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Effect of shoot-bending on productivity and economic value estimation of cut-flower roses grown in Coir and UC Mix

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Abstract

Shoot-bending, a common cultural practice in cut-flower rose production, results in a canopy consisting of horizontally bent shoots in addition to upright shoots. Production of this bent canopy was compared with hedgerow canopy for two rose cultivars, ‘Kardinal’ and ‘Fire N Ice’. In conjunction with the two canopy styles, two soil-less horticultural systems with different growing media (Coir versus UC Mix) were tested in a 2×2 factorial experiment. We investigated the number and length of all harvested flowering shoots as indicators of productivity and quality, respectively, from September 1997 to August 1999. While bent canopy produced longer stems and higher biomass of individual flowering shoots in both cultivars, this also resulted in significantly fewer harvestable flowering shoots. The comparison between Coir versus UC Mix was not as conclusive. ‘Fire N Ice’ plants grown in Coir produced more harvestable flowering shoots than plants grown in UC Mix, while ‘Kardinal’ did not. Neither cultivar showed differences in stem length and biomass production of the flowering shoots between Coir and UC Mix. Calculation of market value using a linearly increasing value index with stem length showed that with ‘Fire N Ice’ the improvement in stem length achieved by bent canopy did not offset the economic loss due to the reduction in the number of shoots per square meter. For ‘Kardinal’ the increased quality as a result of shoot-bending did offset the reduced production. In neither case did the combination of bent canopy and Coir generate significant improvements in value. Bent canopy became economically feasible when both short-stem discount and long-stem bonus were applied together.
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Keywords: Rosa hybrida L.; Canopy management; Economic analysis; Hydroponics

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1. Introduction

Bending non-productive shoots (short stem, small stem caliper, potential blinds) down into the canopy or towards the aisle became a standard method in cut-flower rose production (Ohkawa and Suematsu, 1999; Särkkä and Rita, 1999). Bending is generally done continually over the entire growing season. While in traditional production, a tall hedgerow canopy assures ample foliage area to capture light, with this shoot-bending, it is theoretically possible to maintain the lower canopy height without sacrificing foliage area. Low canopy height also facilitates the light interceptions by basal shoots, emerged from or near the primary shoot. The basal shoots are usually vigorous and important source of flower production (Zieslin and Mor, 1981).

Ohkawa and Suematsu (1999) reported that bending resulted in higher shoot quality but less harvestable shoots per plant in commercial greenhouses. They suggested that the production count per area, however, could be compensated by increasing plant density. Similar results were reported by Särkkä and Rita (1999) who found that bending resulted in higher quality, fewer blind shoots (aborted flower buds) and higher yield in 'Mercedes'. The success of applying bending to rose production has been generally attributed to the possibility of bent shoots acting as a source of carbohydrates, presuming that they capture ample light and actively photosynthesize after bending.

Kool and Lenssen (1997) reported that in newly developing young rose plants, bending increased the development rate, stem diameter, weight, leaf area index (LAI) and cross-sectional area of basal shoots. Stem diameter and degree of branching of basal shoots determine the potential flower production of the plant (Marcelis-Van Acker, 1993). Mosherp and Turner (1999) compared the productivity of a canopy management system that they named "trellis", described as a system restraining the basal shoots at an angle of approximately 30°, with the traditional management system. The trellis system produced more flowering shoots and longer stems for cvs. 'Gabrielle' and 'Kardinal'. Mosher and Turner (1999) attributed the increased production and quality in the trellis system to increased light penetration to basal parts, and to bending of basal shoots per se that stimulated the formation of more basal shoots. Le Bris et al. (1998) reported that when a primary shoot was bent horizontally to promote the growth of proximal secondary buds, these buds gave rise to basal shoots.

In recent years, most rose growers have switched from in-ground to various soil-less media cultures in conjunction with bending. One of the commonly used substrates is coconut coir (Coir). Raviv et al. (2000) found that Coir grown 'Kardinal' plants produced 19% more flowers than plants grown in UC Mix, while quality parameters were identical in both media.

With widespread adoption of these new methods, it is necessary to develop optimal production strategies. In particular, the two methods (bending and hydroponic) and their interactive effect on long term productivity and marketing are of interest. In roses, economic return is directly related to the stem length and number of shoots produced. The objective of the study was to compare the combinations of two canopy styles and two growing media (i.e., bent versus hedgerow, and Coir versus UC Mix) in terms of crop productivity and quality as quantified by number of harvested shoots and their length over 2 years, respectively. We also sought to identify the degree to which these methods separately, or in combination, are economically feasible.

2. Materials and methods

2.1. Plant culture

Rooted cuttings of cultivars ‘Kardinal’ and ‘Fire N Ice’, rootstock ‘Natal Brier’, were transplanted into the experimental plots at a density of 5.2 plants/m^2 on 23 May 1997 in the glasshouse in the Department of Environmental Horticulture at the University of California, Davis, CA.

Containers (12 l), filled with a layer of expanded clay pellets at a depth of 5 cm (approximately 2 l) and coconut coir (Systems USA, Watsonville, CA) at a depth of 18 cm (approximately 10 l) as a substrate, were used with timed drip irrigation. Two plants were planted per container. This culture is called “Coir” hereafter for brevity. Root zone moisture tension of the Coir system was maintained between 0.5 and 1 kPa.

Modified UC Mix, containing sand, redwood sawdust and peat moss (1:1:1, v/v/v) in large redwood boxes (30 cm × 115 cm × 25 cm) was used as a control treatment. The plants in UC Mix were irrigated using an automated tensiometer-based irrigation system with set-points of 1.0 and 3.0 kPa (Lieth and Burger, 1989). Eight plants were planted within each redwood box, resulting in the same planting density as in the Coir system. This system is referred to as “UC Mix” hereafter. Plants were first pinched, on 4 June, leaving 4–6 leaves on the primary shoots followed by the second pinch on 26 June. All plants were watered with modified half-strength Hoagland’s Solution No. 2 plus micronutrients (Hoagland and Arnon, 1950). Air temperature set-points inside the greenhouse were 24 and 20 °C for day and night, respectively.

2.2. Experimental design

A 2 × 2 factorial experiment was set up to compare Coir versus UC Mix, and bent versus hedge plants, for each of the cultivars. The experimental plot in the greenhouse consisted of six rows with north–south row direction and each row was divided into three sections. Environmental variables (air temperature, humidity, and light) along the row direction were maintained uniformly while temperature and humidity were gradient across the rows as the cooled air flowed from east (cooling pads) to west (fans). Hedge plants were designated to the section located on the north side of the greenhouse to prevent these plants from shading and obstructing the airflow for bent plants. Then, growing media treatment (Coir or UC Mix) was randomly assigned to the experimental units, which consisted of eight plants. The first shoot-bending for bent canopy was imposed on 14 July 1997 for the shoots at the stage of a pea-sized flower bud. These shoots were bent into the aisle by making a kink at the base of the shoot. Subsequently, short (mostly 40 cm or less) or blind shoots were bent weekly throughout the experiment. The shoot-bending resulted in a bent canopy consisting of (1) shoots bent horizontally and/or downward in both aisles, as well as (2) an upright canopy consisting of harvestable shoots. Flower buds of the bent shoots were removed when bent. For the hedge plants, bottom breaks were allowed to develop and pinched at the second or higher complete leaf for branching. Blind shoots (i.e., aborted flower buds) were removed from the hedge canopy and all flowering shoots were counted and harvested.

2.3. Data collection and analysis

Stem length and number of harvested flowering shoots per experimental unit were measured three times a week to assess the productivity and quality of cut-flower roses from September 1997 to August 1999. Flowering shoots were deemed harvestable when at least one sepal of the flower had reflexed horizontally. Stem length of flowering shoots was measured from the shoot base to the base of the flower bud before harvesting. The flowering shoots of non-bent canopy were removed approximately 0.5 to 1 cm above the first or second five-leaflet leaf (depending on leaf size). For bent plants, harvesting was done above the first leaf regardless of the number of leaflets.

Dry matter of the harvested flowering shoots was measured during June, July and August 1998. Flower, leaves and stem of each shoot were separated and dried at 75 °C for 2 days, then weighed.

Statistical analyses were done using SAS GLM (Littell et al., 1991). Two separate data analyses were performed, one on all harvested shoots and the other on shoots longer than 40 cm.

2.4. Economic value calculation

Stem length is the primary indicator for economic value in cut-flower rose production. We estimated economic value of every stem that was harvested during the experiment so as to determine whether improved quality, as characterized by longer stems, compensated for the decrease in stem count. Since this is related to market forces that reward longer stems, we also were interested in comparing the economic returns under various market conditions that selectively determine the value of flowers according to their stem length. Thus we calculated six different indices, each representing a separate approach to how the market rewards or discounts rose shoots for quality. We assumed that cost at production are identical for the various management systems.

First, shipping point market price of US domestic roses, including hydroponically grown, at central California coast was obtained for 12 November 1997, 23 August 1999, and 21 August 2000 where the market demand was fairly steady from National Ornamental Shipping Point Report, Agricultural Marketing Service, USDA (http://www.ams.usda.gov/marketnews.htm). A value index (V_1) was developed to reflect the observed pattern, setting 25 cm as a minimally marketable stem length (Fig. 1):

$$V_1 = \begin{cases} 0 & \text{if SL} < 25 \\ 0.231 + 0.00412(\text{SL} - 25) & \text{if SL} \geq 25 \end{cases}$$

where SL is the stem length (cm). This index is intended as a method for accounting economically for stem quality of steady market condition in our analysis. Since it may be

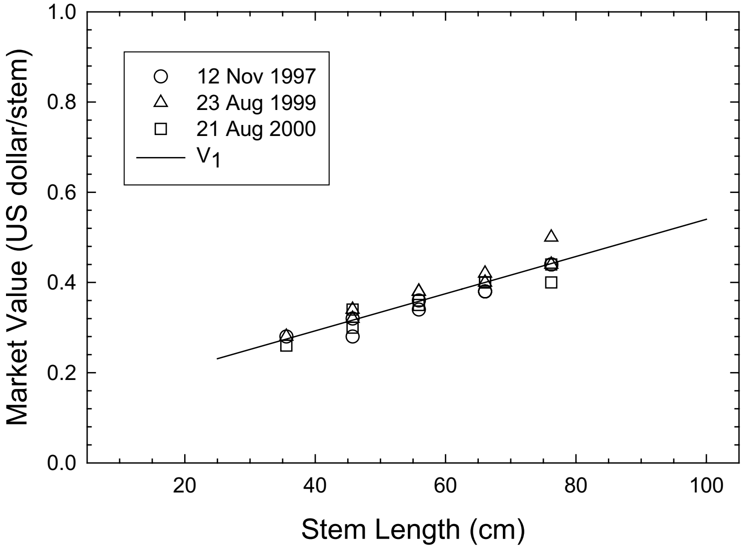

Fig. 1. Market value estimation of a rose stem. Shipping point market value of rose stems at central California coast on 12 November 1997, 23 August 1999, and 21 August 2000 was obtained from National Ornamental Shipping Point Report, Agricultural Marketing Service, USDA. Linear regression of market value on stem length represents estimated value index (V_1).

possible that relatively weaker stems would be sold at much lower price than the value predicted by V_1, we also set up index V_2 to model a value of only 50% of V_1 for stems shorter than 40 cm

$$V_2 = \begin{cases} 0 & \text{if SL} < 25 \\ \dfrac{0.231 + 0.00412(\text{SL} - 25)}{2} & \text{if } 25 \leq \text{SL} < 40 \\ 0.231 + 0.00412(\text{SL} - 25) & \text{if } 40 \leq \text{SL} \end{cases}$$

We calculated V_3 from V_1 for the case where the short stems (<40 cm) are not marketable at all

$$V_3 = \begin{cases} 0 & \text{if SL} < 40 \\ 0.231 + 0.00412(\text{SL} - 25) & \text{if SL} \geq 40 \end{cases}$$

V_4 was calculated from V_1 by doubling the value for stems longer than 60 cm

$$V_4 = \begin{cases} 0 & \text{if SL} < 25 \\ 0.231 + 0.00412(\text{SL} - 25) & \text{if } 25 \leq \text{SL} < 60 \\ [0.231 + 0.00412(\text{SL} - 25)]2 & \text{if } 60 \leq \text{SL} \end{cases}$$

We computed V_5 which applies both the short-stem discount (50%) as in V_2, as well as the long-stem bonus as in V_4

$$V_5 = \begin{cases} 0 & \text{if SL} < 25 \\ \dfrac{0.231 + 0.00412(\text{SL} - 25)}{2} & \text{if } 25 \le \text{SL} < 40 \\ 0.231 + 0.00412(\text{SL} - 25) & \text{if } 40 \le \text{SL} < 60 \\ [0.231 + 0.00412(\text{SL} - 25)]2 & \text{if } 60 \le \text{SL} \end{cases}$$

Finally, we calculated V_6 that holds the long-stem bonus as in V_4 and short-stem discount (100%) as in V_3

$$V_6 = \begin{cases} 0 & \text{if SL} < 40 \\ 0.231 + 0.00412(\text{SL} - 25) & \text{if } 40 \le \text{SL} < 60 \\ [0.231 + 0.00412(\text{SL} - 25)]2 & \text{if } 60 \le \text{SL} \end{cases}$$

The resulting index values for each stem were analyzed for differences among the treatments.

Table 1
Total number of flowering shoots per square meter, average stem length of flowering shoots, and dry matter (g) distribution among parts of individual flowering shoots grown either in Coir or UC Mix, and in bent or hedge canopy[a]

Culture	Canopy	Production count (shoots/m^2)	Stem length (cm)	Dry matter per shoot (g)			
				Stem	Leaves	Flower	Total
cv. Kardinal							
Coir	Bent	284 a	64.9 a	5.15 a	3.61 a	1.58 a	10.30 a
	Hedge	320 a	56.1 b	3.42 b	3.32 ab	1.50 a	8.28 b
UC Mix	Bent	266 a	65.1 a	5.32 a	3.55 ab	1.56 a	10.43 a
	Hedge	331 a	55.7 b	3.72 b	3.15 b	1.45 a	8.22 b
Probability > F	Culture	0.8593	0.9329	0.4632	0.2785	0.6385	0.9289
	Canopy	0.0182	<0.0001	0.0006	0.0081	0.1963	0.0003
	Interaction	0.4311	0.7267	0.8413	0.6015	0.8465	0.7942
cv. Fire N Ice							
Coir	Bent	292 c	76.1 a	6.32 a	6.11 a	1.71 a	14.14 a
	Hedge	537 a	51.6 b	3.09 c	3.96 b	1.42 a	8.32 b
UC Mix	Bent	289 c	73.9 a	6.07 ab	6.02 a	1.70 a	13.81 a
	Hedge	475 b	52.4 b	3.57 bc	4.18 ab	1.46 a	9.09 b
Probability > F	Culture	0.0339	0.4508	0.812	0.8847	0.9153	0.8388
	Canopy	<0.0001	<0.0001	0.0004	0.0017	0.0171	0.0009
	Interaction	0.0499	0.1371	0.475	0.7337	0.8301	0.6055

[a] The number of flowering shoots per square meter and stem length were calculated over the entire experimental period (September 1997–August 1999), while dry matter was measured on shoots harvested from July to September in 1998. Values with the same letter within a column for each cultivar are not significantly different according to Tukey–Kramer method of multiple comparison at $P = 0.05$.

3. Results

3.1. Overall production and quality

Over the course of the experiment bent plants of 'Fire N Ice' resulted in stems that were 23 cm longer than harvested from hedge plants (Table 1). For 'Kardinal' this difference was 9 cm. For 'Fire N Ice' bent canopy produced far fewer harvestable flowering shoots: 340 shoots for bent versus 506 shoots for hedge plants per square meter. Reduction in stem count due to bending was also observed in 'Kardinal' plants ($P = 0.0182$). Bent canopy produced increased dry matter of each part of the harvested shoot in both cultivars except the flower bud for 'Kardinal'. However, no differences between Coir and UC Mix occurred in dry matter of any shoot parts (Table 1). For 'Fire N Ice', a marginal interaction between canopy regimes and growing media was observed in production count ($P = 0.050$) as the shoots per square meter of the bent plants appeared to increase in Coir (Table 1). The frequency distribution of harvested stem lengths with 10 cm interval illustrates that 'Kardinal' plants had more concentrated distribution than 'Fire N Ice' plants (Figs. 2 and 3).

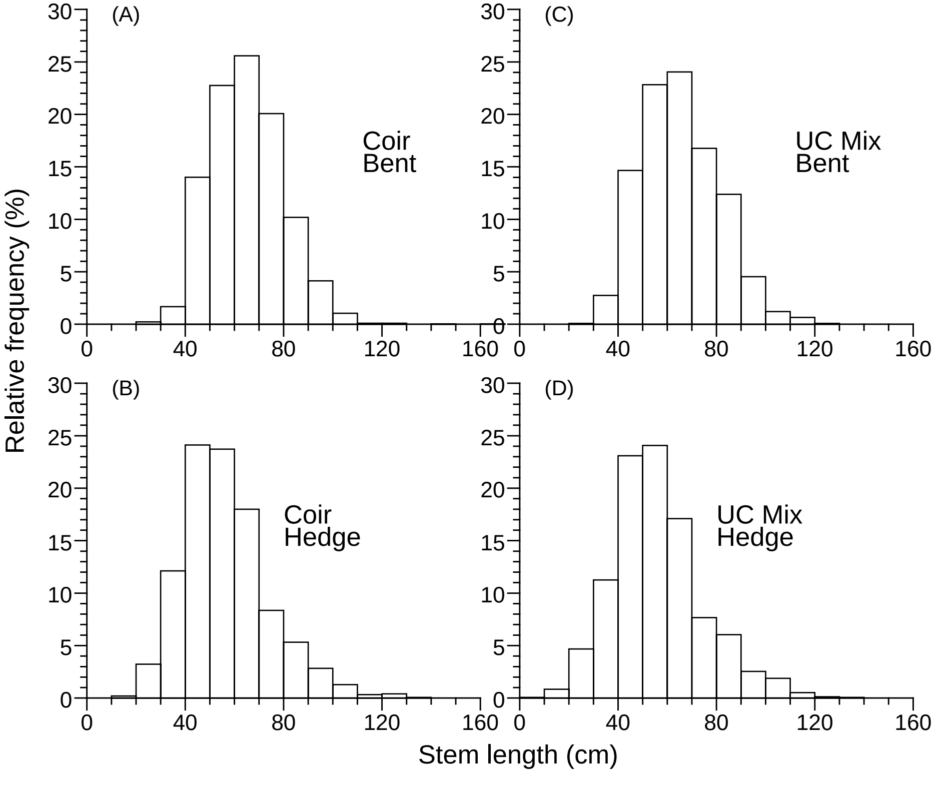

Fig. 2. Relative frequency of stem length distribution of harvested flowering shoots in cv. 'Kardinal'. Each class is a 10 cm stem length interval. Vertical bars represent the frequency of each stem length class relative to total harvested shoots of the treatment.

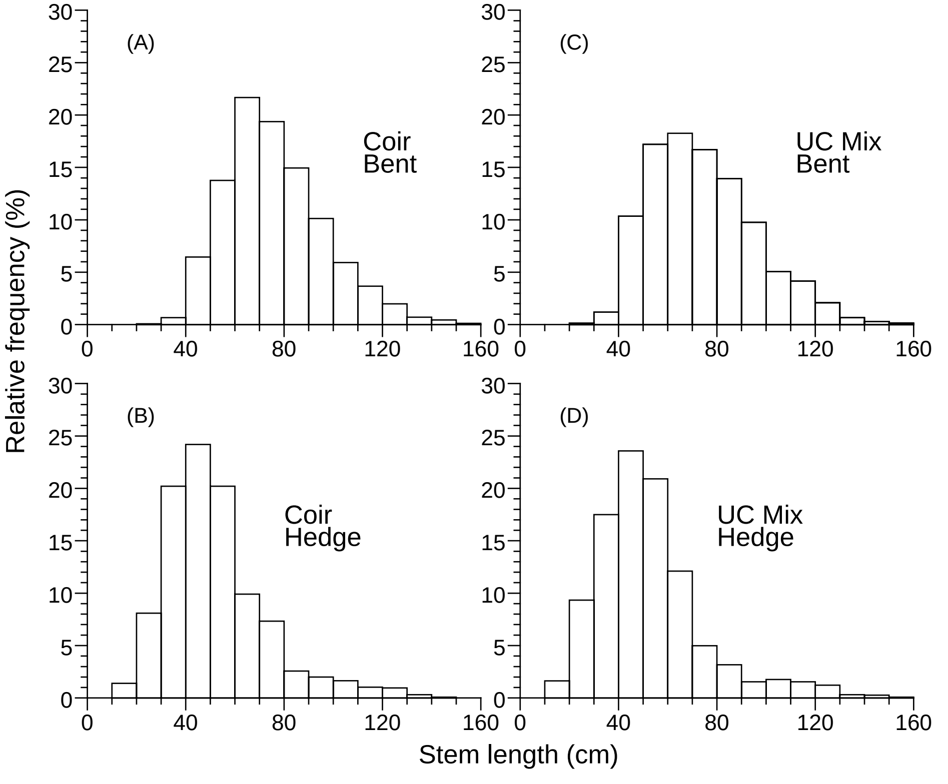

Fig. 3. Relative frequency of stem length distribution of harvested flowering shoots in cv. 'Fire N Ice'. Each class is a 10 cm stem length interval. Vertical bars represent the frequency of each stem length class relative to total harvested shoots of the treatment.

For 'Kardinal', approximately 17 and 3% of the harvested shoots from hedge and bent plants, respectively, were shorter than 40 cm (Fig. 2). For 'Fire N Ice', more than 25% of the shoots of hedge treatment were shorter than 40 cm compared to less than 3% in bending treatment (Fig. 3).

3.2. Production and quality of the shoots longer than 40 cm

When only the shoots longer than 40 cm were considered, the increase in stem length by bent canopy was less striking (Table 2). Shoots from bent canopy were 7 and 15 cm longer for 'Kardinal' and 'Fire N Ice', respectively. For 'Kardinal', bending did not affect stem count, but 'Fire N Ice' produced 63 shoots fewer per square meter in bent canopy ($P = 0.0002$). Bent canopy still produced longer stems and increased total dry matter per shoot for both cultivars. No differences were found between Coir and UC Mix for any of the analyzed variables.

Table 2
Total number of flowering stems per square meter, average stem length and dry matter (g) distribution among parts of the flowering shoots that were longer than 40 cm[a]

Culture	Canopy	Production count (shoots/m^2)	Stem length (cm)	Dry matter per shoot(g)			
				Stem	Leaves	Flower	Total
cv. Kardinal							
Coir	Bent	276	65.7	5.15	3.6	1.58	10.3
	Hedge	263	61	3.65	3.45	1.52	8.67
UC Mix	Bent	255	66.2	5.41	3.59	1.57	10.57
	Hedge	268	61.1	4.08	3.37	1.47	8.81
Probability > F	Culture	0.6792	0.7619	0.3395	0.6788	0.6975	0.6435
	Canopy	0.9944	0.0006	0.0033	0.1322	0.2841	0.0045
	Interaction	0.485	0.8275	0.8105	0.7987	0.7823	0.8948
cv. Fire N Ice							
Coir	Bent	288	76.7	6.36	6.14	1.71	14.22
	Hedge	368	60.6	3.34	4.21	1.46	8.8
UC Mix	Bent	283	74.7	6.15	6.07	1.7	13.93
	Hedge	330	61.4	4.26	4.64	1.54	10.2
Probability > F	Culture	0.0835	0.5295	0.4514	0.67	0.6981	0.5835
	Canopy	0.0002	0.0001	0.0006	0.0032	0.0449	0.0016
	Interaction	0.1754	0.1132	0.2479	0.5519	0.6279	0.4145

[a] The number of flowering shoots per square meter and stem length were calculated over the entire experimental period (September 1997–August 1999), while dry matter was measured on shoots harvested from July to September in 1998.

3.3. Value index estimation

The estimated value indices ranged from 105 to 185 for ‘Kardinal’ plants depending on the simulated market conditions (Table 3). The range was from 124 to 239 for ‘Fire N Ice’. For both ‘Kardinal’ and ‘Fire N Ice’, the effect of bending was most pronounced when a long-stem bonus and a short-stem discount were applied (V_5 and V_6). On the other hand, when neither incentives for long-stems nor discounts for short-stems were applied (V_1), then hedge plants of ‘Fire N Ice’ generated more value than bent plants: 127 versus 167. For ‘Kardinal’ there were no significant differences in value index unless the long-stem bonus was applied in combination with short-stem discount (Table 3).

‘Fire N Ice’ plants grown in Coir had a slightly higher value than those in UC Mix when neither bonus nor discount was applied (V_1): 153 for Coir versus 141 for UC Mix. However, no significant differences were found in any other market conditions (V_2–V_6). For ‘Kardinal’, neither Coir nor UC Mix affected any of the value indices.

4. Discussion

Shoot-bending resulted in a significant increase in stem length for both cultivars. We interpret this increase in stem length as an improvement in shoot quality since the stem

Table 3
Value index estimation[a]

Culture	Canopy	Short-stem discount[b]			Short-stem discount[c]		
		None (V_1)	50% (V_2)	100% (V_3)	None (V_4)	50% (V_5)	100% (V_6)
cv. Kardinal							
Coir	Bent	112	111	110	185	185	184
	Hedge	114	107	102	163	157	151
UC Mix	Bent	105	104	103	174	173	172
	Hedge	116	109	104	167	161	155
Probability > F	Culture	0.7489	0.7199	0.6991	0.6858	0.6694	0.6532
	Canopy	0.356	0.9515	0.5249	0.1516	0.0616	0.0238
	Interaction	0.4822	0.4678	0.4573	0.4244	0.4165	0.4088
cv. Fire N Ice							
Coir	Bent	129	128	128	236	236	235
	Hedge	177	158	142	239	221	203
UC Mix	Bent	125	124	124	220	220	219
	Hedge	157	142	129	214	200	196
Probability > F	Culture	0.0454	0.0624	0.1064	0.0513	0.0671	0.0906
	Canopy	<0.0001	0.0007	0.0958	0.866	0.0816	0.0042
	Interaction	0.1595	0.2465	0.4013	0.6492	0.7907	0.9432

[a] Long-stem bonus was given when the shoots were longer than 60 cm. Short-stem discount was applied to the shoots shorter than 40 cm. The indices were estimated for the entire experimental period (September 1997–August 1999).

[b] Long-stem bonus is none.

[c] Long-stem bonus is 100%.

length is the most important standard for grading the quality of a rose shoot. Supporting the improvement in the harvested shoot quality in bent canopy, we found increases in dry matter of a shoot in bent canopy for both cultivars (Table 1). This improvement in quality was accompanied by a reduction in total harvested shoots per square meter. Reduction was more pronounced for ‘Fire N Ice’ than for ‘Kardinal’.

Increased flower production with Coir over UC Mix was reported in ‘Kardinal’ (Raviv et al., 2000). Raviv et al. (2000) attributed this increase to hydraulic property of Coir characterized by higher total porosity and more free air space at low tensions than that of UC Mix. They discussed that possible effect of transient oxygen deficiency after each irrigation pulse might have caused decreased production in UC Mix. Although Coir production system did not exhibit significant improvement in production than UC Mix for ‘Kardinal’ in our study, an increase in flower production with Coir was observed in ‘Fire N Ice’. While it appears that different cultivars may exhibit different responses to the treatments, it is beyond the scope of this study to draw conclusive comparisons between cultivars.

Bending may increase stem length by altering canopy structure, by altering hormonal or source–sink relations, or by selective removal of short shoots from the harvests. When shorter shoots were excluded from the analysis (Table 2), still significantly greater stem lengths were found for bent canopy in both cultivars, indicating that there was indeed an improvement in stem quality as a result of shoot-bending and not due just to the exclusion of the shorter stems from the data pool. Histograms of stem length confirms that shoot-bending resulted in fewer short stems. Dry matter of the flowering shoots also remained significantly higher as a result of shoot-bending (Table 2).

The effect of excluding short stems from the analysis was more pronounced in ‘Kardinal’. Short stems accounted for the difference in stem counts between bent and hedge plants for ‘Kardinal’. When short stems were excluded from the analysis, there was no significant difference in the number of harvested stems. So, the effect of short stems is large. Those short stems still represent harvested yield in terms of dry weight. These results suggest that removal of the short stems in the hedgerow system may lead to longer stems by removing weak sinks, as long as sufficient foliage area is maintained.

Economic value estimation indicates that reduced productivity, characterized by stem count, in bent canopy for ‘Kardinal’ was compensated for by the improvement in shoot quality (9 cm increase in average stem length), resulting in no differences in V_1 among any treatments. For ‘Fire N Ice’ canopy regimes had a dramatic effect on both the number and length of harvested stems, so market preferences for stem length could have a significant impact on the profitability of bent canopy. The greater stem length gained by bending did not compensate for decreased stem numbers unless short stems were unsaleable (V_3) or there was a long-stem bonus (V_4, V_5 and V_6). If the long-stem bonus was accompanied by a short-stem discount, bent canopy was found to be more profitable than hedgerow (V_5 and V_6). If a cultivar responds to shoot-bending in very dramatic ways (e.g. ‘Fire N Ice’) then it might be more sensitive to market trends than varieties that do not respond as strongly (‘Kardinal’).

It should be noted that the market condition varies with time of the year and also is cultivar dependent among other factors. Estimated stem value shortly prior to the Valentine’s Day in 1999, 2000 and 2001 exhibited considerably higher value than when the market was steady (data not shown): Estimated V_1 during this high demand market was $0.550+0.016(\mathrm{SL}-25)$ resulting in two to four times higher values than steady market condition depending on stem length. It is unlikely that any of the indices is a perfect representation of actual stem value. However, we can predict that shoot-bending practice can be effective when the market is rewarding long-stemmed roses with extra bonus or when short-stemmed roses cannot be sold.

In a traditional hedgerow canopy system, the primary shoot and basal shoots are pinched at the first or second complete leaf from the base of the stem so as to promote further breaks. The remaining leaves provided a source of carbohydrates for the upcoming shoots during the establishment (Langhans, 1987). Growers need to cut-back to lower the canopy at some point. Timing of the cut-back depends on cropping schedule based on market demand. Dealing with a tall and bulky canopy is labor intensive. Byrne and Doss (1981) reported that when pruning position was high, shorter stems were produced, indicating that the position of the origin of a shoot is negatively related to stem length. With a bent canopy, the erect portion of the canopy is managed to be low by harvesting the flowering shoots close to the knuckle. Thus canopy height does not grow as tall as in hedgerow system. Maintaining low canopy height through shoot-bending could present an additional benefit of reduced labor to manage the crop canopy. Ohkawa and Suematsu (1999) accredited labor saving and the accommodation of standard production system as additional benefits of the bending system.

In the bent system, harvested flowering shoots include basal shoots that are usually strong and long. The harvested basal shoots were probably the principal reason for increased stem length but decreased stem counts in bent canopy because otherwise they would have been pinched and allowed to branch out and to produce more than one flowering axillary shoots. Therefore, if growers are to include those basal shoots in their harvests and still to keep high stem counts, they should aim at increasing the number of basal shoots. Basal shoots could be promoted by exposing the basal area to light (Carpenter and Anderson, 1971; Zieslin and Mor, 1981) and/or by bending existing shoots (Faber and White, 1977; Zieslin and Halevy, 1978). In fact, this raises further questions with regard to marketable flower production, such as: how many shoots should be bent to continually promote new basal shoots and what density of leaves or shoots should be allowed in the upright portion of the canopy so that adequate light could reach the basal area to induce basal shoots. Balancing these conditions is likely to be one of the key factors to keep both high quality and high productivity. Byrne and Doss (1981) reported that the time from harvest to bud break was negatively related to the harvesting position, that is the higher the cutting point, the faster the turn over. This implies that not only the number of basal shoots but also their turn over rate could be a major factor determining productivity in bent canopy.

Bending a shoot may inhibit water transport. It may also modify the source–sink relation between leaves and flower buds on bent shoots. These factors may further lead to changes in gas exchange rates (i.e., photosynthesis and transpiration). As a result the contribution of the bent shoots to biomass production may be different from what it is in upright shoots. Studies on the effects of shoot-bending on photosynthesis and water relation at leaf level, shoot level and whole-plant scale would be valuable to understand the physiological responses of plants to bending. Bent canopy is an unique heterogeneous canopy that is different than traditional hedgerow canopy in terms of light interception and leaf area distribution. By accounting for both physiological and architectural properties of the bent canopy, it would be possible to evaluate the efficacy of the bent canopy production system. We observed that there may be considerable differences in how different varieties respond to bending. ‘Fire N Ice’ appeared to respond more dramatically to bending than ‘Kardinal’. Särkkä and Rita (1999) also reported the varietal differences (‘Frisco’ versus ‘Mercedes’) in responding to bending.

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