Ornamental Willow Growth Response Across Five Concentrations of Controlled-Release Fertilizer

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SUMMARY. Growth response of five ornamental willows (*Salix*), with sales potential for the cut-stem industry, was assessed in a 1-year container trial studying various concentrations of fertilizer. Plants were grown in 3-gal nursery containers fertilized with five concentrations of 18N-2.6P-6.6K controlled-release fertilizer (100-day release period) with micronutrients, applied as top dressings at 0, 10, 20, 40, and 60 g/container. Yield data were collected on the commercially important parameters including total stem length, stem quantity, and fresh weight of stems. Additional effects of fertilization on the timing of tip abscission and floral bud burst were also evaluated. Total stem length and fresh weight increased for all willows in the fertilized treatments compared with control; however, treatments above 40 g/container did not result in an increase of these parameters. Kori-yanagi willow (*S. koriyanagi*) had the highest yields across all treatments of fertilization. Fertilizer applications extended the period of stem elongation by delaying tip abscission for all willows, and for 'The Hague' willow (*S. gracilistyla* × *S. caprea*) tip abscission was delayed by 44.0 days at 40 g/container treatment compared with control. Floral bud burst dates, which differed greatly among willows, were unaffected by applications of controlled-release fertilizer.

Willow is one of many genera suitable for field-grown woody floral cut-stem production (Armitage and Laushman, 2003; Greer and Dole, 2008). Selection of ornamental willow species and cultivars for cut stems is based on desirable attributes such as showy catkins and stems that can be harvested in late winter for precocious ornamental catkins, or throughout winter for contorted or colorful stems. Their ornamental attributes combined with off-season flowering timing make willow a desirable crop for floral cut-stem market sales.

Market prices of willow stems are determined by stem length with longer stems commanding higher market prices. When sold by length, stems may be offered as single-stemmed whips or as branched stems (Greer and Dole, 2008). Stem length grading differs slightly depending on market and can be grouped into general categories: tips (1.5 to 3 ft), medium (3 to 5 ft), and large (over 5 ft) (Josiah

et al., 2004). Longer stems command higher market prices; therefore, willow species that produce longer stems are more profitable. Currently, the relationship between cultural practices, input and yield is not clearly defined for ornamental willow production (Saska et al., 2010). Efficient management practices are needed to determine cultural requirements that optimize yields without raising input costs of labor or materials. Species that require less input and produce highest yields would be more desirable for cut-stem producers.

Standard recommendations for fertilizing willows for cut-stem production range from 60 to 80 lb/acre nitrogen (N) (Gouin, 1990). However, studies addressing the effects of fertilizer on stem count and length of cuts of ornamental willows have been

limited. A 2-year study investigated N fertilization rates on field plantings of giant pussy willow (*S. chaenomeloides*) and found no significant effect on stem quantity or length at N concentrations of 0.25, 0.5, 1, or 2 oz/plant (20–150 lb/acre N) within 1 year of harvest (Bir and Conner, 2006). Yet, in another study, stem yields of american pussy willow (*S. discolor*) grown on an unfertilized field buffer were influenced by soil fertility, as plants located next to the fertilized cropland yielded a greater number of stems per plant, whereas yield decreased in plantings located farther away from the cropland (Yoder and Moser, 1993).

Fertilization rates may affect the length and number of stems as well as duration of the growing season subsequently affecting yields. The duration of the stem elongation period is an important consideration for the selection of species suitable for certain hardiness zones. Longer growing seasons, when budbreak takes place earlier in spring and growth continues well into fall, have been recorded as a result of fertilizer treatments for purple osier (*S. purpurea*) and woolly-stemmed willow (*S. dasyclados*) (Fuchigami and Weiser, 1981; Sennerby-Forse and von Fricks, 1987).

The objective of this study was to measure the growth response of five container-grown willows used for cut-stem production based on yield and timing of tip abscission and floral bud burst across five concentrations of controlled-release fertilizer. Yield data were collected on commercially important parameters: total stem length, stem quantity, and stem fresh weight. The effect of fertilizer applications on the timing of growth cessation, signified by tip abscission was evaluated: willows do not form terminal buds, and at the end of the stem elongation, the length of stem apex is reduced in size, followed by the abscission of shoot tips (Lennartson,

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
0.4536	lb	kg	2.2046
1.1209	lb/acre	kg·ha ⁻¹	0.8922
28.3495	oz	g	0.0353
0.9464	qt	L	1.0567
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

2003; Saska and Kuzovkina, 2010). Further, the effect of fertilizer addition on the timing of floral bud burst during the following spring was also evaluated, as this is an important factor for specialty cut-stem growers.

Materials and methods

The study was conducted at the Research Farm of the University of Connecticut located at Storrs, CT (lat. 41°81'N, long. 72°26'W, U.S. Department of Agriculture hardiness zone 6). Five ornamental willows, represented by taxonomically distant species and cultivars, including four precocious (flowering takes place before leaves emerge) pussy willow types: pointed-leaf willow (*S. acutifolia* section *Daphnella*), japanese willow (*S. gracilistyla* section *Subviminalis*), 'The Hague' willow, kori-yanagi willow (section *Helix*), and one cultivar with simultaneous flowering and leaf emergence grown for ornamental yellow stems—golden willow (*S. alba* 'Vitellina' section *Salix*)—were selected for this study. Pointed-leaf willow, japanese willow, and kori-yanagi willow were each propagated from a single male clone, and 'The Hague' willow and golden willow were each propagated from a single female clone. Dormant cuttings 10 inches in length were potted on 30 April in 1-qt pots containing a general purpose potting mix consisting of sphagnum peat-moss, processed pine bark, perlite, vermiculite, wetting agents, and dolomitic limestone (Fafard 3B; Conrad Fafard, Agawam, MA). Plants were rooted in a mist bed for 4 weeks and 20 uniform plants of each willow were transplanted into 3-gal containers containing Fafard 3B potting mix. A completely randomized design with factorial combinations was used including five willows and five fertilizer concentrations with four replications per treatment. The fertilizer treatments of 18N–2.6P–6.6K controlled-release fertilizer Type 100 (80% release of N evenly over a 100-d period) with micronutrients (Nutricote; Arysta LifeScience, Cary, NC) were applied as top dressings on 1 June. The fertilizer manufacturer's guideline of 40 g/container for woody ornamentals and cut-flower crops was assigned to the medium level. Additional treatments included control 0, 10, 20, and 60 g/container. The containers were kept in an outdoor

hoophouse through the fall and into the following spring when the last data were taken. The monthly average day/night temperatures during growing season were as follows: June, 73.4/56.5 °F; July, 78/60.2 °F; August, 78/60.2 °F; and September, 72.4/54.4 °F. All plants were irrigated daily to produce a 15% to 20% leaching fraction. Plants were exposed to natural light; the sides of the hoop-house were wrapped with shaded cloth to prevent deer browsing.

Growth responses in all treatments were estimated through effects on total stem length (the sum of the lengths of all stems on the plant) and stem quantity, stem fresh weight, and the onset of two phenological stages—growth cessation and floral bud burst. Final stem length measurements and stem counts were recorded after leaf drop at the end of November. In addition, the plants were monitored twice per week from August to October for growth cessation signaled by tip abscission. Floral bud burst was monitored for all species/cultivars, except golden willow, every 3 d during the following year from 1 Jan. through 10 Mar. All stems were harvested, weighed with a spring balance, and fresh weight was recorded on 10 Mar. Data were analyzed using the MIXED procedure in the SAS statistical program software appropriate for handling missing data (PC SAS version 9.1; SAS Institute, Cary, NC). The original data for total stem count, fresh weight, and tip abscission were transformed to meet the assumptions of normality. A difference between treatment means of $P \leq 0.05$ was regarded as significant according to Fisher's least significant difference test.

Results

TOTAL STEM LENGTH. For all five willows, stem length was greater in treatments with fertilizer compared with control. We observed an increase in stem length as fertilizer increased from 0 to 40 g/container with no significant increases at 60 g/container in any species/cultivar (Table 1).

NUMBER OF STEMS. The statistical analysis revealed no overall fertilizer effect on stem count across fertilizer treatments. However, the means showed large differences between all fertilizer treatments for all willows. The lack of significance

may be explained by large variation observed in stem count and insufficient number of replications. Stem count comparisons between willows showed that kori-yanagi willow, followed by japanese willow and golden willow, produced the greatest total number of stems per plant across all treatments.

FRESH WEIGHT. Pointed-leaf willow and 'The Hague' willow showed an increase in fresh weight as fertilizer increased from 0 to 20 g/container with no differences in fresh weight at higher fertilizer concentrations. The other willows tested showed an increase in fresh weight as fertilizer increased from 0 to 40 g/container with no significant differences at 60 g/container (Table 1).

'The Hague' willow produced the lowest total stem length and count among all willows, whereas its total fresh weight was not significantly different from kori-yanagi willow and japanese willow; this is explained by typically heavier, larger diameter branches for 'The Hague' willow.

TIP ABSCISSION AND FLORAL BUD BURST. Fertilizer applications extended the stem elongation period for all willows by delaying the tip abscission date (Table 2). 'The Hague' willow exhibited the greatest delay of 44.0 d in the 40 g/container fertilizer treatment compared with control. Floral bud burst dates were unaffected overall by the fertilizer main effect; however, there was a response within species/cultivars. The fertilizer treatments slightly delayed bud burst for japanese willow and 'The Hague' willow, whereas kori-yanagi willows and pointed-leaf willow showed no response to fertilization.

Discussion

The significant effect of fertilizer application on willow growth was previously documented (Christersson, 1987). It has been reported that fertilizer applications result in higher growth rate, biomass production, and leaf area in three Eurasian species—woolly-stemmed willow (*S. dasyclados*), basket willow (*S. viminalis*), and sakhalin willow (*S. sachalinensis*) (Adegbi et al., 2001, 2003; Arevalo et al., 2005; Bollmark et al., 1999; Labrecque et al., 1998; Kopp et al., 1996). Nutrient additions also increase growth of a few North American willows (Simon et al., 1990).

Table 1. Response of five willows to five concentrations of 18N–2.6P–6.6K controlled-release fertilizer presented as total stem length, stem quantity, and fresh weight.

Willow species/cultivar	Fertilizer treatment (g/container) ^z	Total stem length (cm) ^z	Total stems (no./plant) ^y	Fresh wt (kg) ^{z,x}
Pointed-leaf willow	60	1129.1 ab ^v	15.8 ^v	0.2275 ab
	40	1360.4 a	17.0	0.3037 a
	20	1164.4 ab	13.8	0.2300 ab
	10	928.3 b	13.3	0.2062 b
	0	573.6 c	8.0	0.1413 c
Golden willow	60	1680.4 a	27.0	0.4965 a
	40	1814.5 a	32.5	0.5008 a
	20	1286.4 b	18.8	0.3827 b
	10	1025.9 b	17.0	0.2705 b
	0	520.5 c	10.3	0.1280 c
Japanese willow	60	1759.8 a	39.0	0.4737 a
	40	1494.8 ab	33.3	0.3888 a
	20	1277.3 b	42.8	0.2850 b
	10	886.5 c	28.5	0.1762 c
	0	586.2 c	13.7	0.0763 d
‘The Hague’ willow	60	1183.5 a	13.3	0.3625 a
	40	1104.1 a	12.5	0.3613 a
	20	965.8 ab	12.8	0.2950 a
	10	783.4 b	12.8	0.2125 b
	0	386.0 c	6.3	0.0925 c
Kori-yanagi willow	60	2900.6 a	73.0	0.4412 a
	40	2657.4 a	58.0	0.4525 a
	20	1999.4 b	41.8	0.3350 b
	10	1690.3 b	49.8	0.2162 c
	0	825.8 c	30.5	0.0850 d

^z1 g = 0.0353 oz, 1 cm = 0.3937 inch, 1 kg = 2.2046 lb.

^yAnalysis for this column performed on transformed data $\sqrt[3]{x}$.

^xAnalysis performed on square root transformed data. Means presented for untransformed data.

^vMeans within a species/cultivar followed by the same letter are not significantly different according to Fisher's least significant difference test at $P \leq 0.05$.

^wNot significant at $P \leq 0.05$.

Our findings are in accordance with these studies as fertilizer application resulted in greater stem fresh weight for all willows during our experiment.

The results of this study showed that willows responded to fertilizer applications at 10, 20, and 40 g/container treatments, but that at 60 g/container did not significantly increase yield as compared with the 40 g/container. Overall, yield peaked at 40 g/container fertilizer treatment for total stem length and stem fresh weight. The concentration above 40 g/container, which is the recommended rate for woody ornamentals and cut flower crops, did not increase yield and therefore may be wasteful. A similar trend was observed by Adegbidi et al. (2003) and Hakulinen et al. (1995), who

reported that applications of fertilizer and in excessive rates did not increase yields of field- and container-grown willows. Optimal fertilizer application is important not only for achievement of maximum yield of the crop but also in relation to pollution problems and protection of the environment, as excessive fertilization may result in leaching losses and increased risk of water pollution. Higher production costs are also associated with excessive use of fertilizer. In addition, when more fertilizer is supplied than is needed for maximum crop production, uptake by competitive vegetation may be observed, increasing weed problems (Hansen et al., 1988).

The results of our study also revealed a significant increase in stem length for all willows in fertilized

treatments; this contradicts previous findings of field studies of giant pussy willow that have not shown differences in stem length at varying fertilization rates (Bir and Conner, 2006).

Appropriate species selection for commercial cut-stem growers is dependent on overall growth rate, which is critical for crop profitability. The results indicated that the most vigorous willows in all fertilizer treatments were kori-yanagi willow, japanese willow, and golden willow followed by less vigorous pointed-leaf willow and ‘The Hague’ willow as based on the total length and number of stems. The recorded information on yield can assist growers in plant selection because plants that are more productive in stem count and produce longer stems bring a higher profit. Interestingly, different responses of two related willows—japanese willow and ‘The Hague’ willow—were evident: the former was producing longer and three times as many stems.

It has been previously demonstrated that the availability of nutrients is an important factor that may affect the growth stages of willows (Fuchigami and Weiser, 1981; Sennerby-Forsse and von Fricks, 1987). In our study a similar effect of fertilizer on the length of growing season was recorded. The shortest growing seasons were observed in the control treatments, whereas fertilizer treatments noticeably prolonged the growing season for all willows. Similar trends were observed for woolly-stemmed willow and purple osier when fertilized plants ceased growth later in fall; delayed maturity development and frost damage was reported as the result of fertilization (Fuchigami and Weiser, 1981; Sennerby-Forsse and von Fricks, 1987; von Fricks et al., 2001). These findings should be considered for field-grown willows to adjust the fertilizer concentrations according to first frost days in any specific zone. This study reported that 40 and 60 g/container fertilizer applications extended the period of stem elongation, which may discourage growers from fertilizing heavily in northern zones.

Floral bud burst dates were unaffected by applications of controlled-release fertilizer. Similarly, Bollmark et al. (1999) recorded no fertilizer effect on the dates of bud burst of basket willow. Our results provide

Table 2. Response of five willows to five concentrations of 18N–2.6P–6.6K controlled-release fertilizer presented as the onset of tip abscission at the end of growing season and floral bud burst during the following spring.

Willow species/cultivar	Fertilizer treatment (g/container) ^z	Tip abscission (mean day of yr) ^y	Floral bud burst (mean day of yr)
Pointed-leaf willow	60	290.0 a ^x	25.0 ^w
	40	290.0 a	25.0
	20	282.0 b	25.0
	10	270.3 c	25.0
	0	266.0 d	25.0
Golden willow	60	249.0 a	Not applicable
	40	249.0 a	Not applicable
	20	249.0 a	Not applicable
	10	242.3 b	Not applicable
	0	223.5 c	Not applicable
Japanese willow	60	285.3 d	63.5 c
	40	280.5 c	69.0 a
	20	251.3 b	57.3 b
	10	251.3 b	63.5 c
	0	249.0 a	55.0 d
'The Hague' willow	60	285.3 b	52.0 b
	40	288.5 a	50.0 c
	20	282.3 c	53.8 a
	10	261.3 d	50.0 c
	0	244.5 e	50.0 c
Kori-yanagi willow	60	280.5 b	11.0 ^w
	40	271.0 c	11.0
	20	271.0 c	11.0
	10	282.0 a	11.0
	0	258.0 d	11.0

^z1 g = 0.0353 oz.

^yAnalysis performed on data in this column transformed by the reciprocal of the cube : $1/x^3$. Means presented for untransformed data.

^xMeans within a species/cultivar in each column followed by the same letter are not significantly different according to Fisher's least significant difference test at $P \leq 0.05$.

^wNot significant at $P \leq 0.05$.

evidence for species/cultivars differences in timing of bud burst: during this investigation the mean day of year for bud burst varied considerably – from the beginning of January (day 11.0) for kori-yanagi willow to the beginning of March (day 61.6) for japanese willow. The demonstrated differences among selections in timing for floral bud development will allow producers to choose desired traits based on market preference. The previous studies also indicated that considerable phenological differences exist between ornamental willows (Kuzovkina and Quigley, 2004). However, the phenological sequence of floral bud burst differed in this study as compared with previous work, as our results found kori-yanagi willow and pointed-leaf willow developed

earlier than previously reported by Kuzovkina and Quigley (2004). These results may be due to climatic differences between annual weather patterns and research locations.

In summary, this study showed the effects of slow-release fertilizer treatments on some yield and phenological parameters of willow grown in containers during the first year of establishment. Further multiyear research in field plots is required to examine effects of fertilization and to define nutritional requirements of field grown ornamental willows and the cost-benefits of fertilization.

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