Planting Configuration and Plasticulture Effects on Growth, Physiology, and Yield of Globe Artichoke

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Abstract. Globe artichoke is typically grown in Mediterranean and coastal areas. Because of the high profitability as a specialty crop, demand to develop production systems optimized for other semiarid and water-limited regions is rising. Field experiments were conducted over three seasons (2008–09, 2010–11, and 2011–12) in southwest Texas to investigate plant growth, physiology, and yield of artichoke grown as an annual system. Three strategies were evaluated: planting configuration (single and double lines per bed), plasticulture (bare soil and black plastic mulch), and cultivars differing in maturity (‘Imperial Star’, early; ‘Green Globe Improved’, late). Each fall, transplants were established in the field at 2.03 m between rows and 0.90 m between plants (single line) or 4.06 m between rows and 0.90 m between plants (double line). In both cultivars, black plastic mulch enhanced plant growth (leaf number, plant height and width) and increased early yield; however, its effect on total yield and yield components was not consistent. Single line per bed significantly increased head number of jumbo and large size per plant as compared with double line in the 2009 season. Chlorophyll index was unaffected by either planting configuration or plastic mulch. Comparing cultivars, ‘Green Globe Improved’ had lower marketable yield but bigger head size than ‘Imperial Star’ in one and two seasons, respectively. Our results indicate that single line with black plastic mulch can be recommended to improve earliness and water savings as compared with the bare soil system for annual artichoke production.

Commercial production of globe artichoke [*Cynara cardunculus* L. var. *scolymus* (L.) Fiori] in the United States is almost exclusively in California with major areas located along the central and south coast, the Coachella Valley in the southern inland desert, and the central valley. The total cultivated area has shown a decline in the last 2 years, from 3480 ha in 2009 to 2990 ha in 2011 (U.S. Department of Agriculture, 2012). However, the average yield has increased to 14,570 kg·ha⁻¹ with a total crop value of \$48.5 million in 2011. A small number of hectares is also grown in the semiarid areas of the Wintergarden and Lower Rio Grande

Valley regions of Texas and Yuma county in Arizona.

In semiarid regions, artichoke is typically grown as annuals (seed propagation transplants) for 6 to 7 months. Transplants are set in the field in single lines on raised beds at 0.45 to 0.75 m in-row and 1.6 to 2.0 m between-row spacing (Schrader et al., 1992; Schrader and Mayberry, 1992; Socrat and Jani, 2000). Artichoke plants develop a dense and large foliage biomass with a canopy reaching up to 2 m wide and 1 m high at maturity for the early cultivar Imperial Star or even higher for new hybrid cultivars (Ryder et al., 1983). Optimizing plant density and planting configuration (arrangement between and within rows) are important cultural practices of vegetable production because of their effects on plant growth, yield, and quality (Caliskan et al., 2009; Jett et al., 1995; Leskovar et al., 2012; Nerson, 2002). Low plant stands can significantly reduce yield and economic returns as a result of inefficient use of resources, whereas high density may lead to plant competition for growth resources (Schotzko et al., 1984). Studies have been published on plant density for several vegetable crops including bell pepper (*Capsicum annuum* L.) (Cavero et al., 2001; Locasio and Stall, 1994), onion (*Allium cepa* L.) (Leskovar et al., 2012; Russo, 2008), muskmelon (*Cucumis melo* L.) (Nerson, 2002), and broccoli (*Brassica oleracea* L.)

(Francescangeli et al., 2006). In artichoke, Miguel et al. (2004) evaluated early- and late-maturing cultivars at 0.6 × 1.67 m and 1.2 × 1.67 m (in-row × between-row). Increasing planting density increased early but not total yield for early cultivars, whereas it did not affect either early or total yield for late cultivars.

Santoemma et al. (2004) reported that yield of artichoke was unaffected by within-row plant spacing of 0.5 to 1.4 m, although the total number of heads per unit area increased with closer spacing. Also Mauro et al. (2011) found that total head number based on area planted increased and early harvest yield decreased with increasing plant density over a range of 1.0 to 1.8 plant/m². In terms of planting configuration, Sayre (1959) found that tomato (*Lycopersicon esculentum* Mill.) plants in twin rows produced a high-quality crop with few fruit defects as compared with standard single rows. In bell pepper, Kahn and Leskovar (2006) reported that a fixed plant population in a single-row arrangement resulted in an increase of full-season production as compared with double-row arrangement. In artichoke, planting configuration has received very little attention, except for a study in Italy where a single-row arrangement increased artichoke earliness and total head number per unit area as compared with a double-row arrangement (Mauro et al., 2011).

Plastic mulches are attractive in the cultivation of numerous horticultural crops. The benefits of using plastic mulch include improved weed control, reduced evaporation and fertilizer leaching, savings in irrigation water, and prevention of diseases and insect vectors. These combined benefits result in enhanced plant growth, cleaner fruits, and earlier and higher yields (Díaz-Pérez and Batal, 2002; Ham et al., 1993; Kasirajan and Ngouajio, 2012; Lament, 1993). Other studies (Díaz-Pérez and Batal, 2002; Hatt et al., 1995; Lament, 1993) also reported that black mulch greatly enhanced root-zone temperature during spring, which might be beneficial to globe artichoke, because it is typically grown during the winter/spring season of the year (Basnizky, 1985; Shinohara et al., 2011).

Research on the combined effects of black plastic mulch and planting configuration on globe artichoke in southern regions of the United States has not been reported. The aim of this 3-year study was to determine plant growth, physiology, head yield, and yield components in response to planting configuration and plasticulture of two artichoke cultivars differing in maturity.

Materials and Methods

Cultural practices. Experiments were carried out in three seasons, 2008–09, 2010–11, and 2011–12 (herein 2009, 2011, and 2012 seasons, respectively) at the Texas A&M AgriLife Research Center, Uvalde, TX (lat. 29°1' N, long. 99°5' W, elevation 283 m). The soil was a silty clay (fine-silty, mixed, hyperthermic Aridic Calciustolls) with an available soil moisture holding capacity of 17%. The

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main climatic difference among the three seasons was the average minimum temperature in February, which was 8.9, 5.9, and 8.7 °C for 2009, 2011, and 2012 seasons, and rainfall received, which was 97, 146, and 243 mm for 2009, 2011, and 2012, respectively (Table 1). In addition, the 2011 season had 9 d in February with minimum temperature below 0 °C, whereas only 3 and 5 d in 2009 and 2012 seasons, respectively.

Three strategies were evaluated: planting configuration (single and double line per bed with the same plant density of 5378 plants per hectare), plasticulture (bare soil and black plastic mulch), and cultivars differing in maturity ('Imperial Star', early; 'Green Globe Improved', late; herein IS and GGI, respectively). Six-week-old artichoke seedling cvs. IS and GGI (Condor Seed Production, Inc., Yuma, AZ) previously grown in a greenhouse in 128-cell polystyrene flats were transplanted to the field on 24 Oct. 2008, 23 Nov. 2010, and 11 Nov. 2011. Each fall, transplants were established in the field at 2.03-m between-row and 0.90-m in-row spacing for the single line per bed (1L) or 4.06 m between-row and 0.90 m in-row for the double lines per bed (2L). Transplants were established on beds as bare soil or beds covered with black plastic mulch (0.038 mm thickness, 1.80 m width). Subsurface drip irrigation was installed in the center of each bed at 10-cm depth and irrigation was applied at 100% crop evapotranspiration (ETc) for bare soil and 80% ETc for plastic mulch (Shinohara et al., 2011). The ETc values were estimated using data from a local weather station and the Penman-Monteith method used to calculate the reference evapotranspiration (Ko et al., 2009) and adjusted by stage-specific crop coefficients as

described by Shinohara et al. (2011). Total water inputs (rainfall and irrigation) for each season are described in Table 1. Total fertilization applied as fertigation was 97N–25P–31K kg·ha⁻¹ in the 2009 season, 120N–33P–23K kg·ha⁻¹ in the 2011 season, and 135N–43P–50 K kg·ha⁻¹ in the 2012 season. Weeds, pests, and diseases were controlled as previously described (Shinohara et al., 2011).

Plant growth and leaf gas exchange measurements. Four plants per plot were randomly selected before the first measurement. The following growth variables were repeatedly measured on the selected plants throughout development at various days after planting (DAP): leaf number per plant (only green, not dry or senesced leaves), plant height and width, and leaf chlorophyll index in the first fully developed leaf with a SPAD-502 m (Konica Minolta Sensing Inc., Tokyo, Japan). Plant height was measured from the ground level to the highest leaf canopy without stretching leaves. Net photosynthetic rate (*A*, μmol CO₂/m²/s), transpiration (*E*, mmol H₂O/m²/s) and stomatal conductance (*g_s*, mol H₂O/m²/s) were determined for the first fully expanded leaf using a portable infrared gas analyzer (LI-6400; LICOR, Inc., Lincoln, NE). The analyzer was set at 500 μmol·s⁻¹ flow rate (leaf temperature of 30 ± 0.4 °C, 60% ± 5% relative humidity) and a light-emitting diode external light source providing a photosynthetic photon flux density of 1500 μmol·m⁻²·s⁻¹.

Yield and yield components. Artichoke heads were harvested every 3 to 5 d from 27 Mar. to 6 May in the 2009 season, 4 Apr. to 31 May in the 2011 season, 2 Apr. to 16 May in the 2012 season. At harvest, heads were sorted by diameter into four commercial classes: small (less than 7 cm), medium (7 to 9 cm), large (9 to 11 cm), and jumbo (greater than 11 cm). Head number per plant, marketable yield (t·ha⁻¹), total yield (t·ha⁻¹), and average head size (grams/head) were determined. The harvests in the first 3 weeks for each season were grouped as early harvest to indicate yield earliness.

Statistical analysis. The experiments over all three seasons were conducted using a split-split plot design with four replications;

plasticulture treatments were the main plots, planting configuration treatment were the sub-plots, and cultivars were the sub-subplots. Each replication consisted of 10 individual plants. All data analyses were run in SAS (SAS Institute, 1993). Unless otherwise noted, *P* values ≤ 0.05 were considered statistically significant. Main and interaction effects were tested by analysis of variance. Multiple comparisons of least squares means were performed by the Tukey's Studentized range test. When there was no significant interaction, multiple comparisons were performed within each main effect.

Results

Plant growth. Plastic mulch significantly increased leaf number per plant of both cultivars during plant development (Table 2). Compared with bare soil, plastic mulch significantly increased leaf number per plant from 5.1 to 6.0, 6.4 to 7.4, 7.0 to 8.8, and 9.4 to 12.2 at 64, 78, 92, and 106 DAP, respectively, in the 2009 season; and from 3.8 to 5.0 at 87 DAP in the 2011 season. Plastic mulch also increased leaf number per plant in the 2012 season although it was only significant at 98 DAP.

Plant height of both cultivars was significantly increased by plastic mulch during late development in the 2009 and 2011 seasons and slightly increased in the 2012 season (*P* = 0.053 at 112 DAP; *P* = 0.052 at 126 DAP) (Table 3). Plant height in the 2009 season was 25.7 cm and 39.8 cm at 106 DAP and 49.2 cm and 70.8 cm at 120 DAP for bare soil and plastic mulch, respectively. In the 2011 season, plant height was 21.4 cm and 27.5 cm at 115 DAP and 31.9 cm and 41.7 cm at 129 DAP for bare soil and plastic mulch, respectively. For the 2012 season, plant height was 27.5 cm and 38.2 cm at 112 DAP and 35.5 cm and 51.5 cm at 126 DAP for bare soil and plastic mulch, respectively.

Plastic mulch also significantly increased plant width of both cultivars during plant development in 2009 and 2012 seasons (Table 4). Plant width was 77.0 and 108.4 cm at 92 DAP, 99.9 and 128.5 cm at 106 DAP, and 153.3 and 174.0 cm at 120 DAP for bare soil and plastic mulch, respectively, in

Table 1. Rainfall and irrigation applied during 2009, 2011, and 2012 seasons.

Seasons	Treatment	Rainfall (mm)	Irrigation (mm)	Total (mm)
2009	Bare soil	97	452	549
	Plastic mulch	97	367	464
2011	Bare soil	146	460	606
	Plastic mulch	146	367	513
2012	Bare soil	243	358	601
	Plastic mulch	243	318	562

Table 2. Effects of plastic mulch, planting configuration, and cultivar on leaf number per plant of artichoke.

DAP	2009					2011					2012				
	64	78	92	106	120	59	87	101	115	129	56	84	98	112	126
Plastic mulch (PM)															
Bare	5.1 b ^z	6.4 b	7.0 b	9.4 b	15.5	4.6	3.8 b	5.8	7.3	13.5 b	3.2	5.5	6.3 b	7.7	9.4
Mulch	6.0 a	7.4 a	8.8 a	12.2 a	18.1	5.5	5.0 a	7.8	9.2	17.6 a	4.2	6.5	7.9 a	10.4	12.3
Planting configuration (PC)															
1L	5.7	7.1	8.2	11.4	16.7	5.0	4.6	7.2	8.4	14.8	3.5	5.9	6.9 b	8.9	10.5
2L	5.3	6.7	7.5	10.3	16.9	5.1	4.2	6.4	8.1	16.4	3.9	6.2	7.3 a	9.2	11.1
Cultivar (CV)															
GGI	5.4	6.9	8.0	11.3 a	17.2 a	4.9	4.4	6.7	8.1	15.4	3.9	6.4 a	7.5 a	9.7 a	11.5 a
IS	5.7	6.9	7.8	10.4 b	16.3 b	5.2	4.5	6.9	8.3	15.7	3.5	5.6 b	6.7 b	8.4 b	10.1 b
ANOVA															
PM	0.008	0.047	0.015	0.035	0.084	0.185	0.042	0.074	0.082	0.039	0.101	0.107	0.006	0.112	0.247
PC	0.058	0.053	0.163	0.183	0.234	0.904	0.204	0.117	0.488	0.106	0.079	0.136	0.038	0.346	0.216
CV	0.070	0.818	0.483	0.001	0.048	0.135	0.699	0.328	0.429	0.522	0.115	0.001	0.015	0.003	0.010

^zMeans in a column followed by different letters are significantly different at *P* ≤ 0.05 according to the Tukey's Studentized range test. The interactions among plasticulture, planting configuration, and cultivar were not significant at *P* ≤ 0.05, except at 129 DAP during the 2011 season (Fig. 1).

DAP = days after planting; 1L = one line per bed; 2L = two lines per bed; GGI = Green Globe Improved; IS = Imperial Star; ANOVA = analysis of variance.

Table 3. Effects of plastic mulch, planting configuration, and cultivar on plant height (cm) of artichoke.

DAP	2009					2011					2012				
	64	78	92	106	120	59	87	101	115	129	56	84	98	112	126
Plastic mulch (PM)															
Bare	17.6	28.0	30.0	25.7 b ^z	49.2 b	10.7	12.7	13.3	21.4 b	31.9 b	11.9	19.7	30.0	27.5	35.5
Mulch	20.3	29.9	33.9	39.8 a	70.8 a	12.2	14.5	19.2	27.5 a	41.7 a	12.3	22.1	32.8	38.2	51.5
Planting configuration (PC)															
1L	19.5	29.1	31.3	30.3	53.6	11.6	13.1	16.2	22.5	30.8 b	12.5	20.7	29.6	31.2	39.6 b
2L	18.4	28.8	32.5	35.2	66.4	11.3	14.0	16.3	26.4	42.7 a	11.7	21.1	33.2	34.5	47.4 a
Cultivar (CV)															
GGI	22.4 a	34.1 a	38.7 a	39.0 a	66.9 a	14.6 a	15.4 a	19.1 a	28.4 a	41.4 a	14.6 a	24.0 a	36.9 a	38.5 a	52.7 a
IS	15.5 b	23.8 b	25.1 b	26.5 b	53.0 b	8.3 b	11.7 b	13.4 b	20.6 b	32.2 b	9.6 b	17.8 b	25.9 b	27.2 b	34.2 b
ANOVA			<i>P</i>					<i>P</i>					<i>P</i>		
PM	0.125	0.549	0.138	0.040	0.035	0.412	0.217	0.302	0.039	0.019	0.781	0.137	0.479	0.053	0.052
PC	0.511	0.935	0.823	0.479	0.169	0.685	0.279	0.922	0.084	0.029	0.507	0.625	0.359	0.109	0.031
CV	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.001

^zMeans in a column followed by different letters are significantly different at $P \leq 0.05$ according to the Tukey's Studentized range test. The interactions among plasticulture, planting configuration, and cultivar were not significant at $P \leq 0.05$.

DAP = days after planting; 1L = one line per bed; 2L = two lines per bed; GGI = Green Globe Improved; IS = Imperial Star; ANOVA = analysis of variance.

Table 4. Effects of plastic mulch, planting configuration, and cultivar on plant width (cm) of artichoke.

DAP	2009					2011					2012				
	64	78	92	106	120	59	87	101	115	129	56	84	98	112	126
Plastic mulch (PM)															
Bare	44.9	58.8 b ^z	77.0 b	99.9 b	153.3 b	26.6	30.6	69.5	80.9	114.0	18.8	40.3 b	57.6 b	87.9 b	117.2
Mulch	62.1	84.2 a	108.4 a	128.5 a	174.0 a	33.0	40.0	85.8	108.0	147.3	26.4	60.3 a	90.1 a	123.6 a	151.3
Planting configuration (PC)															
1L	56.6	73.8	102.1	122.6	172.4	30.4	34.3	77.5	89.5	141.4	23.4	52.8	74.3	107.9	139.6
2L	50.4	69.2	83.3	105.9	154.8	29.3	36.2	77.8	99.4	120.0	21.8	47.8	73.4	103.5	128.9
Cultivar (CV)															
GGI	53.1	71.0	96.0 a	114.4	166.3	29.6	34.8	76.8	94.9	122.1	24.6 a	55.0 a	81.0 a	115.9 a	142.3 a
IS	53.8	72.0	89.4 b	114.1	160.9	29.9	35.6	78.4	94.0	139.2	20.6 b	45.6 b	66.7 b	95.5 b	126.2 b
ANOVA			<i>P</i>					<i>P</i>					<i>P</i>		
PM	0.058	0.086	0.019	0.021	0.041	0.062	0.154	0.121	0.101	0.125	0.143	0.048	0.0002	0.034	0.229
PC	0.363	0.556	0.226	0.087	0.058	0.799	0.638	0.909	0.354	0.332	0.184	0.218	0.842	0.492	0.219
CV	0.727	0.706	0.045	0.915	0.186	0.799	0.697	0.441	0.853	0.326	0.030	0.009	0.004	0.002	0.012

^zMeans in a column followed by different letters are significantly different at $P \leq 0.05$ according to the Tukey's Studentized range test. The interactions among plasticulture, planting configuration, and cultivar were not significant at $P \leq 0.05$.

DAP = days after planting; 1L = one line per bed; 2L = two lines per bed; GGI = Green Globe Improved; IS = Imperial Star; ANOVA = analysis of variance.

2009. In the 2012 season, it was 40.3 and 60.3 cm at 84 DAP, 57.6 and 90.1 cm at 98 DAP, and 87.9 and 123.6 cm at 112 DAP for bare soil and plastic mulch, respectively.

Leaf number was unaffected by planting configuration except at 98 DAP in the 2012 season at which time leaf number was significantly higher for 2L as compared with 1L (Table 2). This response was also evident for cultivar IS at 126 DAP in the 2012 season. Planting configuration had no effects on plant height during early development for both cultivars (Table 3). However, during late development, plants on 2L were taller than those on 1L at 129 DAP in 2011 and 126 DAP in the 2012 seasons (Table 3). Overall, planting configuration did not affect plant width in all three seasons (Table 4).

Comparing growth of the two cultivars, GGI had more leaves than IS at 106 and 120 DAP in the 2009 season and during most of the growing period in the 2012 season but not in the 2011 season (Table 2). Overall GGI plants were significantly taller than IS plants during early and late development in all three seasons (Table 3). Also GGI plants were wider than IS in 2012 and during mid-development (92 DAP) in 2009 (Table 4).

Leaf gas exchange and chlorophyll content. Plants grown on plastic mulch showed higher *A* than plants on bare soil 74 DAP ($P = 0.030$) in the 2009 season (Table 5), slightly higher

Table 5. Effects of plastic mulch, planting configuration, and cultivar on leaf gas exchange of artichoke.

DAP	2009						2011		
	69			74			59		
	<i>A</i>	<i>g_s</i>	<i>E</i>	<i>A</i>	<i>g_s</i>	<i>E</i>	<i>A</i>	<i>g_s</i>	<i>E</i>
Plastic mulch (PM)									
Bare	21.43	0.444	6.82	20.67 b ^z	0.351 b	6.20 b	20.3	0.197	2.16
Mulch	23.18	0.495	6.34	22.82 a	0.416 a	6.97 a	26.6	0.189	2.27
Planting configuration (PC)									
1L	21.93	0.477	6.66	21.61	0.381	6.57	22.2	0.179	2.09 b
2L	22.67	0.462	6.50	21.88	0.385	6.60	24.7	0.207	2.35 a
Cultivar (CV)									
GGI	23.08	0.487	6.70	21.39	0.380	6.56	24.7 a	0.216 a	2.37 a
IS	21.52	0.452	6.46	22.1	0.386	6.60	22.2 b	0.170 b	2.07 b
ANOVA			<i>P</i>					<i>P</i>	
PM	0.071	0.361	0.323	0.029	0.018	0.008	0.086	0.277	0.168
PC	0.698	0.405	0.226	0.485	0.351	0.196	0.149	0.119	0.015
CV	0.122	0.298	0.329	0.306	0.749	0.821	0.006	0.002	0.026

^zMeans in a column followed by different letters are significantly different at $P \leq 0.05$ according to the Tukey's Studentized range test. The interactions among plasticulture, planting configuration, and cultivar were not significant at $P \leq 0.05$.

DAP = days after planting; *A* = net photosynthetic rate ($\mu\text{mol CO}_2/\text{m}^2/\text{s}$); *E* = transpiration ($\text{mmol H}_2\text{O}/\text{m}^2/\text{s}$); *g_s* = stomatal conductance ($\text{mol H}_2\text{O}/\text{m}^2/\text{s}$); 1L = one line per bed; 2L = two lines per bed; GGI = Green Globe Improved; IS = Imperial Star; ANOVA = analysis of variance.

but not significant in 2011, and similar in the 2012 season (data not shown). Stomatal conductance and *E* were higher for plastic mulch as compared with bare soil in one (2009) of three seasons. Planting configuration did not affect leaf gas exchange responses, except for an increase in *E* for 2L in 2011. In terms of cultivars, GGI had a significantly higher *A*, *g_s*, and *E* than IS during

2011 but not in 2009. Overall, the chlorophyll index was unaffected by plastic mulch, planting configuration, cultivars, or their interactions in all three seasons (data not shown).

Early yields. Plastic mulch significantly increased marketable yield in early harvests as compared with bare soil in 2009 (9.5 vs. 7.3 t·ha⁻¹) and 2012 (9.7 vs. 5.5 t·ha⁻¹), but not in 2011 (Table 6). The same trends were

Table 6. Effects of plastic mulch, planting configuration, and cultivar on head number, size, and yield of artichoke.

Treatments	Early harvest ²			All harvests						
	Marketable		Total yield (t·ha ⁻¹)	Head number ³ /plant				Marketable		Total yield (t·ha ⁻¹)
	Head number/plant	Yield (t·ha ⁻¹)		Jumbo	Large	Medium	Total	Head wt (g)	Yield (t·ha ⁻¹)	
2009										
Plastic mulch (PM)										
Bare	4.54	7.35 b*	7.38 b	0.48	4.75	1.77	7.01	287	10.58	10.60
Mulch	5.33	9.51 a	9.56 a	0.88	4.64	1.33	6.85	313	11.58	11.64
Planting configuration (PC)										
1L	5.96	10.19	10.24	0.91 a	5.99 a	1.96	8.86	300	14.06	14.13
2L	3.91	6.68	6.70	0.45 b	3.40 b	1.13	4.99	301	8.09	8.11
Cultivar (CV)										
GGI	4.27 b	7.87	7.90	0.87 a	4.47	1.29 b	6.62	313 a	11.20	11.22
IS	5.59 a	8.99	9.04	0.50 b	4.93	1.81 a	7.23	287 b	10.96	11.02
ANOVA		<i>P</i>				<i>P</i>			<i>P</i>	
PM	0.455	0.029	0.033	0.207	0.895	0.557	0.900	0.283	0.359	0.354
PC	0.161	0.164	0.159	0.022	0.048	0.202	0.078	0.897	0.084	0.082
CV	0.001	0.052	0.051	0.006	0.111	0.001	0.109	<0.001	0.682	0.722
2011										
Plastic mulch (PM)										
Bare	0.96	0.91	0.94	0.049	0.311	4.2	4.56	179	4.45	4.80
Mulch	2.55	2.52	2.81	0.116	0.667	4.3	5.08	193	5.12	5.75
Planting configuration (PC)										
1L	1.41	1.50	1.76	0.113	0.415	4.14	4.66	187	4.70	5.35
2L	2.09	1.92	1.99	0.052	0.563	4.36	4.98	185	4.87	5.20
Cultivar (CV)										
GGI	1.05 b	1.09 b	1.09 b	0.078	0.354 b	2.53 b	2.96 b	192	3.08 b	3.15 b
IS	2.45 a	2.34 a	2.67 a	0.086	0.624 a	5.97 a	6.68 a	179	6.49 a	7.40 a
ANOVA		<i>P</i>				<i>P</i>			<i>P</i>	
PM	0.123	0.204	0.189	0.410	0.073	0.942	0.735	0.139	0.707	0.645
PC	0.327	0.531	0.698	0.342	0.157	0.822	0.764	0.731	0.864	0.880
CV	0.001	0.003	0.001	0.852	0.014	0.001	0.001	0.105	0.001	0.001
2012										
Plastic mulch (PM)										
Bare	2.45 b	5.48 b	5.83 b	0.29	2.16 b	5.21	7.88	270	11.23	11.86 b
Mulch	4.98 a	9.74 a	10.25 a	0.48	2.69 a	5.09	9.45	278	13.99	14.84 a
Planting configuration (PC)										
1L	4.11	8.4	8.89	0.46	2.65	6.23	10.02	270	14.33	15.15
2L	3.32	6.81	7.19	0.32	2.2	4.06	7.31	278	10.90	11.55
Cultivar (CV)										
GGI	3.52	7.84	8.15	0.52 a	2.80 a	4.18 b	7.74 b	299 a	12.48	12.91
IS	3.91	7.37	7.93	0.25 b	2.05 b	6.12 a	9.59 a	249 b	12.75	13.79
ANOVA		<i>P</i>				<i>P</i>			<i>P</i>	
PM	0.008	0.018	0.035	0.356	0.043	0.444	0.199	0.779	0.094	0.003
PC	0.340	0.378	0.362	0.220	0.206	0.088	0.126	0.516	0.217	0.206
CV	0.203	0.457	0.710	0.001	0.004	0.001	0.001	0.001	0.677	0.145

²The harvests in first 3 weeks for each season were grouped as early harvest to indicate the yield earliness. The interactions among plasticulture, planting configuration, and cultivar were not significant at $P \leq 0.05$.

³Heads were sorted by diameter into four commercial classes: small (less than 7 cm), medium (7 to 9 cm), large (9 to 11 cm), and jumbo (greater than 11 cm).

*Means in a column followed by different letters are significantly different at $P \leq 0.05$ according to the Tukey's Studentized range test.

1L = one line per bed; 2L = two lines per bed; GGI = Green Globe Improved; IS = Imperial Star; ANOVA = analysis of variance.

measured for total early yield. Planting configuration did not significantly affect yield earliness in all seasons despite a numerical increase for 1L during the 2009 season. Both plastic mulch and planting configuration treatments did not affect early head number per plant in 2009 and 2011, but yield significantly increased with mulch in the 2012 season. Comparing cultivars, IS had a significantly higher head number per plant, early marketable, and total yield than GGI in 2009 and 2011 but not in 2012.

Total yield and yield components. Combining all harvests, plastic mulch did not significantly affect the total number of heads per plant or by size class (jumbo, large, medium) but it increased the number of large heads in 2012 season. In all three seasons, plastic mulch numerically but not significantly

increased head size (by weight), marketable, and total yield (Table 6).

Comparing planting configuration, 1L significantly increased the head number per plant of jumbo- (0.9 vs. 0.5) and large- (6.0 vs. 3.4) sized heads as compared with 2L during the 2009 season (Table 6). However, total marketable head number, head size, marketable yield, and total yield were not significantly affected by planting configuration. Overall there was no significant effect of planting configuration on yield and yield components in both 2011 and 2012 seasons.

For all harvests, the late cultivar GGI had significantly less head number per plant but bigger head size than IS in two seasons (Table 6). For example, head number per plant for GGI and IS was 3.0 and 6.7 in the 2011 season and 7.7 and 9.6 in the 2012

season, respectively. The head weight for GGI and IS was 313 and 287 g in the 2009 season and 299 and 249 g in the 2012 season, respectively. Both cultivars had similar marketable and total yield in the 2009 and 2012 seasons, but IS had higher marketable and total yield than GGI in the 2011 season (Table 6).

Discussion

In the present study, growth of artichoke plants was stimulated by black plastic mulch in all three seasons, as indicated by the increased leaf number per plant, plant height, and width as compared with the bare soil system. This is consistent with previous research that evaluated the effects of black plastic mulch on growth of other vegetable

Fig. 1. Effects of plastic mulch (A) and planting configuration (B) on leaf number per plant at 129 d after planting during the 2011 season.

crops. For example, Soltani et al. (1995) reported that black plastic mulch increased relative growth rate and leaf area index of watermelon (*Citrullus lanatus* L.). Hochmuth and Howell (1983) found that shoot biomass and leaf area of sweetpotato (*Ipomoea batatas* L.) were enhanced by black plastic mulch. In tomato plants, black plastic mulch increased plant biomass (Bhella, 1988), root length, and early shoot growth (Teasdale and Abdul-Baki, 1997). In addition, the size of zucchini (*Cucurbita pepo* L.) plants was enhanced by black plastic mulch (Bhella and Kwolek, 1984). Because artichoke produces a rosette of leaves on a compressed stem (Ryder et al., 1983), the increase in plant width indicates that leaves on plastic mulch were larger than those on bare soil. Thus, the combined increase in leaf number and overall plant size suggests that total leaf area per plant increases greatly under plastic mulch, resulting in a larger crop photosynthetic capacity, although A (measured per unit leaf area) showed only slight and transient increases.

Enhanced root-zone temperature, especially during the spring season, and reduced soil water evaporation resulting from a high degree of impermeability of plastic mulches to water vapor are the main advantages of black plastic mulch. The thermal conductivity of the soil is high relative to that of air; a large proportion of the energy absorbed by black plastic can be transferred to the soil by conduction if there is good contact between the plastic mulch and the soil surface (Lament, 1993). Soil temperatures under black plastic mulch during daytime are generally 2.8 °C higher at a 5-cm depth and 1.7 °C higher at a 10-cm depth as compared with that of bare

soil (Ham et al., 1993; Lament, 1993; Tarara, 2000). Díaz-Pérez and Batal (2002) reported that enhanced tomato plant growth is associated with high root-zone temperature. In this study, irrigation was provided at 100% E_{Tc} for both plastic mulch and bare soil; therefore, the stimulated artichoke plant growth by plastic mulch suggests that increased root-zone temperature would have had a major influence in enhancing the overall plant biomass as compared with plants grown on a bare soil system. Other advantages of plastic mulch that may have contributed to this response and as reported previously (Lament, 1993) include less fertilizer leaching and soil compaction.

Increased earliness was the most significant and consistent effect of black plastic mulch on head yield of artichoke. In the 2009 season, 70% of marketable yield came from early harvests for bare soil and 82% for plastic mulch. Similar trends were measured in the 2012 season with 49% in bare soil and 70% in mulch. Black plastic mulch has been reported to increase early yield of pepper (*Capsicum* sp.) (Van Der Werken and Wilcox-Lee, 1988), muskmelon (Bonanno and Lamont, 1987), watermelon (Decoteau and Rhodes, 1990; Soltani et al., 1995), tomato (Mashingaidze et al., 1996; Teasdale and Abdul-Baki, 1997), and strawberry (*Fragaria ×ananassa* Duch.) (Waggoner et al., 1960). Generally, black plastic mulches produced 7 to 14 d earlier yield of many other vegetable crops as a result of the rapid crop development promoted by enhanced soil temperatures (Lament, 1993; Tarara, 2000). Earlier yield and shorter crop duration are significant to growers, because combined may

result in higher profitability as a result of increases in head price and reduction of crop production inputs such as irrigation, fertilizers, and pesticides.

Across all harvests, black plastic mulch had no significant influences on the total head number per plant, head size, and marketable and total yield in the 2009 and 2011 seasons, except in the 2012 season, when total yield was enhanced by black plastic mulch. Ercan et al. (2007) found that black plastic mulch enhanced head yield of artichoke, whereas Baixauli et al. (2004) reported that no differences in head yield were detected between black plastic mulch and bare soil, but head weight was increased with black plastic mulch. Although many researchers have demonstrated increased yield of vegetable crops by black plastic mulch (Abdul-Baki et al., 1992; Lament, 1993; Tarara, 2000), there are still some studies indicating that black plastic mulch reduces yield such as onion (Díaz-Pérez et al., 2004), pepper (Roberts and Anderson, 1994), and parsley (*Petroselinum crispum* Mill.) (Ricotta and Masiunas, 1991). The inconsistent yield responses of certain vegetable crops to black plastic mulches may result from differences in crop morphology (e.g., shallow vs. deeper root systems), easiness to establish the crop (direct seeding vs. transplanting) as well as the environmental conditions associated with season, year, and geographic location.

Planting configuration of 2L increased plant height in two of three seasons but had no consistent effects on plant width and leaf number, indicating the stimulation of upward growth in response to the more crowded environment. In both the 2011 and 2012 seasons, planting configuration had no effects on yield and its components, whereas in the 2009 season, head number of jumbo and large classes was increased by 1L configuration. This suggests that 2L configuration might not be a feasible system despite the advantage of allowing more space for mechanization practices (cultivation, sprays, and harvesting).

Comparing growth on both cultivars, GGI plants were taller than IS but no consistent differences were detected on plant width, leaf number, A, or yield. The major difference was the increase in head size and decrease in head number for GGI as compared with IS and the decrease in yield for GGI in 2011. The relatively low yield in the 2011 season as compared with 2009 and 2012 was related to the lowest average minimum temperature in February (5.9 °C) and more frequent freeze events (9 d) with the lowest temperature dropping to -8.9 °C, which caused greater freeze damage in the late GGI than in the early IS cultivar.

In conclusion, this 3-year study demonstrated that black plastic mulch enhanced growth of artichoke plants as indicated by the increase in plant size and slightly higher photosynthetic rate. These responses may have been influenced by high root-zone temperatures that are typically reported for plants growing on black plastic mulch during winter and spring seasons. Improved earliness

was the most significant and consistent effects of black plastic mulch on head yield. Black plastic mulch also increased the number of high-priced jumbo or large heads, thus increasing potential profit margin for growers. Plants on 1L configuration were wider and shorter than 2L, producing more jumbo and large heads in one season. In two of three seasons, marketable yield of the 1L configuration (14.1 to 14.3 t·ha⁻¹) was relatively high compared with the commercial production in California averaging 11.7 to 13.6 t·ha⁻¹ in 2004–06 (Smith et al., 2008). These results indicate that commercial artichoke production is feasible in our semiarid climate, and we recommend black plastic mulch with 1L configuration to promote yield earliness and water savings. Because drought episodes continue to impose significant threats to agricultural production, especially in semiarid regions, these findings are useful to improve artichoke management practices aimed at optimizing yields for water-restricted areas.

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