysis		
pH	7.70	7.80
Organic matter (%)	0.70	0.84
Total N (g/Kg)	0.51	0.56
Available P (g/Kg)	6.82	6.85
Available K (mg/Kg)	89	105

Experiment detail. Experiments were designed to evaluate the impact of various nitrogen (90, 120, 150, and 180 Kg/ha) and potassium (30, 60, and 90 Kg/ha) levels with different application methods (Soil application, 95% soil + 5% foliar, 90% soil + 10% foliar and 85% soil + 15% foliar) on phenology, growth and quality of wheat. Half of the soil applied N was incorporated at the time of sowing and the remaining half with first irrigation about three weeks after emergence. Complete dose of soil K was applied at the time of sowing. Foliar spray was started at tillering (Zadoks scale no.21) (Zadoks *et al*., 1974) and completed within two weeks. Experiments were carried out in randomized complete block design with split plot arrangement having three replications. Nutrient application methods (M) were allotted to main plots, while combinations of N and K were allotted to subplots. A subplot size of 1.8 m × 5 m comprised of 6 rows 30 cm apart was sown using commercial wheat variety “SIRAN”. Pre-sowing soil tests were carried out for determining total N, available phosphorus (P) and K, organic matter and soil pH, results of which are given in Table 1. Soil N was determined by Kjeldahl procedure (Bremmer and Mulvaney, 1982). N was applied in the form of urea and K in the form of MOP (murate of potash). A basal dose of phosphorous (P) was applied in the form of single super phosphate @ 90 Kg/P_2O_5 /ha. All other cultural practices carried out during the experiments for healthy crop growth were kept uniform for all treatments. Data were recorded for days to anthesis, days to physiological maturity, plant height, leaf area/tiller, flag leaf area, leaf area index, leaf area duration, grain yield, grain N uptake and straw N uptake.

Procedure for recording data. Data regarding days to anthesis were recorded from the date of sowing to date when 80% anthesis occurred in each subplot. Physiological maturity was recorded from the date of sowing till date when all the plants got matured in each subplot. Maturity was determined when glumes become yellow in each subplot. Ten random plants were selected in each subplot at maturity for determining mean plant height for each treatment. Plants were measured from base to the tip of spike with the help of measuring tape. Grain yield was recorded from tillers already harvested for biological yield. The harvested material was dried, threshed, carefully weighed and finally converted into Kg/ha.

Leaf area/tiller (cm^2) was calculated at the time of inflorescence emergence (Zadoks scale no.50) (Zadoks *et al*., 1974) when flag leaf blade was fully extended. Twenty representative plants were selected as samples. Leaf area of all the available leaves was measured by multiplying leaf length with leaf width and averaged. The area obtained was multiplied with factor. Factor was calculated using the following formula:

$$\text{Factor} = \frac{\text{Average leaf area [of Ten representative leaves (cm}^2\text{)]}}{\text{Average leaf lenth (cm)} \times \text{Average leaf width (cm) [of Ten leaves]}}$$

Flag leaf area (cm^2) was calculated at the time of inflorescence emergence (Zadoks scale no.50) (Zadoks *et al*., 1974) when flag leaf blade was fully extended. Leaf area of twenty flag leaves were calculated and averaged.

Leaf area index was calculated as ratio of leaf area to ground area. Leaf area duration was calculated by using the following formula:

$$\text{Leaf area duration} = \frac{(LA1_2 + LA1_1)}{2 \times \text{number of days}}$$

where:

LAI_1 = Leaf area index at anthesis; LAI_2 = Leaf area index at maturity.

Grain N uptake was calculated by Kjeldahl procedure (Bremmer and Mulvaney, 1982) using the following formula:

$$\text{Grain nitrogen (g/Kg of grain)} = \frac{\text{Grain N (g)} \times 1000}{\text{Weight of grain sample (g)}}$$

Straw N uptake was calculated using the following formula:

$$\text{Straw N uptake (g/Kg of straw)} = \frac{\text{Straw N (g)} \times 1000}{\text{Weight of straw sample (g)}}$$

Statistical analysis. Statistical analysis was made using appropriate technique for randomized complete block design (split plot arrangement) according to Jakhro *et al*. (2000). Upon obtaining significant results from ANOVA, least significant difference (LSD) test was used for comparison of treatment means.

Results and Discussion

Days to anthesis. Impact of different levels of N, K and their application methods on days to anthesis of wheat are presented in Table 2. Mean of the two years indicated that various application methods showed no significant effect on days to anthesis of wheat, while N and K levels significantly affected days to anthesis. Increase in N levels substantially increased days to anthesis with more days to anthesis counted for N applied at the rate of 180 Kg/ha followed by 150 Kg/ha. Decreasing N levels decreased number of days to anthesis accordingly with less number of days to anthesis calculated for control plots. Similarly, increase in K level increased number of days to anthesis. More days to anthesis was calculated for 90 Kg, K/ha followed by 60 Kg, K/ha. Control vs rest contrast was found significant for days to anthesis with fewer days to anthesis in control than rest.

Days to physiological maturity. Effect of different levels of N, K and their application methods on days to physiological maturity of wheat is shown in

Table 2. Days to anthesis and physiological maturity of wheat crop as influenced by nitrogen, potassium and their application methods

Treatments (T)	Days to anthesis Years (Y)			Days to physiological maturity Years (Y)		
	2010-11	2011-12	Mean	2010-11	2011-12	Mean
Methods (M)						
M1: All N and K soil applied	129	128	128	167	167	167
M2: 5% foliar + 95% soil applied	129	128	128	167	166	167
M3: 10% foliar + 90% soil applied	129	128	128	167	166	167
M4: 15% foliar + 85% soil applied	129	128	128	167	166	167
$LSD_{0.05}$			ns			ns
Nitrogen (Kg/ha)						
90	126	125	126 d	165	164	165 d
120	129	128	128 c	168	167	167 c
150	131	130	130 b	169	169	169 b
180	132	131	132 a	171	170	171 a
$LSD_{0.05}$			0.2			0.2
Potassium (Kg/ha)						
30	129	128	128 c	167	166	167 c
60	129	129	129 b	168	168	168 b
90	130	129	130 a	169	168	169 a
$LSD_{0.05}$			0.2			0.2
Control	122	122	122b	155	155	155 b
Rest	128	129	129a	168	167	168 a
Interactions	**P value**			**Interactions**	**P value**	
N × K	0.02			N × K	0.000	
				M × N	0.000	
				M × K	0.007	

Means sharing same letter(s) for a parameter in a column are statistically similar at 5% level of significance; ns = non-significant.

Table 2. Analysis showed that various application methods had no profound impact on days to physiological maturity of wheat. However, N and K had significant impact on spikes/m^2. Increase in N level substantially increased number of days to physiological maturity. By taking average of two years, means showed that maximum days to physiological maturity were recorded for highest (180 Kg/ha) level of N followed by 150 Kg/ha. Days to physiological maturity decreased significantly as level of N decreased. Similarly, increase in K level also increased number of days to physiological maturity. Averaged across two years, data revealed that significantly more number of days to physiological maturity was recorded for 90 Kg, K/ha followed by 60 Kg/ha and K application against less number of days to physiological maturity recorded for 30 Kg, K/ha. Control vs rest was found significant for spikes/m^2.

Plant height. Data regarding plant height of wheat as affected by different N, K levels and application methods are given in Table 3. Analysis showed that plant height of wheat was significantly affected by various N, K levels and their application methods. Interaction of treatments was found non-significant. Based on average of two years, application of N and K in such a way that 10% of N and K were applied through foliar and remaining 90% applied directly to soil resulted in tallest plant height followed by rest of the application methods with no statistical differences. Means of the two years showed that increase in N levels significantly increased plant height with maximum plant height recorded for N applied at the rate of 180 Kg/ha followed by 150 Kg/ha. Decreasing N rate decreased plant height of wheat crop. Similarly, increase in K increased plant height when data were averaged across two years.

Table 3. Plant height (cm) and leaf area/tiller of wheat crop as affected by different nitrogen and potassium levels as well as their application methods

Treatments (T)	Plant height (cm) Years (Y)			Leaf area/tiller (cm^2) Years (Y)		
	2010-11	2011-12	Mean	2010-11	2011-12	Mean
Methods (M)						
M1: All N and K soil applied	96	95	95 b	120.3	102.6	111.4 d
M2: 5% foliar + 95% soil applied	95	94	95 b	123.5	109.2	116.3 c
M3: 10% foliar + 90% soil applied	96	96	96 a	127.6	118.2	122.9 b
M4: 15% foliar + 85% soil applied	96	94	95 b	132.7	128.1	130.4 a
$LSD_{0.05}$			0.8			1.4
Nitrogen (Kg/ha)						
90	92	92	92 d	108.1	100.1	104.1 d
120	97	96	96 c	124.3	111.4	117.9 c
150	98	98	98 b	137.5	123.6	130.5 b
180	101	99	100 a	146.6	134.4	140.5 a
$LSD_{0.05}$			0.8			0.8
Potassium (Kg/ha)						
30	97	96	96 b	125.7	113	119.2 c
60	97	96	96 b	129.9	118.1	124.0 b
90	98	97	97 a	132.1	121.1	126.6 a
$LSD_{0.05}$			0.4			0.7
Control	80	79	80 b	88.6	80.3	84.4 b
Rest	97	96	97 a	129.1	117.4	123.3 a
Interactions			**P value**	**Interactions**	**P value**	
N × K			0.044	N × K	0.002	
M × N			0.000	M × N	0.000	

Means sharing same letter(s) for a parameter in a column are statistically similar at 5% level of significance; ns = non-significant.

Highest plant height was recorded for 90 Kg/ha K application, while minimum plant height was recorded for control plots.

Leaf area/tiller. Data regarding leaf area/tiller of wheat as affected by various N, K levels and their application methods are presented in Table 3. Different N, K levels and application methods significantly affected leaf area/tiller of wheat. Based on two years average, minimum leaf area/tiller was documented by the method, where all nutrients were soil applied. Maximum leaf area/tiller was recorded when 15% of the nutrients were applied as foliar and 85% as soil followed by the ratio of 10:90 (foliar: soil). When averaged across two years, significantly maximum leaf area/tiller was recorded for highest (180 Kg/ha) level of N followed by 150 Kg/ha and further decrease in N levels decreased leaf area/tiller also. A profound effect of K was also observed on leaf area/tiller of wheat when means were averaged for both years. Increase in K level from control to 90 Kg/ha increased leaf area/tiller.

Flag leaf area/tiller. Data regarding flag leaf area/tiller of wheat as affected by various N, K levels and application methods (M) are given in Table 4. Various levels of N and K as well as application methods of these nutrients significantly affected flag leaf area/tiller. Flag leaf area/tiller increased substantially with increase in N levels. Average of two years indicated that lowest flag leaf area/tiller was obtained with 90 Kg, N/ha which increased with increase in N levels and gave maximum value for 180 Kg, N/ha. Flag leaf area/tiller showed profound increase with increase in K levels. Means across two years showed that increasing K level increased flag leaf area/tiller with maximum yield recorded for 90 Kg/ha K application. Mean across two

Table 4. Flag leaf area/tiller and leaf area index of wheat crop as influenced by nitrogen, potassium and their application methods

Treatments (T)	Flag leaf area/tiller (cm^2) Years (Y)			Leaf area index Years (Y)		
	2010-11	2011-12	Mean	2010-11	2011-12	Mean
Methods (M)						
M1: All N and K soil applied	20.6	18.9	19.7 c	2.9	2.4	2.6
M2: 5% foliar + 95% soil applied	21.5	19.4	20.5 b	2.7	2.4	2.5
M3: 10% foliar + 90% soil applied	22.4	19.8	21.1 a	2.8	2.4	2.6
M4: 15% foliar + 85% soil applied	22.5	19.9	21.1 a	2.7	2.5	2.6
$LSD_{0.05}$			0.1			ns
Nitrogen (Kg/ha)						
90	18.1	16.2	17.2 d	2.1	2	2.1 d
120	20.9	18.7	19.8 c	2.6	2.3	2.5 c
150	23.7	21.2	22.5 b	3.1	2.7	2.9 b
180	26.6	23.7	25.1 a	3.7	3	3.3 a
$LSD_{0.05}$			0.1			0.1
Potassium (Kg/ha)						
30	21.3	19.1	20.2 c	2.7	2.4	2.5 b
60	22.4	20	21.2 b	2.9	2.5	2.7 a
90	23.2	20.8	22.0 a	3.1	2.6	2.8 a
$LSD_{0.05}$			0.1			0.1
Control	15.1	14	14.6 b	1.5	1.7	1.6 b
Rest	22.3	19.9	21.1 a	2.9	2.5	2.7 a
Interactions	**P value**			**Interactions**	**P value**	
N × K	0.045			M × N	0.042	
M × N	0.000					
M × K	0.000					

Means sharing same letter(s) for a parameter in a column are statistically similar at 5% level of significance; ns = non-significant.

years showed that highest flag leaf area/tiller was obtained when nutrients (N and K) were applied at ratio of 15: 85 (foliar: soil) which was statistically similar with the ratio of 10: 90 (foliar: soil), while lowest flag leaf area/tiller was recorded in plots where all nutrients were applied directly to the soil.

Leaf area index. Impact of different levels of N, K and their application methods on leaf area index of wheat are presented in Table 4. Mean of the two years indicated that various application methods showed no significant effect on leaf area index of wheat. While N and K levels significantly affected leaf area index. Increase in N levels substantially increased leaf area index with maximum leaf area index recorded for N applied at the rate of 180 Kg/ha followed by 150 Kg/ha. Decreasing N levels decreased leaf area index accordingly with minimum leaf area index calculated for control plots. Similarly, increase in K level increased leaf area index. Highest leaf area index was calculated for 90 Kg, K/ha followed by 60 Kg, K/ha with no statistical difference. Control vs rest contrast was found significant for leaf area index with lowest leaf area index recorded in control than rest.

Leaf area duration. Effect of different levels of N, K and their application methods on leaf area duration of wheat is shown in Table 5. Analysis showed that various application methods had no profound impact on leaf area duration of wheat. However, N and K had significant impact on leaf area duration. Increase in N level substantially increased leaf area duration. By taking average of two years, means showed that maximum leaf area duration was recorded for highest (180 Kg/ha) level of N followed by 150 Kg/ha. Leaf area duration decreased significantly as level of N decreased. Similarly, increase in K level also increased leaf area duration. Averaged across two years, data revealed that significantly more leaf area duration was recorded for 90 Kg, K/ha which was followed by 60 Kg/ha and K application against

Table 5. Leaf area duration and grain yield (Kg/ha) of wheat as affected by nitrogen, potassium and their application methods

Treatments (T)	Leaf area duration Years (Y)			Grain yield (Kg/ha) Years (Y)		
	2010-11	2011-12	Mean	2010-11	2011-12	Mean
Methods (M)						
M1: All N and K soil applied	104	87	95	3947.7	3768.9	3858.3c
M2: 5% foliar + 95% soil applied	98	87	93	4082.9	3869.4	3976.2ab
M3: 10% foliar + 90% soil applied	100	87	94	4219.3	4064.7	4142.0a
M4: 15% foliar + 85% soil applied	100	89	94	4253.6	4094.6	4174.1a
LSD$_{0.05}$			ns			71.4
Nitrogen (Kg/ha)						
90	76	68	72d	3969.8	3797.6	3883.7d
120	94	85	90c	4274.7	3962.0	4118.4c
150	114	99	107b	4385.9	4200.6	4293.3b
180	136	111	123a	4424.2	4362.2	4393.2a
LSD$_{0.05}$			2.4			47.5
Potassium (Kg/ha)						
30	97	86	92c	4101.9	3942.1	4022.0c
60	105	91	98b	4311.0	4082.9	4197.0b
90	112	95	104a	4378.1	4216.8	4297.4a
LSD$_{0.05}$			2.1			41.1
Control	48	49	48b	2472.6	2374.9	2423.8b
Rest	105	91	98a	4263.7	4080.6	4172.1a
Interactions	**P value**			**Interactions**	**P value**	
				M × N	0.000	

Means sharing same letter(s) for a parameter in a column are statistically similar at 5% level of significance; ns = non-significant.

minimum leaf area duration recorded for 30 Kg, K/ha. Control vs rest was found significant for leaf area duration.

Grain yield (Kg/ha). Data regarding grain yield of wheat as affected by various N, K levels and M are given in Table 5. Various levels of N and K as well as M of these nutrients significantly affected grain yield. Grain yield increased substantially with increase in N levels. Average of two years indicated that lowest grain yield was obtained with 90 Kg, N/ha which increased with increase in N levels and gave maximum value for 180 Kg, N/ha. Grain yield showed profound increase with increase in K levels. Means across two years showed that increasing K level increased grain yield with maximum yield recorded for 90 Kg/ha K application. Mean across two years showed that highest grain yield was obtained when nutrients (N and K) were applied at ratio of 15: 85 (foliar: soil) which was statistically similar with rest of the ratios while lowest grain yield was recorded in plots where all nutrients were applied directly to the soil.

N uptake by grains (g/Kg). Data regarding N uptake by grains of wheat as affected by different N, K levels and M are given in Table 6. Analysis showed that N uptake by grains of wheat was significantly affected by various N, K levels and their application methods. Based on average of two years, data revealed that application of N and K in such a way that 15% of N and K was applied through foliar and remaining 85% applied directly to soil resulted in maximum N uptake by grains followed by treatment of 10% foliar + 90% soil applied N and K. Minimum N uptake by grains was recorded when all of N and K was applied directly to the soil. Means of the two years showed that increase in N levels

Table 6. Nitrogen uptake by grain (g/Kg) and N uptake by straw (g/Kg) of wheat crop as influenced by nitrogen, potassium and their application methods

Treatments (T)	N uptake by grain (g/Kg) Years (Y)			N uptake by straw (g/Kg) Years (Y)		
	2010-11	2011-12	Mean	2010-11	2011-12	Mean
Methods (M)						
M1: All N and K soil applied	7.3	6.31	6.80d	1.23	1.25	1.24b
M2: 5% foliar + 95% soil applied	7.77	6.56	7.17c	1.31	1.36	1.33b
M3: 10% foliar + 90% soil applied	8.14	7.53	7.84b	1.37	1.23	1.30b
M4: 15% foliar + 85% soil applied	8.51	7.92	8.21a	1.69	1.49	1.59a
$LSD_{0.05}$			0.31			0.18
Nitrogen (Kg/ha)						
90	6.4	5.27	5.83d	0.91	0.96	0.94d
120	7.84	6.73	7.28c	1.25	1.16	1.20c
50	8.96	8.23	8.59b	1.67	1.48	1.57b
80	10.24	9.73	9.98a	1.96	1.93	1.95a
$LSD_{0.05}$			0.18			0.05
Potassium (Kg/ha)						
30	7.68	6.72	7.20 c	1.28	1.26	1.27 c
60	8.42	7.48	7.95 b	1.48	1.35	1.41 b
90	8.97	8.27	8.62 a	1.58	1.54	1.56 a
$LSD_{0.05}$			0.16			0.04
Control	2.79	2.19	2.49 b	0.81	0.72	0.77 b
Rest	8.36	7.49	7.92 a	1.45	1.38	1.42 a
Interactions	**P value**			**Interactions**	**P value**	
N × K	0.000			N × K	0.000	
M × N	0.000			M × N	0.000	
M × K	0.011					

Means sharing same letter(s) for a parameter in a column are statistically similar at 5% level of significance; ns = non-significant.

significantly increased N uptake by grains with maximum N uptake by grains recorded for N applied at the rate of 180 Kg/ha followed by 150 Kg, N/ha application. Similarly, increase in K rate increased N uptake by grains when data were averaged across two years. Highest N uptake by grains was recorded for 90 Kg/ha K application while minimum N uptake by grains was recorded for control plots.

N uptake by straw (g/Kg). Data in Table 6 exhibits N uptake by straw in wheat as affected by various N, K levels and application methods. Based on average of two years, data indicated that N uptake by straw increased significantly with increase in N levels and showed a positive relation with N levels. Maximum N uptake by straw was recorded with the application of 180 Kg, N/ha followed by 120 Kg, N/ha. Lesser value for N uptake by straw was recorded for 90 Kg/ha N application. Based on average of two years, data showed that N uptake by straw increased substantially with increase in K levels and reached to maximum value for K applied at the rate of 90 Kg/ha against minimum value recorded for 30 Kg/ha. Averaged across two years, maximum N uptake by straw was recorded for nutrients applied at the ratio of 15:85 as foliar and soil followed by ratio of 10:90 which was statistically similar with rest of the ratios.

Interactions. ***Interaction between N and K for days to anthesis and physiological maturity of wheat.*** Interaction of N × K for days to anthesis of wheat (Fig. 2) indicated that increasing N level significantly increased days to anthesis for all levels of K and vice versa. Maximum days to anthesis were recorded when N was applied at the rate of 180 Kg/ha and K at the rate of 90 Kg/ha, while minimum days to anthesis were recorded when both N and K were applied at their lowest rate, *i.e.* 90 and 30 Kg/ha, respectively.

Interaction of N × K (Fig. 3) indicated that days to maturity increased significantly when both N and K increased simultaneously with maximum days to maturity recorded when both N and K were at their highest rate *i.e.* 180 and 90 Kg/ha. Minimum days to maturity were recorded when N and K were at their lowest rate.

Interaction between methods and N and K for days to physiological maturity of wheat. This interaction revealed that increasing N rate increased days to maturity for all levels of application methods of nutrients (Fig. 4). Maximum days to maturity were recorded

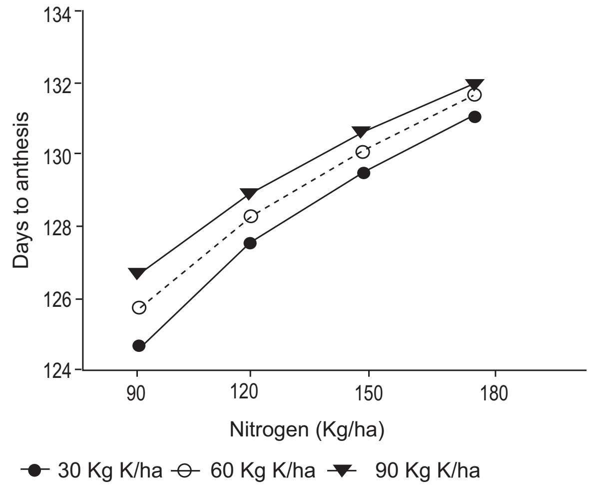

Fig. 2. Interaction of N × K for days to anthesis.

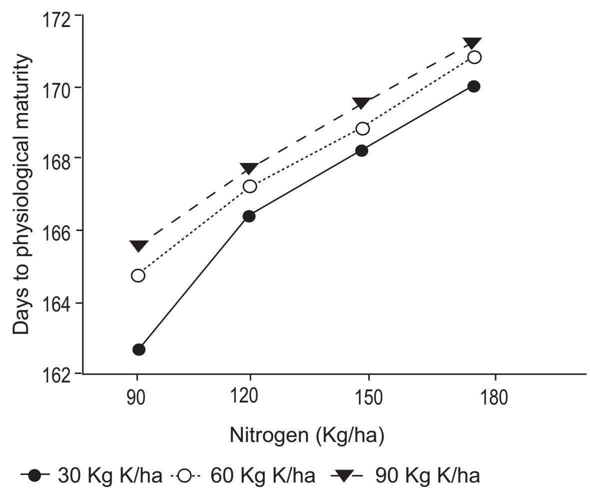

Fig. 3. N × K interaction for physiological maturity.

when 180 Kg, N/ha was applied in such a way that 15% N was applied through foliar and 85% directly to soil. Minimum days to maturity were recorded when 90 Kg/ha of N was applied in the ratio of 5: 95 as foliar: soil.

Methods and K interaction indicated (Fig. 5) that application of 30 Kg, K/ha in such a way that 5% K was supplied through foliar and remaining 95% through soil resulted in less days to physiological maturity while the same ratio of foliar to soil application of K resulted in more days to maturity when K was increased to 90 Kg/ha.

N and K interaction for plant height of wheat. N × K interaction (Fig. 6) showed that with increase in N rate plant height increased substantially for all levels of K. Taller plants were recorded when N and K was applied at the rate of 180 and 90 Kg/ha, respectively. Short statured plants were recorded when both N and K was applied at their lowest rate.

Plant height of wheat in response to methods and N interaction. Plant height substantially increased with increase in N rate with minimum plant height recorded when 90 Kg, N/ha was completely applied to soil (Fig. 7). At 90 Kg, N/ha maximum plant height was recorded when it was applied in the ratio of 15:85 (foliar: soil) while maximum plant height was recorded when complete dose of 180 Kg, N/ha was directly applied to soil with no foliar application.

N and K interaction for leaf area/tiller of wheat. Leaf area/tiller increased profoundly with increase in N and K (Fig. 8) simultaneously and attained maximum value when both N and K were at their highest rate. Decreasing N and K rate decreased leaf area/tiller with minimum value recorded when N was applied at the rate of 90 Kg/ha with K at the rate of 30 Kg/ha.

Leaf area/tiller of wheat in response to methods and N interaction. Methods and N interaction (Fig. 9) indicated that as the percentage of foliar application of N increased leaf area/tiller increased also across all

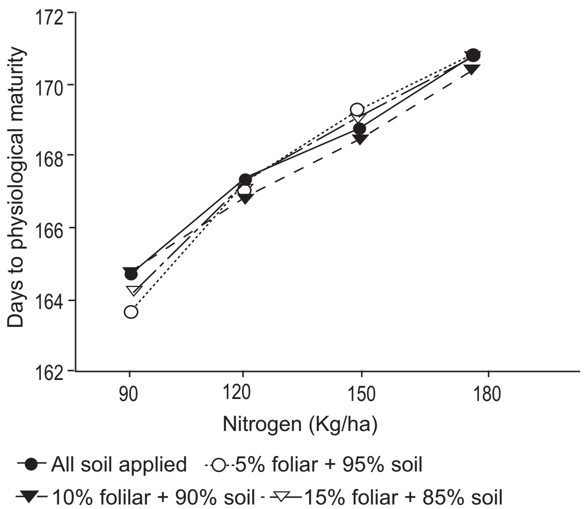

Fig. 4. Interaction N × M for physiological maturity.

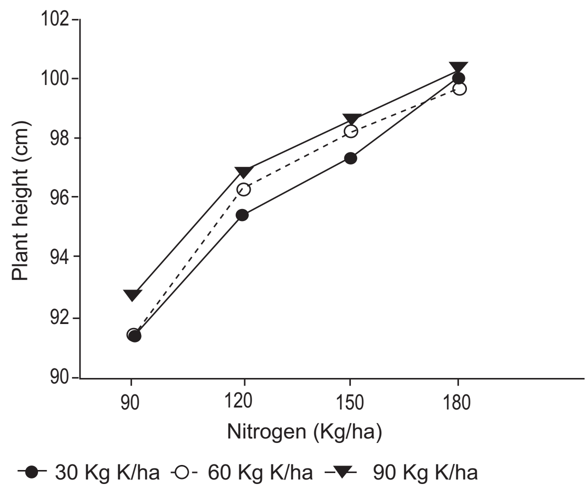

Fig. 6. N × K interaction for plant height.

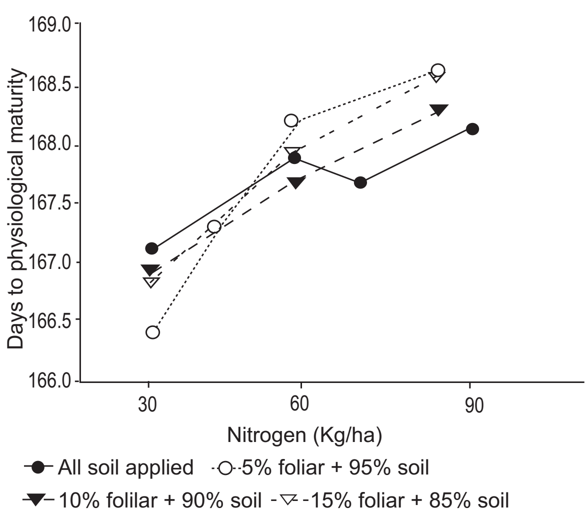

Fig. 5. K × M interaction for physiological maturity.

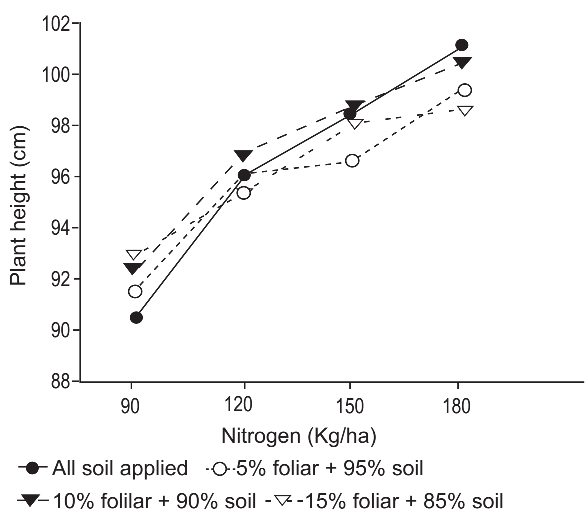

Fig. 7. Interaction of N × M for plant height.

levels of N. Maximum leaf area/tiller was recorded when 180 Kg/ha N was applied in such a way that 15% was supplied through foliar and 85% through soil application while minimum leaf area/tiller was recorded when 90 Kg/ha N was completely applied to soil.

Impact of N and K interaction on flag leaf area/tiller of wheat. Flag leaf area/tiller profoundly increased when both N and K (Fig. 10) was increased simultaneously and attained maximum value when both N and K were at their highest rate *i.e*. 180 and 90 Kg/ha. Minimum flag leaf area/tiller was recorded when both N and K was at their lowest rate *i.e*. 90 and 30 Kg/ha, respectively.

Impact of methods and N interaction on flag leaf area/tiller of wheat. Methods into N interaction (Fig. 11) showed that when N was applied directly into the soil resulted in minimum flag leaf area/tiller and increasing ratio of foliar application significantly increased flag leaf area/tiller across all level of N. Maximum flag leaf area/tiller was recorded when 180 Kg, N/ha was applied in such a way that 15% N was supplied through foliar and rest through soil application which was statistically similar to ratio of 10:90 (foliar: soil).

Methods and K interaction for flag leaf area/tiller of wheat. This interaction clearly indicated that increase

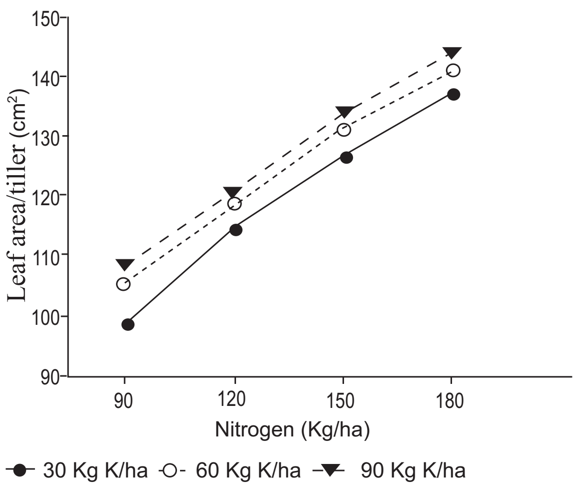

Fig. 8. N × K interaction for leaf area/tiller.

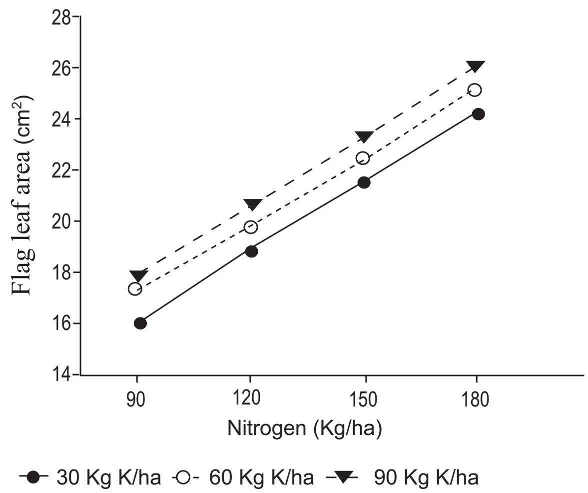

Fig. 10. N × K interaction for flag leaf area (cm^2).

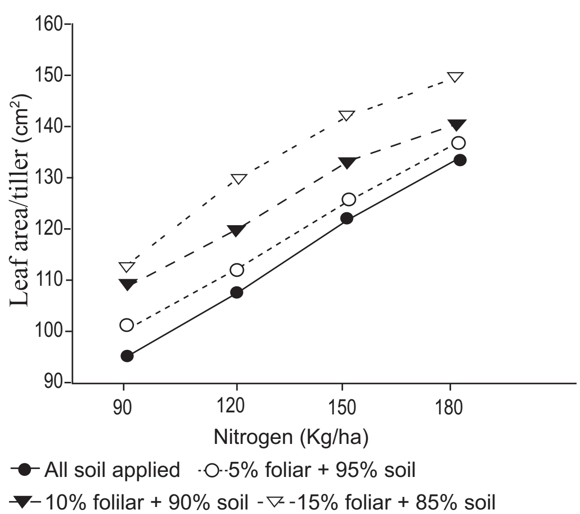

Fig. 9. Interaction of N × M for leaf area/tiller.

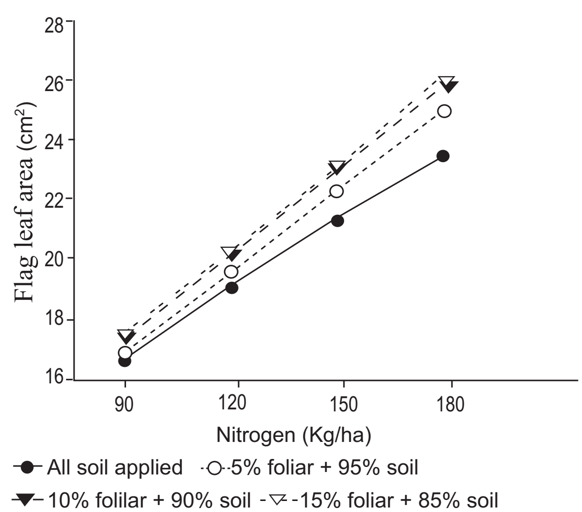

Fig. 11. Interaction of N × M for flag leaf area (cm^2).

in ratio of foliar to soil application of K profoundly increased flag leaf area/tiller with increase in K rate simultaneously (Fig. 12). Maximum flag leaf area/tiller was recorded when K was applied at the rate of 90 Kg/ha in the ratio of 15:85 as foliar: soil application respectively.

Leaf area index of wheat in response to methods and N interaction. Methods into N interaction (Fig. 13) indicated that leaf area index increased linearly across all levels of application methods and attained maximum value when 15% of N was applied through foliar and 85% directly to soil to provide a total of 180 Kg, N/ha.

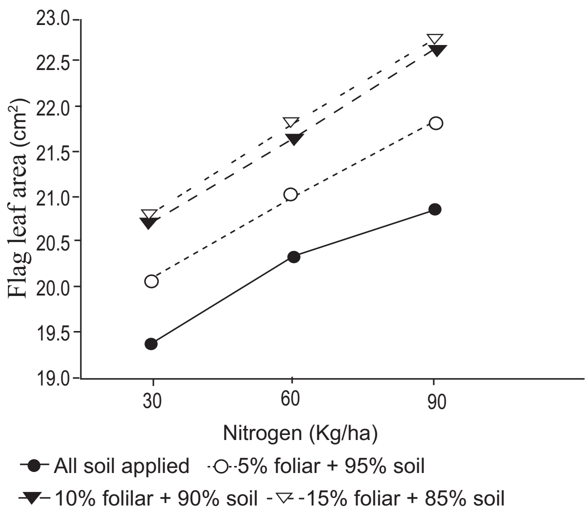

Fig. 12. Interaction of M × K for flag leaf area (cm^2).

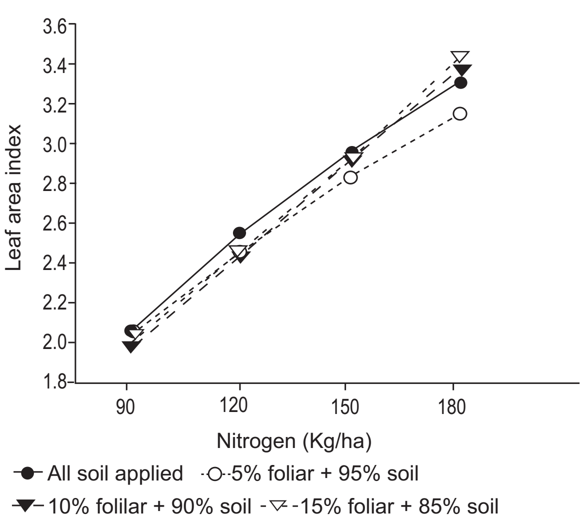

Fig. 13. N x M interaction for leaf area index.

Grain yield of wheat in response to methods and N interaction. Interaction (Fig. 14) showed that increase in N level increased grain yield weather applied directly to soil or in combination with foliar except for treatment of 5% foliar + 95% soil which decreased yield when N was increased from 150 Kg/ha to 180 Kg/ha. Maximum grain yield was recorded when N was applied at the rate of 180 Kg/ha in such a combination that 15% N was applied through foliar and remaining through soil application. Application of 90 Kg, N/ha directly to soil resulted in lower grain yield.

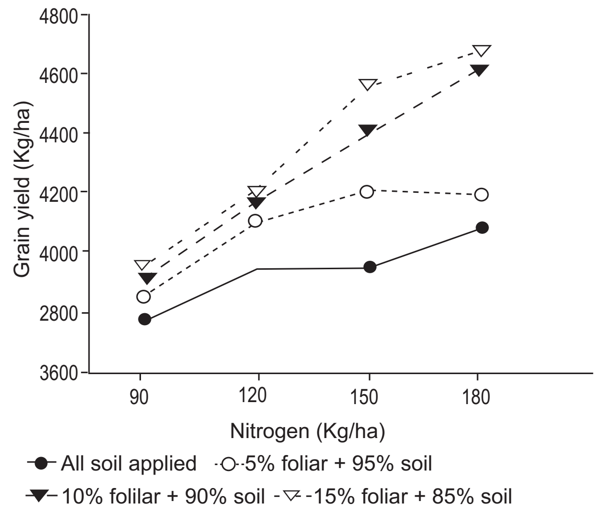

Fig. 14. Interaction of M × N for grain yield (Kg/ha).

Interaction between N and K for N uptake by grains of wheat. Simultaneous increase of N and K substantially increased N uptake by grains (Fig. 15). Maximum N uptake by grains was recorded when both N and K was applied at their highest rate *i.e.* 180 and 90 Kg/ha. Minimum N uptake by grains was recorded when N was applied at the rate of 90 with K at the rate of 30 Kg/ha.

Methods and N interaction for N uptake by grains of wheat. N uptake by grains increased with increase in ratio of foliar to soil N application with maximum N uptake by grains (Fig. 16) recorded for 180 Kg, N/ha applied in such a way that 15% and 85% N was supplied through foliar and soil application respectively. Minimum N uptake by grains was recorded when 90 Kg/ha N was applied directly to the soil.

Impact of methods and K interaction for N uptake by grains of wheat. Methods and K interactions

(Fig. 17) revealed that minimum N uptake by grains was recorded when complete dose of 30 Kg/ha K was applied directly to soil which increased with increase in K rate. Increase in ratio of foliar to soil application of N, uptake of N by grains increased across all levels of N and attained maximum value when 180 Kg/ha N was applied in the ratio of 15: 85 (foliar: soil).

N uptake by straw of wheat in response to N and K interaction. N and K interaction (Fig. 18) significantly increased N uptake by straw of wheat crop. A continuous increase was observed in N uptake by straw when both N and K were increased simultaneously. Maximum N uptake by straw was recorded when both nutrients (N and k) was applied at their highest rate.

Methods and N interaction for N uptake by straw of wheat. This interaction (Fig. 19) revealed that minimum N uptake by straw was observed when 90 Kg/ha N was supplied in such a way that 10% N was applied through foliar and 90% through soil application. Maximum N uptake by straw was recorded when 180 Kg, N/ha was applied in such a way that 15% and 85% N was supplied through foliar and soil application respectively.

Nitrogen and potassium. Crop phenology is a vital phenomenon and can affect wheat productivity. Phenological parameters like days to anthesis and

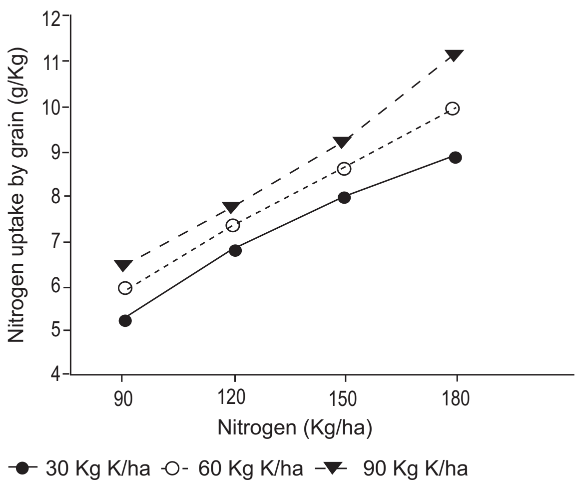

Fig. 15. Interaction of N × K for N uptake by grain.

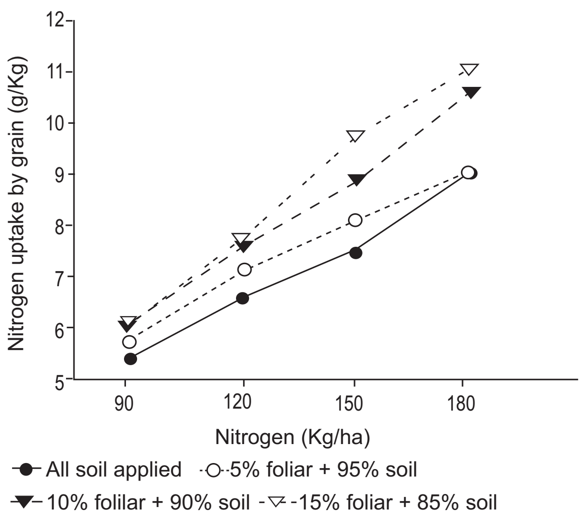

Fig. 16. Interaction of N × M for N uptake by grain.

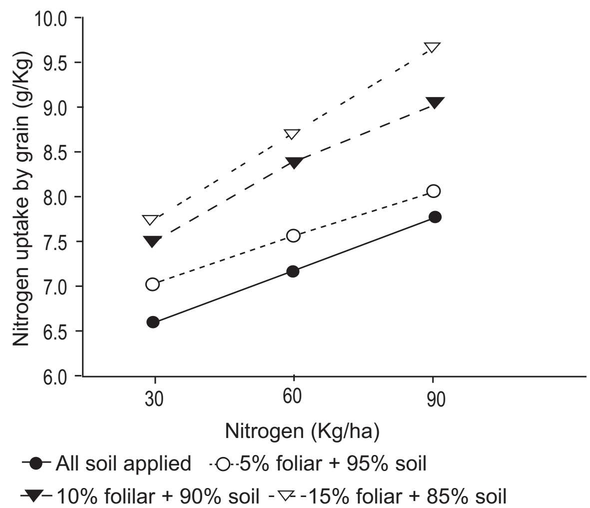

Fig. 17. Interaction of K × M for N uptake by grain.

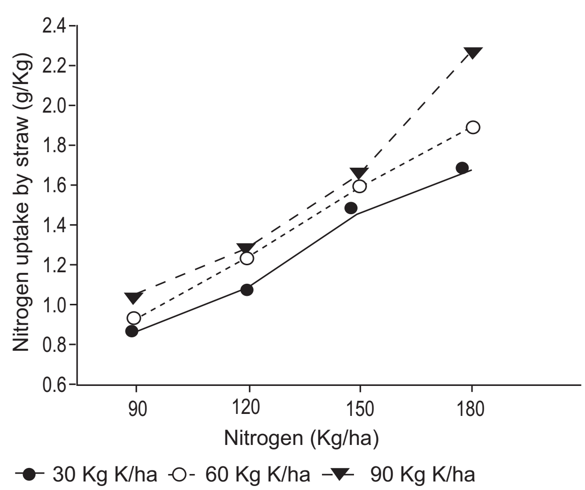

Fig. 18. N × K interaction for N uptake by straw.

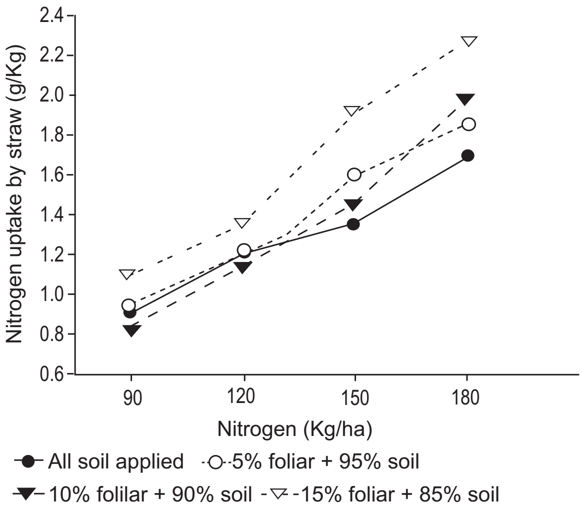

Fig. 19. Interaction of N × M for N uptake by straw.

maturity play a significant role in the final crop yield. Days to anthesis and maturity increased with increasing rate of N and K. More days taken to anthesis and maturity might be due to continuous cell division and multiplication with sufficient amount of N and K which prolonged vegetative stage as reported by Hameed *et al*. (2003). Delayed anthesis and maturity could be attributed to increase in leaf area duration, vegetative growth and enhanced light use efficiency with the use of N fertilizer (Delden, 2001). Increasing N rate increased water use efficiency and duration of growth stages (Deng *et al*., 2004). Our findings are in line with Shahzad and Akmal (2017) who reported delay in maturity with increasing N rate due to extended grain filling duration. Increase in K level significantly delayed maturity probably because of enormous vegetative growth (Seilsepour, 2007).

Plant height increased linearly with each successive increase in rate of N and K which might be attributed to better and vigorous vegetative growth due to application of N and K (Ayub *et al*., 2002). Increase in plant height due to K was also observed by Kubar *et al*. (2019). A linear increase was observed in plant height with simultaneous increase in the levels of N and K. Adnan *et al*. (2016) reported that plant height increased when N was applied in combination with K probably because carbohydrates were more rapidly converted into proteins by application of N which ultimately changed into protoplasm, thus increased cell size and finally plant height. Leaf area/tiller and flag leaf area increased significantly with the application of N and K. Fertilizer application to wheat particularly N and K during early stages of plant growth greatly increased leaf area by keeping leaves green, sustained leaf photosynthesis and prolonged leaf area duration which ultimately resulted in maximum leaf area compared with control as reported by Zhang *et al*. (1998). Application of N increased assimilates content in leaf which might increase leaf area. Application of N stimulates leaf growth and thus increases leaf area (Khan *et al*., 2008). Our outcomes are supported by the results of Delden (2001) who reported that leaf area decreased with decrease in N fertilization.

Leaf area index is one of the major physiological determinant of the crop final yield. Increasing N and K rate increased LAI which might be attributed to enhanced leaf area on account of more accumulation of assimilates. Also, increased in tillers and size of leaves due to increased rate of N and K might enhanced LAI. Heinemann *et al*. (2006) recorded highest LAI at increasing rate of mineral N. Kibe *et al*. (2006) indicated that leaf area and LAI was higher in N fertilized plots than control. Leaf area duration increased significantly with the application of N and K nutrients. Foulkes *et al*. (2007) reported that prolonged green flag leaf area was related with the ability of the crop to produce more yield. Leaf area duration increased with increased N level (Basit, 2003). Grain yield increased significantly with application of N and K nutrients. Improvement in grain yield of wheat might be due to the collective role of N and K as reported by Deng *et al*. (2004). Grain yield increased considerably with increase in application of N levels. It was indicated by Foyer *et al*. (2002) that N played a key role in photosynthesis of plants and thus increased grain yield of the crop. Maximum grain yield might be attributed to the improvement in number of tillers, spike length, grain/spike and 1000 grains weight. Similar results were obtained by Singh *et al*. (2002) who reported that increasing N rates increased grain yield. Maqsood *et al*. (2002) found that application of 150 Kg, N/ha gave the highest grain yield. Grain yield showed profound increase with increase in the application of K levels. K increased root growth, reduced water loss and wilting, enhanced drought resistance (Tiwari, 2002) thus might resulted in more grain yield. Potassium might have increased the rate of CO_2 assimilation, stabilized osmosis regulation, improved stomata closure and enzyme activity as a result of which more carbohydrates might have produced which ultimately increased grain yield as recorded by Tabatabaii *et al*. (2011).

Nitrogen uptake by wheat grains and straw in response to N and K fertilization. Nitrogen uptake by wheat grains and straw increased by increasing N and K fertilization, because they are the most important nutrients for plants, where many physiological processes rely on them, especially those responsible for absorbing elements by enhancing roots and thus increasing the concentration of nutrients in plant such as N. Baque *et al*. (2006) reported that uptake of N was enhanced with increasing K levels. Antoun *et al*. (2010) obtained similar results. Mosaad and Fouda (2016) reported the same findings that increasing K rate significantly increased N uptake by grains and straw. N uptake by straw and grain substantially increased by increasing N rate (Antoun *et al*., 2010). Seadh *et al*. (2009) reported that fertilization with a higher N dose has the most favorable effect on the contents of N in wheat grain. N uptake by grains increased significantly with the application of N and K (Hassan *et al*., 1996).

Application methods of N and K. Foliar application of urea has been proved to be an effective technique of N fertilization. The adoption of foliar urea may help reduce the losses due to denitrification, leaching and immobilization, often associated with N fertilization to the soil system (Gooding, 2005).

In our experiment, the application of urea and murate of potash through soil + foliar spray at 180 and 90 Kg, N/ha in the ratio of 10:90 (foliar: soil) increased plant height while ratio of 15:85 substantially increased leaf area/tiller, flag leaf area/tiller, grain yield, N uptake by grains and straw. This suggested the quick absorption of N and K due to foliar spray. The above findings are in line with the previous studies (Mahajan *et al*., 2004; Abdi *et al*., 2002; Masauskas and Masauskiene, 2002; Siuliouskas *et al*., 2001; Jakhro *et al*., 2000; Emam and Borijan, 2000). These studies reported that foliar spray of N along with soil application increased growth, yield components and yield as compared to single mode of soil application. The effectiveness of foliar applied urea is reported up to 90-160% to that of soil application (Czuba, 1994). This might suggest the better utilization and quicker absorption of N by plants through foliar spray of urea. Khokhar (1985) reported that applying urea through soil application resulted about 50% N loss due to volatilization and leaching. Application of N and K in combination of foliar and soil enhanced plant height than complete supply of these nutrients to soil. This might be due to quick absorption of these nutrients through leaf when applied as foliar which cause vigorous vegetative growth and resulted in taller plants. Foliar application of N and K significantly increased plant height as reported by Lloveras *et al*. (2001). Grain yield increased linearly when 15% of the nutrients were applied to the crop as foliar spray. Foliar spray at flowering and at peak vegetative stage increased grain growth and as a result higher grain yield was produced as reported by Eman and Mogied (1989). Zafar and Mohammad (2007) investigated that foliar spray of N increased grain yield of wheat. Narang *et al*. (1997) reported that foliar application of K increased grain yield. Our results are in accordance with the findings of (Abdi *et al*., 2002; Siuliouskas *et al*., 2001) and Gooding (2005). These researchers reported that foliar spray of urea/N along with soil application increased N content in straw and grain. It was observed that integrated application of N through soil and foliage facilitated the higher N uptake in plants as also investigated by Vagen (2003).

Conclusion

It is revealed from the experimental results that application of nitrogen (N) and potassium (K) in different ratios as foliar and soil markedly enhanced growth, yield and N uptake of wheat crop. Application of N and K at the rate of 180 and 90 Kg/ha respectively improved growth, yield and N uptake when applied in such a way that 15% nutrients (N and K) were applied as foliar and remaining 85% through soil application. Further research on different rates of N and K with various ratios as foliar and soil is also recommended to improve wheat and others major crops yield.

Conflict of Interest. The authors declare no conflict of interest.

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