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Effects of Chemical Weed Control on Root Yield and Quality of Carrots (*Daucus carota* L.)

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Abstract. Three field experiments were conducted during 1993 and 1994 growing seasons, to study the effect of weed control with linuron, metribuzin and their combinations with pendimethalin or propyzamide on root yield and quality of carrots (*Daucus carota* cv. Nantes). Results showed that mixing of pendimethalin with linuron or metribuzin improved weed control without causing phytotoxicities to carrots, while propyzamide mixture did not cause such an improvement. Pendimenthalin mixtures exhibited better weed control, growth of leaves; root yield and quality, marketable roots and higher root contents of ascorbic acid. Although propyzamide mixtures exhibited good weed control, they showed some phytotoxic effects to carrot plants. Both linuron and metribuzin were less effective than their mixtures in weed control and carrot yield. Propyzamide mixtures produced malformed roots, and were phytotoxic to carrot plants.

Introduction

Chemical weed control in carrots may improve crop yield by reducing weed populations, or deteriorate yield through herbicide phytotoxicity to crop plants. Linuron (1 lb/acre) was found to be effective in controlling grassy weeds, in spring sown carrots, but caused some injuries to crop plants although the yield was very good [1]. Incorporation of linuron (6 kg/ha) in the soil (4.8-11% CM), before sowing carrots, had no adverse effects on root yield and quality [2]. Carrots were relatively susceptible to metribuzin [3]. Pre-emergence application of 1.0 - 2.0 lb/acre linuron or 0.25 - 0.50 lb metribuzin provided more than 80% control of *Amaranthus spinosus* and *Portulaca oleracea* in carrots, and up to six weeks after the treatment, metribuzin however, reduced crop vigor [4]. Pendimethalin mixtures with linuron or metribuzin exhibited good weed control, whereas their single applications or their mixtures with pronamide were less in this respect [5].

Post-emergence application of linuron (1.2 lb/acre) gave good control of all weed species without phytotoxicity to crop plants, while metribuzin at 0.125 - 0.250 lb/acre reduced carrot yield and failed to control all weeds [6]. An antagonistic action on grassy weed control was observed between linuron and sethoxydim, that was overcome by the addition of 0.1% corn oil to the tank mix [7]. Combinations of linuron with sethoxydim, fluazifop-butyl or chlorazifop, were non-phytotoxic to carrots, whereas the diclofop combination resulted in severe crop injury with significant yield reduction [7]. Linuron and crop oil concentrate combinations with either sethoxydim or fluazifop-butyl were phytotoxic to carrots, but a 24 hr. delay before or after linuron treatment overcame this effect [6]. Linuron/pendimethalin mixture was non-phytotoxic to any of the tested 21 cultivars of carrots [8], and gave good weed control in both polyethylene - covered or uncovered carrot plots [9]. Such mixture generally controlled weeds under the polyethylene covers, as well as or better than in the open field [10]. Sequential applications to carrots of linuron at 2.0 kg/ha pre-emergence and 1.0 kg/ha post-emergence, or of pendimethalin at 1.5 and 1.0 kg/ha respectively gave effective weed control [11].

The objective of the present work was to study the effect of weed control with linuron, and metribuzin herbicides, or their combinations with pendimethalin or propyzamide on growth, yield and quality of carrots.

Materials and Methods

Three field experiments with six herbicidal treatments each were conducted at the Agricultural Research and Experimental Station (ARES) of King Saud University at Dierab, during the 1993 and 1994 seasons. Treatments included the use of linuron (afalon 50% WP) metribuzin (sencor 70% WP) and their combinations with pendimethalin (stomp 500 EC) or propyzamide (kerb 50% WP). Weed-free and weed-infested plots were also included and considered as controls, (Table 1). Herbicides were applied in pre-emergence treatments to carrots, while the already emerged weed seedlings at the time of herbicidal application in all treatments except that of the control ones, were sprayed with diquat (reglone, 20% SC) solution (0.5%).

The experiments were conducted in two different locations within ARES, with different weed populations. Location of the first and second experiment was abundant with the *Malva* and *Chenopodium* two species, whereas *Chenopodium* and *Phalaris* were in the third. The first experiment was in 1993 season and both second and third were in 1994 (Table 2).

Table 1. Herbicidal treatments and rates

Treatment No.	Treatment component(S)	Application rate (g a.i./ha.)
1	Linuron	375
1a	Linuron + pendimethalin	250 + 750
1b	Linuron + propyzamide	250 + 500
2	Metribuzin	350
2a	Metribuzin + pendimethalin	210 + 750
2b	Metribuzin + propyzamide	210 + 500
3	Hand weeded	--------
4	unweeded check	--------

Table 2. Spectrum and abundance of the dominant weed species, grown in the control treatment (unweeded check) of each of the three experiments, at the time of the mid-season evaluation

Weed species	Fresh weights (FW) in g/m^2 and their percentages (%) in each experiment					
	First		Second		Third	
	FW	%	FW	%	FW	%
Malva spp	1179	58.3	4000	65.8	0147	03.3
Chenopodium murale	0694	34.3	1253	20.6	2154	47.8
Sonchus oleraceous	0130	06.4	0673	11.1	0057	01.3
Phalaris spp	0	00.0	0140	02.3	1869	41.3
Minor weeds	0021	01.0	0010	00.2	0283	06.3
Total	2024	100	6076	100	4510	100

Treatments were arranged in a randomized complete block design with four replicates for the first two experiments and six for the third. Each plot (replica) consisted of four rows 3.25 m long and 70 cm apart. Carrots (cv. Nantes) seeds were hand sown on both sides of the row, and carrot plants were thinned after emergence.

Dominant weed species in the experimental site and their densities recorded in (Table 2) in term of fresh weights (in g/m^2) and percentage relative abundance. On the mid-season, percentages of weed control were estimated where the weeds inside a randomly placed wooden frame (50 × 50 cm) in each plot were collected, weighed, and their fresh weight was compared with weight of weeds in unweeded (control) plots. The end-season weed evaluation was done by visual estimation of the using 0-100 scale system [12,13] in which 100% denotes complete absence of weeds from the plot, and 0.0% means that the plot was fully covered with weeds.

Yield assessments

Biological yield (B.Y.) of the crop was estimated by weighing carrot plants collected randomly from selected two meter long of both sides of a furrow of each plot, from which B.Y. in kg/m^2 was estimated. The collected plants were counted and their B.Y. in term of g/plant was also determined.

Five randomly selected plants from each plot were harvested, their root's fresh weights, length and diameter (at the 2.5 cm below the crown level); their leaves fresh weight and number per plant and dry weights of shoots and roots (oven dried, at 85°C for a week) were determined.

Rating the harvested roots based on their sizes to large, medium and small roots was also followed, at which roots less than 1.5 cm in diameter or 10 cm long were considered unmarketable [14].

The pH, total acidity (as tataric acid) and ascorbic acid content were determined in the juice of the harvested roots in the first-experiment [15].

All data were subjected to analysis of variance [16], and the treatment means were compared using New Multiple Range test of Duncan [17].

Results and Discussion

Since the herbicidal treatments could indirectly affect carrot's growth, development and yield through their ability to suppress weed growth; and/or directly, through their phytotoxicity to carrot plants; thus, it was thought important to consider composition and density of weed population in any competition study. Density of weed population in the first experiment was the lowest and that of the second was the highest. Fresh weight of the total weeds was 2024, and 6076 g/m^2 in the first and the second experiments respectively (Table 2). *Malva* spp., *Chenopodium murale* and a lesser extent *Sonchus oleraceous* were the dominant weed species in the first and second experiment; whereas *C. murale* and *Phalaris* spp were the most abundant in the third experiment. Difference in weed species and density between the three experiments resulted differences in the effect of herbicide treatments, and their consequent effects on crop growth and yield.

Data showed the effectiveness of herbicide treatments, in controlling weeds (more than 95% weed control) on the mid-season evaluation; this may be due to the pre-emergence application of diquat herbicide against the already emerged weeds prior to treatments application (Table 3,4 and 5). On the end-season evaluation, carried out two months later than the first one, linuron/pendimethalin (# 1a) and metribuzin/pendimethalin (# 2a) resulted in more than 90% weed control, whereas linuron (# 1), metribuzin (# 2) or their mixtures with propyzamide (# 1b & 2b respectively) were less effective in this respect (Tables 3,4 & 5). It was reported [18] that linuron and pendimethalin significantly reduced weed population of carrot and increased the crop yield. A combined treatment of linuron or pendimethalin followed by prometryn resulted in a almost 100% weed control [19], whereas single treatment of any of these herbicides were less effective in this respect [2,3 & 20].

Biological yields (B.Y.) of the treatments, reflected their efficiences in weed control (Table 3,4 & 5). Mixtures of linuron/pendimethalin (# 1a) and metribuzin/pendimethalin (# 2a) showed the highest percentages of weed control, and the greatest B.Y. values. However, B.Y.'s of the former treatments (# 1a & #2a) were not significantly different in the three experiments. Values of B.Y. of the propyzamide mixture with linuron (# 1b) or metribuzin (# 2b) in the second and third experiments were significantly lower than other treatments, except the unweeded control (# 4). It was also found that, B.Y. values of linuron/pendimethalin (# 1a) and metribuzin/pendimethalin (# 2a) were greater than those of either linuron (# 1) or metribuzin (# 2); which may be due to the better weed control of the former two treatments than in the latter two. Similar results were obtained in comparing the B.Y. values of the former two treatments (# 1a & 2a) with either linuron/propyzamide (# 1b) or metribuzin/propyzamide (# 2b) in which weed control was less efficient in the latters (# 1b & 2b) than in the formers (# 1a & 2a).

The first experiment was the least in the weed popoulation and density compared with the other two, as previously reported (Table 2), hence, effect of weed control on biological yield was much greater in the second and third experiments than in the first. Biological Yields (B.Y.) of each of linuron/propyzamide (# 1b) and metribuzin/propyzamide (# 2b), in the last two experiments were the least, which may not be attributed to poor weed control alone, but the phytocidal effects of propyzamide to carrot plants should be considered in which development of phytotoxicity on carrots leaves had shown up rapidly.

Leaves number, fresh and dry weights in all treatments were significantly higher than those of the unweeded control (# 4), and were higher with linuron/pendimethalin (# 1a) and metribuzin/pendimethalin mixture (# 2a) than in the handweeded

Table 3. Biological yield (B.Y.), yield characteristics and the percentages of weed control for the FIRST experiment of carrots (season, 1993)

Treatment	Weed control (%)		B.Y.	Leaves for single plant			Characteristics for single root			
	mid-season	end-season	kg/m^2	No.	FW (g)	DW (g)	FW (g)	DW (g)	Length (cm)	Diam. (cm)
1*	97.5	71.7	3.3 cd**	11.2 a	17.2 abc	2.1 ab	66.8 bc	5.7 b	15.5 a	2.7 b
1a	98.9	92.6	4.8 ab	10.8 a	20.5 a	2.4 a	70.8 abc	5.5 b	14.5 abc	2.9 b
1b	99.5	72.2	4.9 a	09.3 a	14.1 cd	1.6 bc	49.7 d	3.6 c	13.9 cd	2.5 b
2	94.1	79.1	3.6 bcd	10.0 a	12.9 d	1.9 ab	61.2 bcd	4.1 c	14.0 bc	2.7 b
2a	99.7	94.8	4.2 abc	09.5 a	15.5 bcd	2.0 ab	76.8 ab	6.3 b	15.5 a	2.6 b
2b	97.0	70.4	3.9 abcd	09.9 a	16.1 bcd	2.0 ab	56.5 cd	4.1 c	13.6 cd	2.4 bc
3	99.4	98.1	2.8 d	10.5 a	18.7 ab	2.6 a	83.8 a	7.8 a	15.3 ab	3.8 a
4	00.0	00.0	0.9 e	06.4 b	07.0 e	1.1 c	26.5 e	2.1 d	12.5 d	1.9 c

N.B., FW = fresh weight; DW = dry weight; Diam. = diameter; and No. = number;

*for legends, see Table 1.

**Means within a column, followed by the same letter are not significantly different (at p=0.05) according to Duncan's New Multiple Range test.

Table 4. Biological yield, yield characteristics and the percentages of weed control for the SECOND experiment of carrots (season, 1994)

Treatments	Weed control (%)		Biological yield		Leaves for single plant			Characteristics for single root			
	mid-season	end-season	kg/m^2	g/plant	No.	FW (g)	DW (g)	FW (g)	DW (g)	L. (cm)	Diam. (cm)
1*	95.3	66.7	3.1 ab**	30.3 cd	6.0 ab	5.2 ab	1.1 bc	25.1 c	3.0 cd	10.4 b	2.2 bc
1a	98.5	93.9	4.0 a	46.9 a	7.5 a	6.8 ab	1.4 ab	40.2 a	4.8 a	11.7 a	2.6 a
1b	94.1	77.0	2.2 b	24.6 d	5.0 b	4.7 b	1.0 c	19.9 c	2.1 d	10.4 b	1.8 d
2	98.0	82.2	3.3 ab	30.2 cd	6.3 ab	4.8 b	1.0 c	25.4 c	3.0 cd	10.4 b	2.2 bc
2a	99.5	97.2	4.0 a	41.0 ab	7.6 a	6.8 ab	1.5 a	34.2 ab	4.2 ab	11.2 ab	2.5 ab
2b	97.2	86.9	2.3 b	23.7 d	7.0 a	4.7 b	1.0 c	19.0 c	2.3 d	10.8 ab	1.9 cd
3	99.6	74.1	2.1 b	37.1 bc	7.3 a	7.2 a	1.6 a	30.0 b	3.7 bc	11.3 ab	2.3 ab
4	00.0	00.0	0.5 c	05.8 e	1.8 c	1.3 c	0.4 d	04.9 d	0.5 e	06.2 c	1.1 e

N.B., FW = fresh weight; DW = dry weight; L. = length; Diam. = diameter; and No. = number; *for legends, see Table 1.

** Means within a column, followed by the same letter, are not significantly different (at $P = 0.05$) according to Duncan's New Multiple Range test.

Table 5. Biological yield, yield characteristics and the percentages of weed control for the THIRD experiment of carrots (season, 1994)

	Weed control (%)		Biological yield		Leaves for single plant			Characteristics for single root			
Treatments	mid-season	end-season	kg/m²	g/plant	No.	FW (g)	DW (g)	FW (g)	DW (g)	L. (cm)	Diam. (cm)
1*	97.8	62.9	5.89 abc***	48.1 cd	6.5 cde	06.5 cd	1.3 bcd	41.6 cd	5.0 cd	12.6 cd	2.6 a
1a	97.7	93.2	6.67 a	64.6 b	7.9 ab	08.4 ab	1.6 b	56.3 b	6.9 b	13.9 b	2.9 a
1b	99.1	51.2	2.42 d	37.1 de	5.6 e	05.1 d	0.9 e	32.2 de	4.0 de	12.1 d	2.3 a
2	97.6	51.1	4.97 c	50.9 c	7.0 bcd	07.0 bc	1.4 bc	44.0 c	5.0 c	13.3 bc	2.7 a
2a	99.7	97.9	6.19 ab	84.4 a	8.5 a	10.7 a	2.3 a	74.1 a	9.6 a	14.6 a	3.2 a
2b	99.2	59.5	1.27 e	30.2 e	5.9 de	05.2 d	1.0 de	25.0 e	3.3 e	10.7 e	2.1 a
3	98.8	97.0	5.23 bc	48.5 cd	7.2 bc	06.1 d	1.2 de	42.4 cd	5.5 c	12.4 cd	2.5 a
4	00.0	00.0	0.03 f	04.2 f	1.6 f	00.4 e	0.1 f	02.8 f	0.6 f	10.7e	0.8 b

N.B., FW = fresh weight; DW = dry weight; L. = length; Diam. = diameter; and No. = number; *for legends, see Table 1.

** Means within a column, followed by the same letter, are not significantly different (at P = 0.05) according to Duncan's New Multiple Range test.

treatment (# 3), (Tables 3,4 & 5). However, linuron/pendimethalin mixture has been reported to be non-phytotoxic to carrots [8]. Similarly, these values for the mentioned treatments (# 1a & 2a) were higher than those of the linuron/propyzamide (# 1b) or metribuzin/propyzamide (# 2b), reflecting the phytotoxicity of propyzamide to carrots. It was observed that carrot leaves in propyzamide treatments (# 1b & 2b) were less turged and yellow at the time of harvesting, whereas with pendimethalin treatments (# 1a & 2a), they were fresh and green.

Root characteristics in the three experiments (Table 3,4 & 5) reflected herbicides efficiency in weed control and their phytotoxicity to crop plants. However. root fresh and dry weights, length and diameter in the pendimethalin treatments (# 1a & 2a) were higher than in the other treatments, however, the lowest values were when the propyzamide (# 1b & 2b) was used.

Size rating of the roots (Table 6) indicates that the marketable roots (large and medium sizes) in the treatments of linuron/pendimethalin (# 1a) metribuzin/pendimethalin (# 2a), linuron (# 1), metribuzin (# 2) and handweeded (# 3) were much greater than those of the non-marketable ones (small - size). Propyzamide two treatments (# 1b & 2b) resulted higher percentage of non-marketable roots than marketable ones. In addition, percentages of malformed roots (especially forked ones) were high with propyzamide treatments (# 1b & 2b); meanwhile, non-malformed roots were found in the other treatments.

In general, linuron (# 1) and metribuzin (# 2) treatments exhibited smaller values for weed control, B.Y., vegetative growth, root characteristics and marketable roots (Tables 3,4,5 & 6), than their mixtures with pendimethalin (# 1a & 2a), but higher values than their mixtures with propyzamide (# 1b & 2b respectively). Field observations during the whole growing seasons indicated that linuron (# 1) showed no phytotoxicity to carrots, whereas metribuzin (# 2) did so. Mixtures with pendimethalin improved the weed control efficiencies of linuron (# 1a) and metribuzin (# 2a) without increasing phytotoxicities, while mixtures with propyzamide caused no actual improvement in the weed control of neither linuron (# 1b) nor metribuzin (# 2b), in contrast they showed some phytotoxicity to crop plants. Additional phytotoxicity to carrots was noticed in the metribuzin/propyzamide (# 2b) treatment. Several workers reported phytotoxicity of linuron and metribuzin to carrots. Linuron (1 lb/A) caused some injury to the carrots, without affecting the final yield [1]; while incorporating the same herbicide (6 kg/ha) in organic soil had no adverse effect on yield, quantity and quality [2]. However, post-emergence application of linuron [1.2 lb/A) showed no crop toxicity [6]. On the other hand, metribuzin at 0.125 - 0.250 lb/A reduced crop yield and failed to control all weeds [4 & 6], although

Table 6. Size rating of the carrot roots and chemical characteristics of their juices

Treatment	Size rating (%) of roots in each experiment									Chemical characteristics of the root juice		
	First			Second			Third					
	Marketable		Non-marketable	Marketable		Non-marketable	Marketable		Non-marketable	ascorbic	acidity	pH
	large	medium	small	large	medium	small	large	medium	small	mg/100ml	(tartaric)%	
1*	53.5 ab**	34.0 ab	12.5 ab	26.0 ef	50.0 a	24.0 c	31.8 bc	52.9 ab	15.4 d	6.383 a	0.237 abc	6.092 abc
1a	58.4 a	36.8 ab	04.8 b	47.2 a	39.8 b	13.0 d	39.1 ab	50.4 ab	10.5 ef	5.898 a	0.218 c	6.128 a
1b	38.8 cd	48.4 a	12.8 ab	29.2 de	33.3 c	37.5 b	23.9 cd	48.3 ab	27.9 c	4.168 b	0.242 ab	6.068 c
2	49.5 abc	34.6 b	15.9 ab	34.0 cd	45.5 ab	20.5 c	32.6 b	54.2 a	13.2 de	6.158 a	0.237 abc	6.092 abc
2a	44.2 bc	46.6 a	09.2 b	42.6 ab	44.7 ab	12.7 d	45.2 a	47.4 b	07.4 f	6.102 a	0.242 ab	6.080 bc
2b	45.2 bc	42.4 ab	12.4 ab	20.9 f	45.4 ab	33.7 b	21.0 d	38.4 c	40.6 b	4.462 b	0.223 bc	6.114 ab
3	42.4 bc	43.0 ab	14.6 ab	39.8 bc	45.2 ab	15.0 d	36.0 b	52.0 ab	12.0 de	6.345 a	0.222 bc	6.121 ab
4	27.6 d	47.9 a	24.5 a	00.1 g	00.1 d	99.8 a	00.1 e	00.1 d	99.8 a	4.375 b	0.250 a	6.014 d

*For legends, see Table 1;

**Means within a column, followed by the same letter, are not significantly different (at P = 0.05) according to Duncan's New Multiple Range test.

when used at 0.5 kg/ha in Romania, it was the most effective for the weed control of carrots and to increase yield [21].

Carrots in propyzamide treatments (# 1b & 2b) and unweeded control (# 4) showed the lowest values of ascorbic acid (Table 6), while differences between the other treatments (# 1, 1a, 2, 2a & 3) were not significant. Acidity (measured as tataric acid %), in linuron/metribuzin treatment (# 1a) was the least, and that of the unweeded control (# 4) was the highest. The pH values were parallel (to certain extent) with the juice content of ascorbic acid; while linuron/pendimethalin (# 1a) exhibted the greatest values of pH, and ascorbic acid, the unweeded control (# 4) showed the lowest values.

In conclusion, chemical weed control in carrots strongly affected root yield and quality. Mixtures of linuron/pendimethalin (# 1a) and metribuzin/pendimethalin (# 2a) exhibited better weed control, growth of leaves; root yield and quality, marketable roots, and higher root contents of ascorbic acid. Mixtures of metribuzin/propyzamide (# 2b) and to some extent linuron/propyzamide (# 1b) resulted good weed control, but showed some phytotoxicity to crop plants. Linuron (# 1) or metribuzin (# 2) were less effective than their tested combinations, in the weed control, and in carrot productivity. Propyzamide, in its tested combinations (# 1b & 2b), produced malformed roots, and were clearly phytotoxic to carrot plants.

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تأثير المكافحة الكيميائية للحشائش على إنتاجية محصول الجزر وعلى مواصفاته

علي تاج الدين، فؤاد شعبان سليمان، و عبدالعزيز الحربي*

قسمي وقاية النبات والإنتاج النباتي، كلية الزراعة،*

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ملخص البحث. أجريت ثلاث تجارب حقلية بمحطة الأبحاث والتجارب الزراعية بديراب لتقويم كفاءة كل من لنيورون وميتريبوزين وخلائطهما مع كل من مبيدات الأعشاب بنديميثالين وبروبيزاميد في مكافحة حشائش الجزر، وتأثير ذلك على إنتاجية ومواصفات المنتج.

أظهر مبيد بنديميثالين فعالية واضحة في تحسين كفاءة كل من لنيورون وميتريبوزين في مكافحة الحشائش بدون إحداث سمية واضحة لنباتات الجزر، بينما لم يكن للبروبيزاميد مثل هذا التأثير. فقد أظهر كلٌّ من الخليطين لنيورون/بنديميثالين، وميتريبوزين/بنديميثالين فعالية أفضل في مكافحة الحشائش وفي تحسين النمو الخضري للجزر وإنتاجيته ومواصفاته، وأيضًا في الأحجام التسويقية منه بالإضافة إلى ارتفاع محتواها من حمض الأسكوربيك. بينما أظهر خليط ميتريبوزين/بروبيزاميد وإلى حد ما لنيورون/بروبيزاميد فعالية جيدة في مكافحة الحشائش ولكنهما أظهرا سميّة واضحة على نباتات الجزر. كما أظهرت الدراسة أيضًا أن المعاملات المنفردة لكل من لنيورون وميتريبوزين أقل فعالية من خلائطهما المختبرة في مكافحة الحشائش وفي نمو وإنتاجية ومواصفات المحصول في حين أظهر البروبيزاميد في كل خلائطه المختبرة تشوهًا في جذور الجزر المعاملة بالإضافة إلى سميته الواضحة على نباتاته.