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Plant Growth Regulator (Ethephon) Alters Maize (*Zea mays* L.) Growth, Water Use and Grain Yield under Water Stress

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Abstract: The aim of the present investigation was to study the growth, yield and yield components of maize (*Zea mays* L.) single cross 704 under different levels of irrigation, plant density and ethephon levels. There were two field experiments during 2003-4 and 2004-5 growing seasons at the experimental farm of the College of Agriculture, Shiraz University, Shiraz, Iran, located at Badjgah. The experimental design was a randomized complete-blocks with four replicates and the treatments in a split-split plot arrangement. Irrigation levels (low and high) were the main plots, the plant densities (53,333 and 80,000 plants ha^{-1}) in the subplots and ethephon levels (0, 0.56, 0.84 kg ha^{-1} a.i., applied at the 6-leaf stage) in the sub-subplots. The results showed that the rates of ethephon foliar application could play an important role in the maize growth indices and attributed grain yield components. Application of ethephon was associated with a decrease in LAI, LAID and CGR. Furthermore, ethephon reduced plant and ear height. Increasing application rates of ethephon showed a significant reduction in early season plant height and LAI, LAID. The control plants had lower grain yield than those treated with different ethephon levels. Indeed, this research showed that under conditions of water stress, a maize plant is able to make better use of available water if vegetative growth is restricted early in the season. The results also indicated that yield response of maize to ethephon application would vary with the plant density and available water conditions. Ethephon treatment was found to be more beneficial to the grain yield at higher plant densities and water stress conditions and it is worthy of further investigations.

Key words: *Zea mays* L., ethephon, water stress, plant density, yield and yield components

INTRODUCTION

Drought, like many other environmental stresses, has adverse effects on crop yield and is the most limiting factor in crop production (Sharp and Davies, 1979, 1985; Netting, 2000; Bruce *et al*., 2002). Maize is reported to be relatively tolerant to water stress during the vegetative growth phase, very sensitive during tasseling, silking and pollination and moderately sensitive during grain filling (Shaw, 1977; Smith *et al*., 2004). Thus if a crop is relying heavily on a limited supply of stored soil water, slowing the rate of soil water extraction prior to anthesis should increase the amount of available water remaining in the soil after anthesis (Kasele *et al*., 1994). One way to slow the rate of soil water extraction would be to reduce the size of the evaporative surface or leaf area index (Rosenberg *et al*., 1983; Kasele *et al*., 1994). Plant growth regulators such as ethephon (2-chloroethyl phosphonic acid) have been primarily used as anti lodging agents in corn fields grown under optimum conditions (Cox and Andrade, 1988; Gaska and Oplinger, 1988; Norberg *et al*., 1988). Alternatively, plant growth retardants could be used to reduce early season crop water use by reducing LAI, resulting in extended water availability for critical reproductive and grain filling processes and thereby increase in grain yield under drought stress (Shanahan and Nielsen, 1987; Kasele *et al*., 1994; D' Andria *et al*., 1997). Some studies confirm that for Mediterranean environments, ethephon can induce modifications in crop growth and development, to improve the efficiency of water use in maize under severe water stress conditions (Riccardo *et al*., 1997). Plant density also affects LAI, which in turn influences the pattern of seasonal water use, as well as grain yield, of corn. Optimal plant densities are highly dependent on available seasonal water; lower plant densities are more suited to lower available seasonal water (Gardner and Gardner, 1983; Kasele *et al*., 1994). The objective of the present study was to examine the effects of water stress, plant density and plant growth regulator (ethephon) on growth, development and grain yield of maize (*Zea mays* L.) single cross 704, under agroclimatic conditions of southern Iran at Badjgah.

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MATERIALS AND METHODS

A field experiment was conducted at the Experimental Farm of College of Agriculture, Shiraz University, Shiraz, Iran, located at Badjgah (29°50′ N and 52°46′ E; elevation 1810 m above mean sea level) during the 2003-2004 and 2004-2005 growing seasons. The soil characteristics of the experimental site, Daneshkadeh soil series (Fine, mixed, mesic, Calcixerollic, Xerochrepts), are given in Table 1. The experimental design consisted of a factorial combination of two irrigation levels (low and high), two plant densities (53, 333 and 80, 000 plants ha^{-1}) and three ethephon treatments (0, 0.56 and 0.84 kg ha^{-1}, applied at the 6-leaf stage) in randomized complete block with a split-split plot arrangement and four replications. Irrigation levels constituted the main plots, plant densities the subplots and ethephon treatments the sub-subplots. The plots were planted on 10 June 2004 and 13 June 2005. The seeds were hand-sown, in plots of 3.5 m wide and 5.5 m long. Within each row the seeds were 16.6 cm (high density) and 25 cm (low density) apart and the space between the two rows were 75 cm in all plots. Uniformity of sowing depth was achieved by using a hand dibber to make holes of 5 cm depth.

Nitrogen and phosphate were applied to each plot as urea and ammonium phosphate at the rate of 400 and 250 kg ha^{-1}, respectively.

Half of the nitrogen fertilizer (urea) was top dressed at the 6-leaf stage. The plots were regularly hand weeded. The low and high irrigation treatments consisted of approximately 30 and 100% speculated replacement of weekly Evapotranspiration (ET) losses.

The plots were irrigated by furrow irrigation. The amount of water applied to each plot was determined by the following equations (Micheal and Ojha, 1987):

$$d = (F_c - P_v)\, D/100$$

F_c: Field capacity, P_v: Porosity volume (%), D: Soil depth, (cm), d: Irrigation depth, (cm).

Table 1: Main soil physicochemical characteristics of the experimental site

Physicochemical characteristics	
Physical characteristics	
Classification	Calcixerollic, Xerochrepts
Field capacity (%)	34
Wilting point (%)	15
Silt (%)	48
Clay (%)	30
Sand (%)	22
Soil texture	Clay
Chemical characteristics	
Soil pH	7.68
Potassium (mg kg^{-1})	590
Phosphorus (mg kg^{-1})	26
Organic carbon (%)	1.17
Organic matter (%)	1.75
Total nitrogen (%)	0.114
Electrical conductivity (dS m^{-1})	0.402

The rates of ethephon application at any individual application were 0 (none, 0), 0.56 (medium, M) and 0.84 (high, H) kg a.i. ha^{-1} and time of application based on crop development included the 6-leaf growth stage. In early morning (to prevent evaporation), ethephon was foliarly sprayed using a back-pack sprayer system consisting of a hand-held boom with nozzles spaced 0.76 m apart. The solution containing ethephon and a surfactant (10 mL L^{-1}), was delivered at a pressure of 207 kPa in a spray volume of 233 L ha^{-1}. During spraying each plot was surrounded by plastic walls to avoid the drift of solution to the adjacent plots.

Plots were sampled at 3-weekly intervals from after sowing to final harvest. At each sampling, 5 adjacent plants in two rows of each plot were taken for laboratory measurements of plant height, internodes length, internodes diameter, LAI and dry matter.

Plant height was measured from the soil surface to the collar of the tassel. Length of each internode was measured individually by tape and then averaged. After detaching the leaves along with the leaf sheath, diameter of each internode including one, two and three were measured with a caliper having accuracy of 0.01 mm. Leaf area index and dry matter yield were determined by destructive vegetative samplings. Plants from two rows within each plot were cut from the soil surface and the leaves were removed at the leaf collar.

Leaf area was determined with a leaf area meter DeltaT Device model. Crop Growth Rate (CGR), Leaf Area Index (LAI) and Leaf Area Index Duration (LAID) were determined using the following equations (Gardner *et al.*, 1985):

$$CGR = 1/G_A . (W_2 - W_1)/(T_2 - T_1)$$

$$LAI = (1/G_A) . (L_{A2} + L_{A1})/2$$

$$LAID = (L_{A1} + L_{A2})/G_A . (T_2 - T_1)/2$$

Where, L_A = Leaf area, G_A = Ground area, T = Time, A = Area, W = Dry weight

Dry weights were determined after the plant materials were oven-dried at 65°C for 72 h. At maturity, the following characters were measured from center of two rows in each plot:

Ear Number per Plant (ENP), Kernel Row Number per Ear (KRNE), Kernel Number per Ear Row (KNER), Kernel Number per Ear (KNE), Mean Kernel Weight (MKW) (mg), Grain Yield (GY) (t ha^{-1}), harvest index (HI) (%), ear length (cm) and ear diameter (mm).

Differences between treatments were statistically analyzed using ANOVA, by MSTATC software and using the SAS statistical technique for the other data analysis, the treatment means were compared using Least Significant Difference (LSD) test. The results of the two years were very similar and therefore, the result of the experiment in 2005 has only been reported in this study.

RESULTS AND DISCUSSION

Effects of water stress, plant density and ethephon application on vegetative growth

Leaf Area Index (LAI) and Leaf Area Index Duration (LAID): Two rates of foliar ethephon treatments (0.56 and 0.84 kg a.i ha^{-1}) at the 6-leaf stage, decreased LAI in both years, compared with control. Ethephon significantly reduced LAI at both rates of application though not at all samplings. This effect is shown in Fig. 1. LAID was also decreased by ethephon application (Table 2) following a decrease in LAI. Similar results were reported by Shanahan and Nielsen (1987) Kasele *et al.* (1994) and Riccardo *et al.* (1997), who used ethephon at the rates of (0, 0.28, 0.56 and 0.84 kg ha^{-1}, applied at the 6 or 8 leaf growth stage) with combination of two irrigation levels (with stress and without stress), two plant densities (high and low) on maize crop. They showed that LAI and dry matter of maize plants were reduced 10 to 40%, under ethephon treatment compared to the control plants.

This reduction in early vegetative growth, particularly LAI, was very likely responsible for a reduction in early season soil water extraction associated with ethephon treatments, resulting in conserving more available soil water for later growth in the season and has also been noted by others e.g., Lee *et al.* (1985) and Shanahan and Nielsen (1987). Results of this experiment also indicated

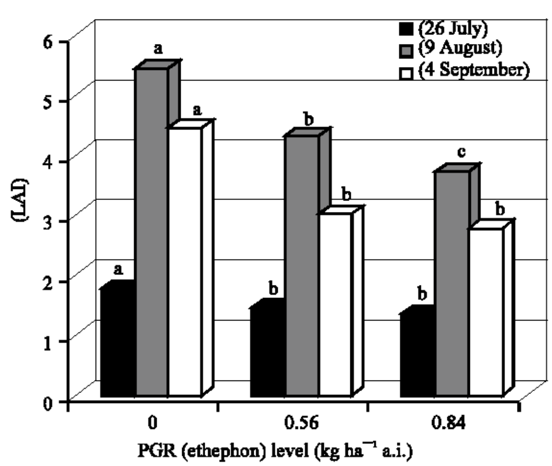

Fig. 1: Effect of ethephon Levels on Leaf Area Index (LAI) of maize plant (2005). Columns with the same letter(s) are not significantly different for each sampling date. LSD (0.05)

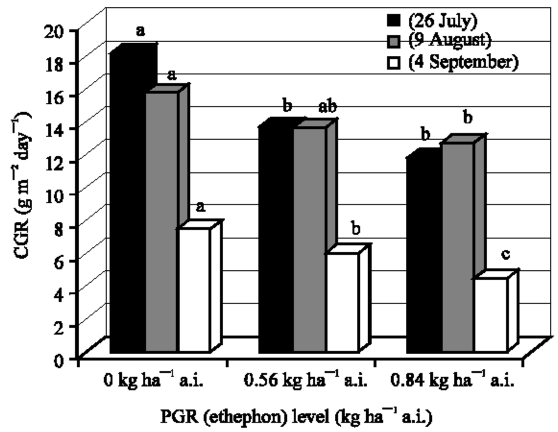

Fig. 2: Seasonal patterns of Crop Growth Rate (CGR) and effect of different ethephon levels on it in 2005 growing season. Columns with the same letters are not significantly different for each sampling date. LSD (0.05)

that, vegetative growth indicators such as LAI and LAID were affected by the irrigation treatment. Water stress reduced both LAI and LAID (Table 2). The plant density and ethephon rate had a significant interaction for LAI (Table 3).

Plants without ethephon at higher plant density had the highest LAI. Other levels of ethephon at higher plant density reduced LAI. Such reduction in LAI and LAID at higher plant density and higher ethephon rate (Table 2), showed a reduction in plant water stress symptoms under water deficit conditions which was associated with an increased late-season plant growth. Present results appear to substantiate the conclusions of Kasele *et al.* (1994), who suggested that PGRs (ethephon) could be used to increase resistance to drought stress under higher plant densities in maize crop.

Crop Growth Rate (CGR) and Total Dry Matter (TDM) Production: In the growth analysis data of this experiment, we observed that CGR was reduced by different levels of ethephon application (Fig. 2). CGR is an index of canopy photosynthesis and its trend represents the rate of biological yield (dry weight) accumulation (Gardner *et al.*, 1985). Ethephon also reduced total dry matter (total dry weight) of each plant. This finding was in agreement with the results of Georgiev (1971) and Cox and Andrade (1988), who evaluated a lodging-susceptible and lodging-tolerant hybrid (Cornell 281 and Pioneer 3901) under recommended (64, 000 plants ha^{-1}) and high plant density (76, 000 plants ha^{-1}) in the absence and presence of ethephon, which was applied at the 15th to 16th stage at 0.42 kg ha^{-1} a.i. Their results showed that ethephon reduced both growth parameters (i.e., CGR and dry matter).

Table 2: Effect of irrigation level, plant density and PGR (ethephon) levels on vegetative growth factors (2005)

Treatments	LAI	LAID (LAI days)	CGR (g m^{-2} day^{-1})	LAI_{max}	Dry matter (g $plant^{-1}$)
Irrigation levels					
High	3.42a	39.99a	12.92a	4.905a	100.1a
Low	2.87b	32.99b	8.727b	4.095b	65.80b
Plant densities (plants ha^{-1})					
80 000	3.23a	37.31a	10.87a	4.816a	74.70b
53 333	3.06b	35.67a	10.78a	4.185b	91.20a
PGR levels (kg ha^{-1})					
0	3.88a	44.32a	12.96a	5.450a	90.35a
0.56	2.93b	34.72b	10.53b	4.327b	84.98ab
0.84	2.61b	30.44c	8.975c	3.724c	73.52b

Means within each column with the same letter(s) are not significantly different using LSD (0.05)

Table 3: Interaction effect of the plant density and PGR (ethephon) levels on LAI (2005)

Treatments	Plant density levels		
PGR levels (kg ha^{-1})	80,000 plants ha^{-1}	53,333 plants ha^{-1}	Mean
0	5.074a	3.842b	3.88A
0.56	3.291bc	2.745cd	2.93B
0.84	3.073c	2.503d	2.61B
Mean	3.23A	3.06B	

Means with the same letter(s) are not significantly different using LSD (0.05)

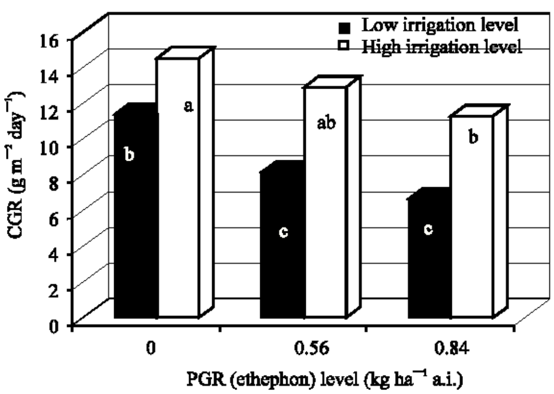

Fig. 3: Interaction between different levels of irrigation and ethephon levels on CGR of maize plant (2005). Columns with similar letter are not significantly different. LSD (0.05)

Indeed, ethephon affected LAI negatively (Fig. 1) and this was associated with the reduction in CGR and total dry matter in both years. Earley and Slife (1969) also demonstrated that increasing rate of ethephon applied at several different stages before tasseling reduced leaf area, LAI and other growth parameters such as CGR. Present data also suggested that growth retardant (ethephon) might be more beneficial under water stress conditions, (Fig. 3) since it reduced LAI and CGR and hence improved water availability for reproductive phase of the crop, however, this reduction in LAI and CGR was not beneficial to maize crop under optimum moisture conditions, because it impaired photosynthetic efficiency or dry matter partitioning to the above ground parts. This finding was in agreement with the results of Georgiev (1971) and Cox and Andrade (1988).

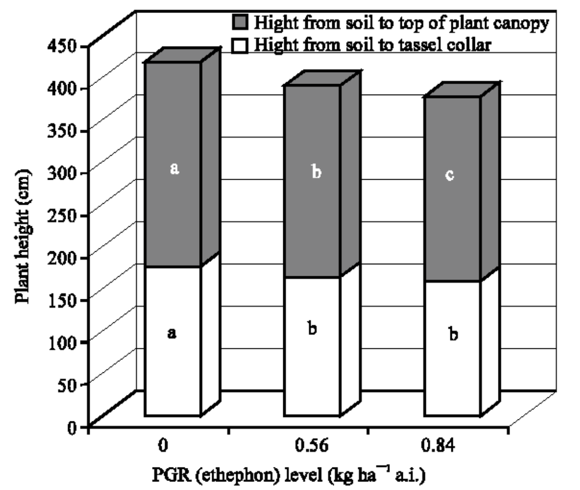

Fig. 4: Effect of ethephon levels on maize final plant height in 2005 growing season. Columns with the same letter(s) are not significantly different for each character. LSD (0.05)

Plant and ear height: Results of the present investigation indicated that ethephon application significantly reduced the maize plant and ear height compared with the control (Fig. 4 and Table 4).

In general, the higher the rate, the greater was the retardation of vertical growth of stems. Ethephon rate has been reported to have highly significant effects on plant height (Cox and Andrade, 1988), ear height (Kasele *et al.*, 1994; Riccardo *et al.*, 1997) and internode length (Earley and Slife, 1969) and increasing ethephon rate has been associated with more reduction in plant height. Hence ethephon could reduce lodging in maize (Gaska and Oplinger, 1988; Kasele *et al.*, 1995; Tripathi *et al.*, 2003). When the potential for lodging is high, ethephon at the higher rates and late applications may be more effective in preserving maize yield (Gaska and Oplinger, 1988). However, if lodging is not a significant problem, (like in present experiment) early ethephon application might be advisable for improving grain yield through increased water saving by reducing LAI and plant height at higher plant densities and under drought stress conditions.

Table 4: Vegetative growth of maize plant as affected by irrigation, plant density and PGR (ethephon) level (2005)

Ttreatments	Plant height	Ear height	Internode length 1st	2nd	3rd	Internode No.	Internode No. from soil to ear	Leaf No.	Internode diameter 1st	2nd	3rd
			----------------cm----------------						----------------mm----------------		
Irrigation levels											
High	260.5a	107.1a	3.875a	7.608a	10.26a	13.29a	8.083a	13.00a	26.74a	27.91a	27.33a
Low	196.8b	78.86b	3.700a	5.996b	7.696b	13.17a	7.958a	12.96a	24.49b	25.56a	25.48a
Plant density (plants ha^{-1})											
53 333	224.7b	90.73a	3.883a	6.675a	8.321b	13.54a	8.042a	13.67a	26.16a	27.31a	27.14a
80 000	232.7a	95.27a	3.692a	6.929a	9.633a	12.92b	8.000a	12.29b	25.06a	25.66a	25.66a
PGR levels (kg ha^{-1})											
0	241.8a	102.6a	5.325a	8.175a	11.35a	14.06a	8.500a	13.50a	23.25b	24.55b	24.42b
0.56	225.6b	91.51b	3.169b	6.306b	8.175b	13.06b	7.875b	13.06ab	27.43a	27.95a	27.80a
0.84	218.6c	84.94c	2.869b	5.925b	7.406b	12.56c	7.688b	12.38b	26.16a	26.95a	26.99a

Means with the same letter(s) in each column are not significantly different using LSD (0.05).

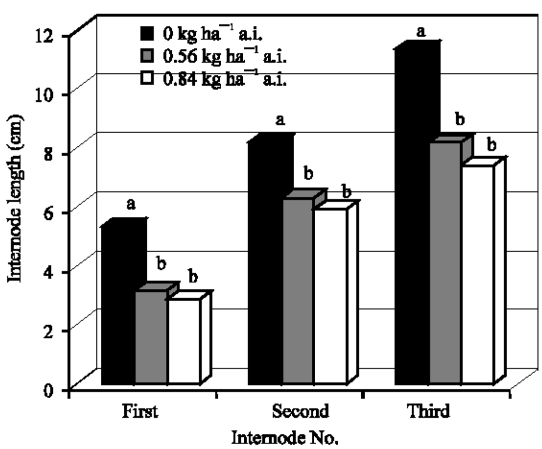

Fig. 5: Effect of ethephon levels on final internode length of maize plant in 2005 growing season. Columns with the same letter(s) are not significantly different for each internode. LSD (0.05)

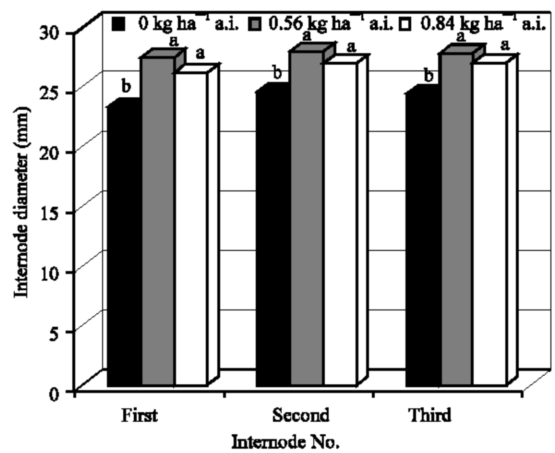

Fig. 6: Effect of ethephon levels on final internode diameter of maize plant in 2005 growing season. Columns with the same letter(s) are not significantly different for each internode. LSD (0.05)

Internode length and diameter: As reported by many workers, reduced plant height might be due to decreased internode length upon ethephon application (Clark and Fedak, 1977; Khosravi and Anderson, 1990; Noberg *et al.*, 1988; Rajala and Peltonen-Sainio, 2001). In our experiment the length of internodes was reduced by ethephon application (Fig. 5). Since internode length of control plants was increased towards the top of the plant, it follows that maximum plant height reduction could be obtained by ethephon treatment immediately prior to cell elongation (i.e., early stage, 6-leaf) of the longest, uppermost stem internodes. The difference between various internodes (1 to 3) length with ethephon application and control plants is shown in Fig. 5.

Ethephon had also a significant effect on internode diameter, so that there was a significant increase in internode diameter following ethephon application (Fig. 6). Therefore, when there is a potential for lodging, ethephon application, might be effective in reducing lodging through increasing basal internodes diameter (Gaska and Oplinger, 1988; Kasele *et al.*, 1995).

Leaf number: It was shown that ethephon application reduced leaf number of maize plants (Fig. 7). There was no significant difference between the two levels of ethephon application in both growing seasons. It appeared that PGR altered morphology and vegetative growth of maize producing plants with lower, smaller and thicker leaves as has been noted by others (Khan and Tsunoda, 1970; Kasele *et al.*, 1995). Leaf number reduction following ethephon application, under low irrigation conditions, could enable maize plant to make a better use of available water, if vegetative top growth is restricted early in the season (Shanahan and Nielsen, 1987).

Effects of water stress, plant density and ethephon application on yield and yield components: The results showed that there was highly significant difference in

Table 5: Yield and yield components of maize plants as affected by irrigation level, plant density and PGR (ethephon) level (2005). Grain yield (GY), ear number per plant (ENP), kernel row number per ear (KRNE), kernel number per ear row (KNER), kernel number per ear (KNE), kernel number per square meter (KN), mean kernel weight (MKW), harvest index (HI), ear length (EL) and ear diameter (ED)

Treatments	GY (t ha^{-1})	ENP	KRNE	KNER	KNE	KN (No. m^{-2})	MKW (mg)	HI (%)	EL (cm)	ED (mm)
Irrigation levels										
High	10.77a	0.8636a	14.75a	42.50a	624.1a	3579a	230.0a	60.74a	20.29a	24.60a
Low	7.298b	0.7389b	14.79a	41.21a	609.5a	3076b	201.9b	48.48b	19.85a	21.63b
Plant densities (plants ha^{-1})										
80 000	10.35a	0.7423b	15.13a	39.46b	596.3a	3615a	217.6a	57.92a	19.38b	22.82a
53 333	7.719b	0.8601a	14.42b	44.25a	637.3a	3041b	214.3a	51.30a	20.77a	23.41a
PGR levels (kg ha^{-1})										
0	9.109a	0.7622a	15.19a	42.19a	639.6a	3189a	210.0b	49.27a	20.94a	21.37b
0.56	9.544a	0.8274a	14.88ab	41.00a	608.5a	3438a	219.1a	59.11a	19.75b	23.73a
0.84	9.574a	0.8141a	14.25b	42.38a	602.4a	3355a	218.8a	55.48a	19.52b	24.25a

Means within each column with the same letter are not significantly different using LSD (0.05)

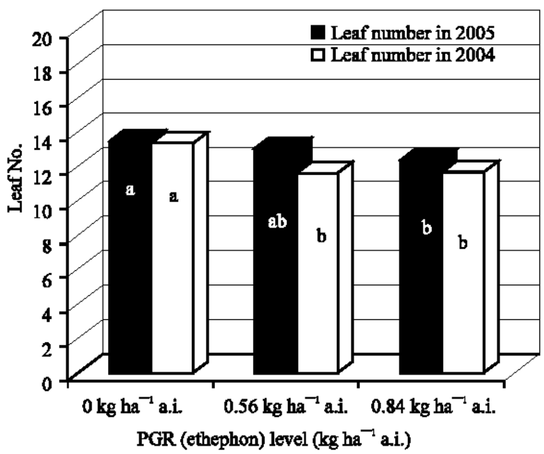

Fig. 7: Effect of ethephon levels on leaf number of maize plant in both growing seasons. Columns with the same letter(s) are not significantly different for ethephon rates. LSD (0.05)

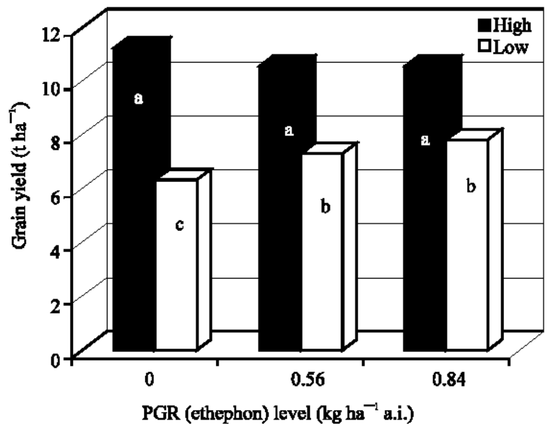

Fig. 8: Interaction between irrigation and ethephon levels on grain yield of maize plant (2005). Columns with similar letter, are not significantly different LSD (0.05)

grain yield for the low and high irrigation levels. Thus, the irrigation variable significantly affected productivity (Table 5). Kernel Number per unit area (KN) and Mean Kernel Weight (MKW) were responsible for the difference in yield between the two irrigation levels, observed in this study (Table 5). Although there was no significant difference between ethephon treated and control plants for the grain yield (Table 5), a significant interaction between irrigation levels and PGR (ethephon) treatment was observed for the grain yield in this study (Fig. 8). This effect was associated with a change in response to grain yield of the ethephon treatments across the two irrigation levels. Grain yield displayed an increase in response to increasing rates of the ethephon under water stress conditions. Conversely, grain yield showed a decrease in response to the ethephon treatment under the high irrigation treatment (Fig. 8). Similar results have been reported by Shanahan and Nielsen (1987) and Kasele *et al.* (1994).

Indeed the effect induced by ethephon in conserving early season soil water use and ultimately reducing water stress during silking and early grain development was very likely to be responsible for the differences in yield under low water level conditions (Table 6). Westgate and Boyer (1985) found that water stress during this critical period (silking to early grain development) inhibits photosynthesis and consequently lowers the carbohydrate reserves to levels that are insufficient to support optimum reproductive development. Such effects explain the observations made in this study concerning the reduction in kernel number per unit area in the control versus ethephon treated plots under water stress conditions (data not shown). In fact the control plants were under greater water stress conditions than were the ethephon treated plants.

However, with optimal irrigation it seems likely that maximum leaf area development is necessary for full interception and conversion of solar radiation to photosynthate and carbohydrate reserves in order to support maximum reproductive development and grain

Table 6: Effect of PGR (ethephon) level, plant density and irrigation levels on grain yield of maize plant (2005) (t/ha)

	Plant densities (plants ha^{-1})		
Ethephon levels (kg ha^{-1})	53, 333	80, 000	Mean
Low irrigation level			
0 (control	5.185de	8.285cd	6.335C
0.56	5.048e	8.600cd	7.324B
0.84	5.115e	8.925c	7.834B
Mean	6.058C	8.537B	
High irrigation level			
0 (control)	9.810bc	12.65a	11.23A
0.56	9.390c	11.70ab	10.55A
0.84	8.740cd	12.15a	10.55A
Mean	9.380B	12.17A	

Means with the same letter are not significantly different using LSD (0.05)

growth. Thus, the reductions in leaf area during vegetative growth, as a result of ethephon application, resulted in lower grain yields when plants were well-watered (Table 6). This finding was in agreement with the results of Shanahan and Nielsen (1987) and Riccardo *et al.* (1997), who reported that under conditions of water stress, a maize plant is able to make better use of available water if vegetative top growth is restricted early in the season by ethephon treatment. Their results also showed lower maize productivity under optimal water conditions.

Under water deficit conditions, maximum yield was attained for ethephon application of 0.84 kg ha^{-1} a.i. and highest plant density (Table 6). Similar modifications in grain yield of corn has been reported by Kasele *et al.* (1994) and for bean plants by Halevy and Kassler (1963).

Ethephon treatments appear effective in reducing leaf surface area, especially during early season and thus conserving water. While direct measurements of plant water stress were not taken in this study, the observed increases in number of kernels per unit area and Mean Kernel Weight (MKW) with ethephon application at high plant density indicated that ethephon application has probably reduced plant water stress during such critical phases as reproductive and grain filling.

Furthermore, the results indicated that ethephon application was most beneficial to yield and yield components at high plant density and under water stress conditions. These results are likely due to the reduction in early-season evapotranspiration associated with ethephon application and reduced plant water stress during reproductive growth, particularly for the high plant density treatment. Several studies have shown that plant water stress during reproductive growth negatively impacts kernel number, kernel size and grain yield (Denmead and Shaw, 1960; Musick and Dusek, 1980).

Ethephon, as a growth regulator, was shown to be an effective means of reducing the excessive vegetative growth of maize plant (Kasele *et al.*, 1994). In this study, it was shown that the yield and yield components could be affected by the foliar ethephon application at the 6-leaf stage. The rates of ethephon foliar treatments can play an important role in the maize growth indices and attributed grain yield components. Indeed, this research has shown that under conditions of water stress, a maize plant is able to make a better use of available water if vegetative growth is restricted early in the season. Apparently, the ethephon mediated effects on crop canopy development and seasonal water use are of greater importance to field performance under water stress conditions than potential reductions in intrinsic single leaf water use efficiency. The results also indicated that yield response of maize to ethephon application would vary with plant density and available water conditions. Ethephon treatment was beneficial to grain yield responses at higher plant density and under water stress conditions.

As the data suggest ethephon application seems to have potential target for improving maize crop performance under water stress conditions which is worthy of further explorations.

REFERENCES

Bruce, B.W., O.E. Gregory and T.C. Barker, 2002. Molecular and physiological approaches to maize improvement for drought tolerance. J. Exp. Bot., 53: 13-25.

Clark, R.V. and G. Fedak, 1977. Effects of chlormequat on plant height, disease development and chemical constituents of cultivars of barley, oats and wheat. Can. J. Plant Sci., 57: 31-36.

Cox, W.J. and H.F. Andrade, 1988. Growth, yield and yield components of maize as influenced by ethephon. Crop Sci., 28: 536-542.

D' Andria, R., F.Q. Chiaranda, A. Lavini and M. Mori, 1997. Grain yield and water consumption of ethephon-treated corn under different irrigation regimes. Agron. J., 89: 104-112.

Denmead, O.T. and R.H. Shaw, 1960. The effects of soil moisture stress at different stages of growth on the development and yield of corn. Agron. J., 52: 272-274.

Earley, E.B. and F.W. Slife, 1969. Effect of ethrel on growth and yield of corn. Agron. J., 61: 821-823.

Gardner, W.R. and H.R. Gardner, 1983. Principles of water management under drought conditions. Agric. Water Manage., 7: 143-155.

Gardner, F.P., R.B. Pearce and R.L. Mitchell, 1985. Physiology of Crop Plants. The Iowa State University Press. Ames, Iowa.

Gaska, J.M. and E.S. Oplinger, 1988. Yield, lodging and growth characteristics in sweet corn as influenced by ethephon timing and rate. Agron. J., 80: 722-726.

Georgiev, T.M., 1971. Effect of ethrel for decreasing stem length in maize. Rasteniev ud. Nauki, 8: 23-28.

Halevy, A.H. and B. Kessler, 1963. Increased tolerance of bean plants to soil drought by means of growth-retarding substances. Nature, 197: 310-311.

Kasele, I.N., F. Nyirenda, J.F. Shanahan, D.C. Nielsen and R. d'Andria, 1994. Ethephon alters corn growth, water use and grain yield under drought stress. Agron. J., 86: 283-288.

Kasele, I.N., J.F. Shanahan and D.C. Nielsen, 1995. Impact of growth retardants on corn leaf morphology and gas exchange traits. Crop Sci., 35: 190-199.

Khan, M.A. and S. Tsunoda, 1970. Evolutionary trends in leaf photosynthesis and related leaf characters among cultivated wheat species and its wild relative. Jpn. J. Breed., 20: 133-140.

Khosravi, Gh.R. and I.C. Anderson, 1990. Growth, yield and yield components of ethephon-treated corn. Springer science+business media B.V., Formerly Kluwer Academic Publishers B.V., 1: 27-37.

Lee, E.H., J.K. Byun and S.J. Wilding, 1985. A new gibberellin biosynthesis inhibitor, paclobutrazol (PP333) confers increased SO_2, tolerance on snap bean plants. Environ. Exp. Bot., 25: 265-275.

Micheal, A.M. and T.P Ojha, 1987. Principles of Agricultural Engineering. Vol. II. New Delhi: Jain Brothers Publisher.

Musick, J.T. and D.A. Dusek, 1980. Irrigated corn yield response to water. Trans. ASAE, 23: 92-98.103.

Netting, A.G., 2000. pH, abscisic acid and the integration of metabolism in plants under stressed and non-stressed conditions: Cellular responses to stress and their implication for plant water relations. J. Exp. Bot., 343: 147-158.

Norberg. O.S., S.C. Mason and S.R. Lowry, 1988. Ethephon influence on harvestable yield, grain quality and lodging of corn. Agron. J., 80: 768-772.

Rajala, A. and P. Peltonen-Sainio, 2001. Plant growth regulator effects on spring cereal root and shoot growth. Agron. J., 93: 936-943.

Riccardo D.A., F.Q. Chiaranda, A. Lavini and M. Mori, 1997. Grain yield and water consumption of ethphon-treated corn under different irrigation regimes. Agron. J., 89: 104-112.

Rosenberg, N.J., B.L. Blad and S.B. Verma, 1983. Microclimate: The Biological Environment. 2nd Edn., Wiley-Interscience, New York, pp: 209-287.

Shanahan, J.F. and D.C. Nielsen, 1987. Influence of growth retardants (Anti-Gibberllins) on corn vegetative growth, water use and grain yield under different levels of water stress. Agron. J., 79: 103-109.

Sharp, R.E. and W.J. Davies, 1979. Solute regulation and growth by roots and shoots of water-stressed maize plants. Planta, 147: 43-49.

Sharp, R.E. and W.J. Davies, 1985. Root growth and water uptake by maize plants in drying soil. J. Exp. Bot., 36: 1441-1456.

Shaw, R.H., 1977. Climatic Requirement. In: Corn and Corn Improvement. Sprague, G.F. (Ed.), Agronomy, 18: 591-623.

Smith, C.W., J. Betran and E.C.A. Runge, 2004. Corn: Origin, History, Technology and Production. John Wiley and Sons Inc (US), Press, pp: 949.

Tripathi, S.C., K.D. Sayre, J.N. Kaul and R.S. Narang, 2003. Growth and morphology of spring wheat culms and their association with lodging: Effects of genotypes, N levels and ethephon. Filed Crops Res., 84: 271-290.

Westgate, M.E. and J.S. Boyer, 1985. Carbohydrate reserves and reproductive development at low leaf water potential in maize. Crop Sci., 25: 762-769.