Economics of Pronamide and Pendimethalin Use in Weed Management during Artichoke Stand Establishment

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Abstract. Field studies were conducted to determine the potential economic impact of the loss of pronamide herbicide to artichoke (*Cynara scolymus* L.) growers, and to evaluate pendimethalin as an alternative herbicide during establishment of artichoke. Two rates of pronamide and one rate of pendimethalin were applied to perennial and annual artichokes. With the exception of wild oat (*Avena fatua* L.), pendimethalin controlled weeds as well as or better than pronamide. Financial analysis of treatment effects was based on weed management expenses and value of yield. The financial effect of using pronamide in perennial artichoke ranged from a loss of \$247 to a gain of \$326 per ha, whereas its use in annual artichoke increased revenue \$542 to \$5499 per ha. The effects on revenue of using pendimethalin varied with weed species composition and density. For three sites, revenue increased from \$267 to \$5056 per ha, while a loss of \$1034 per ha occurred at a site with a heavy infestation of wild oat. We conclude that pendimethalin has potential as a pronamide replacement, or as a complement to pronamide. Chemical names used: 3,5-dichloro(*N*-1,1-dimethyl-2-propynyl)benzamide (pronamide); *N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine (pendimethalin).

Although a minor crop in the United States, artichoke is economically important on a regional basis, with California producing the entire national crop (U.S. Dept. of Agriculture, 1999). In 1998, 41,300 t was produced on 4330 ha, valued at \$62.9 million (California Agricultural Statistics Service, 1999). Principal artichoke production areas include: north central coast counties of Monterey, Santa Cruz, and San Mateo; south coast counties of Santa Barbara, Ventura, and Orange; and Imperial and Riverside counties of the low desert in southeast California (U.S. Dept. of Agriculture, 1999).

Weed management is essential for the successful establishment of artichoke stands (Cudney et al., 1999). Broadleaf weeds are common pests in new artichoke plantings, and compete with artichoke for light, water, and nutrients. Pronamide is the only broadleaf herbicide registered for new artichoke plantings (Cudney et al., 1999), but has been classified as a possible human carcinogen, and all tolerances for pronamide are being reviewed by the Environmental Protection Agency (Goldman,

1997). If pronamide registration in artichoke is cancelled, no herbicides would remain for broadleaf weed control in annual plantings and new perennial plantings.

Artichoke has been traditionally cultivated as a perennial crop. Recently, annual cultivars have provided artichoke producers with a second option (Schrader et al., 1992). Benefits of the annual production system include: 1) a considerable reduction in labor-intensive pruning; 2) harvest during periods of low production for perennial artichoke; and 3) control of certain perennial pests, such as the weed Bermuda buttercup (*Oxalis pes-caprae* L.) and an important vertebrate pest, the California vole (*Microtus californicus* Peale) (Lionel Handel, pest control advisor, Kleen Globe Inc., Castroville, Calif., personal communication; Schrader and Mayberry, 1996). Annual artichoke is more dependent on pronamide for weed management than is the perennial cultivar. Perennial artichoke is planted at wide (1-m) row spacing, which permits cultivation in two directions. Annual artichoke is planted more densely and cultivated in only one direction. A larger area is left uncultivated in annual artichoke, which requires herbicide application or hand-weeding. Loss of pronamide would affect annual more severely than perennial artichoke production.

Artichoke is grown primarily as a perennial on the central coast, but as an annual crop on the southern coast and in the desert (U.S. Dept. of Agriculture, 1999). Under the perennial production system, it is propagated vegetatively using root portions obtained from

mature plants. Propagules are planted from June through September, then maintained for 10 or more years (Schrader and Mayberry, 1996). Annual artichoke is either transplanted or direct-seeded (U.S. Dept. of Agriculture, 1999). On the south coast, artichoke is transplanted from June to August for October to April harvest (Schrader and Mayberry, 1996). Direct-seeding is preferred in the desert areas, and occurs from August to October for January to April harvest. Standard production practices for both annual and perennial artichokes call for new stands to be watered heavily for 30 to 60 d after transplanting. The wet environment is not only conducive to weed growth, but impedes hand-weeding as well (L. Handel, personal communication). A broadleaf herbicide is vital to weed management during this initial period after planting. In 1997, pronamide was applied to 660 ha of artichoke, primarily to new plantings (L. Handel, personal communication).

Pendimethalin, a dinitroaniline herbicide applied preplant and preemergent in soybeans [*Glycine max* (L.) Merrill], and preemergent or postemergent in corn (*Zea mays* L.), is a potential replacement for pronamide use in new artichoke stands. It controls many grasses and certain broadleaf weeds (Ahrens, 1994). Preliminary studies indicate that transplanted artichokes are tolerant to this herbicide (Cudney et al., 1990), and regulatory evaluation for its registration in artichoke is currently under way (U.S. Dept. of Agriculture, 1999). The primary objective of this research was to estimate the potential economic impact of pronamide loss to artichoke growers by comparing weed control costs and artichoke yields with and without pronamide. The second objective was to evaluate pendimethalin as an alternative herbicide for new artichoke plantings.

Materials and Methods

Four field experiments were conducted in the artichoke production district of Monterey County. Sites with weed pressure sufficient to detect differences in treatments were selected. Perennial artichoke, cv. Green Globe, was established at two sites near Castroville, Stroebe Ranch, and Pezzini Farm using root portions obtained from mature plants. Row width was 2.7 m, and plants were spaced 0.9 to 1.2 m apart within the row. Plot size was 5.5 × 27.4 m. Annual artichoke, cv. Imperial Star, stands were established as transplants at another two sites, Armstrong Ranch near Marina, and the U.S. Dept. of Agriculture (USDA) Hartnell Farm at Salinas. Row width was 2.0 m, and plants were spaced 0.6 m apart within the row. Plot size was 4.0 × 12.2 m. Soil characteristics and plant and harvest dates for each site are listed in Table 1. Natural weed infestations at each site were as follows: Stroebe Ranch, common chickweed [*Stellaria media* (L.) Vill.] and wild oat; Pezzini Farm, annual sowthistle (*Sonchus oleraceus* L.), burning nettle (*Urtica urens* L.), common chickweed, and wild oat; Armstrong Ranch, corn spurry (*Spergula arvensis* L.); Hartnell

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Table 1. Artichoke production system, soil type, organic matter, pH, and dates of planting, hand-weeding, and harvesting for four artichoke field sites on the north central coast of California.

Production system	Site	Soil type	Organic		Dates of:		
			matter (%)	pH	Planting (1998)	Hand-weeding (1998–99)	Harvesting (1998–99)
Perennial	Stroebe Ranch	Diablo clay	2.1	6.1–7.8	22 June	18 Aug.	30 Sept. to 26 Apr.
	Pezzini Farm	Pachelo clay loam	2.0	6.1–8.4	9 July	27 Aug.	1 Oct. to Apr.
Annual	Armstrong Ranch	Oceano loamy sand	0.1	5.6–7.3	16 Nov.	28 Jan., 10 Mar., and 12 May	2 June to 23 July
	Hartnell Farm	Chualar loam	2.5	6.1–7.8	23 Nov.	24 Feb. and 21 Apr.	24 May to 12 July

Table 2. Effects of pronamide and pendimethalin on the densities (no. weeds/m²) of eight weed species at annual artichoke field sites.

Herbicide	Rate (kg·ha ⁻¹)	Armstrong	Hartnell						
		Corn spurry	Annual bluegrass	Burning nettle	Common chickweed	Desert rock-purslane	Persian speedwell	Redstem filaree	Shepherdspurse
Pronamide	1.1	57.8 a ^z	1.0 b	7.8 b	5.0 b	4.2 b	4.6 b	0.0 b	33.2 bc
	1.7	47.6 a	1.6 b	5.6 b	2.2 b	2.0 b	2.6 b	2.0 b	54.6 b
Pendimethalin	1.1	12.8 b	8.2 b	2.2 b	0.0 b	0.0 b	0.0 b	0.0 b	0.0 c
None	---	57.0 a	150.6 a	275.0 a	82.6 a	78.6 a	117.6 a	8.6 a	145.2 a
LSD _{0.05}		33.0	26.2	45.0	27.3	47.1	60.8	4.6	49.0

^zMean separation within columns by LSD, $P \leq 0.05$.

Farm, annual bluegrass (*Poa annua* L.), burning nettle, common chickweed, desert rockpurslane [*Calandrinia ciliata* (R.&P.) DC. var. *menziesii* (Hook.) Macbr.], Persian speedwell (*Veronica persica* Poir.), redstem filaree [*Erodium cicutarium* (L.) L'Her.], and shepherdspurse [*Capsella bursa-pastoris* (L.) Medik.].

Pronamide was applied at 2.2 and 1.7 kg·ha⁻¹ to perennial artichoke and at 1.7 and 1.1 kg·ha⁻¹ to annual artichoke. Pendimethalin was applied at 2.2 and 1.1 kg·ha⁻¹ to perennial and annual artichoke, respectively. Both were applied immediately after transplanting with a CO₂-pressurized backpack sprayer equipped with 8002VS nozzles that delivered 187 L·ha⁻¹ at 276 kPa. Spray band width was 1.2 m for perennial artichoke, and 1.0 m for annual artichoke, centered on the plant row. Herbicides were incorporated with overhead irrigation. Treatments at each site were arranged in a randomized complete-block design with four replications.

Before plots were hand-weeded, weed infestation was measured by one of two methods: 1) weed species were counted in two 0.56 × 1 m randomly selected areas per plot; or 2) weed biomass was measured in two 0.1-m² randomly selected areas per plot. In the second method, weeds were cut at the soil line and separated by species, and the fresh mass was measured. Project personnel recorded the time an experienced field worker spent removing weeds from each plot. One individual hand-weeded all plots for a location and date, but individuals differed among sites and dates. The dates of hand-weeding are shown in Table 1. Artichokes were harvested weekly or bi-weekly, depending on production and weather, and the buds were weighed and graded by size according to commercial standards. Growers performed all production operations outside the scope of this study according to standard practices for the area.

The two artichoke production systems were analyzed separately. Agriculture Research Manager (Gylling Data Management Inc., Brookings, S.Dak.) was used for data analysis. Data were subjected to analysis of variance

(ANOVA), and tested for location × treatment interaction. Data were not pooled when location × treatment interaction was significant. Interaction was significant for site × hand-weeding time for perennial artichoke and for site × yield interaction for both perennial and annual artichokes. Mean separation was performed using Fisher's protected least significant difference (LSD) at $P \leq 0.05$.

Current prices for weed management expenditures were obtained by contacting local growers and suppliers. Hand-weeding was valued at \$11.30 per h, pronamide at \$147.49 per kg, pendimethalin at \$15.90 per kg, and herbicide application at \$12.00 per ha. The cost of weed management for a treatment was determined by adding the hand-weeding, herbicide, and application costs. The value of artichoke yield was calculated based on a standard of 10.4 kg/carton, and an average value of \$12.00 per carton (M.A. Bari, Artichoke Research Association, personal communication; Monterey County Agricultural Commissioner, 1998).

The cost of weed management, value of artichoke yield, relative weed management cost, relative yield value, and a net gain or loss for treatments were calculated. Relative weed management costs are comparisons between treated and nontreated plots, and indicate whether the herbicide treatment resulted in a net increase or decrease in expense. Relative yield values represent an increase or decrease in yield associated with a treatment. Addition of the relative weed management cost and yield value gave a net treatment gain or loss.

Results and Discussion

Weed control. Pronamide did not reduce the density of corn spurry plants significantly at Armstrong Ranch, but pendimethalin did (Table 2). Differences among the two pronamide treatments were nonsignificant at Hartnell Farm. Both rates of pronamide and pendimethalin reduced the densities of annual bluegrass, burning nettle, common chickweed, desert rockpurslane, Persian speedwell, redstem filaree, and shepherdspurse. At Pezzini Farm, pendimethalin significantly reduced annual sowthistle biomass (Table 3), but pronamide did not. Both herbicides were effective on burning nettle and common chickweed. Pronamide was effective on light wild oat populations at Pezzini Farm, but control was incomplete at the Stroebe site. Pendimethalin was ineffective on wild oat at either site.

Hand-weeding time. Both pronamide treatments reduced the time required to hand-weed perennial artichoke at Stroebe Ranch, but pendimethalin did not (Table 4). At the Pezzini Farm, 2.2 kg·ha⁻¹ pronamide reduced weeding time, whereas the lower rate of pronamide did not. The pendimethalin treatment was most effective at this site. Both pronamide treatments reduced the time required to hand-weed annual artichoke. In annual artichoke, pronamide was partially effective, but application of pendimethalin was most effective.

Yield. Yield of perennial artichoke was not affected by pronamide treatment at either site (Table 4). The effect of pendimethalin varied

Table 3. Effect of pronamide and pendimethalin on the biomass (Pezzini Farm) or density (Stroebe Ranch) of weeds infesting perennial artichoke.

Herbicide	Rate (kg·ha ⁻¹)	Weed biomass (g·m ⁻²) at Pezzini Farm				Weed density (no./m ²) at Stroebe Ranch	
		Annual sowthistle	Burning nettle	Common chickweed	Wild oat	Common chickweed	Wild oat
Pronamide	1.7	145.3 ab ^z	1.1 b	29.9 b	0.5 b	0.6 b	20.0 b
	2.2	128.1 ab	1.1 b	5.4 b	0.2 b	1.2 b	27.2 b
Pendimethalin	2.2	1.1 b	0.0 b	1.1 b	9.6 ab	0.0 b	91.2 a
None	---	200.2 a	54.9 a	218.5 a	14.7 a	3.0 a	92.2 a
LSD _{0.05}		169.9	45.0	60.9	8.2	1.7	48.6

^zMean separation within columns by LSD, $P \leq 0.05$.

with site; it reduced yield at Stroebel Ranch, but increased it at Pezzini Farm. At Armstrong Ranch, annual artichoke yield was not affected by the lower rate of pronamide or pendimethalin, but the higher rate of pronamide increased yield. At Hartnell Farm, all treatments increased yields.

Yield quality. Pronamide did not affect bud quality of perennial artichoke (Table 5), but pendimethalin reduced the number of size 12 buds. The total number of perennial buds did not differ among treatments. In annual artichoke, the higher rate of pronamide increased the number of size 36 buds and the lower rate increased the number of size 24 buds; both treatments increased the total number of annual buds.

Economic analysis. Pronamide treatments increased relative weed management costs by \$61 to \$118 per ha for perennial artichokes, but reduced them by \$427 to \$765 per ha for annual artichokes (Table 6). Pendimethalin reduced weed management expenses at Pezzini Farm, Armstrong Ranch, and Hartnell Farm, but not at Stroebel Ranch, where wild oat was the dominant weed. The difference in relative weed management costs between annual and perennial artichokes is primarily attributable to the expense of hand-weeding. Annual artichokes were hand-weeded two or three times, depending on the site, while perennial artichokes were hand-weeded once. A larger area of annual artichoke is hand-weeded because it is cultivated in one direction, whereas perennial artichoke is cultivated in two directions, greatly reducing the area that requires hand-weeding.

The lower rate of pronamide increased the value of the perennial artichoke yield by \$176 and \$387 per ha, while the higher rate reduced relative yield. In annual artichoke, pronamide at both rates added \$115 to \$4848 to the yield value per ha. The effects of pendimethalin varied among sites. Greater economic returns were observed at Pezzini and Hartnell Farms (\$2205 and \$3713 per ha, respectively), but value was reduced \$1000 per ha at Stroebel and \$670 per ha at Armstrong Ranch.

For perennial artichokes, the lower rate of pronamide increased income \$326 and \$58 per ha at Stroebel Ranch and Pezzini Farm, respectively, but greater yield value did not compensate for the added expense of the higher rate of pronamide. For annual artichoke, pronamide increased overall financial benefits \$542 to \$5499 per ha. The overall cost or benefit of pendimethalin varied among sites for both artichoke types. At Pezzini Farm, Armstrong Ranch, and Hartnell Farm, overall benefits of \$2273, \$267, and \$5056 per ha were obtained, respectively. At Stroebel Ranch, however, costs exceeded return by \$1034 per ha. The financial loss at Stroebel Ranch can be attributed to pendimethalin's inactivity on wild oat, the effects of competition from wild oat on yield and the expense of controlling this weed by hand.

Results of this study indicate that the loss of pronamide would have a significant economic impact on annual artichoke production system. Without pronamide, weed management

Table 4. Effects of pronamide and pendimethalin on the time required to hand-weed and on yield of perennial and annual artichokes at four field sites: Stroebel Ranch, Pezzini Farm, Armstrong Ranch, and Hartnell Farm.

Herbicide	Perennial artichoke			Annual artichoke		
	Rate (kg·ha ⁻¹)	Stroebel	Pezzini	Rate (kg·ha ⁻¹)	Armstrong	Hartnell
<i>Hand-weeding time (h·ha⁻¹)</i>						
Pronamide	1.7	5.5 b ²	17.2 ab	1.1		96.9 b ³
	2.2	6.4 b	14.3 b	1.7		95.5 b
Pendimethalin	2.2	11.6 a	9.2 c	1.1		55.2 c
None	---	12.6 a	19.2 a	---		159.5 a
LSD _{0.05}		2.7	3.5			14.5
<i>Yield (kg·ha⁻¹)</i>						
Pronamide	1.7	6525 a	5625 ab	1.1	9,359 b	11,050 a
	2.2	6066 a	5467 b	1.7	10,595 a	11,907 a
Pendimethalin	2.2	5323 b	7386 a	1.1	8,678 b	10,923 a
Untreated	---	6190 a	5475 b	---	9,259 b	7,705 b
LSD _{0.05}		743	1852		1,055	2,596

²Mean separation within columns by LSD, $P \leq 0.05$.

³Hand-weeding times were pooled for Armstrong and Hartnell sites.

Table 5. Effect of pronamide and pendimethalin on yield (buds/ha) of perennial and annual artichoke within size categories. Data are means for two field sites.

Production system	Herbicide	Rate (kg·ha ⁻¹)	Size category ² (buds/ha)				
			36	24	18	12	Total
Perennial ³	Pronamide	1.7	2777 a ⁴	6192 a	571 a	239 ab	9,780 a
		2.2	2923 a	5940 a	452 a	399 a	9,714 a
	Pendimethalin	2.2	4066 a	6578 a	651 a	173 b	11,468 a
	None		2698 a	6086 a	611 a	266 ab	9,674 a
	LSD _{0.05}		---	---	---	195	---
Annual ⁴	Pronamide	1.1	2785 ab	14,289 a	4682 a	3956 a	25,671 a
		1.7	3633 a	13,320 ab	5893 a	4965 a	27,810 a
	Pendimethalin	1.1	2745 ab	12,674 ab	5812 a	3875 a	25,065 ab
	None		2341 b	11,302 b	4561 a	3754 a	21,917 b
	LSD _{0.05}		1294	2,462	---	---	3,314

²Size categories represent the number of buds per standard 10.4-kg carton.

³Pooled data from Pezzini and Stroebel sites.

⁴Mean separation within columns and production systems by LSD, $P \leq 0.05$.

⁵Pooled data from Armstrong and Hartnell sites.

Table 6. Gain or loss (\$/ha) from using herbicides on perennial and annual artichokes.

Site	Herbicide	Rate (kg·ha ⁻¹)	Cost of		Value of yield ^b		Net gain or loss
			weed management ^c		Total	Relative	
			Total	Relative ^a			
<i>Perennial production system</i>							
Stroebe l Ranch	Pronamide	1.7	203	-61	7529	387	326
		2.2	246	-104	6999	-143	-247
	Pendimethalin	2.2	176	-34	6142	-1000	-1034
Pezzini Farm	None		142	0	7142	0	0
	Pronamide	1.7	335	-118	6493	176	58
		2.2	335	-118	6308	-9	-128
	Pendimethalin	2.2	149	68	8522	2205	2273
	None		217	0	6317	0	0
<i>Annual production system</i>							
Armstrong Ranch	Pronamide	1.1	1051	427	10,799	115	542
		1.7	993	485	12,225	1542	2027
	Pendimethalin	1.1	541	937	10,013	-670	267
Hartnell Farm	None		1478	0	10,683	0	0
	Pronamide	1.1	1362	765	12,750	3860	4625
		1.7	1476	651	13,739	4848	5499
	Pendimethalin	1.1	783	1343	12,603	3713	5056
	None		2127	0	8,890	0	0

²Includes the costs of hand-weeding, herbicide, and herbicide application.

³Calculated using a standard of 10.4 kg per carton and an average value of \$12.00 per carton.

⁴Relative to controls.

in annual artichoke stands is more expensive and yields may be lower because of weed competition. A similar trend, however, was not found for perennial artichokes. At current prices, hand-weeding in perennial artichokes is as cost-effective as applying pronamide. Pendimethalin has potential as a replacement for pronamide, or as a complement to pronamide use, depending on weed composition. At sites where broadleaf weeds dominated, pendimethalin controlled weeds as well as, or better than, pronamide.

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