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Weed Control in Carrots: The Efficacy and Economic Value of Linuron

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Abstract. **Application of linuron was compared with hand-weeding and a nontreated control (= control) for weed control in carrots. Linuron, applied pre- or postemergent, was slightly less effective than the 100% weed control obtained by hand-weeding. Carrot yields were similar for all treatments, and were at least six times as great as in the control. In 1996, linuron treatments returned net profits ranging from $980 to $1887 per ha, compared to $740 for hand-weeding and –$2975 for the control. In 1997, return on linuron treatments was greater, ranging from $5326 to $6426, compared with $2852 for hand-weeding. Marginal rates of return ranged from 21% to 86% in 1996. In 1997, rates of return for every dollar invested in linuron were over 59%. Chemical name used: *N*´-(3,4-dichlorophenyl)-*N*-methoxy-*N*-methylurea (linuron).**

Weed control options are very limited in carrots. High population densities preclude effective cultivation or hand-hoeing to control weeds without damaging the crop. Carrots are planted at very high population densities of 2.5 million plants/ha to provide for high yields and to meet consumer requirements for appearance, shape, and texture. In California, carrots are grown on raised beds with 55 cm of planted area between irrigation furrows 1 m wide. Carrots are directly sown in six or eight seedlines per bed. Seed spacing in the seedline is ≈3 cm and seedlings are not thinned. One linear meter of bed contains ≈1400 carrots.

Carrots do not compete well against weeds, and herbicides are important tools for producing high-yield, high-quality carrots. The two most commonly used carrot herbicides are linuron and trifluralin [2,6-dinitro-*N,N*-dipropyl-4-(trifluoromethyl)benzenamine]. Linuron was first registered in 1961 (United States Environmental Protection Agency, www.cdpr.ca.gov/docs/epa/m2htm), but research on linuron as an herbicide for carrots has been limited (Hill et al., 1962; Sweet et al., 1962). Its continued registration for weed control in carrots will partially depend upon the availability of data documenting the herbicide's efficacy and economic value (Anderson, 1994).

Henne and Guest (1973) compared linuron treatment to hand-weeding and a nonweeded check. Yields in the weedy check were 10% of those in the hand-weeded plots and 15% those following linuron treatment. A similar experiment (Henne and Paulsen, 1980) produced parallel results; total yield of the weedy check was <10% of that in the hand-hoed and the herbicide-treated plots. In both of these experiments, density was much lower than that currently used for fresh-market carrots in California.

The objective of our research was to evaluate the efficacy and economic benefits of linuron for weed control in carrots. Hand-weeding is the only other weed control option available at the time of linuron application. Yield from our experiments, together with crop production and market statistics, were used to determine the economic costs, benefits, and incremental rates of return from investing in different rates of linuron, hand-weeding, or no investment in weed control. Growers commonly incorporate trifluralin prior to planting and subsequently apply either a preemergent or postemergent application of linuron. However, combined application of two herbicides makes it difficult to determine the value of each herbicide. Our experiments focused on linuron to clarify interpretation of data and meet the data requirements of the U.S. Environmental Protection Agency for comparison of the risks and benefits of herbicide use (Anderson, 1994).

Materials and Methods

Carrots are sown in the fall (September to November) in the low deserts of the southwestern United States and harvested the following winter and spring (January through April). In our study, carrots were grown during the 1995–96 and 1996–97 winter seasons at the Univ. of California Desert Research and Extension Center in Holtville, Calif. The soil type was an Imperial-Glenbar silty clay loam (15% sand, 47% silt, 38% clay, 0.8% organic matter, pH 7.9). The field was fertilized with 125 $kg \cdot ha^{-1}$ P and 40 $kg \cdot ha^{-1}$ N prior to forming the beds. Nitrogen was side-dressed during the season each year at 25 $kg \cdot ha^{-1}$. Carrot, cv. Caropak, seeds were sown in six seedlines per bed with a commercial carrot planter on 4 Oct. 1995 and 9 Oct. 1996. Plot size was four beds, each 1 m wide (55 cm planted width) × 8 (1995) or 9 m (1996) long. We used a randomized complete-block design with three replications. There were three linuron treatments: 1) preemergent (PRE) application of 1.12 $kg \cdot ha^{-1}$ on 5 Oct. 1995 and 9 Oct. 1996; 2) a postemergent (POST) application at 1.12 $kg \cdot ha^{-1}$ on 2 Nov. 1995 and 26 Nov. 1996; and 3) PRE application of 0.56 $kg \cdot ha^{-1}$ on 5 Oct. 1995 or 9 Oct. 1996, followed by a POST application of 1.12 $kg \cdot ha^{-1}$ on 2 Nov. 1995 or 26 Nov. 1996.

POST applications were made when the crop was 8 cm tall. The herbicide was applied with a tractor-mounted sprayer with a PTO roller pump and delivered through 8004 flat fan nozzles spaced 50 cm apart on a boom 4 m wide. Application pressure was 207 kPa and spray volume was 280 $L \cdot ha^{-1}$.

Weeds present were a naturally occurring infestation of nettleleaf goosefoot (*Chenopodium murale* L.), littleseed canarygrass (*Phalaris minor* Retz.), and little mallow (*Malva parviflora* L.). Density of all weed species combined in the nontreated control was 100/m^2. Nettleleaf goosefoot was the most abundant and evenly distributed weed in both years. At the time of the POST application, weeds were 8–15 cm tall. Hand-pulling weeds established weed-free controls; the crop spacing was too close to use hoes or cultivation. Hand-weeding was initiated at weed and crop emergence on 18 Oct. 1995 and 7 Nov. 1996, and continued as needed to maintain weed-free plots. Time of weeding was recorded for each year.

Weed control was assessed immediately prior to the POST applications of linuron and again 2 weeks later. A visual scale of 0–10 was used, where 0 = control and 10 = complete weed control. These numbers were converted to percentages (Table 1), and an arcsine transformation performed to stabilize the variances prior to mean separation. Yield samples were taken when the crop was mature, on 20 Mar. in 1996 and 1997. In 1996, yield samples consisted of the total weight of fresh carrot, including tops, from 3 m of the two inner beds of each plot. Yield samples for 1997 were taken from 6 m of the two inner beds of each plot. These data were converted to $t \cdot ha^{-1}$ for comparison between years. Yield data were compared with a factorial analysis of variance (treatments and years), and the treatment means were separated by LSD at $P \leq 0.05$.

An economic comparison of weed control vs. the effect on yield and incremental rate of return was constructed using partial budget, dominance, and marginal analysis methods (Centro Internacional de Mejoramiento de Maiz y Trigo, Manual, 1988). Crop values were based on the 5-year average from 1992

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Table 1. Effects of hand-weeding vs. application of linuron before (PRE) or after (POST) sowing of carrot seed on weed control and carrot yield (nontreated = 0% control).

	Treatment					
	Linuron					
Observation	PRE[z] 1.12[x] kg	POST[z] 1.12 kg	PRE + POST 0.56 & 1.12 kg	Hand	None	LSD[y] (0.01)
			Weed control (%) 1996			
1 month[w]	99	0	96	100	0	5
2 months	97	91	99	100	0	4
			Weed control (%) 1997			
1 month	99	0	98	100	0	3
2 months	96	90	99	100	0	4
			Yield (t·ha^{-1})			
1996	38.1	35.0	41.8	48.9	6.1	22.4
1997	67.6	66.4	74.6	83.1	10.1	23.8

[z]PRE = preemergent application. POST = postemergent application.
[y]Mean separation within columns by Duncan's multiple range test, $P \le 0.01$.
[x]Rates in kg·ha^{-1}.
[w]One-month evaluations were made on 2 Nov. 1995 and 26 Nov. 1996, immediately prior to postemergent applications of linuron and 2 weeks after hand-weeding. Two-month evaluations were made on 16 Nov. 1995 and 10 Dec. 1996, ≈2 weeks after linuron application.

Table 2. Return on investment from hand-weeding and use of linuron on carrot in 1996 and 1997 based upon: 1) a partial budget and 2) marginal analysis of nondominated treatment. All calculated values in $/ha.

	Treatment[z]				
	Linuron				
	PRE[y] 1.12[x] kg	POST[y] 1.12 kg	PRE + POST 0.56 & 1.12 kg	Hand	None
		1996			
Yield (t·ha^{-1}) (Y)	38.1	35	41.8	48.9	6.1
Gross[w] return (A)	11,392	10,465	12,498	14,621	1,824
Growing[v] costs (B)	3,819	3,819	3,819	3,819	3,819
Weed control costs (C)	45	45	79	2,208[u]	0
Harvest[t] costs (D)	6,119	5,621	6,713	7,853	980
Net return (A-B-C-D)	1,409	980	1,887	740	–2,975
Breakeven cost (B+C+D)/Y	262	271	254	284	787
Net benefit or return	1,409	980	1,887	---	0
Total variable costs	9,983	9,485	10,611	---	4,799
Marginal net benefit	429	980	478	---	0
Marginal variable cost	498	4,686	628	---	4,799
Marginal rate of return (%)	86	21	76	---	0
		1997			
Yield (t·ha^{-1}) (Y)	67.6	66.4	74.6	83.1	10.1
Gross[w] return (A)	20,212	19,854	22,305	24,847	3,020
Growing[v] costs (B)	3,819	3,819	3,819	3,819	3,819
Weed control costs (C)	45	45	79	4,830[u]	0
Harvest[t] costs (D)	10,857	10,664	11,981	13,346	1,622
Net return (A-B-C-D)	5,491	5,326	6,426	2,852	–2,421
Breakeven cost (B+C+D)/Y	218	219	213	265	539
Net benefit or return	5,491	5,326	6,426	---	0
Total variable costs	14,721	14,528	15,879	---	5,441
Marginal net benefit	166	5,326	935	---	0
Marginal variable cost	193	9,087	1,158	---	5,441
Marginal rate of return (%)	85	59	81	---	0

[z]Cost/ha = $20 for linuron plus $22 per application.
[y]PRE = preemergent application. POST = postemergent application.
[x]Rates in kg·ha^{-1}.
[w]Mean yield (Table 1) × $299 = average market value.
[v]Exclusive of weed control (from Mayberry et al., 1994).
[u]Hand-weeding costs are 368 h/ha × $6/h in 1996 and 805 h/ha × $6/h in 1997.
[t]Based upon $160.50/t.

through 1996 of the Imperial County Agricultural Commissioner's Office Crop Report (Birdsall, 1997). A 5-year average was used to avoid confounding interpretation of the data with year-to-year price fluctuations that are often not related to weed control or local conditions. The value of all carrots sold for the fresh market was used, as the values of specific market segments (cellos, cut-peeled, organic, etc.) were not available. Thus, the results are somewhat skewed, as our harvest data consisted of the weight of roots plus tops, and not just the roots. Segments of the market included in the 5-year yield average reflect prices when only the roots are weighed. During the years from 1992 to 1996, the value of a 22.7-kg bag of carrots varied by 12.5% from the 5-year average of $6.80. Carrot production costs were from data compiled for the year immediately preceding our experiments (Mayberry et al., 1995). Crop production costs were changed to reflect the actual costs of the different weed control treatments (labor for hoeing or linuron application, cost of materials) and the change in harvest costs as yield varied for each treatment in each year.

Results and Discussion

The results from the 1995–96 experiments will be referred to as 1996 results, and those for 1996–97 as 1997 results. Analysis of variance indicated significant year and treatment ($P \le 0.001$) effects on carrot yield, but no year by treatment interaction ($P = 0.23$). All linuron treatments effectively controlled the predominant weed species, nettleleaf goosefoot, in both years of this experiment (Table 1), but did not provide 100% control, as did hand-weeding. The linuron and hand-weeded treatments had equivalent yields that were over five times as high as those of control plots. While the postemergent treatment provided slightly poorer weed control than the other linuron applications, carrot yield was not affected (Table 1); apparently the weed control from the postemergent linuron applications was still adequate.

The 1996 and 1997 experimental data were used in partial budget and marginal analyses to compare cost vs. benefits and calculate rates of return from incremental investment in weed control. The highest net return ($1887/ha) and the lowest breakeven ($254/t) cost for 1996 were obtained when linuron was applied both pre and postemergent (Table 2). This treatment may have increased carrot yields by providing slightly better late season weed control (Table 2). The single application linuron treatments also produced a high net return ($1409/ha PRE) in comparison with hand-weeding ($740/ha) or when linuron was applied postemergent ($980/ha). The control had a negative return (–$2975/ha).

Yields for the 1997 experimental weed control treatments ranged from 47% to 84% greater than 5-year average for carrots in the Imperial Valley (Birdsall, 1997). Rains delayed the 1997 harvest; as a result, harvested carrots were large and yields were abnormally high. Many of the carrots harvested in 1997 exceeded desirable market sizes and would have been culled, although data were not collected on this aspect. The increased yield may have made hand-weeding profitable.

Returns were higher in 1997 than 1996 (Table 2) because yield was higher for all treatments in 1997 (Table 1). Linuron applied both pre- and postemergent returned the highest profit ($6426/ha) and lowest breakeven cost ($213/t). The single application linuron treatments also produced higher net returns in 1996 ($5491/ha applied PRE) than the hand-weeded treatment in 1997 ($2852/ha), or linuron applied POST ($5326/ha). Net return for control was negative (–$2421/ha).

Marginal analysis indicates the most favorable treatment by comparing incremental costs and benefits of a nondominated treatment. A treatment is dominated when it produces lower profits than an alternative treatment that has lower variable costs. In our analysis, the hand-weeded control was a dominated treatment (Table 2). Overall, linuron treatments produced marginal rates of return of low 21% and high 86%. In this experiment, the linuron PRE treatment alone produced the highest marginal rate (86%) of return.

Hand-weeding cost $2208/ha in 1996 and $4830/ha in 1997 (Table 2). Organic farmers in the Imperial Valley have reported costs exceeding $4000/ha for hand-weeding high-density crops like carrots and spinach (*Spinacea olevacea* L.) (personal communication with organic farmers). Using the 5-year average yield for Imperial County (45.1 $t \cdot ha^{-1}$), however, hand-weeding would have produced a net return of –$1096/ha, vs. $2132/ha for either linuron treatment with one application of herbicide. Organically grown carrots usually sell for higher prices than conventionally grown carrots. Higher prices may partially compensate organic farmers for increased labor costs for weed control, but weeds are often cited as an important reason why organic farmers quit farming (James E. Leap, Agroecology Program, Univ. of California, Santa Cruz, personal communication).

Linuron is a versatile, efficient and cost-effective herbicide for weed control in carrots. There are no other herbicides available to carrot growers with the same efficacy and safety to the crop. Even though weed control with linuron was less than complete in this study, the low cost and consistency of this herbicide are important factors in its value to carrot farmers.

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