

EFFECTS OF POTASSIUM ON PHENOLOGICAL, PHYSIOLOGICAL AND AGRONOMIC TRAITS OF MAIZE (*ZEA MAYS L.*) UNDER HIGH NITROGEN NUTRITION WITH OPTIMUM AND REDUCED IRRIGATION

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Abstract. Potassium (K) as a macro nutrient governs important physiological mechanisms ensuring optimum plant growth and produce quality. An experiment was conducted during the summer of 2017 to study the effects of potassium application on maize under high nitrogen (N) nutrition with optimum and reduced irrigations. The experiment was comprised of three factors, viz. two irrigation levels (optimum, reduced), three potassium levels (80, 120 and 160 kg ha⁻¹) and four nitrogen levels (100, 150, 200 and 250 kg ha⁻¹). Two separate trials were carried out in randomized complete block design (RCBD), one under optimum (five irrigations) and another under reduced irrigation (three irrigations). One control plot (OK, ON) was used under each replication for both trials. Optimum irrigation had resulted in maximum days of tasseling, silking, physiological maturity, crop growth rate (CGR), net assimilation rate (NAR), absolute growth rate (AGR), plant height, grains ear⁻¹, thousand grains weight, biological yield, grain yield, chlorophyll contents and shelling percentage. High N (250 kg ha⁻¹) delayed tasseling, silking and physiological maturity and resulted in maximum growth, physiological traits and biological yields. However, 150 kg N ha⁻¹ had resulted in maximum number of ears m⁻², number of grains ear⁻¹, thousand grains weight and grain yield. While 100 kg N ha⁻¹ had resulted in early tasseling, silking and physiological maturity. Potassium fertilization at the rate of 160 kg ha⁻¹ delayed phenology and recorded with maximum growth rates, improved physiology and maximum yield traits and grain yield. However, the treatment 120 kg K ha⁻¹ remained almost statistically similar to the 160 kg K ha⁻¹ for most of the parameters. In the case of control vs rest, generally the performance of the control plot was poor. Hence, 150 kg N ha⁻¹ with 120 kg K ha⁻¹ under optimum irrigation is recommended for optimum productivity of maize crop.

Keywords: *fertilizer rate, maize, deficit irrigation, ear characteristics, grain yield*

Introduction

Maize (*Zea mays* L.) is the third most important cereal crop in Pakistan after wheat and rice and ranks second in Khyber Pakhtunkhwa province after wheat. Maize is cultivated in Pakistan on 64% irrigated and 36% on rainfed land (Ahmad and Rashid, 2003). Implementation and adoption of the new production technologies had increased the maize production per unit area due to balance use of agriculture inputs and new methods (Amanullah, 2004).

Improper application of the synthetic fertilizers in Khyber Pakhtunkhwa is the main cause of low yield of maize (Amanullah et al., 2014). In Pakistan only tobacco crop receive potassium due to industrial requirement while farmers do not apply potassium to wheat and maize in general. Deficiency of potassium is reported in most of the Pakistani soils due to multiple cropping systems (Ahmad and Rashid, 2003). Potassium is used by the crops in large amounts (Mengel et al., 2001; White and Karley, 2010). A soil deficient in potassium results in reduced plant photosynthesis (Wang et al., 2015a), which is the main cause of low yield of maize (Amanullah and Khalid, 2016), sunflower (Amanullah and Khan, 2010) and brassica (Amanullah et al., 2011).

Potassium is the primary major nutrient which is a non-structural component of the plant body. After nitrogen it is the second most abundant nutrient in plant tissues generally 1-3% by weight. It is very important for the transport of assimilates in plant cells and activates more than 60 different enzymes. Potassium increases plant tolerance to frost and heat injuries, droughts and enhances the resistance to diseases, different pest incidence and keeps anion balance in plants (Wang et al., 2013). The most important role of K^+ in plants is the osmoregulation which maintains turgor pressure in the cell, crucial for cell elongation and hence the growth and regulation of stomatal opening and closing, affecting carbon dioxide intake by photosynthesis process and transpirational cooling (Marschner, 1995). Potassium is a macro nutrient which is important for the growth of plants. Comparatively the large amounts of mineral potassium are present in the Pakistani soil which is non-soluble, and only a small amount is available to plants. Optimum amount of potassium in the soil in case of water scarcity comparatively enhances deposition of total dry matter in the crops compared to soils with less potassium regimes (Rosenstock et al., 2016). Potassium regulates stomata which in turn enhance photosynthesis (Marschner, 2012). Moreover, the root growth is supported by the crucial role of potassium in the transportation of photosynthetic products (Romheld and Kirkby, 2010).

Being a macro-nutrient, nitrogen is essential for the plant health and acts as a growth-limiting nutrient (Noor, 2017; Wang et al., 2018). Nitrogen is the major part of several essential organic compounds such as amino acids, proteins, coenzymes, nucleic acids, chlorophyll, cytochrome, ribosomes and many vitamins (Noorka et al., 2009, 2011). Among various grasses, maize is the grass whose nitrogen requirements for optimum grain yield is very high (Noor, 2017). Certain metabolic processes of the plants depend on the role of nitrogen in plants (Wang et al., 2015b). During the whole grain-filling stage, it aids to keep the kernels active, affecting the size and number of improved kernels (Huber et al., 1994). Usually nitrogen demand of maize is very different, and approximately 0-250 kg N ha⁻¹ is the range for economically optimal nitrogen rates (EONR) (Scharf et al., 2006). Therefore, it is imperative to manage nitrogenous fertilizers accurately (Noor, 2017), but the capacity to determine the exact EONR had been kept comparatively elusive.

A sufficient amount of water in the soil is important for the growth and development of crops, recovery of water loss through transpiration and as a transport medium for nutrients to roots (Wang et al., 2018). Scarce availability of water to crops in the soil leads to drought. Acute water deficiency reduces water use and hence crop yield. There are three big processes by which maize yield is limited by water scarcity in the soil: (i) decreased absorption of the incident photosynthetically active radiation by canopy, (ii) reduced radiation use efficiency, (iii) decreased harvest index (Earl and Davis, 2003).

To know and keeping in mind the importance of potassium, in case of high nitrogen nutrition impact on maize lodging under optimum and reduced irrigations, the present experiment was designed and conducted to find out optimum level of potassium for improved growth and yield traits by minimizing lodging losses, enhancing resistance to drought and to figure out the best nitrogen level for higher maize productivity in the agro-climatic conditions of Peshawar, Pakistan.

Materials and methods

Site description

Field experiments were conducted to study the response of spring planted maize hybrid, at Agronomy Research Farm, The University of Agriculture Peshawar, Pakistan, during the summer of 2017. The research farm is located at 34.01°N, 71.35°E, at an altitude of 350 m above sea level in the Peshawar valley (*Fig. 1*). Peshawar is located about 1600 km north of the Indian Ocean and has semiarid climate. The research farm is irrigated by the Warsak canal from Kabul River. The soil of the farm is clay loam in texture, alkaline (pH 8.2), and calcareous, with a low organic matter content of 8.7 (g kg⁻¹) and low concentrations of extractable phosphorus of 6.57 mg kg⁻¹ and exchangeable potassium (AB-DTPA) of 121 (mg kg⁻¹). The climate of the area is semiarid where the mean annual rainfall is very low (300 to 500 mm), 60–70% rainfall occurs in summer, while the remaining 30–40% rainfall occurs in winter.

Experimental treatments and management practices

Two trials, one with optimum irrigation (I) (I = 5 irrigations) and another with reduced irrigation (I₂ = 3 irrigations) were carried out in randomized complete block design (RCBD). Nitrogen (N₁ = 100, N₂ = 150, N₃ = 200 and N₄ = 250 kg ha⁻¹) and potassium (K₁ = 80, K₂ = 120 and K₃ = 160 kg ha⁻¹) were applied in combination to both experiments with three replications. Each replication was added with an unfertilized plot (0N, 0K). CS-220 variety of maize was sown on 18th May 2017 with a sub-plot area of 3 m × 4 m, which was consisted of 70 cm apart 3 m long 5 rows. Seeds were planted at the rate of 35 kg ha⁻¹. Before seed bed preparation, presoaking irrigation of 100 mm was given. When the soil reached at field capacity, seedbed was prepared. Subsequently, five irrigations (75 mm each) were applied at VE, V6, V12, V18 and R1 stages of maize for optimum irrigation treatment. For the reduced irrigation, three irrigations (75 mm each) were applied at VE, V12 and R1 stages of maize. Muriate of potash (MOP) was used as a source of potassium which contains 60% K₂O, Similarly N was applied as urea (46% N). Source of phosphorus was triple super phosphate (TSP) at the rate of 90 kg ha⁻¹. Potash and phosphorus were applied as a whole at the planting time, whereas half split of nitrogen was applied at planting and the other half at V6 stage (knee height). Weeds were controlled by applying herbicide Primixtra gold (S-

Metolachlor 400 g/L, Atrazine 320 g/L) at rate of 2000 ml ha⁻¹ two weeks after sowing maize crop. On the basis of calibration for experimental area, 250 l ha⁻¹ water was used for the herbicide application. Furadan (Carbofuran) was applied at rate of 10 kg ha⁻¹ with second irrigation and 10 kg ha⁻¹ with the third irrigation. During the whole growing season, uniform agronomic techniques were performed in all sub plots.



Figure 1. Location of the study site in the Peshawar city of Pakistan. (Modified from the source: www.surveyofpakistan.gov.pk)

Harvesting of whole plots was done manually on 15th August 2017. After harvesting, plants were kept in the field for three days and then tied into bundles and stacked in the sun light for 3 weeks for sun-drying. After 3 weeks the ears of the whole plot were husked and allowed to dry in sunshine for two days. After sun-drying, husked ears were threshed by maize sheller and subsequent calculations were done to determine grain yields.

Measurements

Phenological parameters

Days to tasseling data were recorded by counting days from planting date to the date when 50% plants had produced tassels in each plot. Days to silking data were figured out in each plot by counting the number of days from sowing date to the date when 50% silks

were appeared. Data on days to physiological maturity were recorded by counting the number of days between sowing date and the date when 50% plants in each plot get matured. The sign of physiological maturity i.e. dark brown/black abscission layer appearance in the base of seed was considered. For recording plant height (cm) with the help of meter rod, five plants were randomly chosen at silking stage in each sub-plot and then averaged.

Physiological traits

For calculating CGR (Crop Growth Rate, $\text{g m}^{-2} \text{d}^{-1}$), one meter long row from side rows in each experimental unit was harvested and plants were oven-dried for 72 h at 70 °C to calculate their dry weight at, (1) V6 leaf stage, (2) Blister stage, and (3) R6 (Physiological maturity) stage. Formula used was:

$$\text{CGR (g m}^{-2} \text{d}^{-1}) = [(W_2 - W_1) / (T_2 - T_1) \times (1 / \text{GA})]$$

where, W_1 = Initial weight at 27th day after sowing; W_2 = Last weight at 98th day after sowing; T_1 = Initial date 18th May 2017 (Sowing); T_2 = 30th August 2017 (Harvesting); GA = Row to row distance (0.75 cm) \times plant to plant distance (20 cm) \times number of plants (five plants)

Similarly, for absolute growth rate (AGR) one meter long row was selected from each plot was harvested and oven-dried for 72 h at 70 °C and then dry weight was determined at various growth stages viz. (1) V6 leaf stage, (2) Blister stage, and (3) R6 stage. AGR was figured out by the following formula:

$$\text{AGR (g m}^{-2} \text{d}^{-1}) = W_2 - W_1 / T_2 - T_1$$

where, W_1 = weight at 27th day after sowing; W_2 = weight at 98th day after sowing; T_1 = date 18th May 2017 (sowing); T_2 = 15th August (harvesting).

Net assimilation rate (NAR) was calculated similarly as for CGR in each sub plot by selecting one meter long row from border rows, and harvested and oven-dried at 70 °C for 72 h. Dry weight was found out at two growth stages, (1) V6 stage, and (2) R6 stage (physiological maturity). The following formula was used for NAR:

$$\text{NAR (g m}^{-2} \text{d}^{-1}) = [W_2 - W_1 / T_2 - T_1] \times [\ln L_2 - \ln L_1 / L_2 - L_1]$$

where, W_1 = weight at 27th day after sowing; W_2 = weight at 98th day after sowing; T_1 = date 18th May 2017 (sowing); T_2 = 15th August 2017 (harvesting); L_1 = Initial leaf area at 18th May 2017; L_2 = final leaf area at 15th August 2017.

Chlorophyll contents at different stages

From each experimental unit, five plants and three leaves per plant were randomly selected and sampled. The chlorophyll contents were measured out on three locations per leaf with chlorophyll meter (Model: SPAD-502, Minolta, Japan) and then averaged.

Yield and yield attributes

Ten ears were randomly chosen and sampled from each experimental unit and grains were counted and averaged. From these sampled ears, 1000 grains were randomly

selected and weight was measured by electronic balance. At R6 stage, three central rows in each experimental unit were harvested manually by keeping sufficient border plants, fresh weight was measured and then sun-dried for 7 d and after that their dry weight was recorded. For calculating grain yield, all the ears from sun-dried plants of three central rows for each plot were threshed and weighed for calculating grain and biological yields, and for ear characteristics. The grain yields were adjusted to 15.5% grain moisture content and then presented. For each treatment, shelling percentage was estimated with the following formula:

$$\text{Shelling percentage} = \text{Grain weight of 10 ears} / \text{Total weight of 10 ears} \times 100$$

Statistical analysis

Data were statistically analyzed by analysis of variance (ANOVA) procedure suitable for randomized complete block design. Means were compared using least significant difference (LSD) test at 0.05 probability level, when F-values were significant (Steel et al., 1996). Interaction graphs were made through Sigma plot software (version 12.5).

Results

Phenological parameters

Irrigation, nitrogen, potassium and control vs rest significantly affected number of days to tasseling of maize, whereas all the interactions were found non-significant (*Table 1*). Means values of the data indicated that optimum irrigation significantly enhanced days to tasseling compared with reduced irrigation. Results revealed that lower N (100 kg ha⁻¹) resulted in early tasseling. Days to tasseling were delayed with increase in nitrogen and maximum days to tasseling were noted with 250 kg N ha⁻¹. Potassium fertilization at the rate of 120 kg ha⁻¹ showed maximum days to tasseling which were statistically same to 160 kg K ha⁻¹ treatment, while less days to tasseling were recorded with 80 kg K ha⁻¹. Fertilized plots resulted in more days to tasseling compared with control plots.

Results revealed that days to silking were significantly influenced by nitrogen, potassium and control vs rest comparison, whereas irrigation and all the interactions were found non-significant (*Table 2*). Mean values for nitrogen showed that lower N (120 kg ha⁻¹) resulted in early silking, while delayed silking was observed with nitrogen application at the rate of 250 kg ha⁻¹. Maximum days to silking were noted with 160 kg K ha⁻¹ while less days to silking were recorded with potassium fertilization at the rate of 80. Data regarding physiological maturity was also effected by all treatments, while all the interactions were non-significant (*Table 1*). Optimum irrigation resulted in late physiological maturity compared to reduced irrigation. Mean values for nitrogen reported that minimum days to physiological maturity were observed with lower N (100 kg ha⁻¹) which were statistically identical to 150 kg N ha⁻¹. Increase in N had delayed the maturity and more days to physiological maturity were recorded for 250 kg N ha⁻¹. Potassium fertilization at the rate of 160 kg ha⁻¹ delayed physiological maturity while early maturity was observed with 80 kg K ha⁻¹.

Table 1. Phenology of maize hybrid as influenced by fertilization of potassium and nitrogen under optimum and reduced irrigation

	Days to tasseling	Days to silking	Days to physiological maturity	Plant height (cm)
Potassium levels (kg ha ⁻¹)				
80	49 b	56 b	93 c	192.3
120	50 a	56 b	94 b	191.9
160	50 a	57 a	95 a	192.3
LSD (0.05)	0.5	0.3	0.6	ns
Nitrogen levels (kg ha ⁻¹)				
100	48 c	55 d	93 c	188.2 c
150	49 b	56 c	93 c	191.3 b
200	51 a	57 b	95 b	193.2 b
250	51 a	58 a	97 a	195.9 a
LSD (0.05)	0.6	0.4	0.7	2.6
Irrigation (I)				
Optimum	50	57	95	193.5
Reduced	49	56	94	190.8
LSD (0.05)	**	ns	**	**
Control	47	54	89	185.5
Rest	50	57	94	192.2
Interactions	Significance level			
N x K	ns			
K x I	ns			
N x I	ns			
K x N x I	ns			

Means followed by different letter(s) of the same category are statistically significant using least significant differences (LSD) test at $P \leq 0.05$. **: Significant at 0.05% probability. ns: non-significant

Plant height was also affected significantly due to irrigation and N treatments, whereas potassium and all the interactions were found non-significant (*Table 1*). Taller plants were produced by optimum irrigated plots. Mean values of the data revealed that nitrogen application at the rate of 100 kg ha⁻¹ resulted in shortest plants. Plant height increase with each increment of N and significantly tallest plants were recorded with 250 kg N ha⁻¹. The tallest plants were produced with 160 kg K ha⁻¹ treatment. Fertilized plots produced taller plants as compared to control plots.

Growth parameters

All the treatments had significantly affected the growth parameters at different stages, while all the interactions were found non-significant (*Table 2*). Results showed that S1 (1st sampling stage) recorded with higher crop growth rate than S2 (2nd sampling stage). Mean values of the data indicated that optimum irrigation significantly increased the crop growth rate compared to reduced irrigation treatment. Mean values for nitrogen revealed that lower N (100 kg ha⁻¹) resulted in less crop growth rate. Crop growth rate increased with increase in N and significantly higher crop growth rate was recorded for 250 kg N ha⁻¹. Potassium application at the rate of 160 kg ha⁻¹ resulted in more crop

growth rate while less crop growth rate was observed with 80 kg K ha⁻¹. The treatment 120 kg K ha⁻¹ was statistically similar to the highest K application treatment. Fertilized plots resulted in more crop growth rate compared to control plots.

Table 2. Growth indices of maize hybrid as influenced by fertilization of potassium and nitrogen under optimum and reduced irrigation

	Crop growth rate (g m ⁻² day ⁻¹)	Absolute growth rate (g m ⁻² day ⁻¹)	Net assimilation rate (g m ⁻² day ⁻¹)
Potassium levels (kg ha ⁻¹)			
80	14.59 b	7.59 b	2.10 b
120	15.28 ab	8.22 ab	2.22 a
160	16.17 a	9.24 a	2.23 a
LSD (0.05)	1.12	1.06	0.11
Nitrogen levels (kg ha ⁻¹)			
100	14.12 b	7.03 c	1.95 d
150	14.55 b	7.55 bc	2.10 c
200	15.60 b	8.68 b	2.26 b
250	17.13 a	10.13 a	2.42 a
LSD (0.05)	1.29	1.23	0.13
Irrigation			
Optimum	15.37	8.46	2.2
Reduced	14.85	7.82	2.07
LSD (0.05)	*	*	***
Stages			
S1	16.91 a	9.91 a	2.20 a
S2	13.30 b	6.37 b	2.07 b
LSD (0.05)	***	***	***
Control	12.19	5.62	1.56
Rest	15.35	8.35	2.18
Interactions	Significance level	Interactions	Significance level
S x I	ns	I x N	ns
K x N	ns	I x K x N	ns
S x K	ns	S x I x K	ns
S x N	ns	S x I x N	ns
S x K x N	ns	S x I x K x N	ns
I x K	ns		

Means followed by different letter(s) of the same category are statistically significant using least significant differences (LSD) test at $P \leq 0.05$. *, ***: Significant at 0.05% probability. ns: non-significant

All treatments and stages significantly affected absolute growth rate (AGR) of maize, while all the interactions were found non-significant (*Table 2*). Results showed that S1 produce more AGR than S2. Mean values of the data indicated that optimum irrigation significantly produced more AGR. AGR increased with increase in N and significantly more values were recorded with 250 kg N ha⁻¹. Potassium application at the rate of 160 kg ha⁻¹ was found with maximum AGR, and was similar to 120 kg K ha⁻¹.

Almost same trend was found for net assimilation rate (NAR) of maize (Table 2). Results showed that S1 produce more NAR than S2. Amongst N treatments, 250 kg N ha⁻¹ was found maximum and K application at the rate of 160 kg ha⁻¹ resulted in maximum NAR, and was to 120 kg K ha⁻¹.

Chlorophyll contents at different stages

All the treatments and the control vs rest significantly affected chlorophyll contents at tasseling stage of maize, while all the interactions were found non-significant (Table 3). Lower N (100 kg ha⁻¹) resulted in less chlorophyll contents at tasseling stage. Whereas, 250 kg N ha⁻¹ produced maximum chlorophyll contents at tasseling stage. Optimum irrigation and the potassium application at the rate of 160 kg ha⁻¹ resulted in more chlorophyll contents at tasseling stage.

Table 3. Chlorophyll contents (SPAD values) of maize hybrid as influenced by fertilization of potassium and nitrogen under optimum and reduced irrigation

	Chlorophyll content at tasseling	Chlorophyll content at silking	Chlorophyll content at grain formation
Potassium levels (kg ha ⁻¹)			
80	50 c	52 c	48 c
120	53 b	55 b	51 b
160	56 a	58 a	54 a
LSD (0.05)	3	3	3
Nitrogen levels (kg ha ⁻¹)			
100	46 d	48 d	44 d
150	50 c	52 c	48 c
200	53 b	55 b	51 b
250	62 a	64 a	60 a
LSD (0.05)	3	3	3
Irrigation			
Optimum	53	55	51
Reduced	52	54	50
LSD (0.05)	**	**	**
Control	44	46	42
Rest	53	55	51
Interactions		Significance level	
N x K		ns	
K x I		ns	
N x I		ns	
K x N x I		ns	

Means followed by different letter(s) of the same category are statistically significant using least significant differences (LSD) test at P ≤ 0.05. **: Significant at 0.05% probability. ns: non-significant

Almost the same results pattern for treatments were found for the SPAD values at later stages of silking and grain formation, as recorded for tasseling stage. We observed that silking stage was recorded with maximum SPAD values (chlorophyll contents) as compared to other two stages (Table 3).

Yield and yield attributes

Data concerning grains ear⁻¹ of maize showed that all the treatments (I, N, K) significantly influenced grains ear⁻¹, whereas all the interactions were found non-significant (Table 4). More number of grains ear⁻¹ were produced by optimum irrigated plots. N fertilization at the rate of 100 kg ha⁻¹ produced less grains ear⁻¹. Grains ear⁻¹ increased with increase in nitrogen up to 150 kg ha⁻¹. Thereafter, no increase in grains ear⁻¹ were observed with further increase in N level. Maximum number of grains ear⁻¹ were produced when potassium was applied at the rate of 160 kg ha⁻¹ which was statistically similar with 120 kg K ha⁻¹. Fertilized plots produced more grains ear⁻¹ in contrast to unfertilized plots.

Table 4. Agronomic traits of maize hybrid as influenced by fertilization of potassium and nitrogen under optimum and reduced irrigation

	Grains ear ⁻¹	1000-grain weight (g)	Biological yield (kg ha ⁻¹)	Shelling percentage (%)	Grain yield (kg ha ⁻¹)
Potassium levels (kg ha ⁻¹)					
80	373 b	241 b	10752 b	75.50 c	3847 c
120	382 a	247 a	11260 a	78.60 b	4068 a
160	386 a	246 a	11145 a	81.78 a	3981 b
LSD (0.05)	6	3.4	188	2.77	50
Nitrogen levels (kg ha ⁻¹)					
100	350 c	232 c	10493 c	71.58 d	3515 d
150	397 a	251 a	11111 b	75.61 c	4193 a
200	386 b	247 b	11281 ab	78.92 b	4121 b
250	388 b	249 ab	11323 a	88.42 a	4031 c
LSD (0.05)	7	3.9	204	3.19	58
Irrigation					
Optimum	384	248	11179	79.08	4059
Reduced	378	241	10924	78.18	3871
LSD (0.05)	**	**	**	**	**
Control	354	225	8802	69.5	2388
Rest	381	245	11052	78.63	3965
Interactions					
N x K	ns	ns	** (Fig. 2)	ns	** (Fig. 3)
K x I	ns	ns	ns	ns	ns
N x I	ns	ns	ns	ns	ns
K x N x I	ns	ns	ns	ns	ns

Means followed by different letter (s) of the same category are statistically significant using least significant differences (LSD) test at $P \leq 0.05$. **: significant at 0.05% probability. ns: non-significant

Irrigation (I), nitrogen (N), potassium (K), control vs rest and K x N interaction significantly affected thousand grains weight of maize, whereas other interactions were found non-significant (Table 4). Optimum irrigation significantly produced heavier grains compared to reduced irrigation. Whereas, lower N (100 kg N ha⁻¹) resulted in lighter grains. Grain weight increases with increase in N up to 150 kg N ha⁻¹ which was statistically similar with 250 kg N ha⁻¹. Thereafter, no increase in thousand grains

weight was noted with increase in N level. Potassium application at the rate of 120 kg ha⁻¹ resulted in more thousand grains weight which was statistically similar to 160 kg K ha⁻¹.

Irrigation (I), nitrogen (N), potassium (K), control vs rest and K × N interaction significantly affected biological yield of maize (*Table 4*). Optimum irrigation remained superior in this regard. Mean values for nitrogen revealed that lower N resulted in less biological yield. Biological yield increase with increase in N and significantly more biological yield was recorded with 250 kg N ha⁻¹ which was statistically similar with 200 kg N ha⁻¹. Potassium application at the rate of 120 kg ha⁻¹ resulted in more biological yield which was statistically similar to 160 kg K ha⁻¹. K × N interaction represented that application of K at the rate of 80 kg ha⁻¹ × 100 kg N ha⁻¹ produced less biological yield. Biological yield increased up to 80 kg K ha⁻¹ × 150 kg N ha⁻¹. Thereafter, no increase in biological yield was noted with increase in N level. In case of 120 kg K × N, biological yield increased linearly with increase in N up to 200 kg N ha⁻¹, thereafter a slight decrease in biological yield was noted with increase in N level up to 250 kg ha⁻¹. Similarly in case of 160 kg K × N, biological yield increased linearly with increase in N up to 150 kg N ha⁻¹, thereafter a slight increase in biological yield was noted with increase in N level up to 250 kg ha⁻¹ (*Fig. 2*).

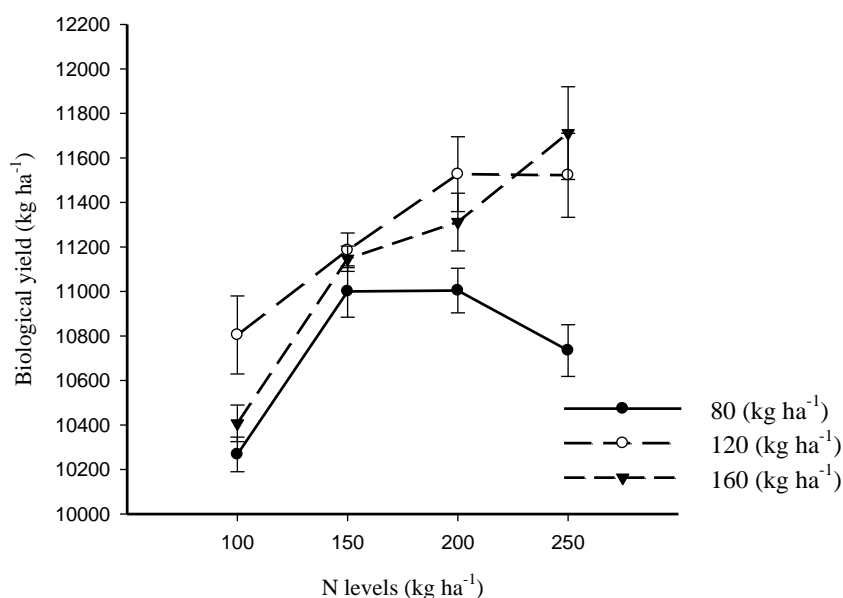


Figure 2. Interactive response of K and N on biological yield (kg ha⁻¹)

Irrigation (I), nitrogen (N), potassium (K), control vs rest and K × N interaction significantly affected grain yield of maize, whereas other interactions were found non-significant (*Table 4*). K × N interaction represented that application of K at the rate of 80 kg ha⁻¹ × 100 kg N ha⁻¹ produced less grain yield. Grain yield increased up to 80 kg K ha⁻¹ × 150 kg N ha⁻¹. Thereafter, no increase in grain yield was noted with increase in N level. In case of 120 kg K × N, grain yield increased with increase in N up to 150 kg N ha⁻¹, thereafter a slight decrease in grain yield was noted with increase in N level up to 250 kg ha⁻¹. Similarly in case of 160 kg K × N, grain yield increased with increase in N up to 150 kg N ha⁻¹, thereafter a slight decrease in grain yield was noted with increase in N level up to 250 kg ha⁻¹ (*Fig. 3*).

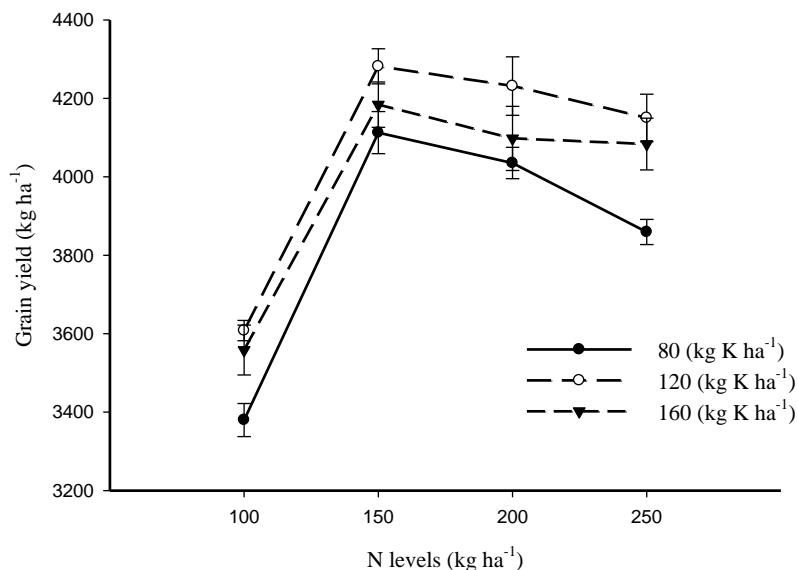


Figure 3. Interactive response of K and N on grain yield (kg ha⁻¹)

Irrigation (I), nitrogen (N), potassium (K) and control vs rest significantly affected shelling percentage of maize, while all the interactions were found non-significant (Table 4). Optimum irrigation significantly recorded with maximum shelling percentage. Shelling percentage increased with increase in N and significantly more shelling percentage was recorded with 250 kg N ha⁻¹. Potassium application at the rate of 160 kg ha⁻¹ resulted in more shelling percentage while less shelling percentage was observed with 80 kg K ha⁻¹. Fertilized plots resulted in more shelling percentage compared with control plots.

Discussion

Effect of N and K on phenology of maize under optimum and reduced irrigation

Delayed tasseling was observed with higher levels of nitrogen and potash. This delayed phenology with increasing N levels could be attributed to the impact of N on vegetative growth of maize crop, and photosynthetic performance (Ma et al., 2015), that might had increased leaf longevity and ultimately phenological development (Wang et al., 2017). These results are in full accordance with that of Peng et al. (2017) who observed delayed phenology with higher levels of N. Likewise, delayed tasseling under high level of potassium could be attributed to the role of potassium in stomata regulation and photosynthetic activity (Shah et al., 2017). These results were supported by Zamir et al. (2015) who observed delayed tasseling from plots having higher levels of potash. The optimum irrigation level had delayed days to tasseling in comparison with reduced irrigation which could be attributed to hormonal changes and greater availability of N and K (Alfredo and Setter, 2000). Delayed silking in plots treated with higher levels of N might be attributed to vigorous vegetative growth in response to higher nitrogen use efficiency that might had delayed the silking (Sharifi and Namvar, 2016). These results are also supported by Muller et al. (2017), as they observed delayed silking with increasing levels of N. Delayed silking with higher levels of K are further evidenced by Aslam et al. (2014).

Delayed maturity in plots treated with higher levels of N could be attributed to prolonged vegetative growth. This prolonged vegetative growth might be attributed to retention of green leaf, higher chlorophyll contents, and greater photosynthetic performance (Zhang et al., 2014). Higher rates of N delayed leaf senescence and uphold extended photosynthetic performance that might have delayed the maturity (Arif et al., 2012). These results are in line with that of Ali et al. (2012), who observed delayed physiological maturity from plots treated with higher N levels. The delayed maturity under higher K levels could be attributed to improved water use efficiency and higher uptake of nutrients that extended the vegetative growth and delayed maturity (Hati et al., 2006). These results are in line with Iqbal et al. (2016), who observed delayed physiological maturity with higher K levels. Although plant height is genetically controlled character however, it is also influenced from environment and management practices (Achieng et al., 2010). Taller plants in plots treated with higher levels of N might be related to impact of N on enzymatic and photosynthetic activities as well as cell division and stem elongation (Cechin and Fumis, 2004). The report of Achieng et al. (2010) are in full accord with our finding. The taller plants obtained from optimum irrigation could be attributed to better physiological activities and improved plant growth (Gaveh et al., 2011). Our results are also in line with that of Cakir (2004).

Effect of N and K on growth indices of maize under optimum and reduced irrigation

The higher crop growth rate in response to optimum nitrogen application is attributed to higher leaf area and leaf area index and higher chlorophyll contents (Azarpour et al., 2014). The higher level of nitrogen promotes hormonal activities in plants that enhance the vegetative growth and leaves enlargement (Azarpour et al., 2014). The higher crop growth rate in early stages compared to later stages of plant development is supported by Peng et al. (2017). The higher CGR means greater dry matter is accumulated by plants per unit area per unit time as a result of enhanced photosynthetic efficiency which might increase in response to higher levels of potassium application and optimum irrigation (Inthichack et al., 2012). These results are supported by Antony and Singandhupe (2004) who observed greater plant growth and final yield in response to optimum irrigation regime. Al-Omran et al. (2010) reported that optimum water supply is essential for higher crop growth, which is in accordance with our findings.

The higher net accumulation rate and absolute growth rate of maize crop was observed from application of higher levels of N and K as well as optimum irrigation. The higher concentration of nitrogen and potassium might had increased enzymatic activities responsible for translocation of assimilates towards the economic portion (Zhong et al., 1997). The higher rates of N and K had increased the dry matter of plants through increased photosynthates production that might had increased the net accumulation rates. Likewise optimum irrigation might had improved the leaf longevity that might results in optimum NAR compared with reduced irrigation (Amanullah and Khalid, 2016). These results are in line with that of Azizian and Sepaskah et al. (2014). The maximum shelling percentage of maize crop was observed from higher levels of nitrogen and potash as well as optimum irrigation treatment was due to optimum leaf area and chlorophyll contents that might had increased the physiological parameters i.e. CGR, NAR and AGR, thus resulting in maximum translocation of assimilates towards the economic portion. This higher translocation of assimilates might had improved the shelling percentage. These results are further supported by the findings of Shah et al. (2017).

Effect of N and K on chlorophyll contents of maize under optimum and reduced irrigation

The increased chlorophyll contents of maize leaf in response to increasing levels of nitrogen might be attributed to the impact of nitrogen on leaf growth and leaf area (Bojovic and Markovic, 2009). The same authors reported a high correlation between nitrogen application and leaf chlorophyll contents. It was reported that nitrogen is the structural element of protein and chlorophyll molecule, and its higher concentrations had proved to increase the chloroplast formation and leaf photosynthetic efficiency (Shah et al., 2017). Hokmalipour and Darbandi (2011) reported that nitrogen fertilization activates the enzymes associated with chlorophyll formation thus results in higher concentration of chlorophyll than control plots. These results are in full accordance with that of Ciompi et al. (1996) and Zhao et al. (2005). The higher chlorophyll contents in plots treated with higher levels of potassium might be associated with better nitrogen uptake under higher N levels (Peng et al., 2017). Potassium is essential for chlorophyll formation, stomatal conductance and RuBP case activities, thus it had great impact on photosynthesis (Liu et al., 2009). These results are further supported by Shah et al. (2017). The maximum chlorophyll content in response to optimum irrigation is supported by Liu et al. (2005).

Effect of N and K on agronomic traits of maize under optimum and reduced irrigation

Number of grains ear⁻¹ was significantly affected by N, K and irrigation levels. Optimum number of grains ear⁻¹ was recorded from plots having 180 kg N ha⁻¹. This increase could be attributed to greater seed row ear⁻¹ and number of grains row⁻¹ (Hokmalipour and Darbandi, 2011) and maximum dry matter accumulation. These results are supported by Shah et al. (2017). The K fertilization has likely to increase the water use efficiency of crops under water limited conditions and hence increased the dry matter production and its ultimate partitioning towards the reproductive part of the plant, that might had increased the number of grains ear⁻¹ (Iqbal et al., 2016). These results are supported by Shah et al. (2017) who observed higher number of grains ear⁻¹ from increasing K levels.

Higher thousand grains weight and grain yield from plots treated with 180 kg N ha⁻¹ might be attributed to higher chlorophyll contents associated with higher leaf area, that might had increased the photosynthetic efficiency and assimilates production and its availability during grains filling stage (Manzoor et al., 2006). The higher assimilates production through photosynthesis and its efficient partitioning towards the grain might had increased the yield and yield components of maize (Khan et al., 2014b). These results are fully supported by the results reported by Hokmalipour and Darbandi (2011). The increased yield and yield components of maize in response to higher levels of K might be attributed to the role of K in increasing water use efficiency that might had increased the cell division, improved plant growth and efficiently translocate the photosynthates towards the grains (Shah et al., 2017). However Enujeke (2013) reported that accumulation of proteins and other reserves food might be the cause for increased yield. The probable reason for optimum yield with higher K levels could be more leaf area, delayed maturity and improved yield attributes (Iqbal et al., 2016), due to stabilized stomatal regulation, greater carbon dioxide assimilation and the more carbohydrate production (Zeidan and Kramany, 2001). The increase in grain yield with

optimum irrigation have also been reported by Pandey et al. (2000) and Khan et al. (2014a). The combination of N and K had boosted 1000 grains weight and grain yield than their sole use. This increase in grain yield is also supported by the study of Shah et al. (2017).

The maximum biological yield in response to increasing levels of nitrogen might be attributed to better vegetative growth, greater leaf area and dry matter production (Keivanrad and Zandi, 2012) probably due to lower completion of plants for N and more even distribution of assimilates (Zangani et al., 2006). These results are in line with that of Imran et al. (2015), who observed maximum biological yield from higher doses of N fertilizer. Likewise the stover and biological yield was increased with increasing levels of potassium which might be attributed to the better plant growth due to the possible role of potassium in water balance, maintenance of turgor pressure, transportation of assimilates and disease resistance (Brar and Tiwari, 2004). The report of Hosinkhani et al. (2013) was also found in accordance with our findings. Shah et al. (2017) also reported similar results as ours. The optimum irrigation had increased the biological yield in comparison with reduced irrigation which might be explained with proper plant growth and better development due to moisture availability at sensitive stages of phenological development (Ngwako and Mashiq, 2013). These results are supported by Hussain et al. (1996). The increase in biological yield with integrated use of N and P was supported by Khan et al. (2014a). Brar and Tiwari (2004) also observed the increase in biological yield of maize from integrated use of N and P, and attributed this increase to greater nitrogen use efficiency.

Conclusion

On the basis of findings obtained in present work, it is concluded that optimum irrigation produced optimum plant growth, yield and yield attributes in maize. Application of 120 kg K ha⁻¹ had resulted in higher grain yields and yield components. Whereas, application of 150 kg N ha⁻¹ boosted maize yield and yield components to their optimum levels. Based on the results, application of 120 kg K ha⁻¹ along with 150 kg N ha⁻¹ is recommended for obtaining optimum growth, yield and yield attributes under optimum irrigation (five irrigations) for maize in agro-climatic conditions of the Peshawar, Pakistan. To strengthen our results, future studies should focus on optimizing the fertilizer (N, P, K) rates by estimating the nutrient use efficiencies, with special emphasis on agronomic- and physiological-use efficiency for the maize hybrids being cultivated in major areas of Pakistan. In addition to nutrient recovery analysis, the data pertaining to the plant organ nutrient analysis for N, P and K under different planting densities are vital for the Pakistani maize production system.

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