Row Arrangements, Seeding Rates, and Gibberellic Acid Treatments to Improve Yield of Machine-harvested Cilantro

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Abstract. Factorial combinations of two row arrangements on 1.8-m-wide beds (either four rows, each 30 cm apart, or eight rows, each 15 cm apart) and two in-row seeding rates (either 48 or 96 seeds per 30 cm of row) were compared on ‘Santo’ cilantro (*Coriandrum sativum* L.) in five experiments at Bixby, OK. Plots were harvested once per experiment by cutting at a height of ≈ 7 cm with a small-plot greens harvester, and fresh weight yields were taken. Treatments minimally affected canopy height at harvest. Eight rows resulted in higher yields than four rows in three of five experiments. Main effects of seeding rate or interactions of row number and seeding rate on yield were rare. Of the four combinations tested, the eight-row arrangement sown at 48 seeds per 30 cm would be recommended. This arrangement was used in three other experiments to test effects of a single preharvest spray application of gibberellic acid (GA). Treatments were a water control and GA at either 10 or 20 g·ha⁻¹. Treatment with GA increased bolting in a 17 Apr. planting and increased canopy height at harvest in two of three experiments. However, GA treatments did not affect yield. Treatment with GA would not be recommended for a spring cilantro crop and may have limited impact on increasing machine recovery of raw product in a fall crop.

Coriander is a crop of worldwide importance, although it is more commonly used for its fruits than as a green herb (Diederichsen, 1996). The name given to the green herb varies regionally, but the Spanish name “cilantro” is commonly used in the Americas.

Cilantro is one of several herbs being studied for production as an extraction processing crop in Oklahoma. Mechanical harvest and high yields will be necessary to produce the volume of fresh product needed to profitably run an extraction facility. Initial trials did not result in adequate product volume. Limited guidance was available for improving yield, because relatively few of the studies on cultural practices for coriander

have focused on its production as a green herb (Diederichsen, 1996). Diederichsen (1996) recommended a sowing rate of 3 to 20 kg·ha⁻¹ for production of coriander fruits but a sowing rate of 50 to 55 kg·ha⁻¹ for production of cilantro. Laemmlein and Smith (1998) described a cilantro production system for California using raised beds 97 to 102 cm wide with two seedlines per bed, sowing rates of 28 to 112 kg·ha⁻¹, and a desired population of two to four plants/in² (6.45 cm²) of seed line. Mangan et al. (2001) grew cilantro at various seedling densities (reported as 3, 13, 23, 33, and 53 plants/ft, roughly equivalent to 10, 42, 75, 108, and 174 plants/m) and obtained increased fresh weight with increased seedling density. Therefore, we hypothesized that a relatively high plant population might improve yield.

Another approach to increase the yield of a machine-harvested leafy greens crop is to use gibberellic acid (GA) to increase crop height at harvest. Gonzalez and Marx (1983) found that, for spinach (*Spinacia oleracea* L.) sown in late summer or fall, 20 g·ha⁻¹ of GA applied 2 weeks before harvest improved plant height and yields. Dainello et al. (1985) got the best fall spinach yield response with GA₃ at 15 to 20 g·ha⁻¹ applied 7 to 14 d before harvest. Johnson et al. (1989) recommended GA₃ at 9 to 17 g·ha⁻¹ applied 7 to 12 d before harvest for fall spinach. Gibberellin promotes flowering in several long-day species (Lang, 1957), but unlike spinach, cilantro has little or no sensitivity to photo-

period for flowering (Diederichsen, 1996). Therefore, we hypothesized that GA might be useful for improving cilantro production.

This research was designed to increase cilantro yields by increasing the plant population on the standard 1.8-m-wide beds used for machine harvest and to examine the potential of GA as a harvest aid to increase machine recovery of raw product.

Materials and Methods

Studies were conducted at the Oklahoma Vegetable Research Station, Bixby, in 2006 and 2007 on a Severn very fine sandy loam [coarse-silty, mixed (calcareous), thermic Typic Udifluvent]. In each experiment, the soil was prepared with a broadcast preplant-incorporated application of urea to supply 56 kg·ha⁻¹ nitrogen (N). Only N fertilizer was applied, because adequate supplies of other macronutrients were available from fertilization of previous trials. The cultivar Santo was used. Seeds were sown with a cone-type plot seeder (Hege Equipment, Colwich, KS) at a depth of 1 to 1.5 cm. Weeds were controlled with a pre-emergence application of S-metolachlor at 730 g·ha⁻¹ supplemented by hand and machine cultivation. Plant water requirements were met with rainfall supplemented by overhead sprinkler irrigation. In each experiment, plants received one topdress application of urea to supply 56 kg·ha⁻¹ N. Heights (soil to the top of the canopy) were measured at 10 randomly selected locations per plot just before harvest. Plots were harvested once per experiment with a compact forage/greens harvester (Kincaid Equipment, Haven, KS). The machine cut plants with a sickle bar at an average height of 7 cm and conveyed the cut material into plastic totes. Fresh weights were recorded immediately after harvest. Dates for key procedures in all experiments are shown in Table 1.

Five experiments (designated P-1 through P-5) compared factorial combinations of two row arrangements on 1.8-m-wide beds (either four rows, each 30 cm apart, or eight rows, each 15 cm apart) and two in-row seeding rates (either 48 or 96 seeds per 30 cm of row). Beds were not raised and not mulched. For convenience, these treatments were designated 4L (four rows, 48 seeds per 30 cm of row); 4H (four rows, 96 seeds per 30 cm of row); 8L (eight rows, 48 seeds per 30 cm of row); and 8H (eight rows, 96 seeds per 30 cm of row). Seeding treatments were adapted for mechanical harvesting on a 1.8-m-wide bed from the general cilantro plant population guidelines of Laemmlein and Smith (1998). Plots were 6 m long with alleys of 1.5 m between plots; thus, the experimental unit was one bed 1.8 m wide and 6 m long. The experimental design for Expts. P-1 through P-5 was a randomized complete block with four replications.

Three other experiments that compared GA treatments (designated G-1 through G-3) used only the 8L arrangement. There was a water control and two treatments based on a 4% solution of GA (Valent U.S.A., Walnut

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Table 1. Dates of key procedures for cilantro field experiments.

	Expt. P-1 (2006)	Expt. P-2 (2007)	Expt. P-3 (2007)	Expt. P-4 (2007)	Expt. P-5 (2007)	Expt. G-1 (2007)	Expt. G-2 (2007)	Expt. G-3 (2007)
Planting (seeding in field)	31 Aug.	20 Mar.	3 Apr.	17 Apr.	13 Sept.	20 Mar.	17 Apr.	13 Sept.
Topdress fertilization ^a	25 Sept.	3 May	17 May	31 May	9 Oct.	3 May	31 May	9 Oct.
Harvest	14 Nov.	24 May	4 June	14 June	14 Nov.	24 May	14 June	14 Nov.

^aTopdressing was with urea to supply 56 kg·ha⁻¹ of nitrogen.

Table 2. Effects of number of rows per bed and in-row seeding rate on height and fresh weight yield of machine-harvested cilantro.

Treatment ^y	Expt. P-1, 2006		Expt. P-2, 2007		Expt. P-3, 2007		Expt. P-4, 2007		Expt. P-5, 2007	
	Ht (cm)	Yield ^z (Mg·ha ⁻¹)	Ht (cm)	Yield (Mg·ha ⁻¹)	Ht (cm)	Yield (Mg·ha ⁻¹)	Ht (cm)	Yield (Mg·ha ⁻¹)	Ht (cm)	Yield (Mg·ha ⁻¹)
4L	29	5.6 b	—	5.1	28	6.5	30	12.1	13	1.1
4H	30	6.8 ab	—	8.8	32	10.3	31	13.6	14	1.2
8L	31	8.2 a	—	9.4	32	10.3	31	16.5	18	3.4
8H	28	6.8 ab	—	11.9	32	11.8	31	17.5	17	3.8

Main effects of row number and seeding rate, their interaction, and correlation (r) of height with yield

Row number	NS	*	—	*	NS	NS	NS	**	*	*
Seeding rate	NS	NS	—	*	NS	NS	NS	NS	NS	NS
Interaction	NS	*	—	NS	NS	NS	NS	NS	NS	NS
Correlation	0.75**		—		0.89**		0.84**		0.84**	

^aFor interpretation of interaction, means in column followed by the same letter do not differ at $P \leq 0.05$ by least significant difference.

^yTreatment symbols show number of rows per bed (four rows, each 30 cm apart; or eight rows, each 15 cm apart) and in-row seeding rate (L = 48 seeds per 30 cm of row, H = 96 seeds per 30 cm of row).

NS, *, **Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

Table 3. Effects of gibberellic acid (GA) treatments on height and fresh weight yield of machine-harvested cilantro.

GA rate (g·ha ⁻¹)	Expt. G-1, 2007		Expt. G-2, 2007			Expt. G-3, 2007	
	Ht (cm)	Yield (Mg·ha ⁻¹)	Bolting rating ^z	Ht (cm)	Yield (Mg·ha ⁻¹)	Ht (cm)	Yield (Mg·ha ⁻¹)
0	26	10.1	1.9	31	16.4	19	4.8
10	27	11.7	3.4	33	15.8	23	5.8
20	25	9.8	3.3	32	16.4	24	5.6
<i>Contrasts within GA rates and correlation (r) of height with yield</i>							
Control (0) versus GA	NS	NS	**	*	NS	**	NS
10 versus 20 g·ha ⁻¹	NS	NS	NS	NS	NS	NS	NS
Correlation	0.89**		0.47 NS		0.59*		

^aBolting rating based on 1 (20% or less bolting) to 5 (80% or greater bolting). A transformation [square root (x + 1)] was applied before analysis. Back-transformed means are shown.

NS, *, **Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

Creek, CA) diluted to provide 10 or 20 g·ha⁻¹ of a.i. A surfactant (polysorbate 20 at 1 mL·L⁻¹) was included in spray solutions. Treatments were applied to the cilantro plants once per experiment with a CO₂ backpack sprayer calibrated to deliver 74 L·ha⁻¹. Dates of application were 17 May 2007, 5 June 2007, and 1 Nov. 2007 for Expts. G-1, G-2, and G-3, respectively. A completely randomized experimental design with five replications was used for each of the three GA experiments.

Data were subjected to analysis of variance procedures. Main effects of row number and seeding rate, and their interaction, were tested in Expts. P-1 through P-5. Effects of GA in Expts. G-1 through G-3 were evaluated with orthogonal contrasts. Correlation coefficients (r) for plant height at harvest with yield (fresh weight) also were calculated in seven of the eight total experiments, the exception being Expt. P-2, in which heights were not measured.

Results and Discussion

Canopy height at harvest was minimally affected by row number and unaffected by seeding rate (Table 2). Eight rows resulted in higher yields than four rows in three of five

experiments. Main effects of seeding rate or interactions of row number and seeding rate on yield were rare. Within a given planting pattern (four or eight rows), the higher seeding rate resulted in higher yields than the lower seeding rate only in Expt. P-2 (Table 2). Given that both the 4H and 8L combinations would produce the same theoretical plant population ($\approx 10.33 \times 10^6$ plants/ha), the data favor the eight-row arrangement. This population is within the range recommended by Laemmle and Smith (1998) but arranged so as to facilitate mechanical harvest on a 1.8-m-wide bed.

Hot weather causes cilantro to bolt to seed very quickly, and development of foliage is inhibited (Laemmle and Smith, 1998). Therefore, it is not surprising that bolting was observed only in our spring-planted cilantro (Table 3). Bolting was just beginning when Expt. G-1 was harvested (24 May), so no data were taken. However, flower stalks had visibly elongated when Expt. G-2 was harvested (14 June), and the GA treatments increased bolting and mean canopy height over the control (Table 3). There was no visible bolting when Expt. G-3 was harvested (14 Nov.), but plants in the GA-treated plots appeared taller than control plants, which was confirmed by measurements (Table 3).

Treatments with GA did not affect yield in any of the experiments, and no effects of GA rate were seen (Table 3). Although treatments with GA have been used to promote flowering and fruit production in coriander (Panda et al., 2007), bolting and flowering are undesirable in cilantro. Reports published after our studies were initiated show that GA applications at higher rates (50 $\mu\text{L}\cdot\text{L}^{-1}$) may enhance cilantro leaf yield (Meena and Malhotra, 2006; Verma and Sen, 2008).

Canopy height at harvest was strongly correlated with yield whenever there were no pronounced plot-to-plot height differences resulting from bolting (Tables 2 and 3). However, even when GA treatments affected canopy height (Expts. G-2 and G-3), there were no corresponding effects on yield (Table 3). Using a plant arrangement and seeding rate combination that maximizes overall biomass production appears to be more important for improving yield than manipulating treatments to increase canopy height.

These studies were not designed specifically to test the effects of planting date. However, stand establishment was difficult under the climatic conditions of August (high temperatures), and fall yields typically were lower than those from spring plantings.

Of the four combinations tested, the eight-row arrangement sown at 48 seeds per 30 cm (8L) would be recommended to improve yield of machine-harvested cilantro. Given the general lack of response to our seeding rates and the range of recommendations in the literature, lower seeding rates should be tested. Treatment with GA would not be recommended for a spring cilantro crop. Although further studies could be conducted, treatment with GA also may have a limited impact on increasing machine recovery of raw product in a fall crop.

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