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Influence of Growth Retardants (Anti-Gibberellins) on Corn Vegetative Growth, Water Use, and Grain Yield under Different Levels of Water Stress[1]

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ABSTRACT

Corn (*Zea mays* L.) grown under the semiarid conditions of the Central Great Plains requires supplemental irrigation to obtain maximum yields. This practice has become increasingly less profitable as the cost of application of irrigation water has risen. It may prove to be more cost effective to reduce the water requirement of corn by limiting the vegetative development of the plant. Two anti-gibberellin, seed-applied, experimental plant growth regulators (PGRs), BAS 106. .W and BAS 110. .W, were used on corn grown under low and high levels of irrigation in a 2-yr (1984 and 1985) field study on a Rago silt loam soil (fine, montmorillonitic, mesic Pachic Argiustolls) to determine the effect of these PGRs on vegetative growth, water use, water stress, grain yield, and yield components. The PGRs were applied at three rates in both years (0, 100, and 200 mg a.i. kg^{-1} of BAS 106. .W in 1984 and 0, 125, and 250 mg a.i. kg^{-1} of BAS 110. .W in 1985). Increasing application rates of the PGRs caused a significant reduction in early season plant height, leaf area index (monitored in 1985 only), and dry matter accumulation (monitored in 1985 only), resulting in reduced early season evapotranspiration in both years. The PGR treatments reduced plant water stress during silking and early grain fill, particularly under the low irrigation treatment. The changes in plant growth and development associated with the PGRs resulted in a 9 and 16% increase in grain yield in 1984 and 1985, respectively, under the low irrigation treatment and a 7 and 9% reduction in grain yield in 1984 and 1985, respectively, under the high irrigation treatment. Therefore, reducing early season vegetative growth with the PGRs proved to be advantageous to productivity under water stress and counterproductive under nonlimiting water conditions.

***Additional index words: Zea mays* L., Yield components, Irrigation, Leaf area, Plant growth regulator.**

YIELDS of many crops grown in the Central Great Plains are critically tied to water availability during the growing season and high evapotranspiration levels (Stewart et al., 1975; Hanks et al., 1978; Musick and Dusek, 1980; Garrity et al., 1982; Stegman, 1982). But the amounts of water needed for maximum corn (*Zea mays* L.) grain yields in this area, where annual precipitation averages 420 mm, are not available. Reported values for seasonal evapotranspiration of corn vary widely (440 to 1000 mm), as influenced by available water and local environmental parameters (Shaw et al., 1958; Musick and Dusek, 1980; Eck, 1984). For maximum yields, the difference between water required and precipitation must come from irrigation. Increasing pumping costs and declining water tables in some areas make use of irrigation unprofitable. Perhaps a more cost effective method of corn production for maximum economic return in this area would be to reduce the water requirement of corn. One way of reducing water use may be to limit vegetative development of the plant.

Water stress is an effective means for limiting vegetative development, but the time at which the stress occurs greatly influences yield reductions. Shaw (1977) reviewed research done regarding the timing of water stress and effects on grain yield. Generally, it is reported that corn is relatively tolerant to water stress in the vegetative stage, very sensitive to water stress during the period of tasseling, silking, and pollination,

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and moderately sensitive during the grain-filling stage. Water stress during the vegetative period stimulates deeper, more prolific root growth (Mayaki et al., 1976; Shaw, 1978) while reducing top growth, thereby increasing the root/shoot ratio (Sharp and Davies, 1979; Westgate and Boyer, 1985b). Such responses to water deficits would have the beneficial effect of reducing leaf area and presumably evapotranspiration while at the same time providing a greater amount of available soil water due to the increased rooting volume. The reduced evapotranspiration should conserve soil water early in the season so that more is available later during the more critical growth stages of reproduction and grain-filling.

Plant growth regulators (PGRs), which act as anti-gibberellins, produce similar changes in the shoot/root ratio as does early season water stress. Wample and Culver (1983) found that an anti-gibberellin, paclobutrozol or PP333 (a triazole compound), significantly reduced plant height, leaf area, shoot fresh and dry weights, and evapotranspiration but did not affect leaf diffusive resistance or the components of leaf water potential of sunflower (*Helianthus annuus* L.). Application of gibberellic acid to the treated plants reversed these effects. Similar height reductions were found by Barrett and Bartuska (1982) on chrysanthemum (*Chrysanthemum morifolium* Ramat.) and snap beans (*Phaseolus vulgaris* L.) treated with PP333. Lee et al. (1985) also found that PP333 applied to snap beans caused shorter plants with smaller total leaf area. Furthermore, root growth was stimulated, resulting in increased root/shoot ratios. Leaf diffusive resistance was not affected by the anti-gibberellin application. Evapotranspiration reductions were due entirely to reductions in vegetative development and did not result from the partial closure of stomata.

The development of early season water stress often does not occur consistently enough to reduce early vegetative development and evapotranspiration of corn. Even though water stress during vegetative growth might reduce leaf area and evapotranspiration, often the stress will also cause some degree of stomatal closure resulting in loss of potential carbon accumulation. Water stress during vegetative growth therefore often results in lower grain yields. By contrast, anti-gibberellins might be used to consistently limit plant growth and water use without affecting stomatal activity or carbon exchange on a leaf area basis. The objective of this study was to determine the effects of PGRs, which act as anti-gibberellins on vegetative growth, evapotranspiration, water stress, grain yield, and yield components of corn, under both full irrigation and limited soil water availability.

MATERIALS AND METHODS

Experiments were conducted at the Central Great Plains Research Station (40° 09′N, 103° 09′W, 1384 m above m.s.l.) near Akron, CO, during the 1984 and 1985 growing seasons. A preplant application of 202 kg ha^{-1} of N and 56 kg ha^{-1} of P was made to the entire plot area in both years. The plots were planted on 15 May 1984 and 7 May 1985. A preemergent application of cyanazine (2-{[4-chloro-6-(ethylamino)-S-triazine-2-yl] amino}-2-methylpropionitrile) at 2.24 kg a.i. ha^{-1} and metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl) acetamide] at 2.24 kg a.i. ha^{-1} effectively controlled weed growth throughout the growing season.

The corn hybrid Pioneer Brand 3732[3] (Pioneer Hi-Bred Int., Johnson, IA) was used in the 1984 study. Treatments in 1984 consisted of a factorial combination of two irrigation levels (low and high) and three rates (0, 100, and 200 mg a.i. kg^{-1} of seed) of BAS 106. .W in a randomized complete block (six blocks) design with a split-plot arrangement. Irrigation treatments served as the main plots (4.6 m by 18.3 m) and PGR treatments were the split plots (4.6 m by 6.1 m).

Two separate PGRs, BAS 106. .W and BAS 110. .W[3], were obtained from the BASF Wyandotte Corp. (Parsippany, NJ) for use in this study. The chemical name of the active ingredient of BAS 106. .W is 5-(4-chlorophenyl)-3,4,5,-9,10-pentaazatetracyclo (5,4,1,O$^{2.6}$, O$^{8.11}$) dodeca-3-,9-dien and it has been shown to possess growth retardant effects (Jung, 1984). The active ingredient of BAS 110. .W belongs in the triazole class of anti-gibberellin PGRs (Dr. D. O'Neal, 1985, personal communication); thus, it is related to the compound PP333. The chemical formula for BAS 110. .W is 1-(2,4-dichlorophenyl)-2-methoxy-1-methyl-2-(1*H*-1,2,4-triazol-1-yl)ethanol.

A solid set line-source sprinkler irrigation system (Hanks et al., 1976) was used to apply the irrigation treatments with the row direction of the plots oriented parallel to the sprinkler line. The line-source system delivers water in a linear gradient across the plots, perpendicular to the sprinkler line. The plots closest to the sprinkler heads receive full irrigation, while plots farther away receive lesser amounts. The high irrigation treatment consisted of six rows planted closest to the irrigation line and the low irrigation treatment consisted of the six rows at the outside edge of the gradient. Rain gauges were placed in the center rows of the plots and adjusted to extend above the canopy height throughout the season. The PGR treatments were randomly assigned within an irrigation level. A split plot was comprised of six 0.76-m rows, 6.1 m in length. A plant population of 66 717 plants ha^{-1} was established for all the plots by over-planting and thinning to the desired level.

The treatment design was changed in 1985 to provide space for vegetative sampling and inclusion of another cultivar. The second cultivar was used to determine if the effect of the growth regulator was uniform across cultivars. The treatments in 1985 consisted of a factorial combination of two irrigation levels (low and high), two corn hybrids (Dekalb Dk-524 and Pioneer Brand 3732), and three rates (0, 125, and 250 mg a.i. kg^{-1}) of BAS 110. .W in a randomized complete block (five blocks) in a split split-plot arrangement. Irrigation levels were the main plots, while corn genotypes were the split plots, and PGR treatments were the split split plots. The split split-plot dimensions were the same as the split-plot dimensions in 1984. A plant population of 86 485 plants ha^{-1} was established for all plots by over-planting and thinning to the desired population. This high population ensured development of water stress. The irrigation system in 1985 consisted of drip tubing placed on the soil surface in alternate rows of each plot with emitters spaced 230 mm. The application rate was 3.2 mm h^{-1}.

Aluminum access tubes were installed in the center of each plot after crop emergence to determine soil water to a depth of 1.8 m in 0.3-m increments at selected dates during the growing season by the neutron scatter method. The neutron probe was calibrated at the beginning of the season by correlating probe readings with gravimetric soil water of soil cores taken at the time of access tube installation. Cumulative evapotranspiration (ET) at various dates throughout the season was determined by the water balance method.

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[3] Trade names are included for the information of the reader and do not constitute endorsement by the performing institutions.

Soil water readings were initiated on 25 June 1984 and 21 June 1985. Cumulative ET is reported from these sampling dates.

The two irrigation treatments (low and high) were initiated on 16 July 1984 and 2 July 1985. Beginning on these dates, water was applied at weekly intervals based upon the amount of water used by the high irrigation treatment in the previous week. The high irrigation treatments received the full amount that had been used during the previous week while the low treatments received approximately one-half that amount. This irrigation scheduling regime continued until 30 August in both years. The total amounts of irrigation water applied to the high treatments were 180 and 240 mm in 1984 and 1985, respectively, while 120 and 100 mm were applied to the low treatments in 1984 and 1985, respectively.

Plant height was determined by averaging measurements of six plants in the center two rows of each plot. Heights were measured on three dates in 1984 and weekly in 1985, beginning shortly after crop emergence and continuing until full tassel emergence. Leaf area index (LAI) and total dry matter yield (TDMY) were measured at three dates during the 1985 growing season. LAI was determined by harvesting plants from a 0.77-m^2 plot area and removing all the leaves at the leaf collar. Leaf area was determined with a LICOR[3] leaf area meter (Model 3100) (LICOR Inc., Lincoln, NE). The total leaf area was converted to an LAI basis. After LAI was determined, the plants were oven dried (65°C) for 48 h to determine TDMY.

The relative level of water stress imposed on the various treatments was determined in 1985 by measuring canopy temperatures and calculating the crop water stress index (CWSI) value (Idso et al., 1981). Canopy temperatures were measured with a hand-held infrared thermometer, IRT[3] (Model 112 Agritherm) (Everest Interscience, Fullerton, CA). The IRT has a field of view of 3° and detects radiation in the 8- to 14-micron waveband. Measurements were made on 5 days between 12 July and 22 August, between 1330 and 1500 h MDT when the sun was unobscurred by clouds. Three instantaneous measurements were made on each of the two center rows from the east and west sides of the plots. Data were recorded by a portable data logger (Polycorder[3], Model 516B) (Omnidata International, Logan, UT). The IRT was checked before and after each daily measurement period against a blackbody reference. The IRT was hand-held at approximately 1.5 m until 22 July 1985. After this date, the IRT was mounted on a pole and carried at a height of approximately 2.4 m.

Air temperature and vapor pressure deficit were measured with an Assman psychrometer (Qualimetrics, Inc., Sacramento, CA) at a height of 1.5 m before and after each measurement period in an open area adjacent to the plots. The 12 canopy temperature measurements per plot were averaged and the CWSI calculated as:

$$\mathrm{CWSI} = \frac{T_c - T_a - D_2}{D_1 - D_2} \qquad [1]$$

where T_c = canopy temperature (°C); T_a = air temperature (°C); D_2 = $T_c - T_a$ predicted from baseline equation, = 2.67 − 2.059×VPD [VPD = vapor pressure deficit (kPa)]; and D_1 = theoretical maximum difference between T_c and T_a (3°C).

The baseline equation, D_2, differs slightly from that given for corn by Idso (1982). The baseline equation used in this study was derived from temperature and humidity data collected over irrigated corn at the Sandhills Agricultural Laboratory, Tryon, NE (Dr. B.R. Gardner, 1985, personal communication). Idso et al. (1981) formulated CWSI values in which D_1 varies with air temperature. The variation is slight under normal ambient field conditions, and a constant value of 3°C was used for D_1 in this study.

A 2.32-m^2 area from the center two rows of each plot was harvested at maturity to determine plant number and TDMY. Ears were then harvested from these plants to determine grain yield and various yield components. Grain yield and TDMY at maturity were reported at 15% water content. Harvest index was calculated by dividing grain yield by TDMY at maturity.

The effect of the various treatments on the measured variables was determined with the Analysis of Variance (AOV). Since the PGR treatment rates were equally spaced increments in both years, orthogonal polynomials (Steel and Torrie, 1960) were used to determine the type of response of the dependent variables to the PGR.

RESULTS AND DISCUSSION

Climatological measurements recorded throughout both the 1984 and 1985 growing seasons at Akron were very near the 70-yr avg for this location (Table 1). However, precipitation was slightly below average during the periods prior to and after silking but was above average during silking in 1985. Rainfall followed normal distribution patterns in 1984. Evaporative demand substantially exceeded growing season precipitation in both years, thus confirming the water-deficit nature of this environment for corn production.

The AOV indicated there was a significant PGR by irrigation treatment interaction for grain yield (1984) and 1985), plant height (1984 and 1985), LAI (1985), TDMY (1985), and CWSI (1985). Thus, the PGR treatments did not respond similarly across irrigation levels. The AOV showed that in 1985 both genotypes (Dekalb DK-524 and Pioneer Brand 3732) responded similarly to PGR treatments and irrigation levels for all variables measured. Therefore, the data for both years (Tables 2-8) are presented as averages for the PGR treatments (averaged across genotypes in 1985) within each irrigation treatment, with the exception of cumulative ET (Table 5).

The growth reducing effect of both PGR products was observed both years at crop emergence. The PGR-treated seeds emerged approximately 1 week later than did the control in both growing seasons, and the silking date was delayed by approximately 3 days over the control treatment (7 August 1984 and 29 July 1985).

The effect of the irrigation variable on plant height became apparent on 25 July in 1984 and 12 July in 1985 (Table 2), at which time the high irrigation treatment showed a significant height advantage over the low irrigation treatment where soil water was limiting. This plant height difference was maintained throughout the remainder of the season. The three PGR rates resulted in a curvilinear (quadratic and linear components were significant) decrease in plant height on 9 July 1984 under both irrigation treatments (Table

Table 1. Climatological measurements for the 1984 and 1985 growing seasons at Akron, CO.

Climatological variable	Growing season‡ 1984	Growing season‡ 1985	70-yr avg
Average mean daily temperature (°C)	15.3	16.0	16.0
Open pan evaporation (mm)†	1571	1655	1689
Precipitation (mm)	387	399	357

† Class A open pan evaporation.
‡ Data for growing season was recorded from 1 April to 30 October.

Table 2. Response of corn plant height at various dates to three rates of a seed-applied plant growth regulator (PGR) under two levels of irrigation during the 1984 and 1985 growing seasons at Akron, CO.

Irrigation level	PGR trt.	1984 dates			1985 dates				
		9 July	25 July	7 Aug.	14 June	28 June	12 July	26 July	9 Aug.
		m							
Low	1†	0.89	1.75	2.06	0.21	0.48	0.90	1.72	2.07
	2	0.76	1.78	2.21	0.17	0.41	0.78	1.65	2.11
	3	0.79	1.78	2.21	0.15	0.38	0.74	1.66	2.09
x̄		0.81	1.77	2.16	0.17a‡	0.43a	0.81a	1.68a	2.09a
High	1	0.91	1.91	2.34	0.19	0.48	0.95	1.92	2.34
	2	0.76	1.83	2.36	0.17	0.42	0.82	1.86	2.35
	3	0.79	1.83	2.36	0.16	0.40	0.82	1.86	2.36
x̄		0.82	1.86	2.35	0.17a	0.43a	0.86b	1.88b	2.35b
		Polynomial response for PGR treatments							
Low irrigation trt.									
Linear		**	NS	**	**	**	**	**	NS
Quadratic		*	NS	**	**	**	**	**	*
High irrigation trt.									
Linear		**	*	NS	**	**	**	**	NS
Quadratic		**	NS	NS	NS	**	**	**	NS

*,** Significant at the 0.05 and 0.01 levels, respectively. NS = nonsignificant.

† The PGR rates corresponding to treatments 1, 2, and 3 were 0, 100, and 200 mg a.i. kg^{-1} of BAS 106. .W in 1984 and 0, 125, and 250 mg a.i. kg^{-1} of BAS 110. .W in 1985, respectively.

‡ Irrigation treatment means followed by a similar letter within a date are not significantly different at the 0.05 level as determined by the LSD test. The LSD test was not performed on the irrigation means in 1984 because irrigation treatments were not randomized in 1984.

2). By 25 July 1984, as water stress began to develop, reductions in plant height due to the PGR were apparent only under the high irrigation treatment. On 7 Aug. 1984, the PGR had lost its controlling influence on plant height under the high irrigation treatment but continued to influence plant height under the low irrigation level. At this time, plant height in the low irrigation treatment increased curvilinearly with increasing rates of the PGR, suggesting that the control treatment was under greater water stress than the treated plots. The control treatment displayed more visual signs of water stress, such as flaccid leaves and light green color, than did the PGR treatments at this time. The response of plant height to the PGR in 1985 was similar to the 1984 response. The PGR produced a curvilinear reduction in plant height under both irrigation treatments early in the 1985 season (14 June through 26 July) but lost its primary effect on plant height after 9 August. There was again a secondary effect of the PGR on the expression of plant height

Table 3. Response of corn leaf area index (LAI) at three dates to three rates of a seed-applied plant growth regulator (PGR) under two levels of irrigation during the 1985 growing season at Akron, CO.

Irrigation level	PGR trt.	Date		
		28 June	19 July	9 Aug.
		LAI		
Low	1†	0.69	2.80	3.16
	2	0.53	274	3.35
	3	0.48	2.74	3.40
x̄		0.57a‡	2.76a	3.30a
High	1	0.73	3.37	3.62
	2	0.63	3.00	3.62
	3	0.53	2.81	3.28
x̄		0.63a	3.06b	3.51b
		Polynomial response for PGR treatments		
Low irrigation trt.				
Linear		**	NS	NS
Quadratic		**	NS	NS
High irrigation trt.				
Linear		**	**	**
Quadratic		NS	NS	**

*,** Significant at the 0.05 and 0.01 levels, respectively. NS = nonsignificant.

† The PGR rates corresponding to treatments 1, 2, and 3 were 0, 125, and 250 mg a.i. kg^{-1} of BAS 110. .W, respectively.

‡ Irrigation treatment means followed by a similar letter within a date are not significantly different at the 0.05 level as determined by the LSD test.

Table 4. Response of corn total dry matter yields at three dates to three rates of a seed-applied plant growth regulator (PGR) under two levels of irrigation during the 1985 growing season at Akron, CO.

Irrigation level	PGR trt.	Date		
		28 June	19 July	9 Aug.
		kg ha^{-1}		
Low	1†	768	2877	7861
	2	572	2851	8120
	3	499	2776	7797
x̄		613a‡	2745a	7926a
High	1	824	3724	9552
	2	658	3632	9175
	3	547	3282	8747
x̄		676a	3546b	9158b
		Polynomial response for PGR treatments		
Low irrigation trt.				
Linear		**	NS	NS
Quadratic		**	NS	NS
High irrigation trt.				
Linear		**	**	NS
Quadratic		NS	*	NS

*,** Significant at the 0.05 and 0.01 levels, respectively. NS = nonsignificant.

† The PGR rates corresponding to treatments 1, 2, and 3 were 0, 125, and 250 mg a.i. kg^{-1} of BAS 110. .W, respectively.

‡ Irrigation treatment means followed by a similar letter within a date are not significantly different at the 0.05 level as determined by the LSD test.

Table 5. Cumulative evapotranspiration (ET) of corn at various dates for three seed-applied plant growth regulator (PGR) rates under two levels of irrigation during the 1984 and 1985 growing seasons at Akron, CO.

Irrigation level	PGR trt.	1984 dates‡		1985 dates‡				
		9 July	7 Aug.	28 June	12 July	26 July	9 Aug.	6 Sept.
		mm						
	1†	28	300	21	102	211	321	466
	2	21	285	18	82	193	312	462
	3	12	275	13	84	192	311	460
Low		21	260	18a§	88a	191a	294a	403a
High		22	315	17a	91a	206b	335b	522b
				Polynomial response for PGR treatments				
Linear		*	*	**	**	**	NS	NS
Quadratic		NS	NS	NS	**	**	NS	NS

*,** Significant at the 0.05 and 0.01 levels, respectively. NS = nonsignfiicant.

† The PGR rates corresponding to treatments 1, 2, and 3 were 0, 100, and 200 mg a.i. kg^{-1} of BAS 106. .W in 1984 and 0, 125, and 250 mg a.i. kg^{-1} of BAS 110. .W in 1985, respectively.

‡ Cumulative ET readings were initiated on 25 June and 21 June in 1984 and 1985, respectively.

§ Irrigation treatment means followed by a similar letter within a date are not significantly different at the 0.05 level as determined by the LSD test. The LSD test was not performed on the irrigation means in 1984 because irrigation treatments were not randomized in 1984.

under the low irrigation treatment on this date, in that plant height showed a quadratic increase with increasing rates of the PGR.

The irrigation treatment differential was initiated 2 July; therefore, neither LAI nor TDMY was affected by irrigation level on 28 June (Tables 3 and 4). However, the high irrigation treatment produced larger LAI and TDMY than did the low irrigation level on the other two sample dates of 19 July and 9 August. The effect of the PGR on LAI and TDMY varied with date and irrigation level. On 28 June, the PGR treatments resulted in a curvilinear decrease in LAI, with the highest PGR rate producing a 29% reduction (average for low and high irrigation treatments) in LAI over that of the control. This reduction in LAI associated with the PGR was apparent only under the high irrigation treatment on the two remaining sampling dates (19 July and 9 August). The response of TDMY to the PGR across sampling dates was similar to the trends for LAI.

Cumulative ET means for PGR treatments and irrigation levels are shown for various times during the season in both years in Table 5. There was no significant interaction (data not shown) between PGR treatment rate and irrigation level; therefore, water use trends for PGR treatments were consistent across irrigation levels. The influence of the PGR treatments on cumulative ET in 1984 was evident on both dates that it was monitored (9 July and 7 August), showing a linear decrease in response to increasing rates of PGR. In 1985, the effect of the PGR on cumulative ET was dependent on the date within the growing season. For example, beginning on 28 June and continuing up until 26 July, cumulative ET exhibited a linear or curvilinear reduction in response to the PGR variable. Then beginning on 9 August and to the end of the season, no effect of the PGR was apparent on cumulative ET. Therefore, between 26 July and 9 August, the ET rate of the two PGR treatments increased over that of the control treatments so that there was no longer any effect of the PGR on cumulative ET by 9 August.

The response of CWSI to PGR treatments varied across irrigation levels in 1985 (Table 6). The low irrigation treatment was under greater water stress on all sampling dates, with the exception of 25 July. However, this date was during a short time period when cool and damp weather minimized the effect of the irrigation variable. Under the low irrigation level, the CWSI showed a linear or curvilinear reduction in response to increasing rates of the PGR on all five dates. These data taken in 1985 support visual observations made in both seasons on the low irrigation treatments which indicated that the control treatments were under greater water stress than the PGR treatments. Reductions in CWSI with increasing PGR rates occurred on only two of the five dates under the high irrigation treatment. Thus, the water conserving effect of the PGR on minimizing plant water stress was not as important under the high irrigation treatments as under the low irrigation level.

Table 6. Response of corn crop water stress index (CWSI) at five dates to three rates of a seed-applied plant growth regulator (PGR) under two levels of irrigation during the 1985 growing season at Akron, CO.

Irrigation level	PGR trt.	Date				
		12 July	17 July	25 July	9 Aug.	22 Aug.
		CWSI				
Low	1†	0.68	0.40	0.29	0.85	0.80
	2	0.45	0.30	0.14	0.77	0.72
	3	0.38	0.31	0.13	0.72	0.76
$\bar{x}$		0.50b‡	0.34b	0.19a	0.78b	0.76b
High	1	0.40	0.11	0.22	0.51	0.39
	2	0.34	0.07	0.12	0.47	0.40
	3	0.30	0.07	0.11	0.44	0.39
$\bar{x}$		0.35a	0.08a	0.15a	0.47a	0.39a
		Polynomial response for PGR treatments				
Low irrigation trt.						
Linear		**	**	**	**	NS
Quadratic		**	**	*	NS	*
High irrigation trt.						
Linear		**	NS	NS	**	NS
Quadratic		NS	NS	NS	NS	NS

*,** Significant at the 0.05 and 0.01 levels, respectively. NS = nonsignificant.

† The PGR rates corresponding to treatments 1, 2, and 3 were 0, 125, and 250 mg a.i. kg^{-1} of BAS 110. .W, respectively.

‡ Irrigation treatment means followed by a similar letter within a date are not significantly different at the 0.05 level as determined by the LSD test.

From these data, it would appear that both the PGRs used in this study, BAS 106. .W and BAS 110. .W, had a similar influence on reducing early season vegetative growth, as reflected in the plant height measurements taken in both seasons. In addition, the LAI and TDMY data collected in 1985 indicated that the reduction in plant height was also associated with a reduction in leaf area expansion and dry matter accumulation. This reduction in early vegetative growth, particularly LAI, was very likely responsible for the reduction in early season soil water extraction associated with the PGR treatments, resulting in more available soil water for growth later in the season. This was confirmed by the CWSI readings and visual observations during the critical time of silking and early grain development. These results agree with those of Wample and Culver (1983), who found that application of the anti-gibberellin, PP333, to sunflower caused reductions in plant height, leaf area expansion, and water use without affecting leaf diffusive resistance. Lee et al. (1985) also made similar observations regarding application of PP333 to snap bean plants. Therefore, the application of anti-gibberellin type PGRs would not likely affect transpiration per unit leaf area, but rather the PGRs would have their major impact on water use through reductions in leaf area expansion. Passioura (1983) has also indicated that a low LAI enables a crop to maintain a high water status while using water slowly.

Grain yield and various yield attributes for the irrigation and PGR treatments in 1984 and 1985 are shown in Tables 7 and 8, respectively. Grain yields averaged 5 666 and 8 870 kg ha^{-1} in 1984 and 6 196 and 10 318 kg ha^{-1} in 1985 for the low and high irrigation treatments, respectively. Thus, the irrigation variable significantly affected productivity. The significant interaction between irrigation level and PGR treatment observed for grain yield in both years was associated with a change in response of grain yield to the PGR treatments across the two irrigation levels. Grain yields displayed a curvilinear increase in 1984 and a linear increase in 1985 in response to increasing rates of the PGRs under the low irrigation level, representing a 9 and 16% increase over the control in the respective years. Conversely, grain yields showed a curvilinear decrease in response to the PGR variable under the high irrigation treatment in both years, resulting in a maximum reduction of 7 and 9% in 1984 and 1985, respectively. Kernel number per unit area and kernel weight were responsible for the differences in yield between the two irrigation levels observed in both years. The yield components associated with the yield differences among PGR treatments varied across irrigation treatments and years. Kernel number per unit area was responsible for the increase in grain yield that occurred in response to the PGR treatments under the low irrigation level in both years.

The secondary effect that the PGRs induced in conserving early season soil water use and ultimately reducing water stress during silking and early grain development was very likely responsible for the differences in yield among the PGR treatments under the low water level. Westgate and Boyer (1985a) found that water stress during this critical time period inhibits photosynthesis and consequently lowers 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 associated with the control versus PGR treatments under the low irrigation level, since the control treatment was under greater water stress than were the PGR treatments. However, with optimal irrigation it seems

Table 7. Response of corn grain yield and yield attributes to three rates of a seed-applied plant growth regulator (PGR) under two levels of irrigation during the 1984 growing season at Akron, CO.

Irrigation level	PGR trt.	Grain yield	Kernel number	Kernel weight	Total dry matter yield	Harvest index
		kg ha^{-1}	no. m^{-2}	mg	kg ha^{-1}	%
Low	1†	5 342	2 830	189	10 102	52.9
	2	5 858	3 166	185	10 297	56.9
	3	5 799	3 141	185	10 181	57.0
$\bar{x}$		5 666‡	3 046	186	10 193	55.6
High	1	9 263	3 630	255	18 322	50.4
	2	8 624	3 546	243	16 341	52.8
	3	8 749	3 586	244	16 472	53.1
$\bar{x}$		8 870	3 587	247	17 045	52.1
		Polynomial response for PGR treatments				
Low irrigation trt.						
Linear		*	*	NS	NS	*
Quadratic		**	**	NS	NS	NS
High irrigation trt.						
Linear		**	NS	*	*	NS
Quadratic		**	NS	*	**	NS

*,** Significant at the 0.05 and 0.01 levels, respectively. NS = nonsignificant.

† The PGR rates corresponding to treatments 1, 2, and 3 were 0, 100, and 200 mg a.i. kg^{-1} of BAS 106. .W, respectively.

‡ The LSD test was not performed on the irrigation means in 1984 because irrigation treatments were not randomized in 1984.

Table 8. Response of corn grain yield and yield attributes to three rates of a seed-applied plant growth regulator (PGR) under two levels of irrigation during the 1985 growing season at Akron, CO.

Irrigation level	PGR trt.	Grain yield	Kernel number	Kernel weight	Total dry matter yield	Harvest index
		kg ha^{-1}	no. m^{-2}	mg	kg ha^{-1}	%
Low	1†	5 709	3 035	187	12 200	47.0
	2	6 272	3 355	186	13 068	48.1
	3	6 608	3 559	185	12 873	51.4
$\bar{x}$		6 196a‡	3 310a	186a	12 714a	48.8a
High	1	10 840	4 953	222	18 615	58.3
	2	9 885	4 537	219	17 634	56.1
	3	10 228	4 652	221	17 981	57.0
$\bar{x}$		10 318b	4 713b	221b	18 077b	57.1b
		Polynomial response for PGR treatments				
Low irrigation trt.						
Linear		**	**	NS	NS	**
Quadratic		NS	NS	NS	*	NS
High irrigation trt.						
Linear		*	*	NS	NS	NS
Quadratic		**	**	NS	**	NS

*,** Significant at the 0.05 and 0.01 levels, respectively. NS = nonsignificant.

† The PGR rates corresponding to treatments 1, 2, and 3 were 0, 125, and 250 mg a.i. kg^{-1} of BAS 110. .W, respectively.

‡ Irrigation treatment means followed by a similar letter are not significantly different at the 0.05 level as determined by the LSD test.

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 growth under optimum moisture conditions. Thus, the reductions in leaf area during vegetative growth as a result of the PGR treatments resulted in lower grain yields when plants were well-watered.

Harvest index, the ratio between harvestable yield and aboveground biomass, has been shown to depend on the pattern of water use during the season under water stress conditions (De Wit, 1958). The observations made in this study would tend to confirm this statement. For example, under the low irrigation treatment, increasing rates of the PGRs resulted in a linear increase in harvest index in both years (Tables 7 and 8). Thus, the PGR treatments, which limited early season water use and utilized more water during the post-anthesis period, produced larger harvest indices. Passioura (1977) also found that harvest index in wheat (*Triticum aestivum* L.) was proportional to the percentage of total seasonal evapotranspiration used during the post-anthesis period. Harvest index was unaffected by the PGRs under the high irrigation level in this study.

This research has shown that under conditions of water stress, a corn plant is able to make better use of available water if vegetative top growth is restricted early in the season. This leaves a greater reservoir of stored soil water to be used during the more critical growth stages of reproduction and grain filling. This objective was accomplished in this study through the use of the PGRs BAS 106. .W and BAS 110. .W. Another approach to accomplish the same objective might be through the selection of genotypes which exhibit reduced vegetative growth. However, this approach will likely result in lower productivity under more optimal water conditions.

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