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# Impact of irrigation and crop nutrients (N, K) levels on physiology and morphology of maize

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**Abstract**
An experiment was conducted at Agronomy Research Farm, The University of Agriculture Peshawar, during summer 2015, to study "effect of irrigation, potassium and nitrogen levels on physiology and morphology of maize crop". The experiment was comprised of three factors irrigation (Optimum, Reduced), three potassium levels (80, 120 and 160 kg ha$^{-1}$) and four nitrogen levels (120, 180, 240 and 300 kg ha$^{-1}$). Two separate trials were carried out in randomized complete block design (RCBD), one under optimum and other under reduced irrigation. One control plot (0K, 0N) was used. Optimum irrigation had resulted in higher CGR (15.37 g m$^{-2}$ day$^{-1}$), NAR (2.20 g cm$^{-2}$ day$^{-1}$), AGR (8.46 g m$^{-2}$ day$^{-1}$), chlorophyll contents (55) and harvest index (36.3 %), High N (300 kg ha$^{-1}$) resulted in higher CGR (17.13 g m$^{-2}$ day$^{-1}$), NAR (2.42 g cm$^{-2}$ day$^{-1}$), AGR (10.13 g m$^{-2}$ day$^{-1}$), chlorophyll contents at tasseling (62), silking (64) and grains filling stages (60). However 180 kg N ha$^{-1}$ had resulted in higher grain yield (4193 kg ha$^{-1}$) and harvest index (37.7 %). Potassium fertilization at the rate of 120 and160 kg ha$^{-1}$ resulted in statistically similar results and produced maximum CGR (16.16 g m$^{-2}$ day$^{-1}$), NAR (2.23 g cm$^{-2}$ day$^{-1}$), AGR (9.24 g m$^{-2}$ day$^{-1}$), chlorophyll contents at tasseling (56), silking (58) and grains filling stages (54) and grain yield (4068 kg ha$^{-1}$). In case of control vs rest, generally performance of control plot was poor. Hence, 180 kg N ha$^{-1}$ with 120 kg K ha$^{-1}$ under optimum irrigation is recommended for optimum productivity of maize crop.

**Keywords:** Irrigation, productivity, nitrogen levels, potassium and dry matter partitioning

## 1. Introduction

Maize (*Zea mays* L.) is third most essential cereal crop in Pakistan, after wheat and rice and second in Khyber Pakhtunkhwa after wheat. Maize was cultivated on 1,117 thousand hectares in 2014 having a high production of 4,527 thousand tons and average national yield of 4,053 kg ha$^{-1}$, on the other hand cultivated area of maize in Khyber Pakhtunkhwa was about 475.3 thousand hectares which resulted in a total production of 887.8 thousand tons with 1868 kg ha$^{-1}$ less average yield [1]. Maize is cultivated in Pakistan on 64 % irrigated and 36 % on rainfed land [2]. USA, Russia, Argentina, India, China and Brazil produced 70 % more yield as compared to Pakistan. Implementation and adoption of new production technologies increase maize production per unit area due to balance use of agriculture inputs and new methods [3]. Improper application of synthetic fertilizers in Khyber Pakhtunkhwa is the main cause of low yield of maize [4]. In Pakistan only tobacco crop receive potassium due to industrial requirement while farmers do not apply potassium to wheat and maize. Deficiency of potassium reported in most Pakistani soils due to multiple cropping systems [5]. Potassium is used by crops in large amount [6-7]. A soil deficient in potassium results in minimum photosynthesis [8-9] which is the main cause of low yield of maize, sunflower and brassica [10-11]. Potassium is a primary major nutrient which is non-structural component of plant body. After nitrogen it is second most abundant nutrient in plant tissue generally 1-3 % by weight. It has a significant role in the growth and metabolism of plants [12]. It is very important for the transport of assimilates in plant cells and activates more than 60 different enzymes. It increases plant tolerance to frost and heat injuries, droughts and enhances resistance to diseases, different pest incidence and keeps anion balance in plants [6]. The most important role of $K^+$ in plants is osmoregulation which maintains turgor pressure in the cell, crucial for cell elongation and hence growth and regulation of stomatal opening and closing, affecting carbon dioxide intake by photosynthesis process and transpirational cooling [13]. Potassium is a macro nutrient which is important for the growth of plants. Comparatively large amount of mineral potassium is present in Pakistani soil which is not soluble and only small amount is available to plants. A soil with less than 150 mg replaceable K kg$^{-1}$ is considered a deficient soil [14]. Optimum amount of potassium in soil in case of water scarcity comparatively enhance deposition of total dry matter in crops compared with soil with less potassium regimes [15]. Potassium regulate stomata which in turn enhance photosynthesis [16]. Moreover, root growth is supported by the crucial role of potassium in transportation of photosynthetic products [17]. Optimum utilization of potassium is enhancing growth, yield and yield attributes of maize crop [18-19-20]. The Growth and yielding traits of maize are conspicuously enhanced by potassium application like plant height, leaf area [21-22] crop growth rate grains ear$^{-1}$, Ear length, thousand grains weight biological yield and grain yield [20-23]. In spite of increase in morphological and yield parameters of maize, it enhances the quality traits of maize such as crude oil content [24] crude, starch content [25] and crude protein contents [26]. Maximum absorption and accumulation of potassium in maize is at flowering condition [27]. Maize requires abundant supply of potassium for attaining high yield. At vegetative stage maize contains approximately 300 kg K ha$^{-1}$ [28]. Grain contains 0.3% potassium usually in the range of 25-45% and 10 t ha$^{-1}$ grains are produced by a crop when its uptake is 30 kg K ha$^{-}$

[1]. For the proper maintenance of membrane and turgor potential the potassium role is very important it also helps balancing osmotic potential, control opening and closing of stomata and helps in enzymes activation [29]. To maintain the proper turgor potential, osmoregulation of cell, opening and closing of stomata, protein synthesis as well as photosynthesis for all these appropriate $K^+/Na^+$ proportion is utmost important [30]. There are three big processes by which maize yield is limited by water scarcity in soil: (i) Decreased absorption of incident photo synthetically active radiation by canopy, (ii) reduced radiation use efficiency, (iii) decreased harvest index [31].

To know and keep in mind, potassium importance in case of high nitrogen nutrition on maize lodging with optimum and reduced irrigation, the experiment was designed and conducted to find out optimum level of potassium for decreasing lodging, enhancing resistance to drought and to figure out best nitrogen level for higher maize productivity in the agro climatic condition of Peshawar.

**Materials and methods**

An experiment was conducted at Agronomy Research Farm, The University of Agriculture Peshawar, during summer 2015, to study "effect of irrigation, potassium and nitrogen levels on maize"

Factors studied in the experiment were:

**Factor A:** Irrigation (I): $I_1$= Optimum irrigation (5 irrigations), $I_2$= Reduced irrigation (3 irrigations)

**Factor B:** Potassium levels (K) (Kg $ha^{-1}$): K1= 80, K2= 120 and K3= 160

**Factor C:** Nitrogen levels (N) (Kg $ha^{-1}$): N1= 120, N2=180, N3= 240 and N4= 300

**Treatment combination**

| | |
|---|---|
| T1= Control (0 N, 0 K), | T7= N2K3 |
| T2= N1K1 | T8= N3K1 |
| T3= N1K2 | T9= N3K2 |
| T4= N1K3 | T10= N3K3 |
| T5= N2K1 | T11= N4K1 |
| T6= N2K2 | T12= N4K2 |
| | T13= N4K3 |

Two trials, one with optimum and another with reduced irrigation were carried out in randomized complete block design (RCBD). Potassium and nitrogen were applied in combination to both experiments with three replications. Each replication was added with an unfertilized plot (0K, 0N). Azam variety of maize was sown on 18th August 2015 with a sub plot area of 3 m x 3.5 m which consisted of 70 cm apart 3 m long 5 rows. Seed was planted at the rate of 35 kg $ha^{-1}$. Muriate of potash (MOP) was used as a source of potassium which contains 60 % K2O, Similarly N was applied from urea. Source of phosphorus was di ammonium phosphate (DAP) at the rate of 90 kg $ha^{-1}$. Potash and phosphorus were applied as a whole at planting time, whereas nitrogen schedule was half at planting and half at V6 leaf stage (knee height). During the whole growing season, uniform agronomic techniques were performed in all sub plots. Prior to sowing a composite sample of soil was analyzed for potassium contents.

Meteorological data of the experimental period (Source: Watch Dog weather station at Agronomy Research Farm, The University of Agriculture Peshawar).

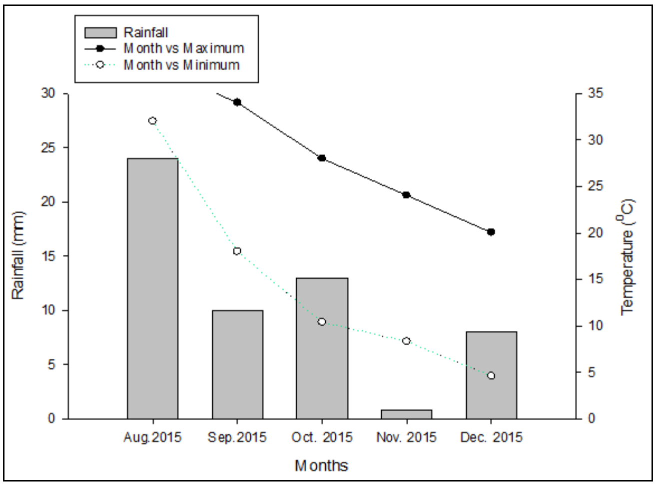


**Fig 1**

**Data were recorded on the following parameters**

1. Crop growth rate (CGR)
2. Absolute growth rate (AGR)
3. Net assimilation rate (NAR)
4. Chlorophyll contents
5. Grain yield (Kg $ha^{-1}$)
6. Harvest index (%)

**Composite sample analysis**

Two composite samples of soil were collected randomly from each replication, one prior to sowing and other after crop harvesting and were analyzed in laboratory for potassium concentration which was 1.53 mg/g of soil.

**Crop growth rate (CGR)**

For calculating CGR ($g.m^{-2}.day^{-1}$), one meter long row from side rows in each experimental unit was harvested and was sun dried for 72 hours at 70 $^0$C to calculate their dry weight at (1) V6 leaf stage (2) Blister stage (3) R6 (Physiological maturity) stage. Formula used was:

CGR= [(W2-W1)/ (T2-T1) x (1/GA)] g $m^{-2}d^{-1}$

Where,

W1= Initial weight at 27th day after sowing

W2= Last weight at 98th day after sowing

T1 = Initial date 18th August 2015 (Sowing)

T2= 30th November 2016 (Harvesting)

GA= Row to row distance (75 cm) x plant to plant distance (20) x number of plants (5)

**Absolute growth rate (AGR)**

From side rows in each experimental unit one meter long row was selected, harvested, sun dried for 72 hours at 70 $^0$C and then dry weight was determined at various growth stages viz (1) Six leaf stage (2) Blister stage and (3) R6 stage. AGR was figured out by the following formula.

AGR= W2-W1/T2-T1

Where,

W1= Weight at 27th day after sowing

W2= Weight at 98th day after sowing

T1= Date 18th August 2015 (Sowing)

T2= 30th November (Harvesting)

**Net assimilation rate (NAR)**

NAR was calculated in each sub plot by selecting one-meter ling row from border rows and harvested and sun dried at 70

$^0$C for 72 hours. Dry weight was find out at two growth stages (1) V6 six leaf stage (2) Physiological maturity. The following formula was used for NAR:

NAR= W2-W1/T2-T1 x lnL2-lnL1/L2-L1
Where,
W1= Weight at 27th day after sowing, W2= Weight at 98th day after sowing, T1= Date 18th August 2015 (Sowing), T2= 30th November 2015 (Harvesting), L1= Initial leaf area at 18th August 2015, L2= Final leaf area at 30th November 2015

### Chlorophyll contents

From each experimental unit five plants and three leaves plant$^{-1}$ were randomly selected. The chlorophyll contents were figured out on three locations per leaf with chlorophyll meter (Model: SPAD-502) and then averaged.

### Grain yield (kg ha$^{-1}$)

For calculating grain yield, three central rows in each sub plot was harvested, sun dried, threshed and weighed and then converted into kg ha$^{-1}$ by using the following formula:

$$\text{Grain yield (kg ha}^{-1}) = \frac{\text{Grain yield}}{\text{R - R distance} \times \text{Row length} \times \text{No of rows}} \times 10000$$

### Harvest index (%)

It was determined for each experimental unit by the following formula:
H.I % = Economic yield (kg ha$^{-1}$) x 100
Biological yield (kg ha$^{-1}$)

### Statistical Analysis

Data was statistically analyzed by analysis of variance procedure suitable for randomized complete block design. Means were compared using least significant differences (LSD) test at 0.05 probability level, when F-values were significant [32].

## Results

### Crop growth rate (g m$^{-2}$ day$^{-1}$)

Irrigation (I), nitrogen (N), potassium (K), control vs rest and stages significantly affected crop growth rate of maize, while all the interactions were found non-significant (Table 1). Results showed that S1 produce more crop growth rate (16.91 g m$^{-2}$ day$^{-1}$) than S2. Mean values of the data indicated that optimum irrigation significantly produced more crop growth rate (15.37 g m$^{-2}$ day$^{-1}$) compared with reduced irrigation (14.85 g m$^{-2}$ day$^{-1}$). Mean values for nitrogen revealed that lower N (120 kg ha$^{-1}$) resulted in less crop growth rate (14.12 g m$^{-2}$ day$^{-1}$). Crop growth rate increased with increase in N and significantly more crop growth rate (17.13 g m$^{-2}$ day$^{-1}$) was recorded with 300 kg N ha$^{-1}$. Potassium application at the rate of 160 kg ha$^{-1}$ resulted in more crop growth rate (16.17 g m$^{-2}$ day$^{-1}$) while less crop growth rate (14.59 g m$^{-2}$ day$^{-1}$) was observed with 80 kg K ha$^{-1}$. Fertilized plots resulted in more crop growth rate (15.35 g m$^{-2}$ day$^{-1}$) compared with control plots (12.19 g m$^{-2}$ day$^{-1}$).

**Table 1:** Crop growth rate (g m$^{-2}$ day$^{-1}$) of maize as affected by various levels of irrigation potassium and nitrogen

| | **Irrigation** | | |
|---|---|---|---|
| **Nitrogen (kg ha$^{-1}$)** | **Optimum** | **Reduced** | **Means** |
| 120 | 14.58 | 13.65 | 14.12 b |
| 180 | 14.79 | 14.31 | 14.55 b |
| 240 | 15.73 | 15.46 | 15.60 b |
| 300 | 17.46 | 16.81 | 17.13 a |
| LSD For N | 1.29 | | |
| Potassium (kg ha$^{-1}$) | | | |
| 80 | 15.13 | 14.06 | 14.59 b |
| 120 | 15.58 | 14.97 | 15.28 ab |
| 160 | 16.21 | 16.14 | 16.17 a |
| LSD for K | 1.12 | | |
| Stages | | | |
| S 1 | 17.13 | 16.69 | 16.91 a |
| S 2 | 13.60 | 13.00 | 13.30 b |
| Significance (S) | *** | | |
| Irrigation (I) | | | |
| Optimum | | | 15.37 |
| Reduced | | | 14.85 |
| Significance (I) | * | | |
| Interaction | Significance | Interaction | Significance |
| 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 | | |
| Planned mean comparison | | Means | Significance |
| Control | | 12.19 | *** |
| Rest | | 15.35 | |

### Absolute growth rate (g m$^{-2}$ day$^{-1}$)

Irrigation (I), nitrogen (N), potassium (K), control vs rest and stages significantly affected absolute growth rate of maize, while all the interactions were found non-significant (Table 2). Results showed that S1 produce more absolute growth rate (9.91 g m$^{-2}$ day$^{-1}$) than S2. Mean values of the data indicated that optimum irrigation significantly produced more absolute growth rate (8.47 g m$^{-2}$ day$^{-1}$) compared with reduced irrigation (7.85 g m$^{-2}$ day$^{-1}$). Mean values for nitrogen revealed that lower N (120 kg ha$^{-1}$) resulted in less absolute growth rate (7.12 g m$^{-2}$ day$^{-1}$). Absolute growth rate increased with increase in N and significantly more absolute growth rate (10.13 g m$^{-2}$ day$^{-1}$) was recorded with 300 kg N ha$^{-1}$. Potassium application at the rate of 160 kg ha$^{-1}$ resulted in more absolute growth rate (9.26 g m$^{-2}$ day$^{-1}$) while less absolute growth rate (7.59 g m$^{-2}$

day$^{-1}$) was observed with 80 kg K ha$^{-1}$. Fertilized plots resulted in more absolute growth rate (8.38 g m$^{-2}$ day$^{-1}$) compared with control plots (5.53 g m$^{-2}$ day$^{-1}$).

**Table 2:** Absolute growth rate (g m$^{-2}$ day$^{-1}$) of maize as affected by various levels of irrigation potassium and nitrogen

| | Irrigation | | |
|---|---|---|---|
| **Nitrogen (kg ha$^{-1}$)** | **Optimum** | **Reduced** | **Means** |
| 120 | 7.58 | 6.48 | 7.03 c |
| 180 | 7.79 | 7.31 | 7.55 bc |
| 240 | 8.91 | 8.46 | 8.68 b |
| 300 | 10.46 | 9.81 | 10.13 a |
| LSD For N | 1.23 | | |
| Potassium (kg ha$^{-1}$) | | | |
| 80 | 8.13 | 7.06 | 7.59 b |
| 120 | 8.58 | 7.85 | 8.22 ab |
| 160 | 9.34 | 9.14 | 9.24 a |
| LSD for K | 1.06 | | |
| Stages | | | |
| S 1 | 10.13 | 9.69 | 9.91 a |
| S 2 | 6.79 | 5.95 | 6.37 b |
| Significance (S) | *** | | |
| Irrigation (I) | | | |
| Optimum | | | 8.46 |
| Reduced | | | 7.82 |
| Significance (I) | * | | |
| Interaction | Significance | Interaction | Significance |
| 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 | | |
| Planned mean comparison | | Means | Significance |
| Control | | 5.62 | *** |
| Rest | | 8.35 | |

## Net assimilation rate (g m$^{-2}$ day$^{-1}$)

Irrigation (I), nitrogen (N), potassium (K), control vs rest and stages significantly affected net assimilation rate of maize, while all the interactions were found non-significant (Table 3). Results showed that S1 produce more net assimilation rate (2.20 g m$^{-2}$ day$^{-1}$) than S2. Mean values of the data indicated that optimum irrigation significantly produced more net assimilation rate (2.20 g m$^{-2}$ day$^{-1}$) compared with reduced irrigation (2.07 g m$^{-2}$ day$^{-1}$). Mean values for nitrogen revealed that lower N (120 kg ha$^{-1}$) resulted in less net assimilation rate (1.95 g m$^{-2}$ day$^{-1}$). Net assimilation rate increased with increase in N and significantly more net assimilation rate (2.42 g m$^{-2}$ day$^{-1}$) was recorded with 300 kg N ha-1. Potassium application at the rate of 160 kg ha$^{-1}$ resulted in more net assimilation rate (2.23 g m$^{-2}$ day$^{-1}$) while less net assimilation rate (2.10 g m$^{-2}$ day$^{-1}$) was observed with 80 kg K ha$^{-1}$. Fertilized plots resulted in more net assimilation rate (2.18 g m$^{-2}$ day$^{-1}$) compared with control plots (1.56 g m$^{-2}$ day$^{-1}$).

**Table 3:** Net assimilation rate (g m$^{-2}$ day$^{-1}$) of maize as affected by various levels of irrigation potassium and nitrogen

| | Irrigation | | |
|---|---|---|---|
| **Nitrogen (kg ha$^{-1}$)** | **Optimum** | **Reduced** | **Means** |
| 120 | 1.97 | 1.94 | 1.95 d |
| 180 | 2.16 | 2.03 | 2.10 c |
| 240 | 2.29 | 2.23 | 2.26 b |
| 300 | 2.53 | 2.31 | 2.42 a |
| LSD For N | 0.13 | | |
| Potassium (kg ha$^{-1}$) | | | |
| 80 | 2.15 | 2.04 | 2.10 b |
| 120 | 2.26 | 2.19 | 2.22 a |
| 160 | 2.30 | 2.16 | 2.23 a |
| LSD for K | 0.11 | | |
| Stages | | | |
| S 1 | 2.24 | 2.16 | 2.20 a |
| S 2 | 2.15 | 1.98 | 2.07 b |
| Significance (S) | *** | | |
| Irrigation (I) | | | |
| Optimum | | | 2.20 |
| Reduced | | | 2.07 |
| Significance (I) | *** | | |
| Interaction | Significance | Interaction | Significance |
| 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 | | |
| Planned mean comparison | | Means | Significance |
| Control | | 1.56 | *** |
| Rest | | 2.18 | |

## Chlorophyll contents (SPAD) at tasseling stage

Irrigation (I), nitrogen (N), potassium (K) and control vs rest significantly affected chlorophyll contents at tasseling stage of maize, while all the interactions were found non-significant (Table 4). Mean values of the data indicated that optimum irrigation significantly produced more chlorophyll contents at tasseling stage (53) compared with reduced irrigation (52). Mean values for nitrogen revealed that lower N (120 kg ha$^{-1}$) resulted in less chlorophyll contents at tasseling stage (46). Chlorophyll contents at tasseling stage increased with increase in N and significantly more chlorophyll contents at tasseling stage (62) were recorded with 300 kg N ha$^{-1}$. Potassium application at the rate of 160 kg ha$^{-1}$ resulted in more chlorophyll contents at tasseling stage (56) while less chlorophyll contents at tasseling stage (50) were observed with 80 kg K ha$^{-1}$. Fertilized plots resulted in more chlorophyll contents at tasseling stage (53) compared with control plots (44).

**Table 4:** Chlorophyll contents (SPAD) at tasseling stage of maize as affected by various levels of irrigation potassium and nitrogen

| **Irrigation (I)** | **Potassium (kg ha$^{-1}$)** | **Nitrogen (kg ha$^{-1}$)** | | | | |
|---|---|---|---|---|---|---|
| | | **120** | **180** | **240** | **300** | **Means** |
| Optimum | 80 | 44 | 51 | 49 | 59 | 51 |
| | 120 | 44 | 52 | 52 | 62 | 53 |
| | 160 | 47 | 52 | 56 | 69 | 56 |
| Reduced | 80 | 41 | 44 | 50 | 58 | 48 |
| | 120 | 48 | 49 | 53 | 60 | 53 |
| | 160 | 50 | 50 | 58 | 65 | 56 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Optimum | | 45 | 52 | 52 | 64 | 53 |
| Reduced | | 46 | 48 | 53 | 61 | 52 |
| | 80 | 43 | 47 | 49 | 59 | 50 c |
| | 120 | 46 | 51 | 53 | 61 | 53 b |
| | 160 | 49 | 51 | 57 | 67 | 56 a |
| Means | | 46 d | 50 c | 53 b | 62 a | |
| Control vs rest | | ** | | | | |
| Control | | 44 | | | | |
| Rest | | 53 | | | | |
| LSD (0.05) | | | | | | |
| Irrigation (I) | ** | | | | | |
| Nitrogen (N) | 3 | | | | | |
| Potassium (K) | 3 | | | | | |

**Chlorophyll contents (SPAD) at silking stage**

Irrigation (I), nitrogen (N), potassium (K) and control vs rest significantly affected chlorophyll contents at silking stage of maize, while all the interactions were found non-significant (Table 5). Mean values of the data indicated that optimum irrigation significantly produced more chlorophyll contents at silking stage (55) compared with reduced irrigation (54). Mean values for nitrogen revealed that lower N (120 kg ha$^{-1}$) resulted in less chlorophyll contents (48) at silking stage. Chlorophyll contents at silking stage increased with increase in N and significantly more chlorophyll contents at silking stage (64) were recorded with 300 kg N ha$^{-1}$. Potassium application at the rate of 160 kg ha$^{-1}$ resulted in more chlorophyll contents at silking stage (58) while less chlorophyll contents at silking stage (52) were observed with 80 kg K ha$^{-1}$. Fertilized plots resulted in more chlorophyll contents at silking stage (55) compared with control plots (46).

**Table 5:** Chlorophyll contents (SPAD) at silking stage of maize as affected by various levels of irrigation potassium and nitrogen

| **Irrigation (I)** | **Potassium (kg ha$^{-1}$)** | **Nitrogen (kg ha$^{-1}$)** | | | | |
|---|---|---|---|---|---|---|
| | | **120** | **180** | **240** | **300** | **Means** |
| Optimum | 80 | 46 | 53 | 51 | 61 | 53 |
| | 120 | 46 | 54 | 54 | 64 | 55 |
| | 160 | 49 | 54 | 58 | 71 | 58 |
| Reduced | 80 | 43 | 46 | 52 | 60 | 50 |
| | 120 | 50 | 51 | 55 | 62 | 55 |
| | 160 | 52 | 52 | 60 | 67 | 58 |
| Optimum | | 47 | 54 | 54 | 66 | 55 |
| Reduced | | 48 | 50 | 55 | 63 | 54 |
| | 80 | 45 | 49 | 51 | 61 | 52 c |
| | 120 | 48 | 53 | 55 | 63 | 55 b |
| | 160 | 51 | 53 | 59 | 69 | 58 a |
| Means | | 48 d | 52 c | 55 b | 64 a | |
| Control vs rest | | ** | | | | |
| Control | | 46 | | | | |
| Rest | | 55 | | | | |
| LSD (0.05) | | | | | | |
| Irrigation (I) | ** | | | | | |
| Nitrogen (N) | 3 | | | | | |
| Potassium (K) | 3 | | | | | |

**Chlorophyll contents (SPAD) at grain formation stage**

Irrigation (I), nitrogen (N), potassium (K) and control vs rest significantly affected chlorophyll contents at grain formation stage of maize, while all the interactions were found non-significant (Table 6). Mean values of the data indicated that optimum irrigation significantly produced more chlorophyll contents at grain formation stage (51) compared with reduced irrigation (50). Mean values for nitrogen revealed that lower N (120 kg ha$^{-1}$) resulted in less chlorophyll contents (44) at grain formation stage. Chlorophyll contents at grain formation stage increased with increase in N and significantly more chlorophyll contents at grain formation stage (60) were recorded with 300 kg N ha$^{-1}$. Potassium application at the rate of 160 kg ha$^{-1}$ resulted in more chlorophyll contents at grain formation stage (54) while less chlorophyll contents at grain formation stage (48) were observed with 80 kg K ha$^{-1}$. Fertilized plots resulted in more chlorophyll contents at grain formation stage (51) compared with control plots (42).

**Table 6:** Chlorophyll contents (SPAD) at grain formation stage of maize as affected by various levels of irrigation potassium and nitrogen

| **Irrigation (I)** | **Potassium (kg ha$^{-1}$)** | **Nitrogen (kg ha$^{-1}$)** | | | | |
|---|---|---|---|---|---|---|
| | | **120** | **180** | **240** | **300** | **Means** |
| Optimum | 80 | 42 | 49 | 47 | 57 | 49 |
| | 120 | 42 | 50 | 50 | 60 | 51 |
| | 160 | 45 | 50 | 54 | 67 | 54 |
| Reduced | 80 | 39 | 42 | 48 | 56 | 46 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 120 | 46 | 47 | 51 | 58 | 51 |
| | 160 | 48 | 48 | 56 | 63 | 54 |
| Optimum | | 43 | 50 | 50 | 62 | 51 |
| Reduced | | 44 | 46 | 51 | 59 | 50 |
| | 80 | 41 | 45 | 47 | 57 | 48 c |
| | 120 | 44 | 49 | 51 | 59 | 51 b |
| | 160 | 47 | 49 | 55 | 65 | 54 a |
| Means | | 44 d | 48 c | 51 b | 60 a | |
| Control vs rest | | ** | | | | |
| Control | | 42 | | | | |
| Rest | | 51 | | | | |
| LSD (0.05) | | | | | | |
| Irrigation (I) | ** | | | | | |
| Nitrogen (N) | 3 | | | | | |
| Potassium (K) | 3 | | | | | |

**Grain yield (kg ha$^{-1}$)**

Irrigation (I), nitrogen (N), potassium (K), control vs rest and K x N interaction significantly affected grain yield of maize, whereas other interactions were found non-significant (Table 7). Mean values of the data indicated that optimum irrigation significantly produced more grain yield (4059 kg ha$^{-1}$) compared with reduced irrigation (3871 kg ha$^{-1}$). Mean values for nitrogen revealed that lower N (120 kg N ha$^{-1}$) resulted in less grain yield (3515 kg ha$^{-1}$). Grain yield increased with increase in N up to 180 kg N ha$^{-1}$ (4193 kg ha$^{-1}$). Thereafter, no increase in grain yield was noted with increase in N level. Potassium application at the rate of 120 kg ha$^{-1}$ resulted in more grain yield (4068 kg ha$^{-1}$) while less grain yield (3847 kg ha$^{-1}$) was observed with 80 kg K ha$^{-1}$. Fertilized plots resulted in more grain yield (3965 kg ha$^{-1}$) compared with control plots (2388 kg ha$^{-1}$). K x N interaction represented that application of K at the rate of 80 kg ha$^{-1}$ x 120 kg N ha$^{-1}$ produced less grain yield (3380 kg ha$^{-1}$). Grain yield increased up to 80 kg K ha$^{-1}$ x 180 kg N ha$^{-1}$. Thereafter, no increase in grain yield was noted with increase in N level. In case of 120 kg K x N, grain yield increased with increase in N up to 180 kg N ha$^{-1}$, thereafter a slight decrease in grain yield was noted with increase in N level up to 300 kg ha$^{-1}$. Similarly in case of 160 kg K x N, grain yield increased with increase in N up to 180 kg N ha$^{-1}$, thereafter a slight decrease in grain yield was noted with increase in N level up to 300 kg ha$^{-1}$ (Fig.1).

**Table 7:** Grain yield (kg ha$^{-1}$) and harvest index (%) of maize as affected by various levels of irrigation potassium and nitrogen

| **Potassium (kg ha$^{-1}$)** | **Grain yield (kg ha$^{-1}$)** | **Harvest index (%)** |
|---|---|---|
| 80 | 3847 c | 35.7 |
| 120 | 4068 a | 36.1 |
| 160 | 3981 b | 35.7 |
| LSD (0.05) for potassium | 50 | NS |
| Nitrogen (kg ha$^{-1}$) | | |
| 120 | 3515 d | 33.5 d |
| 180 | 4193 a | 37.7 a |
| 240 | 4121 b | 36.5 b |
| 300 | 4031 c | 35.6 c |
| LSD (0.05) for nitrogen | 58 | 0.9 |
| Irrigation (I) | | |
| Optimum | 4059 | 36.3 |
| Reduced | 3871 | 35.4 |
| Significance | ** | ** |
| Planned Mean comparison | | |
| Control | 2388 | 27.1 |
| Rest | 3965 | 35.9 |
| Significance | ** | ** |
| Interaction | | |
| I x K | NS | NS |
| I x N | NS | NS |
| K x N | ** | * |
| I x K x N | NS | NS |

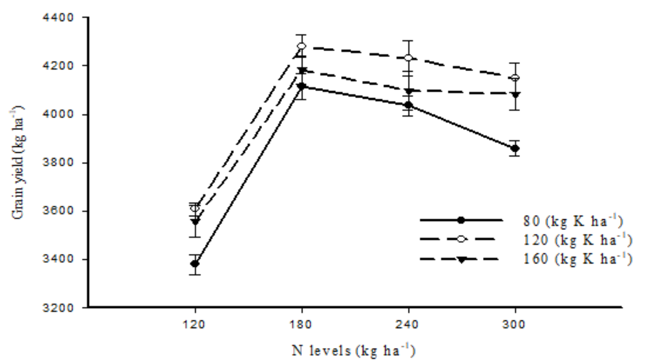


**Fig 1:** Interactive effect of K and N on grain yield (kg ha$^{-1}$) of maize.

### Harvest index (%)

Irrigation (I), nitrogen (N), control vs rest and K x N interaction significantly affected harvest index of maize, whereas potassium (K) and other interactions were found non-significant (Table 7). Mean values of the data indicated that optimum irrigation significantly produced more harvest index (36.3 %) compared with reduced irrigation (35.4 %). Mean values for nitrogen indicated that lower N (120 kg N ha$^{-1}$) resulted in less harvest index (33.5 %). Harvest index increased with increase in N up to 180 kg N ha$^{-1}$ (37.7 %). Thereafter, no increase in harvest index was noted with increase in N level. Potassium application at the rate of 120 kg ha$^{-1}$ resulted in more harvest index (36.1 %) while less harvest index (35.7 %) was observed with 80 kg K ha$^{-1}$. Fertilized plots resulted in more harvest index (35.9 %) compared with control plots (27.1 %). K x N interaction indicated that application of K at the rate of 80 kg ha$^{-1}$ x 120 kg N ha$^{-1}$ produced less harvest index (32.9 %). Harvest index increased up to 80 kg K ha$^{-1}$ x 180 kg N ha$^{-1}$. Thereafter, no increase in harvest index was noted with increase in N level. In case of 120 kg K x N, harvest index increased with increase in N upto 180 kg N ha$^{-1}$, thereafter no increase in harvest index was noted with increase in N level. Similarly in case of 160 kg K x N, harvest index increased with increase in N upto 180 kg N ha$^{-1}$, thereafter decrease in harvest index was noted with increase in N level upto 300 kg ha$^{-1}$ (Fig. 2).

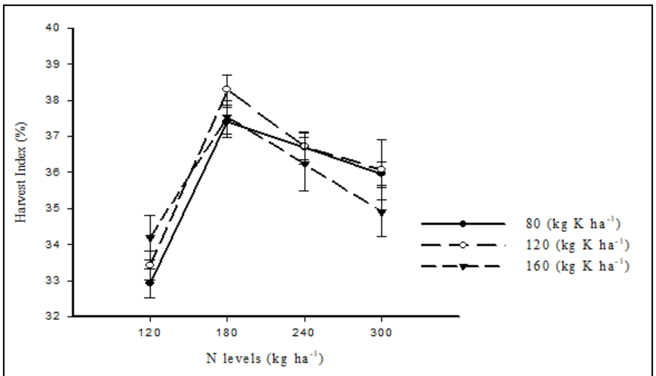


**Fig 2:** Interactive effect of K and N on harvest index (%) of maize.

### Discussion

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 [33]. The higher levels of nitrogen promote hormonal activities in plants that enhance the vegetative growth and leaves enlargement [33]. The higher crop growth rate in early stages compared to later stages of plant development is supported by [34]. 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 [34]. These results are supported by [35] who observed greater plant growth and final yield in response to optimum irrigation regime. Optimum water supply is essential for higher crop growth, which is in accordance with our findings [36]. 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 [37]. The higher rates of N and K had increased the dry matter of plants through increased photosynthates production that might have increased the net accumulation rates [38]. Likewise optimum irrigation might have improved the leaf longevity that might results in optimum NAR compared with reduced irrigation [19]. These results are in full accord with [39]. The increasing 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 [40]. 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 have proved to increase the chloroplast formation and leaf photosynthetic efficiency [41]. Nitrogen fertilization activates the enzymes associated with chlorophyll formation thus results in higher concentration of chlorophyll than control plots [42-43-44]. The higher chlorophyll contents in plots treated with higher levels of potassium might be associated with better nitrogen uptake under higher N levels [45]. Potassium is essential for chlorophyll formation, stomatal conductance and RuBP case activities thus, it had great impact on photosynthesis [46]. These results are supported by [37] the maximum chlorophyll contents in response to optimum irrigation are supported by [46].

Grain yield increased up to 180 kg N ha$^{-1}$ and beyond 180 kg N ha$^{-1}$ nitrogen fertilization contributed towards biological yield. The higher assimilates production through photosynthesis and their efficient partitioning towards the grain might had increased the yield and yield components of maize [47]. These results are fully supported by [29]. 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 [13]. However [45] 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 [37] due to stabilized stomatal regulation, greater carbon dioxide assimilation and more carbohydrate production [35]. The increases in grain yield with optimum irrigation have been reported by [48]. The combination of N and K had boosted 1000 grains weight and grain yield than their sole use. This increase in grain yield is supported by [49]. The physiological efficiency of crop plants in converting photosynthetic products into grain yield is termed as harvest index [19]. Maximum harvest index was observed plots treated with 180 kg N ha$^{-1}$. Which could be attributed to efficient assimilates translocation toward the grains in respective plots. These findings are in line with [43] and [31] who observed significant response of harvest index to nitrogen fertilization. The maximum harvest index observed from plots treated with optimum irrigation in comparison with reduced irrigation might be due to better water usage that in turn influence nutrients uptake, photosynthesis, plant growth, grain yield and ultimately harvest index [50]. These results are in line with [36] who observed the profound effect of irrigation levels on harvest index. The non- significant response of harvest index to various levels of K [51]. The highest 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 resulted in maximum translocation of assimilates towards the economic portion. This higher translocation of assimilates might had improved the shelling percentage. These results are supported by [35].

On the basis of findings obtained in the experiment 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 yield and yield component.

Application of 180 kg N ha$^{-1}$ boosted maize yield and yield components.

Based on the results, application of 120 kg K ha$^{-1}$ along with 180 kg N ha$^{-1}$ was recommended for obtaining optimum growth, yield and yield attributes under optimum irrigation for maize in agro-climatic condition of the Peshawar.

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