Effect of Plant Density on Carrot Seed Yield and Quality Under Seed-to-Seed Production Systems in California, Oregon, and Washington

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ABSTRACT

Low carrot (*Daucus carota* L.) seed germination is a recurrent problem facing seed growers. This study was conducted to determine if plant density could be used to improve seed quality. The effect of plant density (PD) on carrot seed yield and quality was examined in California (CA), Oregon (OR), and Washington (WA). In CA and OR an optimum PD of 8 to 32 plants m^{-2} resulted in maximum seed yield. In WA the highest PD of 47 plants m^{-2} produced the highest yield (7,134 kg ha^{-1}), but due to sampling bias, this value was probably artificially inflated. No consistent relationship between PD and the seed quality parameters of percent germination, speed of germination, and seed weight were found. Therefore, manipulation of plant density may be used to maximize carrot seed yield, but will not significantly improve seed quality.

Additional index words: *Daucus carota* **L., plant population, open-pollinated, hybrid, seed weight, germination.**

INTRODUCTION

Over thirty years ago, Robinson (1954) recognized low germination percentage of carrot (*Daucus carota* L.) seed as a recurrent problem that had plagued seed growers for decades. This problem continues today with occasional poor quality carrot seed crops still being produced (Dean et al., 1988). Through the years, various cultural methods to improve carrot seed quality and/or yield have been tested (Franklin, 1946; Harrington, 1951; Hawthorn et al., 1962; Longden, 1968; Gray, 1981; Andreoli, 1985). Attempts to improve carrot seed yield by manipulation of plant density (PD) have produced conflicting results. Most of these studies (Franklin, 1946; Gray and Steckel, 1983; Gray et al., 1983; Harrington, 1951; Hawthorn, 1951; Jacobsohn and Globerson, 1980; Longden, 1968) used only the root-to-seed method of seed production, which delays competition between plants when compared to the seed-to-seed method because in the root-to-seed method stecklings are not planted out until the spring of the second growing season. All of these researchers concluded that higher PDs resulted in greater seed yield. Two workers using the seed-to-seed method reported contradictory results. Gray (1981) claimed that yield continues to increase with PDs up to 256m^{-2}, whereas Hawthorn (1952) stated that seed yield declined above an optimum PD.

The precise effect of PD on carrot seed quality is unresolved. For example, Gray (1981) hypothesized that increasing PD should improve carrot seed quality because of the greater proportion of higher quality primary umbel seed being produced. However, he found no relationship between increasing PD and time to 50% germination, percent seedling emergence, and final percent germination of the seed. In one study, seed harvested from low planting densities (10 m^{-2}) were heavier than those from high planting densities (80 m^{-2}) (Gray et al., 1983). Since large carrot seed tend to germinate and emerge better than small seed (Borthwick, 1931; Jacobsohn and Globerson, 1980), this suggests that higher quality seed are produced at the lower PD. On the other hand, some support for Gray's hypothesis can be found in a report of slightly lower coefficients of variation for seed produced at a high density (80 plants m^{-2}) than at the lower density (10 plants m^{-2}) (Gray and Steckel, 1983).

These conflicting results indicate the need for more conclusive information on the effects of PD on carrot seed yield and quality. In addition, most studies used the root-to-seed method to examine PD effects. Currently, the seed-to-seed method is used almost exclusively for commercial carrot seed production in the United States. Therefore, more information is needed on how PD affects carrot seed yield and quality when employing the seed-to-seed production system. This study presents the results from three similar seed-to-seed PD experiments performed in the major carrot seed production areas of the United States: California, Oregon, and Washington.

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[1]Joint publication of USDA-CSRS Western Regional Technical Committee W-168. Research funded, in part, by a grant from the Columbia Basin Vegetable Seed Growers Association. Received 4 April, 1988.

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MATERIALS AND METHODS

California

The experiment was carried out in a commercial field located near Davis, CA. Carrot seed of an open-pollinated (OP) variety ('Danvers' type) were sown in August 1985 in single rows, spaced 80 cm apart. Accepted cultural practices were used throughout the study. Each plot consisted of two rows 3.30 m long (5.28 m^{-2} $plot^{-1}$). There were two guard rows (which were thinned to match the spacing of adjacent plots) between plots and a 0.70-m guard strip at the end of each plot. The seedlings were thinned at the 5th true leaf stage (8 Feb. 1986) in order to leave 5 (17 plants m^{-2}), 10 (12 plants m^{-2}), 20 (6 plants m^{-2}), or 30 cm (4 plants m^{-2}) between plants within a row. The experimental design was a randomized complete block with five replications.

Each treatment had an equivalent proportion (20%) of the plants harvested from a randomly selected 1.2-m section of row within each plot (five plants for the lowest density treatment). In order to document the effects of an unthinned (UT) plant population (36 plants m^{-2}), five random samples (all plants in a 1.2-m section of row) were taken from adjacent areas of the surrounding commercial field. Plots were harvested on 12 and 13 July 1986, when the seed on the primary umbels were mature and starting to shatter. The different umbel orders were harvested separately in each plot, placed in burlap bags, and dried at 27°C for 8 days. The seed were threshed, rubbed, cleaned, and stored at 6°C and 35% RH.

Oregon

Plots of hybrid (HYB) ('Imperator' type) carrots were established on the Madras research site of the Central Oregon Experiment Station on 6 August 1985. Each plot was 5.5 m long by 3 m wide (four 76-cm rows). The planting pattern was eight female rows, one blank row, and four male pollinator rows for the entire field. Recommended cultural practices were employed during the study. Thinning was performed on 14-17 March 1986. The plant densities used were UT (53 plants m^{-2}), removal of all plants in every other 10-cm segment of row (32 plants m^{-2}), 15 cm (8 plants m^{-2}), or 30 cm (4 plants m^{-2}) between plants within the row. Each treatment was replicated four times in a randomized complete block design on the female rows.

The two center rows of each plot (3 m of each) were hand harvested on 10 and 11 September 1986. All plants from one row were placed in a plastic-lined tote box for drying at ambient temperature. These plants were handled as the bulk portion of the plot. Plants from the other row were separated and the umbels were clipped according to umbel order. Samples were threshed with a belt thresher and scalped before a second threshing. A clipper M-2B air-screen cleaner was used to condition the seed.

Washington

Plots were established at the Irrigated Agriculture Research and Extension Unit at Othello, WA. One OP and one HYB carrot (both 'Nantes' types) were planted on 30 August 1985 in rows spaced 56 cm apart. The hybrid was planted in the following configuration: two rows pollen parent, two blank rows, and six rows of the seed parent. Each plot was three rows wide (two outside rows were guard rows) and 4.6-m long. Accepted commercial practices were performed for fertilization and weed control. At bolting (21 and 22 May 1986) three rows of carrots (one treatment and two guard) from each treated plot were left UT (47 plants m^{-2}), and thinned to 15 (12 plants m^{-2}), 30 (6 plants m^{-2}), and 56 cm (3 plants m^{-2}) between plants within the row. Each treatment was replicated four times in a completely randomized design.

When primary umbel seed were mature (13 August 1986) and beginning to shatter, four randomly chosen plants from each treatment were harvested. The primary and secondary umbels were removed during harvest, placed in separate paper bags, and dried in a greenhouse at ambient temperatures (about 30°C) for 10 to 14 days. The tertiary umbels were left on the plant, stored overnight in a greenhouse, removed from the plant the next day, and placed in paper bags to dry. All seed samples were threshed using a hammer mill and then conditioned with a Clipper small-model air-screen cleaner.

Parameters Measured in the Studies

Seed yield and 1,000-seed weight for each umbel order were determined. Germination percentage of all umbel orders (CA & WA) or of the bulk seeds (OR) was determined according to Association of Official Seed Analysts (AOSA) rules (AOSA, 1981). Germination rate for umbel order germinations (CA & WA) was calculated according to Maguire (1962). Mean values, computed according to the contribution of each umbel order to the total seed yield, were used for analysis. Mean separations were performed using Fisher's protected least significant difference (FLSD) at the 5% level.

RESULTS AND DISCUSSION

Seed Yield

Total carrot seed yield generally increased with increasing PD (Figure 1). In the CA and OR experiments, yield increased in response to increasing PD up to a point and then declined at the highest PD. However, in both the OP and HYB carrot plots of WA, yield contin-

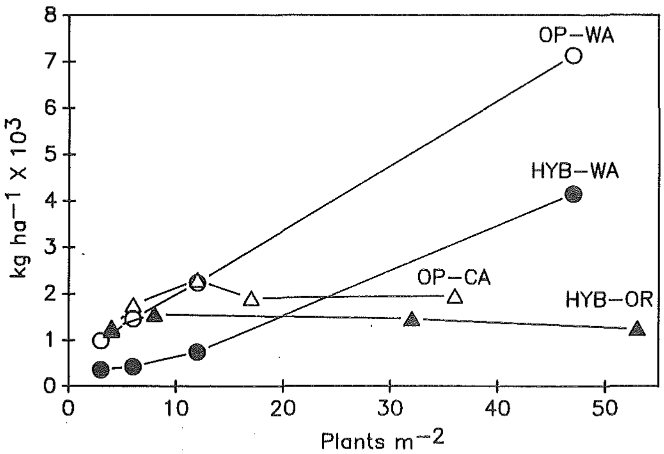

Fig. 1 The effect of plant density on total carrot seed yield at three locations.

ued to increase with increasing PD. The CA and OR results indicate there is an optimum PD (8 to 32 plants m^{-2}) at which maximum seed yield is attained. Carrot stands with PDs beyond this optimum appear to yield about the same or less. Hawthorn (1952) reported a similar trend with increasing PDs resulting in decreasing carrot seed yield in seed-to-seed production fields. However, in both the OP and HYB carrot plots of WA, seed yield continued to increase with PD, in agreement with Gray's (1981) report that carrot seed yield had no apparent upper limit with respect to PD.

Subsequent examination of harvesting methods employed in each of the preceding studies suggests a possible explanation for this discrepancy. In each of the studies indicating an apparent optimum PD for maximum seed yield (CA and OR from this study; Hawthorn, 1952) all carrot plants in a row or predetermined section of row were harvested for analysis. In the two studies indicating seed yield and PD were positively correlated with no apparent optimum (WA in this study; Gray, 1981), a certain number of carrot plants were randomly chosen for harvest. Even though these plants were chosen at "random", a bias towards plants which had seed present probably existed, especially at the higher densities. At the highest PD (36 plants m^{-2}) in CA about 10% of the plants failed to flower, and this value would likely increase with higher PDs. Therefore, randomly harvesting only plants with seeds could inflate the seed yield beyond its actual value. In the WA study, only plants with seed were harvested at all PDs. This bias, combined with the small number of plants harvested per plot (four), suggests that the abnormally high yields reported for the WA UT plots and Gray (1981) probably represent inflated values. Therefore, an optimum PD, at which carrot seed yield is maximized, probably does exist. The CA and OR data indicate the optimum PD is probably in the range of 8 to 32 plants m^{-2}. Oliva et al. (1988) showed that harvest index (carrot seed yield divided by total above ground biomass) also reached an optimum in this PD range, in agreement with the general response of many seed crops to increasing PD (Willey and Heath, 1969).

Increasing PD also tended to change the relative contribution of each umbel order to the total seed yield (Table 1). The primary (1°) umbel percentage contribution increased in response to higher PDs. On the other hand, tertiary (3°) umbel contribution to yield tended to decrease with increasing PD. This trend was evident at all three locations but was most prominent in the CA results where the 1° umbels contributed 62% of the yield and 3° umbels 0% at the highest PD. Secondary (2°) umbel contribution to yield changed little in response to PD alterations in WA, whereas in OR and CA the percentage contribution to yield by 2° umbels tended to decrease as PD increased.

Seed Quality

Carrot seed quality as measured by percentage germination was not significantly affected by PD while speed of germination was only slightly affected (Table 2). The maximum difference in overall mean percent germination between PDs was only 4% in the WA OP (86-90%) and 5% in the HYB (85-90%) seed. The OR HYB seed (88-91%) varied even less with a 3% difference, while the CA OP seed (66-73%) had the greatest, albeit nonsignificant, difference of 7%. WA HYB seed grown at 3 plants m^{-2}, on a whole plant basis, germinated somewhat faster than did the seeds harvested from all other PDs. Umbel order had a much greater effect, with the mean germination rate across all PDs tending to decrease with increasing umbel order in both the WA and CA seeds.

Umbel order had a significant effect on seed weight in WA and CA (Figure 2). The trend was for the 1° umbel seed to be the heaviest, the 2° seed intermediate, and the 3° umbel seed the lightest. This tendency was also noted by Thomas et al., 1978.

Seed weight was affected by PD, but only in the OR study, where one plant density, 32 plts m^{-2}, tended to produce heavier seed from 2° and 3° umbels (Table 3). However, these heavier seeds did not influence the mean percent germination. One study reported that carrot seed harvested from a relatively low density planting were heavier than those taken from a high density plot (Gray et al., 1983). Although these seeds were not tested for germination, other investigators have positively correlated carrot seed size with its ability to germinate and emerge (Borthwick, 1931; Jacobsohn and Globerson, 1980).

Table 1. Effect of plant density on carrot seed yield and percent contribution of each umbel order to total seed yield.

Plant density	Umbel order 1°	2°	3°		Umbel order 1°	2°	3°
	----kg ha^{-1}----				----% of Total yield----		
Plants m^{-2}							
				Washington OP			
47 [x]	1401 a[xx]	4283 a	1450 a		20	60	20
12	378 a	1215 b	642 a		17	54	29
6	251 a	793 b	414 a		17	55	28
3	125 a	513 b	348 a		13	52	35
				California OP			
36 [x]	1013 a	932 b	--		62	38	--
17	745 ab	1111 b	41 a		42	57	1
12	550 abc	1654 a	93 a		29	68	4
6	316 bc	1221 ab	225 a		20	70	10
4	219 c	910 b	90 a		22	72	6
				Oregon HYB			
53 [x]	438 a	676 c	138 b		35	54	11
32	336 b	921 bc	205 ab		23	63	14
8	93 c	1106 a	358 a		6	71	23
4	38 c	1018 ab	204 ab		3	80	16
				Washington HYB			
47 [x]	902 a	2599 a	647 a		22	63	15
12	167 a	399 b	178 a		22	54	24
6	83 a	255 b	86 a		20	60	20
3	53 a	210 b	95 a		15	59	26

[x]Unthinned control plots.
[xx]Values within a column of a single data set with the same letter are not significantly different using FLSD at the 5% level.

Table 2. Effect of plant density on carrot seed germination rate.

Plant density	Umbel order 1°		2°		3°		Mean	
	-----Germination rate-----							
Plants m^{-2}								
	Washington OP							
47 [x]	11.3	a[x]	11.8	a	10.0	a	11.0	a
12	10.8	a	11.6	a	9.5	a	10.7	a
6	11.2	a	11.9	a	10.2	a	11.1	a
3	12.3	a	11.8	a	10.8	a	11.6	a
UO Mean [xxx]	11.4	a	11.8	a	10.1	b	--	
	California OP							
36 [x]	11.1	a	9.2	a	--		10.2	a
17	10.8	a	9.7	a	4.5	a	8.3	a
12	11.0	a	8.7	a	8.4	a	9.1	a
6	10.9	a	10.1	a	8.6	a	9.9	a
4	11.8	a	9.1	a	4.8	a	8.6	a
UO Mean	11.1	a	9.4	b	6.6	c	--	
	Washington HYB							
47 [x]	10.3	a	10.3	a	8.0	a	9.5	b
12	9.6	a	9.4	a	7.3	a	8.8	b
6	10.2	a	11.0	a	7.7	a	9.7	b
3	12.1	a	12.1	a	9.6	a	11.3	a
UO Mean	10.5	a	10.7	a	8.1	b	--	

[x]Unthinned control plots.
[xx]Differences among means within a column of a single data set followed by the same letter are not significantly different using FLSD at the 5% level. The germination rate value is directly proportional to the speed of germination.
[xxx]Umbel order (UO) mean values within a single row followed by the same letter are not significantly different using FLSD at the 5% level.

Table 3. Effect of plant density on carrot seed weight.

Plant density	Umbel order 1°		2°		3°		Mean	
	-----g 1000^{-1} seeds-----							
Plants m^{-2}								
	Washington OP							
47 [x]	1.68	a[x]	1.69	a	1.68	a	1.69	a
12	2.04	a	1.81	a	1.63	a	1.80	a
6	2.02	a	1.74	a	1.70	a	1.78	a
3	1.99	a	1.79	a	1.64	a	1.76	a
	California OP							
36 [x]	1.36	a	1.15	a	--		1.27	a
17	1.27	a	1.06	a	1.01	a	1.17	a
12	1.32	a	1.19	a	1.00	a	1.21	a
6	1.31	a	1.14	a	0.99	a	1.19	a
4	1.27	a	1.17	a	0.86	a	1.20	a
	Oregon HYB							
53 [x]	1.60	a	1.44	b	1.40	ab	1.48	a
32	1.68	a	1.60	a	1.54	a	1.61	a
8	1.60	a	1.43	b	1.30	b	1.45	a
4	1.64	a	1.45	b	1.44	ab	1.51	a
	Washington HYB							
47 [x]	1.79	a	1.60	a	1.53	a	1.63	a
12	1.99	a	1.69	a	1.84	a	1.79	a
6	2.11	a	1.84	a	1.46	a	1.82	a
3	1.79	a	1.71	a	1.62	a	1.70	a

[x]Unthinned control plots.
[xx]Differences among means within a column of a single data set with the same letter are not significantly different using FLSD at the 5% level.

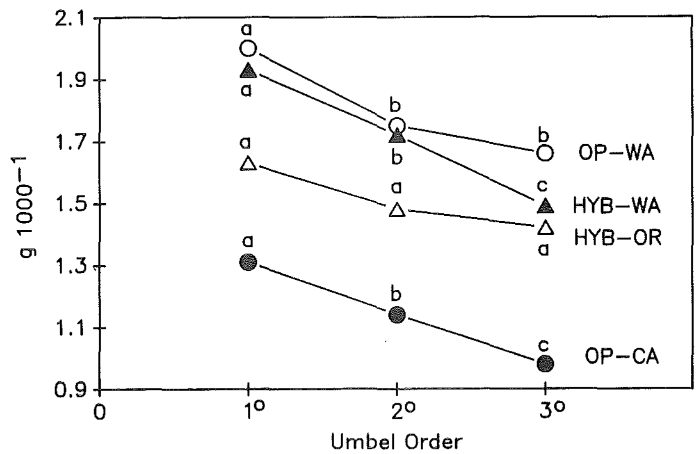

Fig. 2 The effect of umbel order on carrot seed weight at three locations. Values represent umbel order means averaged over all plant densities. Any value within a single line accompanied by the same letter are not significantly different using FLSD at the 5% level.

Based on the preceding results, it appears that manipulation of carrot seed quality by changing PD does not seem to be feasible. Although increasing PD usually increased the proportion of seed in the 1° umbel, no consistent relationship between percent germination or speed of germination and PD was noticed. Others have also failed to establish any correlation between PD and percent germination (Gray, 1981; Hawthorn, 1951; Harrington, 1951) or speed of germination (Gray, 1981) of carrot seed. Thus, despite the greater proportion of 1° umbel seed at high PDs, other factors apparently limit seed quality. Therefore, it is also interesting to note that the seed from the cooler growing areas of OR and WA were considerably heavier than the seed produced in the warmer climate of CA. In fact, in the 1° and 2° umbel seed, there appeared to be a positive relationship between seed weight and degrees of N latitude. This observation tends to support Gray et al.'s (1983) assertion that a warmer than usual growing season accentuated the differences in carrot seed weight between the low and high PDs. In addition, the heavier WA and OR seed had a notably higher percent germination than did the lighter CA seed. Also the WA OP seeds tended to germinate faster than did the CA OP seeds. In fact, wild carrot (*Daucus carota* L.) seed collected from 36° to 45° N latitude was germinated and found to have a positive correlation between percent germination and degrees of N latitude (Lacey, 1984). Although the growing environment has been shown to affect the carrot seed quality of many different commercial cultivars similarly (Dean et al., 1988), it should also be noted that different cultivars were used at the different sites in this study and their genetic differences also influenced seed weight and percent germination. In other words, genotype interaction may have influenced seed quality parameters about as much as did the environment.

CONCLUSIONS

1. In a seed-to-seed production system, there appears to be an optimum plant density in the range of 8 to 32 plants m^{-2} for maximum seed yield of carrots.
2. Except for slight effects on speed of germination and seed weight, plant density does not seem to affect carrot seed quality.
3. Manipulation of plant density may maximize carrot seed yield, but will not significantly improve seed quality.

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Outbreaks of March Fly *Bibio xanthopus* (Wiedemann) in Grass Seed Fields in Western Oregon

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ABSTRACT

The seasonal biology of the March fly, *Bibio xanthopus* (Wiedemann), is described for western Oregon. During outbreaks, large numbers of larvae destroyed seedling stands of commercial grass seed fields. Damage was most severe in minimum or no-tillage fields when winter rains saturated the soil and forced larvae to the surface where they aggregated in the seed furrow made by the coulter on the drill. Plowed fields sustained less damage because larvae were not as concentrated in the seed row. In laboratory tests, larvae fed only dead organic matter completed development and emerged as adults. During outbreaks, larvae inadvertently chew through small seedlings as they move through the soil. Because outbreaks cannot be predicted, early fall planting is recommended to obtain well-rooted plants that can withstand large larval populations.

Additional index words: **grass pests, fine fescue, ryegrass, pest management**

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INTRODUCTION

In 1977-78 and 1984-85, large numbers of *Bibio xanthopus* (Wiedemann) occurred in grass seed fields throughout the Willamette Valley of western Oregon. In Europe and Canada, March flies in the family Bibionidae occasionally damage cereals, grasses, and other crops. Most species feed on decaying plant material and play a valuable role in recycling nutrients (Hardy, 1945). A few species are omnivorous, first feeding as scavengers, but later feeding on living plant tissue. Swarms of adults that disperse from peat bogs in Florida are attracted to the hydrocarbon odors in automobile exhaust and become a nuisance near highways (Callahan and Denmark, 1973). Females prefer to oviposit in dead leaves, grass clippings, lawns, and pastures (Schremer, 1958). Little or no biological information is available for the Bibionidae because most are unmanaged beneficial decomposers of plant residues.

The present paper describes observations and tests with *Bibio xanthopus* (Wiedemann) in grass seed fields in the Willamette Valley of Oregon.