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INTEGRATED NUTRIENT MANAGEMENT STRATEGIES TO ALLEVIATE DROUGHT STRESS IN HYBRID MAIZE IN PUNJAB, PAKISTAN

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ABSTRACT

Drought stress is the principal global threat to crop productivity. Approximately, one third of the global cultivated area is prone to perpetual drought. Yield of maize (*Zea mays* L.) in Pakistan is often reduced by drought, and the severity of the problem may increase due to the protected climate change. Therefore, developing different approaches to mitigate drought stress are inevitable. A 2-year field experiment was conducted to assess the effects of drought on maize growth, productivity and yield. The experiment was conducted at Agronomic Research Area, University of Agriculture, Faisalabad during spring seasons of 2013 and 2014. A randomized complete block design involving a split plot arrangement with three replications was used. Three soil moisture regimes were maintained as main plots: (I_1) well-watered treatment, (I_2) mild drought with 25 mm of potential soil moisture deficit (PSMD), and (I_3) severe drought with 50 mm of PSMD. Nutrient levels were laid out as sub-plots: (T_1) control, (T_2) 100 kg ha^{-1} K, (T_3) 150 kg ha^{-1} K, (T_4) 12 kg ha^{-1} Zn, (T_5) 100 kg ha^{-1} K + 12 kg ha^{-1} Zn, and (T_6) 150 kg ha^{-1} K + 12 kg ha^{-1} Zn. The highest grains yield of 8760 kg ha^{-1} in 2013 and 8040 kg ha^{-1} in 2014 was obtained for I_1T_6 treatment. Increasing drought stress significantly reduced all agronomic parameters. Hence, higher rates of application of potassium with zinc are needed to enhance maize production, increase net income, and alleviate the adverse effects of drought stress.

Key words: Potential soil moisture deficit, zinc, drought stress, field capacity, *zea mays* l.

INTRODUCTION

Agronomic drought is caused by the lack of adequate soil moisture at critical stages of crop growth. Adequate soil moisture is essential for healthy plant growth and development (Manivannan et al., 2008). In general, crops suffer from drought stress during spring in Punjab, Pakistan due to higher transpiration rate and high temperatures. Drought, more than any abiotic stress, adversely affects crop growth and development with strong yield losses, because severity and length of drought are critical and unpredictable (Farooq et al., 2009).

Drought stress jeopardizes crop production in arid and semi- arid regions throughout the world (Beheshti and Behboodifard, 2010). Maize (*Zea mays* L.) is the 3rd globally important cereal crop after rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.). It is grown under a wide range of physiographic, soil, climatic and socio-economic conditions. Many factors such as poor production technology, genetic makeup of cultivars and prevailing environmental conditions affect the growth and yield of maize. The adverse effects of drought stress on maize yield comprise reduction in crop vigor and growth, poor canopy development, low dry matter accumulation, and low kernel number and weight (Plaut et al., 2004).

Being a C_4 plant, maize uses limited soil moisture rather efficiently. Yet, drought stress occurring at any stage of growth can reduce its productivity and agronomic yield, but sensitivity to drought varies with growth stage at which drought may occur. Drought stress at

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tasseling or flowering stages is the most detrimental and causes severe decline in yield and related parameters (Hammer and Broad, 2003). Optimum fertilization and well-developed root system are useful traits under drought conditions. Thus, significance of optimum fertilization to enhance crop productivity is gaining popularity even among plant breeders. Fertilizer response of different maize hybrids depends upon the specific soil and environmental conditions. Maize genotypes with drought resistance are of economic importance (Rahman et al., 2004). Potassium (K) is a macronutrient, and plays a vital role in the activation of more than sixty enzymes. It creates immunity in plants against drought (Asada, 2000). Yet, available K (0.8 kg ha^{-1} $year^{-1}$) level is decreasing in soils of Pakistan (Ahmad and Rashid, 2003), due to low application rate as compared to global average use (15.1 kg ha^{-1} $year^{-1}$). Crops grown under intensive farming are especially sensitive to K deficiency. Unfilled grains at the top of cob and smaller grain size are caused by the deficiency of K (Bly et al., 2002). Thus, application of K can increase the grain yield, 1000-grain weight and shelling percentage (Ahmad and Rashid, 2003). Enhancing concentration of K in plant tissue can be important to obtaining high and sustainable yield under drought conditions (Valadabadi and Farahani, 2009).

Maize is also sensitive to zinc (Zn) deficiency (Aref, 2010). Crop yields are often limited by low soil levels of Zn especially in calcareous soils of arid and semiarid regions (Cakmak et al., 1999). It is an essential mineral nutrient and a cofactor of over 300 enzymes and proteins involved in cell division, nucleic acid metabolism and protein synthesis. Zn deficiency may inhibit the activities of a number of antioxidant enzymes, resulting in extensive oxidative damage to lipids, proteins, chlorophyll and nucleic acids (Cakmak, 2008).

The objective of this field study was to assess the performance of hybrid maize to different rates of input of K and Zn fertilizer, crop allometry and agronomic productivity in response to drought stress under semi-arid environment in irrigated areas of Punjab, Pakistan. It was hypothesized that integrated application of Zn with K can increase the drought tolerance in maize hybrid, and alleviate adverse effects of drought stress on maize yield.

MATERIAL AND METHODS

Experimental site description

Field experiments were conducted during 2013 and 2014 on a sandy loam soil at the Agronomic Research Area, University of Agriculture, Faisalabad, Punjab, Pakistan. The experimental site is located at 73° east longitude, 31° north latitude, and at an altitude of 135 meters above the sea level. Baseline soil characteristics were determined prior to initiating the experiment (Table 1). The experimental site comes under subtropical and semi-arid environment.

Meteorological data

The data were collected from the Department of Crop Physiology, University of Agriculture, Faisalabad, Pakistan. The daily rainfall was measured by a non-recording rain guage, the minimum and maximum temperatures by mercury-in-glass thermometer, relative humidity by a hygrometer, sun shine hours by a solarimeter and evaporation by class A pan evaporimeter (WMO, 1997). The detail of climatic data for the experimental duration from the 2nd week of February to the 3rd week of June 2013 and 2014 are given in Figures 1 and 2, and briefly explained below.

The experiment was conducted during the spring dry season from February to June in both years. During the spring season of 2013, the total rainfall was 79.3 mm with the maximum of 26.9 mm in June, maximum average temperature was 39.7°C in May, and the minimum average temperature was 8.3°C in February, The average relative humidity was 81% in February and 24.5% in May. The average sunshine hours were 10.4 in May and 5.2 in February. During the spring season of 2014, total rain fall from February to June was 118.2 mm with the maximum of 41.2 mm in May. The maximum average temperature was 40.9°C in June, and the minimum average temperature was 8.9°C in February.

The average relative humidity was 65% in February and 33.2% in May. The sunshine hours were 10.4 in May and 6.5 in February (Figures 1 and 2).

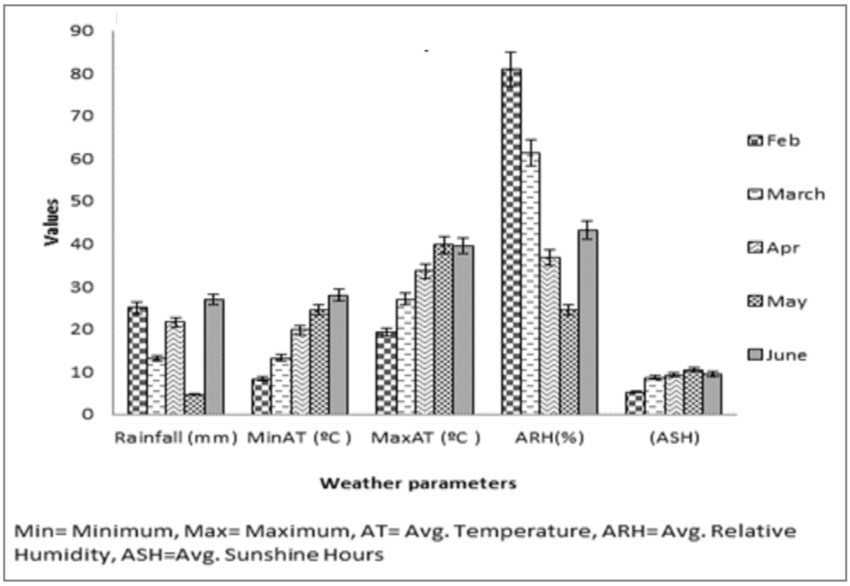

Figure 1. Mean monthly weather data during the growing season of maize crop in 2013

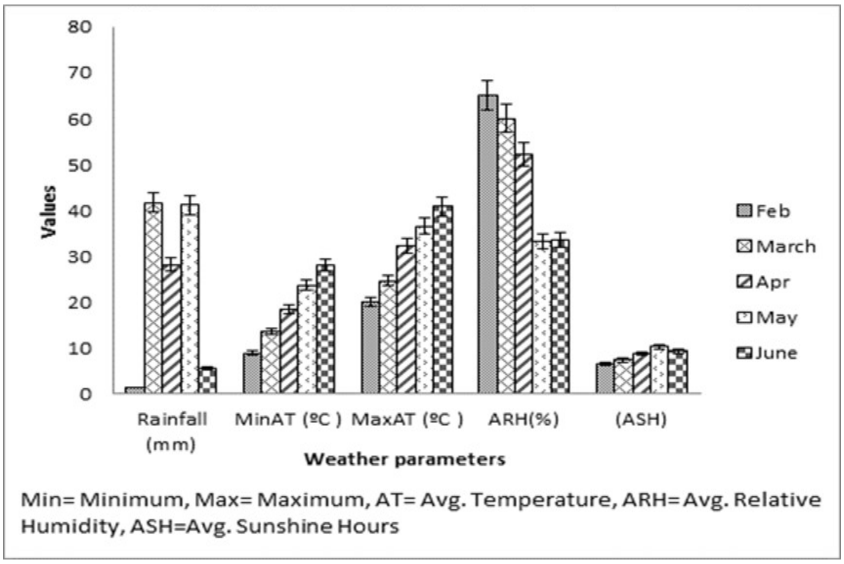

Figure 2. Mean monthly weather data during the growing season of maize crop in 2014

Soil

Predominant soils of the experimental site are Aridisols belonging to Lyallpur series, and classified as Fine silty, mixed hyperthermic-vstalfic haplagid (USDA, 1975). Generic soil properties shown in Table 1 indicate that texture is sandy loam, P^H is >8, the field moisture capacity (FC) is ~ 25% by weight and the bulk density (Bd) is 1.40 -1.48 Mg m^{-3}. Soil samples were taken from the experimental site for analysis in the soil testing laboratory at the beginning of each experiment. Disturbed and undisturbed soil samples were obtained from 0-15 and 15-30 cm depths from five sampling points using the diagonal technique for the comprehensive representation of the research area (4048 m^2), and were composited. Undisturbed core soil samples were obtained after the harvest to measure soil Bd (Grossman and Reinsch, 2002). Core cylinders were 50 mm in diameter 50 mm deep. Undisturbed core samples were obtained for 0-15 and 15-30 cm soil depths. Wet Bd was corrected for the soil moisture content to obtain dry Bd. Bulk samples were air dried, gently ground, and sieved through a 2-mm sieve. Sieved samples were analyzed for particle size distribution using the hydrometer method (Bouyoucos, 1962). Soil pH was determined in 1:1 soil: water suspensions with a pH meter in the laboratory. Electrical conductivity was determined in a 1: 5 soil: water mixture. Total nitrogen (N) was measured through kjeldahl procedure (Thomas, 1996). Total phosphorus (P) was measured by the wet digestion process (Taylor, 2000), and total K by using flame emission spectrophotometry (Rayment and Lyons, 2011). The FC was determined by the pressure plate method by subjecting saturated samples to 0.3 bar pressure (Merriam, 1960).

Table 1. General properties of soil of the experimental site

Parameter	Units	2013			2014		
		0-15 cm	15-30 cm	Mean	0-15 cm	15-30 cm	Mean
Texture	-	Sandy loam	Sandy loam		Sandy loam	Sandy loam	
pH	-	8.0	8.1	8.1	8.3	8.0	8.2
Electrical conductivity	(dS m^{-1})	0.7	0.5	0.6	0.7	0.5	0.6
Nitrogen	(%)	0.04	0.04	0.04	0.04	0.04	0.04
Available P	(ppm)	7.5	5.5	6.5	7.1	5.2	5.7
Extractable K	(ppm)	125.5	111.1	118.3	122.5	112.7	117.8
Sand	(%)	55.0	48.0	52.0	54.0	49.0	52.0
Silt	(%)	22.0	28.0	25.0	22.0	27.0	25.0
Clay	(%)	23.0	24.0	24.0	24.0	26.0	25.0
Field capacity	(%)	26.1	25.4	25.8	25.5	26.2	25.9
Bulk density	(Mg m^{-3})	1.4	1.43	1.42	1.44	1.48	1.46

Water

In addition to canal, ground water is also used for irrigation. This experiment was conducted by using canal irrigation water.

Crop hybrid

The commercial exotic hybrid Dekalb-6525 (for spring) from Monsanto Pakistan Agri. Tech. Pvt. Ltd was sown during both the years of experimentation. The hybrid is drought tolerant Hussain et al. (2006).

Experimental details

The experiment comprised of a 2-factorial design with split plot arrangement. Two factors were soil moisture regimes (as regulated by irrigation), and fertilizer treatments. Three levels of soil moisture regimes were maintained as main plots and included I_1 (well-watered) maintaining 100% field capacity, I_2 (mild drought) by maintaining 75% field capacity after 25 mm potential soil moisture deficit (PSMD), and I_3 (severe drought) by maintaining 50% field capacity after 50 mm PSMD. Six levels of nutrient were used as sub-plots and included the following treatments: (T_1) control with recommended amount of NPK (250-125-125 kg ha^{-1}), (T_2) 100 kg ha^{-1} K plus NP (250-125 kg ha^{-1}), (T_3) 150 kg ha^{-1} K plus NP (250-125 kg ha^{-1}), (T_4) 12 kg ha^{-1} Zn with recommended amount of NPK (250-125-125 kg ha^{-1}), (T_5) 100 kg ha^{-1} K + 12 kg ha^{-1} Zn plus NP (250-125 kg ha^{-1}), and (T_6) 150 kg ha^{-1} K + 12 kg ha^{-1} Zn plus NP (250-125 kg ha^{-1}). The experiment was replicated three times, and the net plot size of each experimental unit was 5 × 3 m.

Determination of irrigation levels at field

Gravimetric soil moisture content was measured by drying in the oven at 105°C for 24 hours. Regular measurements of soil moisture contents were made on composited soil samples at 30-cm depth interval to 1-m depth taking into consideration the entire root system.

Depth of irrigation water

Irrigation was applied to respective plots as soon as the desired soil moisture level was attained. Depth of irrigation for each FC level was predetermined by adopting the direct measurement or field sampling method of crop water requirement (Mujumdar, 2002):

$$d = \frac{(FC - M_b)\,(Bd) \times D}{100}$$

where:

d = Depth of water to be applied (cm);
D = Depth of root zone (cm);
FC = Field moisture capacity (%);
Bd = Bulk density (Mg m^{-3});
M_b = Moisture contents in soil before irrigation.

The amount of water applied to each treatment was determined with the help of a cut throat flume (Skogerboe et al., 1972). The time to supply the required depth of irrigation water to each plot was calculated according to following equation (Rafiq, 2001):

$$t = \frac{1.02\,d\,x\,a}{q}$$

where:

T = time (hours);
d = Depth of water (cm);
a = Area (ha);
q = Discharge (m^3/s);

1.02 is the conversion factor from acre to hectare and inches to cm. The total amount of water for the irrigation levels treatment I_1, I_2, and I_3 were 700 mm, 525 mm, and 350 mm excluding the amount of rainfall in 2013 respectively; while in 2014 the total amount of water for the irrigation levels treatment I_1, I_2, and I_3 were 600 mm, 450 mm, and 300 mm excluding the amount of rainfall, respectively.

Crop Husbandry

The initial irrigation of 10 cm was given to the field prior to seedbed preparation. After attaining the workable soil moisture level, field was cultivated twice with tractor-mounted cultivator followed by planking to break the clods. Maize was sown manually during the 2nd week of February in both 2013 and 2014. The seeding was done on ridges 75 cm apart, and at plant spacing of 20 cm by using a single row hand drill at a seed rate of 30 kg ha^{-1}. Seedlings were thinned at 4-leaf stage. Manual weeding was done, as and when needed, to control the weeds. Furadan (3-G) with 3% carbofuran active ingredient was applied at 4-leaf stage at 20 kg ha^{-1} to control borer and shoot fly. Seeds were treated with fungicide (Benlate® having a chemical benzimidazole at 2g kg^{-1}) for the control of seed-borne diseases. Fertilizer used were urea (46% N), diammonium phosphate (46% P_2O_5 and 16% N), and sulphate of potash (50% K_2SO_4). Zn was applied according to treatments as $ZnSO_4$ (2% Zn). The basal rate of NPK (250-125-125 kg ha^{-1}) fertilizer was used as the control treatment. The entire amount of Zn, P_2O_5, K_2O, and 1/3 of total N were applied at the time of sowing. Of the remaining N, 1/3 was applied at 15 days after sowing, and the final 1/3 at tasseling. Maize was harvested manually during the 3rd week of June in both the years.

Yield and related traits

Ten plants were selected at random from each plot to monitor plant height (cm) to the top of the tassel and number of cobs $plant^{-1}$. The same ten plants in each plot were used for measuring number of grains cob^{-1} and 1000-grain weight (g). Grain yield (GY) was recorded on subplot basis and reported as kg ha^{-1}. Each plot was harvested manually; cobs were separated from the plants and put in the mesh bags. After sun drying for one week, cobs were shelled by a mechanical sheller. Concentration of Zn in grains was determined through wet digestion method using HNO_3-$HClO_4$ (Jackson, 1973).

Statistical analysis

MSTAT-C statistical program was used to statistically analyze the data (Mirza et al., 2008). Fischer's analysis of variance (ANOVA) was computed, and comparison among treatments' means was performed by LSD test at 5% level of probability (Steel et al., 1997). Further, graphical presentation of data was accomplished by using Microsoft Excel 2010 computer program.

Economic analysis

The cost and benefits analysis of the experiment was conducted to assess the economic feasibility of different fertilizer application rates for improving maize productivity under drought conditions. Total expenses incurred on maize production were computed from sowing to harvesting. The expenses included the land rent, seedbed preparation, seed sowing, fertilizers, irrigation and plant protection measures. The gross income was estimated by considering the current prices of maize grains. Net income was computed by subtracting expenses from the gross income, and benefit: cost ratio (BCR) by dividing the gross income with total expenses incurred.

RESULTS AND DISCUSSION

The analysis of variance table of all parameters measured in relation to treatments and their interaction are shown in Table 2 and discussed for each parameter as follows:

Table 2. Analysis of variance of different plant parameters of maize as affected by different irrigation regimes and plant nutrient levels (Mean Squares)

SOV	df	Plant height	No. of cobs plant^{-1}	No. of grains cob^{-1}	1000-grain weight	Grain yield	Grain zinc contents
Replication	2	5.4	0.005	57	67	0.02	0.001
Irrigation	2	1301**	0.80*	22744**	24754*	17.4**	1.05*
Error Repl*Irrigation	4	16.0	0.02	80	63	0.02	0.03
Nutrients	5	95.0*	0.10*	1274*	359*	0.42*	0.05*
Irrigation*Nutrients	10	50.4	0.04	1209*	414*	0.49*	0.005
Error Repl* Irrigation	30	11.0	0.01	189	62	0.03	0.004

* Nutrients; * $p \leq 0.01$; ** $p \leq 0.05$.

Plant height

The data in Table 3 show that the maximum plant height of 208 cm was achieved under I$_1$, and of 212 cm with T$_6$. Expectedly, increase in availability of water and nutrients increased plant vigor and height. The average plant height increased from 195 cm under severely stressed condition to 208 cm in well- watered treatment. Similarly, the average height increased from 193 cm for control to 212 cm for T$_6$ treatment. The data about plant height (Table 3) reveals that plant height was increased with the optimum irrigation and with the higher doses of inorganic fertilizer.

Number of cobs plant^{-1}

The data in Table 3 show that the maximum number of cobs plant^{-1} was achieved under I$_1$ and T$_6$. Plant growth and yield decreased with increase in degree of drought stress. Thus, the lowest yields were obtained when the moisture regime was low (severe drought) and rate of inorganic fertilizer applied was also low (100 kg ha^{-1} K). There were significant differences in number of cobs plant^{-1} among irrigation and nutrient levels (Table 3). The average number of cobs plant^{-1} increased from 1.3 in severely stressed to 1.5 in well-watered treatment. Similarly, the average number of cobs plant^{-1} increased from 1.2 for control to 1.6 for the T$_6$ treatment. The interaction among number of cobs plant^{-1} was non- significant (Table 2).

Number of grains cob^{-1}

Significant differences in numbers of grains cob^{-1} were evident among different irrigation and nutrient levels in both years (Table 3). Number of grains cob^{-1} differed significantly among treatments during both the years (Table 3). However, the average number of grains cob^{-1} was 435 for irrigation and 466 for fertilizer in both the years (Table 3). There was a significant interaction for numbers of grains cob^{-1} between irrigation and nutrient levels during both the years. The average numbers of grains cob^{-1} increased from 391 in I$_3$T$_1$ to 499 in I$_1$T$_6$ (Table 4). Trends in grain yield and parameters may be due to the synergistic effects of K and Zn in alleviating drought stress. The data presented show more grains cob^{-1} with the higher application of fertilizer. Probably due to the reduced number of ovules, restricted ovule fertilization or cessation of development of some apical ovule after fertilization under drought stress. An optimal supply of essential nutrients can enhanced pollination efficacy and increase seed number cob^{-1} (Ogola et al., 2001).

Table 3. Effect of different irrigation regimes and plant nutrient levels on agronomic and yield parameters of maize

Treatments	Yield parameters											
	Plant height (cm)		No. of cobs plant^{-1}		No. of grains cob^{-1}		1000-grain weight (g)		Grain yield (kg ha^{-1})		Grain zinc contents (mg kg^{-1})	
Irrigation levels	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Well watered	212 a	203 a	1.6 a	1.4 a	461 a	442 a	320 a	306 a	7600 a	6720 a	33.7 a	30.2 a
Mild drought (25 mm PSMD)	204 b	199 b	1.4 b	1.3 b	445 b	425 b	309 b	290 b	6900 b	6140 b	31.4 b	28.3 b
Severe drought (50 mm PSMD)	199 c	191 c	1.4 c	1.2 c	430 c	406 c	283 c	269 c	5640 c	5280 c	27.2 c	25.7 c
LSD 5%	0.3	0.8	0.05	0.03	4	4	1.9	2.1	42	43	0.2	0.2
Nutrient levels												
Control	196 e	190 e	1.3 e	1.1 e	441 e	418 e	286 e	268 e	6100 e	5760 e	27.8 e	26.5 e
100 kg ha^{-1} K	190 f	186 f	1.2 f	1.0 f	396 f	382 f	244 f	237 f	5100 f	4830 f	26.3 f	26.0 f
150 kg ha^{-1} K	202 c	196 c	1.5 c	1.4 c	471 c	447 c	310 c	294 c	7650 c	6850 c	30.4 c	28.3 c
12 kg ha^{-1} Zn	208 b	201 b	1.6 b	1.5 b	490 b	466 b	322 b	302 b	8100 b	7350 b	32.7 b	29.7 b
100 kg ha^{-1} K + 12 kg ha^{-1} Zn	198 d	193 d	1.5 d	1.2 d	455 d	438 d	299 d	286 d	7100 d	6450 d	29.0 d	27.8 d
150 kg ha^{-1} K + 12 kg ha^{-1} Zn	216 a	208 a	1.7 a	1.5 a	502 a	484 a	338 a	312 a	8450 a	7750 a	34.0 a	30.8 a
LSD 5%	0.6	1.0	0.02	0.02	7	7	4	3	90	80	0.05	0.05
Interaction	NS	NS	NS	NS	*	*	*	*	*	*	NS	NS

Means followed by the same letter are not significantly different at $p \leq 0.05$, NS is non–significant.

1000-grain weight

The data presented show that application of K and Zn enhanced the 1000-grain weight, probably due to an efficient translocation of assimilates to cob. The average 1000-grain weight increased from 276 g in severely stressed to 313 g in well-watered treatment. Similarly, the average 1000-grain weight increased from 277 g for control to 325 g for the T_6 treatment. Reduction in 1000-grain weight under drought stress was also reported by Plaut et al. (2004) due to less efficient and disturbed nutrient uptake, and limited translation of photosynthates within the plant hastening maturity with shriveled kernels. The average 1000-grain weight increased from 247 g in I_3T_1 to 342 g in I_1T_6 (Table 4). There was also a significant interaction for 1000-grain weight between irrigation and nutrient levels during both the years (Table 4). Application of K improves soil moisture uptake by root elongation, and photosynthesis action by many enzymes.

Grain yield

Irrigation and nutrient levels significantly influenced GY, which decreased with decrease in the amount of supplemental irrigation applied in both the years. The maximum GY of 7160 kg ha^{-1} during 2013 and 2014 was achieved under I_1, and the minimum average GY of 5460 kg ha^{-1} under I_3 (Table 3). The average GY increased from 5930 kg ha^{-1} for T_1 to 8100 kg ha^{-1} for the T_6 treatment. The highest GY of 8400 kg ha^{-1} was obtained in I_1T_6 treatment compared with 3550 kg ha^{-1} in I_3T_1 (Table 4). There was also a significant interaction for GY between irrigation and nutrient levels during both the years (Table 4). Three main mechanisms by which maize yield are reduced by soil water deficit are: (i) reduced absorption of radiation incident photosynthetically active canopy, (ii) decreased effectiveness of radiation use, and (iii) reduced (HI Earl and Davis, 2003). Drought reduces plant yield components especially grain weight (Nasri, 2005), due to reduced production of photosynthates (Wahid and Rasul, 2005).

Grain zinc contents

Increasing rate of K and Zn application significantly increased the grain Zn concentration during both the years (Table 3). The average grain zinc concentrations were 29.7 mg kg^{-1} for irrigation and 29.5 mg kg^{-1} for fertilizer treatments. The maximum Zn concentration in maize grains was observed in T_6. Accordingly, the minimum Zn concentration was observed in T_2. The interaction between two factors affecting Zn concentration was non-significant during both years (Table 3).

Table 4. Interactive effects of different irrigation levels and nutrients on the number of grains cob^{-1}, 1000-grain weight and grain yield of hybrid maize

Treatment	2013	2014	2013	2014	2013	2014
	Number of grains cob^{-1}		1000-grain weight (g)		Grain yield (kg ha^{-1})	
I_1T_1	473 e	472 d	325 d	315 d	7220 d	6980 d
I_1T_2	460 f	462 e	312 e	310 e	6860 e	6720 de
I_1T_3	490 c	480 c	344 bc	324 c	8110 bc	7720 bc
I_1T_4	498 b	487 b	346 b	329 b	8430 b	7850 b
I_1T_5	483 d	478 cd	340 c	323 cd	7650 c	7400 c
I_1T_6	505 a	492 a	351 a	332 a	8760 a	8040 a
I_2T_1	435 k	444 i	296 j	293 i	5400 j	5450 i
I_2T_2	423 l	435 j	283 k	281 j	4960 k	5080 j
I_2T_3	450 hi	461 g	306 gh	303 g	5920 gh	6020 g
I_2T_4	452 h	465 fg	309 fg	306 fg	6320 fg	6430 fg
I_2T_5	444 j	452 h	304 hi	297 h	5820 hi	5880 gh
I_2T_6	458 fg	469 ef	310 ef	308 ef	6560 ef	6650 ef
I_3T_1	382 q	399 o	250 o	243 o	3500 no	3600 n
I_3T_2	377 r	387 p	233 p	226 p	3040 p	2930 o
I_3T_3	402 no	419 m	278 m	260 m	4200 m	4180 m
I_3T_4	404 n	425 l	279 lm	271 l	4600 lm	4560 kl
I_3T_5	396 p	411 n	271 n	254 n	3780 n	4070 mn
I_3T_6	413 m	431 jk	280 kl	278 jk	4850 kl	4780 jk
LSD 5%	5.0	5.3	3.0	2.9	0.40	0.38

Means followed by the same letter are not significantly different at $p \leq 0.05$.

Economic analysis

Net income and BCR (benefit: cost ratio) increased linearly with increase in the number of irrigations during both the years (Table 5). The maximum and the minimum net income were obtained from I_1 and I_3 treatments, respectively. The highest net income in both years was obtained with the integrated application of inorganic fertilizer (T_6). Similarly, the maximum and the minimum BCR in both years were recorded in T_6 and T_2, respectively.

Table 5. Economic analysis as affected by different irrigation levels and plant nutrient levels during 2013 and 2014

Treatment	Total Cost (10^3 Rs. ha^{-1})		Gross Income (10^3 Rs. ha^{-1})		Net Income (10^3 Rs. ha^{-1})		Benefit Cost Ratio	
Irrigation levels	2013	2014	2013	2014	2013	2014	2013	2014
Well watered	68.2	67.5	173.7	153.8	1055.6	863.9	2.55	2.28
Mild drought (25 mm PSMD)	66.7	66.0	158.2	141.1	915.0	751.3	2.37	2.14
Severe drought (50 mm PSMD)	64.4	63.8	131.3	122.3	669.0	585.8	2.04	1.92

Table 5 continued

Nutrient levels								
Control	66.0	65.2	140.5	131.3	744.8	661.2	2.13	2.01
100 kg ha^{-1} K	63.9	63.2	117.8	110.6	538.8	473.6	1.84	1.75
150 kg ha^{-1} K	68.1	67.2	174.5	155.8	1064.1	886.5	2.56	2.32
12 kg ha^{-1} Zn	67.2	67.5	184.4	166.9	1172.4	993.5	2.70	2.47
100 kg ha^{-1} K + 12 kg ha^{-1} Zn	64.8	64.1	162.3	146.8	975.2	827.9	2.50	2.29
150 kg ha^{-1} K + 12 kg ha^{-1} Zn	69.1	67.3	192.0	175.7	1229.6	1084.7	2.78	2.61

CONCLUSIONS

The data presented support the following conclusions:

1. Water deficit at any crop growth stage significantly reduced GY and related traits.
2. Water deficit decreased the GY and the HI, but the magnitude of decrease was lower with the application of chemical fertilizers.
3. The maximum profit was obtained with T6 Rs 110700 ha^{-1}.
4. Application of K with Zn increased the tolerance of maize to drought.

Thus the data presented prove the hypothesis that “the application of K and Zn with supplemental irrigation increased the growth and yield of maize, the number of grains, and the unit grain weight, the grain Zn contents, tolerance to drought stress, and increased the net income”.

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