Invinsa Application to Reduce Water Stress Effects on Corn Growth and Yield at Maricopa, AZ, 2011

M. J. Ottman and B. A. Kimball

Abstract

Invinsa blocks ethylene perception by plants and can reduce the negative effects of water stress on crop growth. The objective of this study is to measure the effect on corn growth and yield of Invinsa application at incipient water stress. A study was conducted at the University of Arizona Maricopa Agricultural Center where Invinsa was applied on 15 June and 20 June in blocks with adequate irrigation or deficit irrigation, which received no irrigation water for 10 days past incipient stress beginning on 15 June. Invinsa had inconsistent effects on corn growth and yield. The most notable effect of Invinsa, however, was an increase in total plant yield from 11.09 to13.43 t/a measured on 23 July and from 11.36 to 13.61 t/a measured on 13 Aug in the adequate irrigation block for Invinsa application on 15 June. However, Invinsa had no effect on final grain yield. The lack of a consistent response to Invinsa may be explained by the higher than optimum temperature at time of application or other unknown factors.

Introduction

Invinsa (1-methycyclopropene, 1-MCP) is similar in structure to ethylene and interacts with the ethylene receptors in plants. An increase in ethylene is a stress signal to the plant. Blocking ethylene perception by application of Invinsa prevents the plant from sensing stress and could reduce the negative effects of stress on plant growth. The produce industry has used Invinsa since 1997 to maintain the quality of harvested fruits and vegetables during transportation, storage, and retail display.

Recent work has shown that Invinsa may have a use not only post-harvest on fruits and vegetables, but also during the growth of crops. Preliminary trials have shown that application of Invinsa at incipient water stress between the 10^{th} leaf and milk stage in corn results in a 10 bu/acre yield gain (5-10%) by mitigating a decline in photosynthesis. A negative effect can be observed about 10% of the time for applications at tasseling. Direct effects can be observed for 10-14 days, but morphological effects may be observed for up to 30-40 days after application. Best results have been obtained where corn yielded between 120 and 180 bu/acre.

The highest yield increases have been obtained when Invinsa has been applied at "incipient" stress. Soil water measurements using tensiometers combined with weather forecasts have not been effective in predicting plant response. Visible stress combined with weather forecasts is a slightly better in predicting plant response to Invinsa. However, photosynthesis can decrease before water stress is visible to the eye, so visible stress provides a signal that is too late. The "Decision Support System for Agrotechnology Transfer (DSSAT) Drought Stress Pattern" may provide an indication of incipient water stress, but this tool requires the water holding capacity of the soil to be provided. A promising tool to determine incipient water stress is the infrared thermometer to measure canopy temperature. As plants become stressed for water, the stomates begin to close and leaf temperature rises before stress can be observed visibly.

The objective of this study is to measure the corn yield response to Invinsa application at incipient stress measured with infrared thermometry.

Methodology

A field test of the effect of Invinsa on corn growth and yield was conducted at the University of Arizona Maricopa Agricultural Center. The field was previously cropped to camelina. For weed control, Atrazine was applied preplant and Roundup was applied 26 May. Nitrogen fertilizer was be applied preplant at a rate of 100 lbs N/acre as urea (46-0-0), sidedressed as UAN 32 (32-0-0) on 12 May, and applied in the irrigation water in three applications of 50 lbs N/acre as UAN32 (32-0-0) on 27 May, 3 June, and 24 June, for a total seasonal nitrogen rate of 300 lbs N/acre. The corn hybrid Pioneer 31G71 (HX1, LL, RR2) was seeded on beds spaced 40 inches apart at a rate of 35,840 seeds/acre on 22 April 2011 in 48 rows 400 feet long. The corn hybrid Croplan 9009 (conventional) was planted in 4 rows on either side of the experiment as a non Bt refugia. Irrigation water was applied in furrows to wet the bed and germinate the seed on 25 April. Irrigation water was applied in alternate rows in the first four irrigations through 27 May to conserve water and push salt away from the seed line. Irrigation water timing and amount were estimated using soil moisture measurements with a neutron probe. Irrigation water was applied when 50% or less of the plant available water was depleted in the rooting zone. The maximum rooting depth was assumed to be 1.2 m. Irrigation water application is presented in Table 1.

The soil type was a Casa Grande sandy loam to sandy clay loam. The soil contained 13.5 ppm NO_3-N and 5.2 ppm NH_4-N in the top 5 ft of soil at planting time. The chemical characteristics of the surface 6 inches of soil are: pH = 7.8, OM = 1.05, total exchange capacity = 18.78 meq/100 g, soluble sulfur = 44 ppm, Olsen phosphorus = 5 ppm P, Ca = 2875 ppm (76.54% base saturation), Mg = 215 ppm (9.54% base saturation), K = 335 ppm (4.57 base saturation), Na = 247 ppm (5.72 base saturation), other bases (3.60 base saturation), Fe = 7 ppm, Mn = 5 ppm, Cu = 1.16 ppm, Zn < 0.4 ppm.

The experimental design was a randomized complete block with 3 treatments and 6 replications (randomized as two 3 x 3 latin squares) and duplicated in two irrigation blocks. The individual plots were 8 rows wide and about 50 feet long including a 6.7 ft alley. The Invinsa treatments were applied at the 12-13 leaf stage as follows: 1) control – not treated, 2) Invinsa applied at incipient stress on 15 June, and 3) Invinsa applied 5 days after incipient stress on 20 June. The two irrigation blocks received adequate irrigation or deficit irrigation near the timing of the Invinsa application. For the deficit irrigation block, irrigation water was withheld for about 10 days past incipient stress (5days past incipient stress to the second Invinsa application on 20 June plus another 5 days). The deficit irrigation block received adequate water before and after the "stress period". Irrigation water was applied approximately weekly for "adequate" irrigation. After the deficit irrigation period, the crop was permanently damaged and water use was decreased even with adequate water applied, so the amount of irrigation water applied to the deficit irrigation block after the water stress period was reduced accordingly.

The Invinsa was sprayed using a backpack spraying unit that consisted of a boom with four fan-type nozzles (Teejet 8002 EVS, ~500 mls/min at 20 psi) on 20 inch spacing and a 5 gallon tank pressurized by CO_2. The tank was filled with 4 gallons of water, 53.3 g of Invinsa (3.8% ai, lot # 0005944207) was added to the water, and the mixture was stirred with a wooden lathe stake for several minutes. The tank was pressurized to 20 psi. The two outside rows of the plots (rows 1 and 8) were not sprayed and the rows next to the outside rows (rows 2 and 7) received a single pass of the spray whereas the other rows received two passes of the spray. Therefore, the effective area was calculated based on five rows instead of six. Each irrigation block was sprayed separately and a fresh batch of Invinsa was mixed for each block. About 2 gallons of solution was sprayed and 2 gallons of residual solution remained in the tank before discarding in preparation for mixture of a new batch. The details of the Invinsa application are presented in Table 2.

The number of fully expanded leaves was determined by counting exposed collars on three designated plants per plot. The 5^{th} and 10^{th} leaves on these plants were marked for ease of counting and to ensure that senesced leaves are accounted for.

The initial volumetric soil water content averaged over the top 5 ft of soil was 11.6% v/v determined from soil samples before planting. Neutron access tubes were installed to a depth of 5 ft on 11 May, and water use after this time was determined using neutron attenuation. Daily water use was calculated from the difference of neutron probe readings about 3 days after an irrigation after drainage had occurred to the day of or 1 day before the next irrigation. For much of the season, irrigations were applied weekly, so neutron probe readings were taken twice per week during this time.

Plants were sampled five times during the season for height, leaf area index, and yield of leaves, stalks, and ears. The ears were comprised of the kernels, cobs, and husks except for the last sampling at harvest on 5 September where the husks were not included. The sampling area comprised two 18-inch sections of row, which included about 10 plants. Leaf area index and dry weight were determined from all the plants at the first sampling date. At subsequent sampling times, four plants were sub-sampled for leaf area index and moisture content. The moisture content was used to obtain the dry weight conversion for the fresh weight of the entire sample. Plant moisture content was determined by drying the samples in an oven at 65 ºC. Leaf area index was determined from a Li-Cor leaf area instrument.

Grain was harvested on 5 September from 15 ft of the center two rows of the plot for a total of 30 ft of row. In a few cases due to lodging or lack of plot uniformity, the center four rows of the plot were harvested by necessity, but the length of row harvested always equaled 30 ft. The grain was shelled with a corn sheller, the kernel moisture content determined with an electronic moisture meter, and the cobs were dried in an oven at 65 ºC to obtain oven-dry cob weight.

Results and Discussion

The crop emerged on 1 May, silked and shed pollen between 29 June (adequate irrigation) and 3 July (deficit irrigation), and on 24 August the number of kernels at black layer was 80% (adequate irrigation) or 100% (deficit irrigation). The crop was planted about 6 weeks later than is optimum for the area. Nevertheless, the plants appeared robust and progressed well. A dust storm with winds greater than 50 mph occurred on 5 July and caused lodging, the worst of which was on two replications of the adequately watered block that was subsequently abandoned. Overall, the growing season was warmer than normal, except the month of May, which was cooler than normal (Table 3). The growing season was also drier than normal, especially in July and August (Table 3).

Invinsa had some effect on crop growth measured at five different dates during the growing season (Table 4). Invinsa compared to the control had no effect at the 5% probability level on leaf area index, plant height, leaf yield, water use, or change in water use at any of the sampling dates. Some differences in plant height and leaf yield were detected on 11 June, but this was before the Invinsa was applied and attributed to random error. Plant moisture content was reduced by Invinsa as measured on 13 Aug for the adequate irrigation regime and averaged over the deficit and adequate irrigation regimes. Stem and total yield were increased by Invinsa application on 23 July, 13 Aug, and the average of the four sampling times between 2 July and 5 Sep. Ear yield on 23 July was decreased by Invinsa in the deficit irrigation regime but increased by Invinsa in the adequate irrigation regime. Water use efficiency in the adequate irrigation regime was increased by Invinsa application on 23 July and 13 Aug. The negative change in total yield and water use efficiency between 13 Aug and 5 Sep was greatest for the Invinsa treatment.

Invinsa had no effect on leaf number, except for an increase in the number of leaves observed on 23 July for Invinsa applied on 15 June in the deficit irrigation regime (Table 5). Invinsa also had no effect on tassel or silking date, lodging, grain moisture, harvest index or yield of grain, stover, total plant or the yield components of plant density, ear number, kernel number, or kernel weight at final harvest on 5 September (Table 6). The grain yield for the adequately irrigated block averaged 2.8 t/a on a dry basis, which is equivalent to 120 bu/a on a 15.5% moisture basis. This grain yield is low compared to the total plant yield and can be explained by the low harvest index of about 29% instead of a more normal harvest index of around 50%. The total yield of 9.86 t/a at harvest is equivalent to a yield of about 33 t/a on a 70% moisture basis, which is close to the silage corn yields obtained in this growing region.

Cumulative water use was not affected by Invinsa application for either irrigation regime (Fig. 1).

The lack of a consistent response to Invinsa can be explained by several factors. First, the temperature at the time of application was at or above 30 º C for most of the Invinsa applications, which may have reduced the effectiveness of the chemical. Second, the amount of stress in the deficit irrigation block may have been so great that Invinsa may not have been able to affect stomata behavior. Third, and perhaps most importantly, there is some indication that the particular batch of Invinsa that was used in this experiment may not have mixed well in the tank due to a defect in producing the chemical, and the concentration of the active ingredient may have been variable. However, when the Invinsa was mixed in the spray tank, the smell of the chemical was quite noticeable and very distinct and no residue was evident at the bottom of the tank.

Acknowledgments

The technical assistance of Dick Simer, Glenda Simer, Mary Comeau, Cory Runyon, and Ken Randolph is greatly appreciated. This project was funded by AgroFresh and Dr. Al Green provided guidance in developing the protocol.

Table 1. Irrigation dates and amounts for the adequate and deficit irrigation blocks.

	Irrigation	
Date	Adequate	Deficit
	---------- inches ----------	
4/25	4.84	3.83
5/01	2.81	1.63
5/16	2.54	2.34
5/27	1.90	2.35
6/03	6.48	3.96
6/06	1.93	1.90
6/13	5.36	0.00
6/20	3.82	0.00
6/24	3.01	6.20
6/29	2.55	2.53
7/03	1.92	1.92
7/08	2.39	2.39
7/13	2.42	2.42
7/20	3.40	3.40
7/27	4.79	2.86
8/03	3.34	2.39
8/10	2.82	2.05
8/17	2.34	1.91
Sum	58.65	44.09

Table 2. Invinsa application gallonage, rates, and start and end times and temperatures for the two application dates. The target application was a volume of 2 gal, 20 gal/acre, and 25 g ai/ha.

Date	Irrigation	Volume	Rate	Rate ai	Start	End	Start	End
		gal	gal/acre	g ai/ha	time	time	º C	º C
6/15	Deficit	2.25	22.6	27.7	7:43 am	7:56 am	29.7	31.6
	Adequate	2.38	23.9	29.6	8:13 am	8:30 am	30.9	33.4
6/20	Deficit	1.87	18.7	23.3	6:36 am	6:46 am	22.2	23.1
	Adequate	1.84	18.5	22.9	7:04 am	7:14 am	30.9	30.2

Table 3. Mean daily maximum, minimum, and average temperature and the sum of monthly precipitation during the growing season in 2011compared to normal.

	Maximum temperature		Minimum temperature		Average temperature		Precipitation	
Month	2011	Normal	2011	Normal	2011	Normal	2011	Normal
	---------- º F ----------						------- inches -------	
May	90	94	57	59	75	78	0.00	0.17
June	103	103	68	67	87	86	0.00	0.09
July	105	104	76	74	91	87	0.44	0.76
August	107	102	79	74	93	87	0.04	0.81
Average	101.3	100.8	70.0	68.5	86.5	84.5	---	---
Sum	---	---	---	---	---	---	0.48	1.83

Table 4a. For plants sampled 6/11, effect of Invinsa applied at two different times on various plant characteristics, yield and water use for corn grown with deficit or adequate irrigation in a trial conducted at Maricopa, AZ in 2011.

Sampling date	Irrigation	Invinsa timing	Leaf area index	Plant height	Plant moisture	Leaf yield	Stem yield	Ear yield	Total yield	Water use	WUE	Total yield change	Water use change	WUE change
				ft	%	t/a	t/a	t/a	t/a	in	t/a/in	t/a	in	t/a/in
6/11	Deficit	Control	4.11	5.9	72	0.74	0.59	0.00	1.34	11.7	0.12	0.98	11.7	0.09
		6/15	3.93	5.9	70	0.83	0.59	0.00	1.42	11.1	0.13	1.05	11.1	0.10
		6/20	3.62	6.0	72	0.79	0.56	0.00	1.35	10.2	0.14	0.99	10.2	0.10
		Avg	3.89	5.9	71	0.79	0.58	0.00	1.37	11.0	0.13	1.01	11.0	0.09
CV (%)			21.37	3.94	5.82	9.67	33.11	---	14.59	13.58	25.17	14.59	13.58	25.17
Treatment (P>F)			0.596	0.703	0.734	0.196	0.930	---	0.734	0.265	0.503	0.734	0.265	0.503
Control vs 6/15 (P>F)			0.717	1.000	0.481	0.079	0.988	---	0.481	0.477	0.473	0.481	0.477	0.473
Control vs 6/20 (P>F)			0.327	0.476	0.929	0.301	0.743	---	0.929	0.113	0.257	0.929	0.113	0.257
Control vs treated (P>F)			0.437	0.678	0.644	0.109	0.843	---	0.644	0.183	0.287	0.644	0.183	0.287
6/15 vs 6/20 (P>F)			0.525	0.476	0.536	0.406	0.754	---	0.536	0.341	0.657	0.536	0.341	0.657
	Adequate	Control	4.02	5.9	70	0.78	0.68	0.00	1.46	11.6	0.13	1.15	11.6	0.10
		6/15	4.04	6.0	71	0.81	0.58	0.00	1.39	12.1	0.12	1.09	12.1	0.09
		6/20	4.12	6.0	66	0.90	0.71	0.00	1.61	11.2	0.15	1.27	11.2	0.12
		Avg	4.06	5.9	69	0.83	0.66	0.00	1.49	11.6	0.13	1.17	11.6	0.10
CV (%)			10.23	1.77	5.36	6.35	24.85	---	11.97	10.27	13.88	11.97	10.27	13.88
Treatment (P>F)			0.904	0.103	0.127	0.007	0.357	---	0.127	0.447	0.038	0.127	0.447	0.038
Control vs 6/15 (P>F)			0.950	0.083	0.522	0.323	0.313	---	0.522	0.433	0.280	0.522	0.433	0.280
Control vs 6/20 (P>F)			0.684	0.052	0.155	0.003	0.697	---	0.155	0.634	0.093	0.155	0.634	0.092
Control vs treated (P>F)			0.786	0.038	0.624	0.016	0.711	---	0.624	0.854	0.687	0.624	0.854	0.687
6/15 vs 6/20 (P>F)			0.731	0.789	0.052	0.015	0.174	---	0.052	0.220	0.013	0.052	0.220	0.013
	Avg	Control	4.07	5.9	71	0.76	0.63	0.00	1.40	11.6	0.12	1.07	11.6	0.09
		6/15	3.98	5.9	71	0.82	0.58	0.00	1.40	11.6	0.12	1.07	11.6	0.09
		6/20	3.87	6.0	69	0.85	0.63	0.00	1.48	10.7	0.14	1.13	10.7	0.11
		Avg	3.97	5.9	70	0.81	0.62	0.00	1.43	11.3	0.13	1.09	11.3	0.10
CV (%)			19.92	6.15	9.15	15.29	34.07	---	21.64	11.67	22.39	21.64	11.67	22.39
Treatment (P>F)			0.838	0.305	0.417	0.026	0.689	---	0.417	0.222	0.160	0.417	0.222	0.160
Control vs 6/15 (P>F)			0.810	0.432	0.906	0.050	0.464	---	0.906	0.948	0.932	0.906	0.948	0.932
Control vs 6/20 (P>F)			0.564	0.133	0.239	0.010	0.999	---	0.239	0.129	0.092	0.239	0.129	0.092
Control vs treated (P>F)			0.636	0.187	0.446	0.011	0.671	---	0.446	0.343	0.286	0.446	0.343	0.286
6/15 vs 6/20 (P>F)			0.734	0.432	0.284	0.360	0.463	---	0.284	0.143	0.106	0.284	0.143	0.106

Table 4b. For plants sampled 7/2, effect of Invinsa applied at two different times on various plant characteristics, yield and water use for corn grown with deficit or adequate irrigation in a trial conducted at Maricopa, AZ in 2011.

Sampling date	Irrigation	Invinsa timing	Leaf area index	Plant height	Plant moisture	Leaf yield	Stem yield	Ear yield	Total yield	Water use	WUE	Total yield change	Water use change	WUE change
				ft	%	t/a	t/a	t/a	t/a	in	t/a/in	t/a	in	t/a/in
7/2	Deficit	Control	6.79	7.8	83	1.96	2.25	0.00	4.22	16.7	0.25	2.12	4.9	0.43
		6/15	6.24	7.5	85	1.75	1.67	0.00	3.41	16.2	0.21	1.47	5.1	0.29
		6/20	6.52	7.5	85	1.79	2.01	0.00	3.80	15.0	0.26	1.80	4.7	0.37
		Avg	6.52	7.6	84	1.83	1.98	0.00	3.81	15.9	0.24	1.80	4.9	0.37
CV (%)			12.41	8.19	3.97	16.53	36.49	---	23.17	9.30	25.39	35.80	11.92	29.46
Treatment (P>F)			0.519	0.680	0.513	0.457	0.398	---	0.330	0.176	0.415	0.260	0.559	0.129
Control vs 6/15 (P>F)			0.264	0.423	0.290	0.251	0.187	---	0.147	0.617	0.258	0.109	0.575	0.048
Control vs 6/20 (P>F)			0.577	0.502	0.374	0.338	0.572	---	0.430	0.078	0.999	0.414	0.607	0.343
Control vs treated (P>F)			0.334	0.397	0.265	0.228	0.275	---	0.197	0.183	0.504	0.163	0.978	0.091
6/15 vs 6/20 (P>F)			0.557	0.892	0.856	0.836	0.425	---	0.469	0.178	0.257	0.386	0.293	0.239
	Adequate	Control	7.93	10.4	86	2.20	3.03	0.00	5.23	21.8	0.25	2.97	10.4	0.29
		6/15	8.45	10.4	85	2.10	3.34	0.00	5.45	22.8	0.25	3.20	10.2	0.32
		6/20	7.85	10.5	85	2.22	3.22	0.00	5.45	21.4	0.26	3.02	9.8	0.31
		Avg	8.08	10.4	85	2.18	3.20	0.00	5.37	22.0	0.25	3.07	10.1	0.31
CV (%)			11.43	4.86	1.95	10.54	17.27	---	13.49	16.50	7.46	12.17	7.79	15.98
Treatment (P>F)			0.500	0.837	0.896	0.650	0.619	---	0.836	0.719	0.506	0.874	0.621	0.670
Control vs 6/15 (P>F)			0.350	0.912	0.785	0.486	0.344	---	0.609	0.453	0.419	0.944	0.752	0.391
Control vs 6/20 (P>F)			0.894	0.659	0.650	0.869	0.555	---	0.615	0.877	0.753	0.694	0.357	0.632
Control vs treated (P>F)			0.637	0.848	0.675	0.755	0.376	---	0.559	0.599	0.767	0.851	0.472	0.441
6/15 vs 6/20 (P>F)			0.290	0.582	0.855	0.393	0.709	---	0.992	0.548	0.276	0.644	0.530	0.689
	Avg	Control	7.36	9.1	84	2.08	2.64	0.00	4.72	19.2	0.25	3.33	7.7	0.48
		6/15	7.34	8.9	85	1.93	2.50	0.00	4.43	19.5	0.23	3.03	7.7	0.40
		6/20	7.19	9.0	85	2.00	2.62	0.00	4.62	18.2	0.26	3.14	7.3	0.45
		Avg	7.30	9.0	85	2.00	2.59	0.00	4.59	19.0	0.24	3.16	7.5	0.44
CV (%)			11.90	6.30	2.67	13.41	22.97	---	16.78	8.14	19.46	23.13	8.90	27.47
Treatment (P>F)			0.868	0.769	0.580	0.388	0.837	---	0.648	0.178	0.443	0.606	0.396	0.423
Control vs 6/15 (P>F)			0.967	0.480	0.315	0.174	0.579	---	0.363	0.695	0.323	0.325	0.985	0.199
Control vs 6/20 (P>F)			0.635	0.804	0.471	0.492	0.921	---	0.750	0.162	0.840	0.540	0.246	0.585
Control vs treated (P>F)			0.765	0.581	0.320	0.238	0.706	---	0.478	0.547	0.647	0.357	0.503	0.289
6/15 vs 6/20 (P>F)			0.664	0.645	0.772	0.487	0.648	---	0.551	0.081	0.237	0.707	0.239	0.444

Table 4c. For plants sampled 7/23, effect of Invinsa applied at two different times on various plant characteristics, yield and water use for corn grown with deficit or adequate irrigation in a trial conducted at Maricopa, AZ in 2011.

Sampling date	Irrigation	Invinsa timing	Leaf area index	Plant height	Plant moisture	Leaf yield	Stem yield	Ear yield	Total yield	Water use	WUE	Total yield change	Water use change	WUE change
				ft	%	t/a	t/a	t/a	t/a	in	t/a/in	t/a	in	t/a/in
7/23	Deficit	Control	5.59	8.1	73	2.07	4.82	1.08	7.97	23.8	0.33	2.77	7.2	0.37
		6/15	5.28	7.7	75	1.84	3.90	0.76	6.49	23.9	0.28	2.27	7.7	0.30
		6/20	5.74	7.5	73	2.04	4.63	0.90	7.57	21.9	0.35	2.77	7.0	0.42
		Avg	5.53	7.8	74	1.98	4.45	0.91	7.34	23.2	0.32	2.60	7.3	0.37
CV (%)			12.33	5.63	5.47	12.72	22.92	19.59	17.51	9.84	20.26	50.88	13.25	50.62
Treatment (P>F)			0.519	0.153	0.540	0.264	0.301	0.031	0.170	0.294	0.149	0.754	0.481	0.551
Control vs 6/15 (P>F)			0.455	0.216	0.354	0.137	0.150	0.010	0.074	0.978	0.146	0.528	0.410	0.538
Control vs 6/20 (P>F)			0.709	0.061	0.971	0.822	0.754	0.106	0.596	0.184	0.639	0.991	0.724	0.639
Control vs treated (P>F)			0.825	0.075	0.601	0.312	0.303	0.017	0.173	0.438	0.543	0.719	0.780	0.931
6/15 vs 6/20 (P>F)			0.273	0.446	0.336	0.196	0.244	0.194	0.179	0.176	0.066	0.521	0.249	0.288
	Adequate	Control	6.25	10.4	72	2.21	5.51	3.37	11.09	32.5	0.34	4.52	10.7	0.43
		6/15	7.46	10.7	68	2.53	6.74	4.16	13.43	32.7	0.42	6.17	9.9	0.65
		6/20	6.38	10.9	72	2.21	5.73	3.27	11.21	30.8	0.37	4.55	9.4	0.51
		Avg	6.70	10.7	71	2.32	5.99	3.60	11.91	32.0	0.38	5.08	10.0	0.53
CV (%)			10.77	2.58	3.33	8.96	11.57	9.98	4.84	8.26	11.06	18.88	15.24	27.12
Treatment (P>F)			0.104	0.147	0.134	0.118	0.095	0.024	0.002	0.561	0.112	0.083	0.509	0.173
Control vs 6/15 (P>F)			0.056	0.246	0.092	0.074	0.046	0.021	0.001	0.906	0.046	0.051	0.499	0.074
Control vs 6/20 (P>F)			0.810	0.060	0.904	0.992	0.670	0.691	0.787	0.398	0.396	0.959	0.267	0.434
Control vs treated (P>F)			0.182	0.083	0.319	0.256	0.139	0.173	0.013	0.665	0.096	0.200	0.305	0.133
6/15 vs 6/20 (P>F)			0.079	0.343	0.077	0.075	0.085	0.013	0.002	0.341	0.162	0.054	0.632	0.233
	Avg	Control	5.92	9.2	72	2.14	5.17	2.23	9.53	28.1	0.34	4.74	8.9	0.52
		6/15	6.37	9.2	72	2.18	5.32	2.46	9.96	28.3	0.35	5.45	8.8	0.62
		6/20	6.06	9.2	72	2.12	5.18	2.08	9.39	26.3	0.36	4.77	8.2	0.61
		Avg	6.12	9.2	72	2.15	5.22	2.26	9.63	27.6	0.35	4.99	8.6	0.58
CV (%)			11.40	4.17	4.85	11.00	17.45	11.59	11.18	8.79	16.44	32.17	13.95	39.06
Treatment (P>F)			0.373	0.963	0.919	0.861	0.918	0.020	0.495	0.184	0.686	0.560	0.365	0.610
Control vs 6/15 (P>F)			0.176	0.815	0.741	0.706	0.713	0.072	0.397	0.906	0.780	0.347	0.791	0.385
Control vs 6/20 (P>F)			0.667	0.815	0.970	0.884	0.972	0.243	0.770	0.125	0.402	0.969	0.186	0.405
Control vs treated (P>F)			0.300	0.787	0.865	0.893	0.816	0.686	0.745	0.400	0.518	0.569	0.354	0.328
6/15 vs 6/20 (P>F)			0.344	1.000	0.713	0.601	0.739	0.006	0.260	0.101	0.572	0.366	0.282	0.971

Table 4d. For plants sampled 8/13, effect of Invinsa applied at two different times on various plant characteristics, yield and water use for corn grown with deficit or adequate irrigation in a trial conducted at Maricopa, AZ in 2011.

Sampling date	Irrigation	Invinsa timing	Leaf area index	Plant height	Plant moisture	Leaf yield	Stem yield	Ear yield	Total yield	Water use	WUE	Total yield change	Water use change	WUE change
				ft	%	t/a	t/a	t/a	t/a	in	t/a/in	t/a	in	t/a/in
8/13	Deficit	Control	1.91	6.7	71	1.85	3.44	1.42	6.71	30.5	0.22	-0.93	6.7	-0.14
		6/15	1.79	6.6	69	1.93	3.76	1.43	7.12	30.9	0.24	0.47	7.0	0.09
		6/20	1.89	6.9	69	1.84	3.98	1.50	7.32	28.9	0.26	-0.18	6.9	-0.04
		Avg	1.86	6.7	70	1.87	3.73	1.45	7.05	30.1	0.24	-0.22	6.9	-0.03
CV (%)			31.83	5.48	3.80	11.68	20.80	72.50	19.37	10.84	17.03	703.21	16.66	689.46
Treatment (P>F)			0.930	0.284	0.217	0.738	0.502	0.990	0.734	0.547	0.327	0.323	0.870	0.240
Control vs 6/15 (P>F)			0.737	0.649	0.101	0.516	0.491	0.983	0.607	0.846	0.556	0.143	0.621	0.101
Control vs 6/20 (P>F)			0.975	0.268	0.195	0.982	0.255	0.899	0.452	0.407	0.147	0.411	0.712	0.466
Control vs treated (P>F)			0.832	0.693	0.095	0.715	0.293	0.932	0.466	0.708	0.237	0.188	0.618	0.169
6/15 vs 6/20 (P>F)			0.760	0.132	0.686	0.502	0.633	0.916	0.807	0.312	0.359	0.480	0.899	0.318
	Adequate	Control	4.55	9.7	68	2.31	4.56	4.50	11.36	43.5	0.26	0.21	11.1	0.02
		6/15	4.45	9.5	63	2.47	5.87	5.27	13.61	42.6	0.32	0.14	9.9	0.00
		6/20	4.57	9.8	64	2.17	5.08	5.64	12.89	40.0	0.33	1.33	9.2	0.16
		Avg	4.52	9.7	65	2.32	5.17	5.13	12.62	42.0	0.31	0.56	10.1	0.06
CV (%)			18.58	7.30	2.89	8.44	13.94	18.72	8.47	9.93	13.26	185.53	18.35	184.20
Treatment (P>F)			0.977	0.827	0.020	0.179	0.105	0.303	0.061	0.499	0.098	0.273	0.409	0.169
Control vs 6/15 (P>F)			0.872	0.667	0.009	0.302	0.042	0.297	0.025	0.759	0.077	0.925	0.402	0.793
Control vs 6/20 (P>F)			0.977	0.885	0.021	0.344	0.341	0.145	0.090	0.272	0.052	0.182	0.203	0.129
Control vs treated (P>F)			0.939	0.868	0.008	0.955	0.082	0.155	0.028	0.411	0.039	0.446	0.227	0.425
6/15 vs 6/20 (P>F)			0.849	0.569	0.527	0.075	0.174	0.612	0.377	0.409	0.782	0.159	0.618	0.088
	Avg	Control	3.23	8.2	70	2.08	4.00	2.96	9.03	37.0	0.24	-0.50	8.9	-0.08
		6/15	3.12	8.0	66	2.20	4.81	3.35	10.37	36.7	0.28	0.41	8.5	0.06
		6/20	3.23	8.4	67	2.01	4.53	3.57	10.10	34.4	0.29	0.72	8.1	0.07
		Avg	3.19	8.2	67	2.09	4.45	3.29	9.83	36.1	0.27	0.21	8.5	0.02
CV (%)			21.80	6.36	3.55	10.04	16.98	29.01	12.84	10.07	14.90	875.55	17.10	1457.2
Treatment (P>F)			0.922	0.413	0.006	0.160	0.085	0.381	0.078	0.258	0.031	0.341	0.491	0.336
Control vs 6/15 (P>F)			0.736	0.504	0.003	0.227	0.031	0.374	0.035	0.865	0.058	0.294	0.535	0.222
Control vs 6/20 (P>F)			0.991	0.504	0.012	0.462	0.141	0.175	0.082	0.137	0.011	0.163	0.241	0.187
Control vs treated (P>F)			0.850	1.000	0.002	0.776	0.038	0.196	0.029	0.330	0.012	0.161	0.301	0.145
6/15 vs 6/20 (P>F)			0.727	0.191	0.493	0.062	0.424	0.627	0.657	0.182	0.418	0.713	0.567	0.918

Table 4e. For plants sampled 9/5, effect of Invinsa applied at two different times on various plant characteristics, yield and water use for corn grown with deficit or adequate irrigation in a trial conducted at Maricopa, AZ in 2011.

Sampling date	Irrigation	Invinsa timing	Leaf area index	Plant height	Plant moisture	Leaf yield	Stem yield	Ear yield	Total yield	Water use	WUE	Total yield change	Water use change	WUE change
				ft	%	t/a	t/a	t/a	t/a	in	t/a/in	t/a	in	t/a/in
9/5	Deficit	Control	---	---	44	1.58	3.55	0.83	5.96	33.8	0.18	-0.55	3.3	-0.23
		6/15	---	---	40	1.47	3.63	0.59	5.69	34.2	0.17	-0.69	3.3	-0.20
		6/20	---	---	49	1.56	3.37	0.75	5.68	32.4	0.18	-1.21	3.6	-0.35
		Avg	---	---	44	1.54	3.52	0.72	5.78	33.5	0.17	-0.82	3.4	-0.26
CV (%)			---	---	14.99	19.51	18.09	42.94	18.00	11.28	17.26	91.94	21.87	92.03
Treatment (P>F)			---	---	0.115	0.804	0.772	0.439	0.870	0.718	0.731	0.268	0.743	0.457
Control vs 6/15 (P>F)			---	---	0.407	0.544	0.849	0.220	0.661	0.878	0.533	0.879	0.942	0.707
Control vs 6/20 (P>F)			---	---	0.182	0.908	0.621	0.689	0.649	0.547	0.927	0.146	0.538	0.398
Control vs treated (P>F)			---	---	0.749	0.676	0.859	0.344	0.606	0.793	0.757	0.341	0.752	0.780
6/15 vs 6/20 (P>F)			---	---	0.044	0.621	0.496	0.391	0.987	0.452	0.477	0.187	0.493	0.233
	Adequate	Control	---	---	34	1.99	4.66	3.58	10.22	49.9	0.21	-0.90	6.4	-0.14
		6/15	---	---	38	1.85	4.44	3.29	9.57	48.1	0.20	-3.19	5.5	-0.60
		6/20	---	---	41	1.91	4.62	3.28	9.80	45.9	0.22	-2.43	5.9	-0.42
		Avg	---	---	37	1.92	4.57	3.38	9.86	48.0	0.21	-2.17	5.9	-0.39
CV (%)			---	---	40.46	21.50	15.82	12.02	12.94	10.83	17.63	57.10	18.44	57.64
Treatment (P>F)			---	---	0.780	0.890	0.899	0.531	0.771	0.573	0.750	0.097	0.579	0.071
Control vs 6/15 (P>F)			---	---	0.729	0.644	0.675	0.352	0.494	0.643	0.896	0.040	0.318	0.028
Control vs 6/20 (P>F)			---	---	0.499	0.805	0.933	0.336	0.658	0.312	0.574	0.131	0.551	0.127
Control vs treated (P>F)			---	---	0.555	0.682	0.771	0.280	0.517	0.394	0.800	0.046	0.359	0.036
6/15 vs 6/20 (P>F)			---	---	0.734	0.827	0.736	0.972	0.802	0.561	0.492	0.423	0.663	0.303
	Avg	Control	---	---	39	1.78	4.11	2.20	8.09	41.9	0.19	-0.94	4.8	-0.25
		6/15	---	---	39	1.66	4.03	1.94	7.63	41.1	0.18	-2.44	4.4	-0.50
		6/20	---	---	45	1.74	3.99	2.01	7.74	39.2	0.20	-2.36	4.7	-0.51
		Avg	---	---	41	1.73	4.04	2.05	7.82	40.7	0.19	-1.92	4.7	-0.42
CV (%)			---	---	25.74	20.03	16.57	17.04	14.51	10.71	17.11	64.72	19.09	72.89
Treatment (P>F)			---	---	0.316	0.729	0.928	0.267	0.653	0.393	0.577	0.023	0.544	0.136
Control vs 6/15 (P>F)			---	---	0.953	0.435	0.805	0.120	0.383	0.721	0.629	0.014	0.296	0.086
Control vs 6/20 (P>F)			---	---	0.182	0.764	0.709	0.258	0.507	0.193	0.575	0.019	0.791	0.082
Control vs treated (P>F)			---	---	0.416	0.533	0.721	0.123	0.377	0.335	0.964	0.007	0.448	0.049
6/15 vs 6/20 (P>F)			---	---	0.200	0.628	0.899	0.644	0.830	0.334	0.302	0.897	0.429	0.981

Table 4f. For plants sampled 7/2-9/5, effect of Invinsa applied at two different times on various plant characteristics, yield and water use for corn grown with deficit or adequate irrigation in a trial conducted at Maricopa, AZ in 2011.

Sampling date	Irrigation	Invinsa timing	Leaf area index	Plant height	Plant moisture	Leaf yield	Stem yield	Ear yield	Total yield	Water use	WUE	Total yield change	Water use change	WUE change
				ft	%	t/a	t/a	t/a	t/a	in	t/a/in	t/a	in	t/a/in
7/2-9/5	Deficit	Control	4.76	7.5	68	1.86	3.52	0.83	6.21	26.2	0.25	1.16	5.5	0.15
		6/15	4.43	7.3	67	1.75	3.24	0.70	5.68	26.3	0.22	1.22	5.8	0.17
		6/20	4.72	7.3	69	1.81	3.50	0.79	6.09	24.6	0.26	1.08	5.6	0.14
		Avg	4.64	7.4	68	1.81	3.42	0.77	5.99	25.7	0.24	1.15	5.6	0.15
	CV (%)		18.57	4.56	7.74	15.60	22.73	70.77	18.91	12.57	19.57	119.85	17.16	174.55
	Treatment (P>F)		0.347	0.470	0.435	0.424	0.476	0.749	0.241	0.563	0.077	0.894	0.814	0.803
	Control vs 6/15 (P>F)		0.184	0.245	0.759	0.198	0.283	0.464	0.110	0.965	0.136	0.830	0.560	0.656
	Control vs 6/20 (P>F)		0.858	0.390	0.352	0.515	0.937	0.811	0.705	0.373	0.373	0.798	0.933	0.844
	Control vs treated (P>F)		0.379	0.246	0.715	0.263	0.499	0.574	0.250	0.619	0.698	0.981	0.699	0.886
	6/15 vs 6/20 (P>F)		0.246	0.744	0.220	0.505	0.317	0.619	0.213	0.351	0.029	0.638	0.618	0.522
	Adequate	Control	6.18	10.1	65	2.16	4.43	2.86	9.44	36.9	0.26	2.16	9.6	0.19
		6/15	6.71	10.1	64	2.22	5.09	3.18	10.48	36.5	0.30	2.02	8.9	0.12
		6/20	6.21	10.4	66	2.12	4.66	3.04	9.80	34.5	0.29	2.05	8.6	0.18
		Avg	6.37	10.2	65	2.16	4.72	3.03	9.91	36.0	0.29	2.08	9.0	0.16
	CV (%)		15.03	5.23	9.64	11.59	14.09	16.10	9.96	11.44	12.17	64.08	15.48	126.40
	Treatment (P>F)		0.351	0.416	0.561	0.645	0.065	0.345	0.022	0.650	0.200	0.892	0.418	0.429
	Control vs 6/15 (P>F)		0.205	0.972	0.538	0.606	0.024	0.156	0.008	0.894	0.114	0.654	0.366	0.229
	Control vs 6/20 (P>F)		0.940	0.251	0.651	0.682	0.373	0.398	0.263	0.406	0.137	0.721	0.211	0.840
	Control vs treated (P>F)		0.426	0.486	0.924	0.951	0.065	0.193	0.026	0.573	0.086	0.642	0.218	0.414
	6/15 vs 6/20 (P>F)		0.229	0.264	0.292	0.365	0.110	0.530	0.049	0.478	0.900	0.927	0.699	0.313
	Avg	Control	5.47	8.8	66	2.01	3.97	1.85	7.83	31.6	0.26	1.66	7.6	0.17
		6/15	5.58	8.7	65	1.98	4.16	1.94	8.08	31.4	0.26	1.62	7.3	0.14
		6/20	5.46	8.9	67	1.96	4.08	1.92	7.95	29.5	0.28	1.56	7.1	0.16
		Avg	5.50	8.8	66	1.99	4.07	1.90	7.95	30.8	0.26	1.61	7.3	0.16
	CV (%)		16.33	4.88	8.57	13.97	18.02	27.50	13.57	11.64	16.39	84.27	15.72	156.52
	Treatment (P>F)		0.818	0.486	0.261	0.707	0.580	0.801	0.545	0.364	0.170	0.908	0.471	0.858
	Control vs 6/15 (P>F)		0.606	0.445	0.483	0.643	0.303	0.530	0.274	0.924	0.743	0.847	0.548	0.582
	Control vs 6/20 (P>F)		0.959	0.674	0.346	0.411	0.568	0.629	0.608	0.207	0.080	0.663	0.225	0.787
	Control vs treated (P>F)		0.788	0.840	0.888	0.458	0.356	0.522	0.354	0.427	0.222	0.717	0.295	0.636
	6/15 vs 6/20 (P>F)		0.571	0.243	0.105	0.716	0.639	0.883	0.556	0.240	0.145	0.808	0.531	0.779

Table 5. Effect of Invinsa applied at two different times on leaf number at various dates for corn grown with deficit or adequate irrigation in a trial conducted at Maricopa, AZ in 2011.

Irrigation	Invinsa timing	Number of leaves						
		02 June	11 June	15 June	20June	02 July	23 July	Average
Deficit	Control	8.06	10.39	12.50	13.00	20.06	20.86	14.15
	6/15	7.94	10.44	12.17	13.00	20.39	21.39	14.22
	6/20	7.89	10.06	12.28	12.61	20.00	21.11	13.99
	Avg	7.96	10.30	12.31	12.87	20.15	21.12	14.12
CV (%)		2.83	3.82	4.96	4.33	4.27	1.47	2.51
Treatment (P>F)		0.455	0.228	0.642	0.410	0.707	0.044	0.537
Control vs 6/15 (P>F)		0.412	0.811	0.367	1.000	0.517	0.015	0.708
Control vs 6/20 (P>F)		0.228	0.172	0.543	0.254	0.913	0.193	0.472
Control vs treated (P>F)		0.245	0.496	0.384	0.501	0.753	0.031	0.839
6/15 vs 6/20 (P>F)		0.678	0.117	0.759	0.254	0.452	0.152	0.284
Adequate	Control	7.78	10.06	12.44	14.89	20.78	21.00	14.49
	6/15	7.94	9.94	13.00	14.44	21.00	21.00	14.55
	6/20	7.83	10.28	12.72	14.94	21.22	21.33	14.72
	Avg	7.85	10.09	12.72	14.76	21.00	21.11	14.59
CV (%)		2.65	4.62	4.36	4.84	2.09	1.75	2.73
Treatment (P>F)		0.402	0.478	0.268	0.443	0.262	0.394	0.705
Control vs 6/15 (P>F)		0.195	0.688	0.113	0.306	0.401	1.000	0.925
Control vs 6/20 (P>F)		0.653	0.428	0.406	0.896	0.110	0.248	0.516
Control vs treated (P>F)		0.310	0.816	0.164	0.598	0.160	0.488	0.744
6/15 vs 6/20 (P>F)		0.376	0.244	0.406	0.253	0.401	0.248	0.460
Average	Control	7.92	10.22	12.47	13.94	20.42	20.93	14.33
	6/15	7.94	10.19	12.58	13.72	20.69	21.19	14.35
	6/20	7.86	10.17	12.50	13.78	20.61	21.22	14.35
	Avg	7.91	10.19	12.52	13.81	20.57	21.12	14.34
CV (%)		3.44	5.53	5.44	11.46	6.65	0.32	0.36
Treatment (P>F)		0.667	0.958	0.890	0.733	0.529	0.139	0.987
Control vs 6/15 (P>F)		0.770	0.887	0.651	0.460	0.282	0.102	0.882
Control vs 6/20 (P>F)		0.561	0.776	0.909	0.577	0.445	0.073	0.904
Control vs treated (P>F)		0.866	0.805	0.743	0.455	0.291	0.051	0.877
6/15 vs 6/20 (P>F)		0.388	0.887	0.734	0.851	0.740	0.857	0.979

Table 6. Effect of Invinsa applied at two different times on tasseling, silking, lodging, and grain yield, grain moisture, stover yield, total yield, harvest index, plant density, ear number, kernel number, and kernel weight at harvest on 5 September for corn grown with deficit or adequate irrigation in a trial conducted at Maricopa, AZ in 2011.

Irrigation	Invinsa timing	Tassel	Silk	Lodging	Grain yield	Grain moisture	Stover yield	Total yield	Harvest Index	Plant density	Ear number	Kernel number	Kernel weight
				%	t/a	%	t/a	t/a	%	acre^{-1}	plant^{-1}	ear^{-1}	mg
Deficit	Control	7/3	7/3	33	0.51	8.43	5.45	5.96	8.2	32,234	0.73	81	259
	6/15	7/3	7/3	25	0.32	8.50	5.37	5.69	5.5	31,944	0.74	50	262
	6/20	7/3	7/3	33	0.44	8.50	5.24	5.68	7.3	32,017	0.76	65	261
	Avg	7/3	7/3	31	0.42	8.48	5.35	5.78	7.0	32,065	0.74	65	261
CV (%)		0.01	0.01	38.57	58.33	3.17	16.33	18.00	49.00	3.31	11.74	59.34	4.54
Treatment (P>F)		0.526	0.526	0.402	0.433	0.886	0.921	0.870	0.419	0.887	0.811	0.429	0.933
Control vs 6/15 (P>F)		0.294	0.294	0.249	0.209	0.677	0.877	0.661	0.206	0.645	0.921	0.204	0.722
Control vs 6/20 (P>F)		0.829	0.829	1.000	0.598	0.677	0.694	0.649	0.662	0.729	0.555	0.499	0.812
Control vs treated (P>F)		0.461	0.461	0.496	0.302	0.631	0.752	0.606	0.322	0.642	0.689	0.262	0.732
6/15 vs 6/20 (P>F)		0.397	0.397	0.249	0.444	1.000	0.811	0.987	0.388	0.908	0.622	0.527	0.905
Adequate	Control	6/28	6/28	46	2.97	9.28	7.26	10.23	29.1	34,412	0.96	376	239
	6/15	6/29	6/29	46	2.72	9.35	6.85	9.57	28.5	35,610	0.91	356	236
	6/20	6/28	6/28	50	2.72	9.35	7.08	9.80	28.1	32,997	1.00	347	239
	Avg	6/29	6/29	47	2.80	9.33	7.06	9.87	28.6	34,340	0.96	360	238
CV (%)		0.00	0.00	63.87	13.02	2.64	15.18	12.94	11.23	9.15	10.69	7.84	7.58
Treatment (P>F)		0.245	0.245	0.963	0.568	0.886	0.868	0.771	0.911	0.365	0.309	0.406	0.975
Control vs 6/15 (P>F)		0.150	0.150	1.000	0.370	0.682	0.611	0.494	0.803	0.198	0.150	0.368	0.851
Control vs 6/20 (P>F)		1.000	1.000	0.816	0.372	0.682	0.828	0.658	0.680	0.811	0.636	0.206	1.000
Control vs treated (P>F)		0.389	0.389	0.893	0.307	0.637	0.675	0.517	0.702	0.365	0.261	0.217	0.914
6/15 vs 6/20 (P>F)		0.150	0.150	0.816	0.996	1.000	0.767	0.802	0.869	0.276	0.293	0.672	0.851
Average	Control	7/1	7/1	40	1.50	8.77	6.36	8.10	18.6	33,106	0.82	199	251
	6/15	7/1	7/1	35	1.28	8.84	6.11	7.63	17.0	33,411	0.81	173	252
	6/20	7/1	7/1	42	1.35	8.84	6.16	7.74	17.7	32,409	0.85	178	252
	Avg	7/1	7/1	39	1.38	8.82	6.21	7.83	17.8	32,975	0.83	183	252
CV (%)		0.02	0.02	87.04	21.52	2.96	15.36	14.50	18.85	6.26	11.33	19.21	5.75
Treatment (P>F)		0.963	0.963	0.802	0.269	0.792	0.843	0.653	0.572	0.278	0.333	0.266	0.989
Control vs 6/15 (P>F)		1.000	1.000	0.669	0.123	0.560	0.583	0.383	0.300	0.148	0.192	0.141	1.000
Control vs 6/20 (P>F)		0.816	0.816	0.830	0.246	0.560	0.672	0.507	0.548	0.865	0.944	0.190	0.901
Control vs treated (P>F)		0.893	0.893	0.902	0.121	0.502	0.575	0.377	0.345	0.343	0.419	0.111	0.943
6/15 vs 6/20 (P>F)		0.816	0.816	0.524	0.677	1.000	0.900	0.830	0.653	0.197	0.215	0.859	0.901

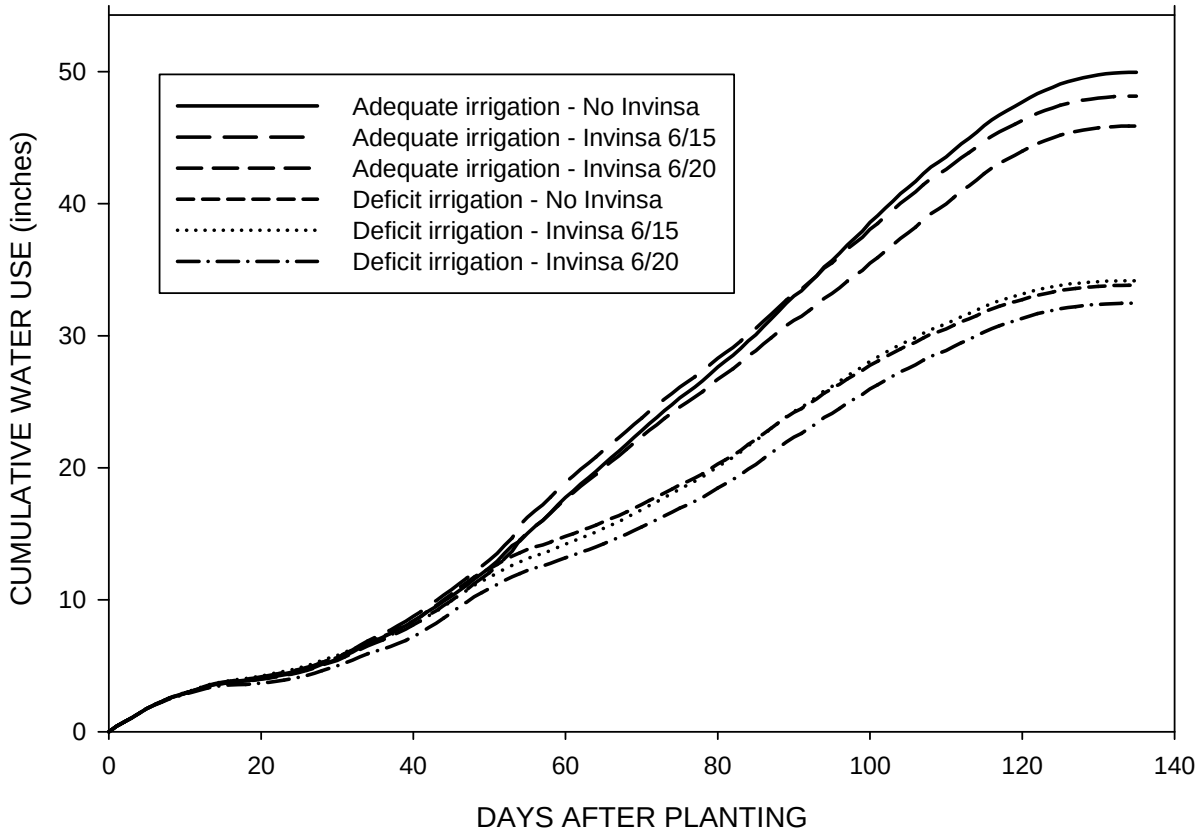

Fig. 1. Cumulative water use of corn as affected by Invinsa application irrigation level in a study conducted at Maricopa, AZ in 2011. No differences in water use due to Invinsa application were detected.