Ethephon Alters Corn Growth, Water Use, and Grain Yield under Drought Stress

I. N. Kasele, F. Nyirenda, J. F. Shanahan,* D. C. Nielsen, and R. d'Andria

ABSTRACT

The plant growth regulator ethephon has been used to reduce height and lodging of intensively managed corn (*Zea mays* L.). However, the impact of ethephon-induced changes in vegetative growth on water use and grain yield of corn grown at various densities under drought stress conditions has not been widely studied. Field studies were conducted for 2 yr in semiarid eastern Colorado to determine if foliar ethephon application can alter vegetative growth and water use and promote drought stress resistance of corn. In 1989, treatments consisted of a factorial combination of two irrigation levels (low and high), two plant densities (53 333 and 80 000 plants ha^{-1}), and five ethephon treatments (0, 0.28, 0.56, and 0.84 kg ha^{-1}, applied at the 6- or 8-leaf growth stage) at one site. In 1990, treatments consisted of a factorial combination of four plant densities (24 700, 37 045, 49 390, and 61 735 plants ha^{-1}) and three ethephon rates (0, 0.28, and 0.56 kg ha^{-1} applied at the 6-leaf stage) at two sites. Plant height, leaf area index (LAI), dry matter yield, cumulative evapotranspiration (ET), and grain yield were measured. In both seasons, ethephon application reduced plant height and LAI by 10 to 40%, relative to the control, and this resulted in early season ET reductions. Ethephon application either had no effect or decreased yields in 1989 under all irrigation and plant density treatments, because of a lack of significant drought stress. However, when drought occurred in 1990, ethephon application decreased yields at low plant densities but enhanced yields at high plant densities at both locations, with a maximum 37% yield increase for the intermediate ethephon rate. Our data indicate that ethephon application has the potential for improving resistance to drought in corn.

Drought stress is the most limiting factor for corn production in the semiarid Central Great Plains region, where annual precipitation averages 420 mm, and supplemental irrigation water must be provided for maximum yields. Increasing pumping costs and declining water tables have made irrigation unprofitable in many areas. It is important to achieve increasingly more efficient corn production under both irrigated and rainfed conditions in this region.

Corn is reported to be relatively tolerant to water stress during the vegetative stage, very sensitive during tasseling, silking and pollination, and moderately sensitive during grain filling (Shaw, 1977). For most grain crops, grain yields depend more on water use after anthesis than on total water used (de Wit 1958; Passioura, 1976). 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. Greater water availability during grain filling not only allows the plant to maintain efficient photosynthesis after anthesis, but also extends the period during which the plant can remobilize stored reserves to the grain. 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, p. 209–287).

Plant growth retardants such as ethephon (2-chloroethyl phosphonic acid) have been primarily used as anti-lodging agents in corn grown under optimum conditions (Langan and Oplinger, 1987; Cox and Andrade, 1988; Gaska and Oplinger, 1988; Norberg et al., 1988). Alternatively, 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 grain yield under drought stress (Shanahan and Nielsen, 1987). Other researchers (Halevy and Kessler, 1963; Del et al., 1982) also have noted that growth retardant-treated plants are more drought resistant.

Finally, plant density 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 (Downey, 1971; Gardner and Gardner, 1983). We hypothesized that the water use and grain yield responses of corn to growth retardant application may vary with plant density and available seasonal water conditions. Therefore, this study was conducted to determine the influence of foliar ethephon application and its interaction with plant density and seasonal water availability on plant height, leaf area, total dry matter yield, water use, and grain yield of corn grown under the semiarid conditions of eastern Colorado.

MATERIALS AND METHODS

Experimental Design and Treatments

Field experiments were conducted at the Central Great Plains Research Station at Akron, CO (40°09′ N, 103°09′ W; elevation 1384 m above mean sea level) in 1989 and at Akron and Sterling (40°37′ N, 103°13′ W; elevation 1343 m above mean sea level) in 1990. The soil type at Akron was a Rago silt loam (fine, montmorillonitic, mesic Pachic Argiustoll) and at Sterling a Weld silt loam (fine, montmorillonitic, mesic Aridic Paleustolls). All experimental units received 125–45–0 (N–P–K kg ha^{-1}) in 1989, 100–0–0 in 1990 at Akron, and 70–25–0 in 1990 at Sterling. Weeds were controlled by preemergence application of 2.24 kg a.i. ha^{-1} of cyanazine (2-{[4-chloro-6-(ethylamino)-1,3,5-triazine-2-yl] amino}-2-methylpropanenitrile) and 1.8 kg a.i. ha^{-1} of metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide]. The plots were planted on 10 May 1989 and 7 May 1990 at Akron and 8 May 1990 at Sterling using the corn hybrid Pioneer 3902.

The experimental design in 1989 consisted of a factorial combination of two irrigation levels (low and high), two plant densities (53 333 and 80 000 plants ha^{-1}), and five ethephon treatments in randomized complete blocks with a split-split plot arrangement and four replications. Irrigation levels constituted

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Abbreviations: GBI, gibberellin biosynthesis inhibitor; LAI, leaf area index; ET, evapotranspiration. 0, L, M, and H represent zero, low, medium, and high ethephon treatments (0, 0.28, 0.56, and 0.84 kg a.i. ha^{-1}); as subscripts to E, combined letters indicate treatments at successive applications. **Significant at the 0.01 probability level.

the main plots, plant densities the subplots, and ethephon treatments the sub-subplots. An individual sub-subplot was 15.2 m long and 4.6 m wide in 1989, consisting of six rows spaced 0.76 m apart. The low and high irrigation treatments consisted of approximately 30 and 100% replacement of weekly ET losses. The irrigation treatments were delivered through drip tubing placed on the soil surface in alternate rows of each plot and were initiated on 7 July 1989. The amount of water applied for each treatment was monitored by a flow meter and was based on the amount used by the high irrigation treatment in the previous week. The total seasonal amount applied to the low and high irrigation treatments was 73 mm and 233 mm, respectively. Plant density treatments were established by overplanting and hand thinning to the desired density. The ethephon treatments varied according to rate and timing of application and were devised to provide a control with no ethephon and four combinations of split applications. The rates of ethephon application at any individual application were 0 (none, 0), 0.28 (Low, L), 0.56 (Medium, M), and 0.84 (High, H) kg a.i. ha^{-1} and times of application based on crop development included the 6- and 8-leaf growth stages. Treatments designations appear as subscripts to the letter E (E_{00}, E_{H0}, E_{HL}, E_{M0}, and E_{ML}, for example, with E_{00} indicating the control). Ethephon was foliarly sprayed using a back-pack sprayer system consisting of a hand-held boom with nozzles spaced 0.76 m apart, a pressurized tank, and a solution container. 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}.

In 1990, experiments were conducted only under rainfed conditions and treatments were altered to include a factorial combination of four plant densities (24 700, 37 045, 49 390, and 61 735 plants ha^{-1}) and three rates of ethephon (0, 0.28, and 0.56 kg a.i. ha^{-1} applied at the 6-leaf growth stage) in a randomized complete block design with four replications. The plots were 15.2 m long and 4.6 m wide (six rows spaced 0.76 m apart) at Akron and 9.1 m long and 3.1 m wide (four rows) at Sterling.

Sampling and Analytical Procedures

Detailed soil water and ET measurements were made only at Akron in both seasons. Aluminum access tubes were installed in the center of each plot after crop emergence to determine soil water content to a depth of 1.8 m in 0.3-m increments at selected dates during the growing season by the neutron scatter method, using a Model 3321 Troxler depth moisture gauge (Troxler Electronic Lab., Research Triangle Park, NC). The neutron gauge readings were initiated on 23 June 1989 and 12 June 1990 and continued at weekly intervals until the corn reached physiological maturity. Cumulative ET at various dates throughout the season was determined by the water balance method assuming no runoff or percolation of water below the root zone.

Treatment effects on vegetative growth were assessed by plant height, LAI, and dry matter yield measurements at Akron in both seasons. Plant height on selected dates was determined by taking six measurements in the center two rows of each plot. Height was measured from the soil surface to the top of the plant canopy. Leaf area index and dry matter yield were determined by destructive vegetative sampling on two sampling dates, 7 to 8 wk after crop emergence and at tasseling. Plants from a 0.76-m^2 area within each plot were harvested and leaves removed at the leaf collar. Leaf area was determined with a model 3100 LI-COR leaf area meter (LI-COR, Lincoln, NE). The total leaf area was converted to a LAI basis. The plants were then oven-dried at 65°C for 72 h to determine dry matter yield.

At maturity, ears were removed from the plants in the center two rows (4.6 m^2) of each plot, dried at 65°C for 72 h, shelled, and the grain weighed to determine grain yield. A subsample of grain was used to determine weight per kernel, using an electronic seed counter and balance. Kernel number per unit area was calculated from grain yield and kernel weight data.

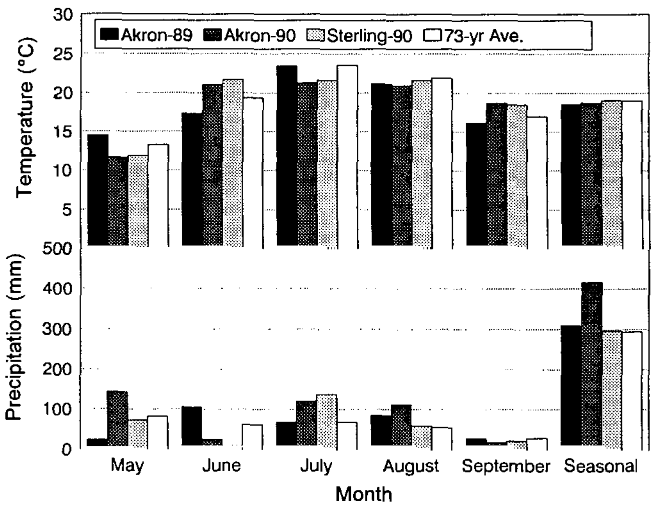

Fig. 1 Average daily temperatures and precipitation for each month and growing season for the 1989 and 1990 Akron locations and the 1990 Sterling location in Colorado. The 73-yr average temperature and precipitation records from Akron are provided for comparison purposes. The long-term Sterling meteorological data were similar to the Akron data, so only the Akron data are given.

Statistical Analysis

Data were analyzed using the analysis of variance (ANOVA) technique and treatment means compared using LSD values. Since plant densities and ethephon applications in 1990 were equally spaced increments, orthogonal polynomials (Steel and Torrie, 1980) were used to determine the shape of the response curve for dependent variables to plant density and ethephon rates.

RESULTS AND DISCUSSION

Environmental Conditions

Weather data measurements for the three locations are shown in Fig. 1. Seasonal average temperatures at the three sites were near the 73-yr average for this region; however, monthly temperatures deviated from the average temperatures at each site. For example, the 1989 Akron data indicated that temperatures during May were warmer than normal, while they were cooler than normal in June, and near average for July, August, and September; at the 1990 Akron and Sterling sites, however, average temperatures during May and July were cooler than average, warmer than average during June and September, and near average during August. Total seasonal precipitation was also near average for all sites except the 1990 Akron site, which was above average. Distribution of seasonal precipitation was quite different at each site. Relatively wet conditions occurred in June of 1989 at Akron and in May, July, and August of 1990 at Akron. August was drier at Sterling than the at other two sites.

Treatment Effects on Vegetative Growth

In 1989, increasing irrigation increased plant height on 14 August (Table 1). Irrigation level had no effect on LAI,

Table 1. Corn plant height, leaf area index (LAI), and dry matter yield (DMY) for two dates as affected by irrigation levels, plant densities, and ethephon treatments during the 1989 growing season at Akron, CO.

Irrigation level†	Plant density‡	Ethephon treatment§	Plant height 3 July	Plant height 14 Aug.	LAI 12 July	LAI 2 Aug.	DMY 12 July	DMY 2 Aug.
			m				g m^{-2}	
Low	–	–	0.48	1.40	1.69	2.65	191	595
High	–	–	0.49	1.52	1.77	2.57	177	663
LSD (0.05)	–	–	NS	0.04	NS	NS	NS	53
–	Low	–	0.48	1.46	1.47	2.13	158	581
–	High	–	0.49	1.46	1.99	3.10	211	674
–	LSD (0.05)	–	NS	NS	0.13	0.09	17	34
–	–	E_{00}	0.56	1.60	2.19	3.41	212	673
–	–	E_{H0}	0.46	1.56	1.58	2.41	175	617
–	–	E_{HL}	0.46	1.33	1.63	2.46	171	628
–	–	E_{M0}	0.46	1.54	1.63	2.37	175	621
–	–	E_{ML}	0.46	1.28	1.63	2.42	187	606
		LSD (0.05)	0.01	0.03	0.15	0.17	26	46

† Low and high irrigation levels correspond to 30 and 100% replacement of weekly evapotranspiration amounts.
‡ Low and high plant densities correspond to 53 333 and 80 000 plants ha^{-1}.
§ Ethephon treatments involved various rates and times of application. Rates of application were 0 (0), 0.28 (L) 0.56 (M), and 0.84 (H) kg a.i. ha^{-1}; times of application were the 6- and 8-leaf growth stages. Treatment designations appear as subscripts to the letter E; thus, for example, E_{H0} indicates 0.84 and 0 kg ha^{-1} applied at the 6- and 8-leaf stage, respectively.

but increasing irrigation increased dry matter yield on 2 August.

Plant density had no effect on plant height at any date in 1989, but increasing plant density increased LAI and dry matter yield on both sampling dates in 1989 (Table 1). In 1990, increasing plant density resulted in a linear decrease in early-season (10 July) and late-season (2 Aug.) plant height. Leaf area index and dry matter yield increased linearly with increasing plant density for both sampling dates in 1990 (Table 2), with a maximum increase of 147% for LAI and 63% for dry matter yield on 2 August.

Ethephon application in 1989 resulted in significant reduction in plant height compared with the control, shortly after application. This reduction was maintained throughout the remainder of the growing season with split application treatments (E_{HL} and E_{ML}) causing the most plant height reduction. All ethephon treatments in 1989 reduced LAI by ≈29% relative to the control for both sampling dates, with no significant differences in LAI among various timings or rates of application (Table 1). Increasing ethephon rates in 1990 produced either a linear or curvilinear reduction in plant height, LAI and dry matter yield on all dates monitored, except on 10 July for dry matter yield. The maximum reduction associated with ethephon application was 40% for LAI and 27% for dry matter yield. The reduction in plant height, LAI, and dry matter yield with ethephon application observed in these studies was similar to that obtained in other studies involving growth retardant treatments (Early and Slife, 1969; Konsler and Grabau, 1989; Shanahan and Nielsen, 1987).

Treatment Effects on Water Use

The 1989 results indicated that increasing irrigation level resulted in increased cumulative ET on all dates monitored (Table 3). These results agree with conclusions by Rosenberg et al. (1983, p. 209–287), who indicated that ET will proceed according to atmospheric demand as long as soil

Table 2. Corn plant height, leaf area index (LAI) and dry matter yield (DMY) for two dates as affected by plant densities and ethephon rates during the 1990 growing season at Akron, CO.

Plant density	Ethephon rate§	Plant height 10 July	Plant height 2 Aug.	LAI 10 July	LAI 2 Aug.	DMY 10 July	DMY 2 Aug.
no. ha^{-1}	kg ha^{-1}	m				g m^{-2}	
24 700	–	1.02	1.46	0.81	0.89	221	440
37 045	–	0.98	1.46	1.14	1.25	278	523
49 390	–	0.89	1.41	1.49	1.79	310	681
61 735	–	0.89	1.38	1.79	2.20	331	719
–	0	1.04	1.50	1.73	2.00	298	707
–	0.28	0.94	1.43	1.13	1.38	302	547
–	0.56	0.86	1.36	1.04	1.21	255	518
				Polynomial response			
Density							
Linear	–	**	**	**	**	*	**
Quadratic	–	NS	NS	NS	NS	NS	NS
Cubic	–	NS	NS	NS	NS	NS	NS
	Ethephon						
–	Linear	**	**	**	**	NS	**
–	Quadratic	NS	NS	**	**	NS	†

†,*,** Significant at the 0.10, 0.05, and 0.01 levels.
‡ Ethephon treatments were applied 6-leaf growth stage.

Table 3. Cumulative evapotranspiration (ET) (from 23 June through 30 Sept.) as affected by irrigation levels, plant densities, and ethephon treatments at Akron, CO, during the 1989 growing season.

			Dates of measurement				
Irrigation level†	Plant density‡	Ethephon treatment§	5 July	18 July	23 Aug.	20 Sept.	30 Sept.
			mm				
Low	–	–	38	121	325	399	412
High	–	–	34	126	341	477	511
LSD (0.05)	–	–	NS	NS	8	11	13
–	Low	–	34	119	329	435	461
–	High	–	38	128	340	440	462
–	LSD (0.05)	–	NS	5	11	NS	NS
–	–	E_{00}	38	131	343	450	476
–	–	E_{H0}	37	123	334	437	460
–	–	E_{HL}	37	124	340	440	461
–	–	E_{M0}	31	119	327	437	462
–	–	E_{ML}	36	120	322	425	449
–	–	LSD (0.05)	NS	8	14	10	10

† Low and high irrigation levels correspond to 30 and 100% replacement of weekly ET amounts.
‡ Low and high plant densities correspond to 53 333 and 80 000 plants ha^{-1}.
§ Ethephon treatments involved various rates and times of application. Rates of application were 0 (0), 0.28 (L) 0.56 (M), and 0.84 (H) kg a.i. ha^{-1}; times of application were the 6- and 8-leaf growth stages. Treatment designations appear as subscripts to the letter E; thus, for example, E_{H0} indicates 0.84 and 0 kg ha^{-1} applied at the 6- and 8-leaf stage, respectively.

water supply is adequate, suggesting that with the low irrigation treatment in our study, soil water supply obviously limited ET. Although plant height and ET were affected by the irrigation variable, vegetative growth indicators such as LAI and dry matter yield did not respond greatly to the irrigation variable (Table 1), indicating that early-season water deficits in 1989 were not severe—because early-season water deficits have been shown to have a negative affect on vegetative growth parameters such as LAI (Shaw, 1977).

Increasing plant density increased cumulative ET on two dates (18 and 23 July), in 1989 and resulted in a linear increase in cumulative ET across all sampling dates in 1990 (Table 4). The increase in cumulative ET associated with increasing plant density in both years (Tables 3 and 4) was due to an increase in LAI, as the size of the evaporative surface has been shown to be one of the main plant factors controlling ET (Rosenberg et al., 1983, p. 209-287). Our results indicate that crop water use can be manipulated through changes in planting density, as suggested by Downey (1971). Since crop water use can be manipulated with changes in plant density, it is likely that crop water stress can be minimized by reducing plant density. The data (Tables 1 and 2) showing a reduction in late-season plant height with increasing plant density, particularly in 1990, would tend to support this hypothesis. The reduction in plant height for high plant density treatments was probably due to increased soil water use for high plant densities (Table 4), resulting in increased plant water stress and reduced late-season vegetative growth.

Ethephon application reduced cumulative ET throughout most of the 1989 growing season, with the greatest savings in ET occurring earlier in the season (9% on 18 July) and the savings decreasing as the season progressed (6% on 30 Sept.). Increasing ethephon application caused either a linear or curvilinear reduction in ET in 1990, with the greatest savings in ET again occurring earlier in the season (15% on 12 July, 13% on 18 July) and decreasing

Table 4. Cumulative evapotranspiration (ET) (from 12 June to 5 Sept.) as affected by plant densities and ethephon rates at Akron, CO, during the 1990 growing season using Pioneer hybrid 3902.

		Dates of measurement					
Plant density	Ethephon rate‡	27 June	12 July	18 July	1 Aug.	9 Aug.	5 Sept.
no. ha^{-1}	kg ha^{-1}	mm					
24 700	–	17	83	103	163	208	344
37 045	–	22	90	117	181	221	360
49 390	–	22	102	126	190	224	362
61 735	–	31	102	126	193	235	362
–	0	27	104	129	202	233	371
–	0.28	21	89	112	179	216	352
–	0.56	20	88	113	164	217	347
		Polynomial response					
Density							
Linear		**	**	**	**	**	†
Quadratic		NS	NS	NS	NS	NS	NS
Cubic		NS	NS	NS	NS	NS	NS
	Ethephon						
	Linear	NS	*	*	**	*	**
	Quadratic	NS	NS	†	NS	†	NS

†,*,** Significant at the 0.10, 0.05, and 0.01 levels.
‡ Ethephon treatments were applied 6-leaf growth stage.

Table 5. Corn grain yield and yield attributes as affected by irrigation levels, plant densities, and ethephon rates at Akron, CO, in 1989.

Irrigation level†	Plant density‡	Ethephon treatment§	Grain yield	Kernel no.	Kernel wt.
			Mg ha^{-1}	no. m^{-1}	mg kernel^{-1}
Low	–	–	6.89	3932	177
High	–	–	8.98	4082	222
LSD (0.05)	–	–	0.49	NS	4
–	Low	–	7.35	3430	214
–	High	–	8.52	4584	85
–	LSD (0.05)	–	0.47	130	8
–		E_{00}	8.29	4250	196
–		E_{H0}	7.63	3831	200
–		E_{HL}	7.69	3841	201
–		E_{M0}	8.24	4073	204
–		E_{ML}	7.83	4040	195
–		LSD (0.05)	0.31	124	NS

† Low and high irrigation levels correspond to 30 and 100% replacement of weekly ET amounts.
‡ Low and high plant densities correspond to 53 333 and 80 000 plants ha^{-1}.
§ Ethephon treatments involved various rates and times of application. Rates of application at individual application were 0 (0), 0.28 (L) 0.56 (M), and 0.84 (H) kg a.i. ha^{-1} and times of application were 6- and 8-leaf growth stage. Treatment designations appear as subscripts to the letter E (E_{H0}, for example, indicates 0.84 and 0 kg ha^{-1} applied at 6- and 8-leaf stage, respectively).

as the season progressed (7% on 15 Sept.). Similar modifications in crop water use with growth retardant application were reported by Shanahan and Nielsen (1987) for corn and Del et al. (1982) for wheat, and were attributed to concomitant reductions in LAI. Passioura (1983) has also indicated that a low LAI enables a crop to maintain a high plant water status while using soil water slowly. The reduction in ET with ethephon application supports our visual observations (leaf rolling and leaf color changes) from both seasons, which indicated that control plants were more water stressed than those treated with ethephon.

Treatment Effects on Grain Yield

There were no significant interactions among treatments for grain yield and yield components in 1989; consequently, data are presented as main effects (Table 5). However, there was a significant plant density × ethephon rate interaction for grain yield components at both locations in 1990, and data are presented accordingly (Tables 6 and 7).

Increasing irrigation level and plant density increased grain yields in 1989. The increase in grain yield was attributed mainly to increase in kernel number per unit area, which was most likely associated with increased ear-bearing plant number. In 1989, all ethephon treatments reduced grain yield relative to the control, except the E_{M0} treatment (which involved a single application of 0.56 kg a.i. ha^{-1} of ethephon).

At Akron in 1990 (Table 6), increasing ethephon rates caused either a linear or curvilinear reduction in grain yield across the first three plant densities, but increased (curvilinear) grain yield at the highest plant density by 24% relative to the control. Ethephon had a similar effect on kernel number, decreasing it at low plant densities and increasing it at high plant densities, while kernel weight was not affected by ethephon.

At Sterling, the site with the overall lowest yields, grain yield decreased linearly with increasing ethephon rate at the two lowest plant densities and increased linearly or curvilinearly at the two highest plant densities (Table 7) with maximum yield attained for the intermediate ethephon rate and highest plant density; representing a 37.4% increase (4.63 vs. 3.37 Mg ha^{-1}). Increasing ethephon rate decreased kernel number at low plant densities and

Table 6. Corn grain yield and yield attributes as affected by plant density and ethephon rates at Akron, CO, in 1990.

Plant density	Ethephon rate‡	Grain yield	Kernel no.	Kernel wt.
no. ha^{-1}	kg ha^{-1}	Mg ha^{-1}	no. m^{-2}	mg kernel^{-1}
24 700 (D1)	0	3.51	1565	224
	0.28	3.04	1469	207
	0.56	2.97	1404	212
37 045 (D2)	0	4.77	2171	220
	0.28	4.02	1825	220
	0.56	4.07	1815	224
49 390 (D3)	0	4.80	2287	210
	0.28	4.86	2313	210
	0.56	4.32	2248	192
61 735 (D4)	0	4.26	2276	187
	0.28	5.26	2785	189
	0.56	5.19	2663	195
	LSD (0.05)	0.50	253	22
		Polynomial response for ethephon		
D1 treatment	Linear	*	NS	NS
	Quadratic	NS	NS	NS
D2 treatment	Linear	**	**	NS
	Quadratic	†	NS	NS
D3 treatment	Linear	†	NS	NS
	Quadratic	NS	NS	NS
D4 treatment	Linear	**	**	NS
	Quadratic	*	**	NS

†,*,** Significant at the 0.10, 0.05, and 0.01 levels.
‡ Ethephon treatments were applied at the 6-leaf growth stage.

Table 7. Corn grain yield and yield attributes as affected by plant density and ethephon rates at Sterling, CO, in 1990.

Plant density	Ethephon rate†	Grain yield	Kernel no.	Kernel wt.
no. ha^{-1}	kg ha^{-1}	Mg ha^{-1}	no. m^{-2}	mg kernel^{-1}
24 700 (D1)	0	3.11	1440	216
	0.28	2.92	1324	221
	0.56	2.34	1106	212
37 045 (D2)	0	3.85	1905	202
	0.28	3.32	1634	203
	0.56	3.22	1604	201
49 390 (D3)	0	3.34	1994	168
	0.28	3.86	2075	186
	0.56	3.86	1969	196
61 735 (D4)	0	3.37	2144	157
	0.28	4.63	2647	175
	0.56	4.11	2185	188
	LSD (0.05)	0.43	270	21
		Polynomial response for ethephon		
D1 treatment	Linear	**	*	NS
	Quadratic	NS	NS	NS
D2 treatment	Linear	**	*	NS
	Quadratic	NS	NS	NS
D3 treatment	Linear	*	NS	**
	Quadratic	NS	NS	NS
D4 treatment	Linear	**	NS	**
	Quadratic	**	**	NS

*,** Significant at the 0.05 and 0.01 levels.
† Ethephon treatments were applied at the 6-leaf growth stage.

increased kernel number at high plant densities. Ethephon increased kernel weight at the two highest plant densities.

Our initial hypothesis was that yield response of corn to ethephon application would vary with plant density and available water conditions. As anticipated, ethephon application was most beneficial to grain yield responses at high plant densities and under significant drought stress. This was especially evident at Sterling where in August seasonal precipitation was the lowest (Fig. 1). These results are likely due to the reduction in early-season ET associated with ethephon application and reduced plant water stress during reproductive growth, particularly for the high plant density treatments. While direct measurements of plant water stress were not taken in our study, the observed increases in kernel number per unit area and kernel size (Tables 6 and 7) with ethephon application at high plant densities indicate that ethephon application probably reduced plant water stress during reproductive growth and grain filling. Several studies have shown that plant water stress during reproductive growth negatively impacts kernel number, kernel size, and grain yield (Denmead and Shaw, 1960; Shaw, 1977; Musick and Dusek, 1980). Our work also substantiates the importance of kernel number to grain yield, as kernel number per unit area was highly correlated with grain yield at the 1990 Akron ($r^2 = 0.96^{**}$) and Sterling ($r^2 = 0.92^{**}$) sites. In a related experiment, Shanahan and Nielsen (1987) also noted that growth retardant application reduced early-season vegetative growth and water use, resulting in reduced plant water stress during reproductive growth as determined by measurements of crop canopy temperatures using infrared thermometry.

The 1989 results indicate that ethephon application probably would not provide a positive benefit under fully or even limited-irrigated conditions. Shanahan and Nielsen (1987) also noted that growth retardant application was most beneficial under substantial water stress. Additionally, the 1989 data indicate that one early-season ethephon application would be adequate to produce season-long effects on vegetative growth and crop water use, as split application treatments did not provide any additional benefit in LAI reduction or water use savings beyond single application treatments. These results are encouraging, since one application of ethephon would be more practical and economical than split applications. Finally, the 1990 data indicate that the intermediate application rate (0.28 kg a.i. ha^{-1}) would provide an optimum level of growth retardation and the most positive effect on water savings and grain yield.

Our results appear to substantiate the conclusions of Shanahan and Nielsen (1987), who suggested that growth retardants could be used to increase resistance to drought stress in corn. The ethephon treatment used in our work and the gibberellin biosynthesis inhibitor (GBI) seed treatments used by Shanahan and Nielsen (1987) appear to produce similar alterations in vegetative growth and water use, but via different mechanisms. Ethephon functions through release of ethylene in plant tissue (Warner and Leopold, 1969), as opposed to inhibiting gibberellin biosynthesis (Izumi et al., 1984). Nonetheless, both ethephon and GBI treatments appear to be equally effective in reducing the impact of drought by decreasing leaf surface area, especially during early growth, and thus conserving water. While neither treatment is currently commercially used or recommended for managing drought stress in corn, ethephon appears to have more commercial potential for being used than GBI treatments, because ethephon has already been evaluated for use in lodging control in corn (Langan and Oplinger, 1987; Gaska and Oplinger, 1988; Konsler and Grabau, 1989). However, further work is required to determine the effect of corn genotypes and varying environmental conditions on ethephon responses. Additionally, economic analyses of the added inputs (ethephon and increased seed rate) will be necessary to justify the use of ethephon.

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