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Fertigation and Crop Load Affect Yield, Nutrition, and Fruit Quality of 'Lapins' Sweet Cherry on Gisela 5 Rootstock

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***Abstract*. 'Lapins' sweet cherry (*Prunus avium* L.) on Gisela 5 (*Prunus cerasus* × *Prunus canescens*) rootstock were subjected to a factorial combination of two crop load and eight fertigation treatments from the sixth to the eight growing seasons. Crop load treatments included full crop and dormant spur thinning to remove and maintain 50% of fruiting spurs. The eight fertigation treatments, which had been maintained since the first growing season, included low (42 mg·L^{-1}), medium (84 mg·L^{-1}), and high (168 mg·L^{-1}) concentrations of N applied by sprinkler fertigation of $Ca(NO_3)_2$ annually ≈8 weeks postbloom. The medium N concentration was also applied with P fertigated in early spring or K fertigated in June. A standard N treatment involved broadcast application of NH_4NO_3 in early spring at 75 kg·ha^{-1} also followed with medium N sprinkler-fertigated postharvest in August. The medium N concentration was also supplied for 8 weeks postbloom through drip emitters. Removal of 50% of fruiting spurs decreased annual yield on average by only 10%. Average fruit size could be increased in years of high crop load (greater than 400 g fruit/cm^2 trunk cross-sectional area), but in a year of low crop load (less than 100 g fruit/cm^2), fruit size was very large (averaging greater than 14 g) and unaffected by crop load adjustment. Minimal effects on fruit and leaf NPK concentrations, fruit firmness, soluble solids concentration (SSC), and titratable acidity (TA) were associated with yield reductions of 10%. Fertigation treatments resulted in a large range in tree vigor and yield during the experiment. High N applications reduced tree and fruit size and fruit TA and were undesirable. Annual P and K fertigation by sprinklers was generally ineffective, having minimal effects on tree PK nutrition and fruit quality with the exception of increased fruit firmness associated with P fertigation in 2005, when yield was low. Drip-fertigated trees were small, frequently had fruit with elevated SSC, but had deficient leaf K concentrations in 2004 implying a need to fertigate K when drip-irrigating.**

Dwarfing rootstocks have been economically advantageous in the production of apple (*Malus ×domestica* Borkh.) by increasing the precocity and unit area yield of closely spaced trees (Quamme et al., 1997). Modern sweet cherry (*Prunus avium* L.) orchards based on dwarfing, precocious, and productive rootstocks are similarly advocated as inherently more profitable than low-density plantings where vigorous growth, large tree size, and delayed production act to decrease economic return (Whiting et al., 2005). A major management issue concerning cherry production on dwarfing rootstocks has been the possibility of reduced fruit size (Franken-Bembeck, 1998). Hence, a number of bloom (Whiting et al., 2006) and postbloom (Lenahan and Whiting, 2006) strategies are being researched in the Pacific Northwest and show potential to increase fruit size in some years. In Europe, dormant spur thinning has been advocated as a method of improving fruit size (Lauri and Claverie, 2005), but this method has not been systematically assessed under Pacific Northwest growing conditions. Crop load adjustment has the potential to affect other cherry attributes such as soluble solids concentration (SSC), although effects are not always consistent (Whiting et al., 2006).

Limited information is available concerning nutrient and water application strategies for optimizing yield and quality of sweet cherry, especially when grown on dwarfing rootstocks (Hanson and Proebsting, 1996). Our previous research indicated that fertigation method affected tree size and nutrition but had minimal effects on fruit quality in the first four growing seasons, when cropping was initiating and yields were low (Neilsen et al., 2004a). It is unknown whether relationships established between tree performance and fertigation for young plantings would persist as trees crop more heavily. For other fruit crops such as apples, high crop loads can depress leaf K concentration (Hansen, 1980) and decrease fruit size in an interaction with amount of applied irrigation (Naor et al., 1997). It is not known whether such relationships would be pertinent to sweet cherry, which has a short growing season and partitions less dry matter to fruit relative to vegetative growth (Kappel, 1991).

Thus, a study was undertaken with 'Lapins' on Gisela 5 with the objectives of testing the effects of crop load adjustment through dormant spur thinning and fertigation treatments on yield, nutrition, and quality of sweet cherry in high-density plantings.

Materials and Methods

The experimental block of 'Lapins' sweet cherry on Gisela 5 (*Prunus cerasus* × *Prunus canescens*) rootstock was planted in Apr. 1998 at the Pacific Agri-Food Research Center in Summerland, B.C. The spacing was 4 m (between trees in a row) × 4.5 m (between rows) for a planting density of 555 trees/ha. Beginning the year of planting, eight annual fertigation treatments were established and maintained for the first eight growing seasons in a randomized complete block design with six replicates. Each treatment plot contained the two measurement trees and two unmonitored border trees. Treatments included sprinkler–fertigation of 1) low (42 mg·N·L^{-1}), 2) medium (84 mg·N·L^{-1}), and 3) high (168 mg·N·L^{-1}) concentrations of N as calcium nitrate (15.5N–0P–0K) for 8 weeks (May through June) after full bloom until after pit hardening. Also, 4) the medium N concentration in combination with 20 g P/tree as ammonium polyphosphate (10N–15P–0K) was fertigated as a single-day application within a week of full bloom each spring. 5) The medium N treatment was also coapplied with potassium chloride (0N–0P–50K) annually fertigated daily for 4 weeks in June. 6) A standard industry broadcast N fertilization strategy was included that involved annual application in late April/early May of 75 kg·N·ha^{-1}/year as ammonium nitrate (34N–0P–0K) uniformly broadcast on the soil surface in a 1-m wide weed-free strip centered on the tree row. 7) This standard treatment was also combined with fertigation of medium N concentration for 4 weeks postharvest in August. 8) The medium N treatment (treatment 2) was also applied through drip emitters. In 2003, at the beginning of the sixth growing season, when fruiting was well established in all trees, one of the two measurement trees in each treatment and replicate was randomly selected for dormant spur removal (extinction spur thinning). In late dormancy (early April), half of the fruiting spurs on 2-year and older wood was removed by pruning flush to the branch. In early 2004 and 2005, crop load (thinning) treatments were maintained by similar removal of 50% of fruiting spurs on 2-year-old wood from the same trees.

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Irrigation for treatments 1 through 7 was applied by Dan 2001 pressure-compensating microsprinklers (PSI Irrigation, Fresno, CA) located between each tree in the row. These sprinklers applied 35 $L \cdot h^{-1}$ and uniformly wet an area extending halfway to the next tree row. For treatment 8, irrigation was applied through 4 × 4-$L \cdot h^{-1}$ pressure-compensating emitters located at 0.7 and 1.3 m on each side of the trees within the tree rows. The duration of irrigation applied each day was scheduled according to the previous day's evaporative demand as measured by an atmometer (ET Gauge Co., Loveland, CO). Daily irrigation quantities were thus adjusted to compensate for the previous day's estimated water use (Parchomchuk et al., 1996). Because N and K fertigation treatments were based on maintenance of a constant solution of N concentration, amounts of these fertilizers applied per tree varied in response to variation in amount of water applied. Irrigation applications were adjusted by the previous day's evaporative demand and hence weather conditions. The details of timing and amount of nutrients and water applied per tree per treatment during the pertinent 2003 to 2005 growing seasons are summarized in Table 1.

The experiment was located on a Skaha gravelly sandy loam (Wittneben, 1986), an Orthic Brown soil, typical of cherry growing soils in the Pacific Northwest of North America, which have developed under semiarid climatic conditions. At this site, soil N and P were low, pH neutral, and subsoils were well drained ranging from gravelly loamy sands to loamy sands. A low organic matter content averaging 1% to 2% resulted in low mineralizable N. Kelowna-extractable P averaged 11 $mg \cdot kg^{-1}$ before P fertilization (Neilsen et al., 1993). Standard commercial production practices were used to control insects and diseases as required (British Columbia Ministry of Agriculture, Food and Fisheries, 2002). No gibberellic acid was applied in the planting.

Data collected for all measurement trees (n = 96) included trunk diameter at 0.3 m above the graft union before (Nov. 2002) and at the end (Nov. 2005) of the experiment. From these measurements, trunk cross-sectional area (TCSA) was calculated. Composite samples comprising 30 leaves per tree were collected from the midthird portion of extension shoots of the current year's growth in mid-July each year. Samples were oven-dried at 65 °C and ground in a stainless steel mill. Nitrogen was determined on a 0.125-g sample by Leco N dry combustion (St. Joseph, MI), whereas P and K were determined by inductively coupled argon plasma spectrophotometry (Spectro Analytical Instruments, Kleve, Germany) on 0.500-g samples dry ashed (Miller, 1998) and dissolved in 1.2 M HCl.

Yield was measured at commercial harvest 28 to 29 July 2003, 19 to 22 July 2004, and 18 to 19 July 2005. Each year, a randomly harvested 100-fruit subsample from each plot was obtained for determination of average fruit weight. Juice SSC was determined by digital refractometry (AO Scientific Instruments, Keene, NM) on a 20-fruit subsample. Juice titratable acidity (TA) was also determined by titration to an 8.1 pH end point by an autotitrater (Metrohm, Herisau, Switzerland). On another 20-fruit subsample, fruit firmness (FirmTech; Bioworks, Stillwater, OK) was measured. A 60-fruit sample was collected and half of each fruit minus the pit was freeze-dried before determination of N on 0.135 g and P and K on 0.50-g samples by the methods and instrumentation previously described for leaf samples and expressed on a fresh weight (FW) basis.

Analysis of variance was performed on all response variables as a split-plot experimental design with fertigation treatments as main plot units and crop load (thinned versus unthinned) treatments as subplots with six replicates. Differences among means were tested using orthogonal polynomials to determine linear and quadratic trends of fertigated N concentration. Individual degree of freedom contrasts were undertaken to determine the effects of P and K fertigation, drip and broadcast N, all versus medium sprinkler-fertigated N. Drip fertigation was also compared with broadcast N application. All statistical analyses were undertaken using the general linear model procedure (SAS Institute Inc., 1989).

Results and Discussion

Tree vigor, yield, and fruit size. Tree vigor was unaffected by the imposition of different crop load treatments for 3 years from 2003 to 2005 as indicated by similar TCSA for thinned and unthinned trees in Nov. 2005 (Table 2). There was, however, a linear decrease in TCSA, because concentration of fertigated N increased from low to high both in Nov. 2002 and 2005. TCSA of drip-irrigated trees was less than trees receiving the same concentration of fertigated N by sprinklers, averaging 66% of their size in Nov. 2002 and 60% in Nov. 2005. Similarly, size of trees receiving broadcast applications of N were smaller than trees receiving medium N, sprinkler-fertigated, averaging 85% of their size in Nov. 2002 and 83% of their size in Nov. 2005. TCSA of trees receiving broadcast N applications exceeded those of drip-irrigated trees in Nov. 2002 but were similar in size by Nov. 2005 (Table 2). Annual supplemental fertigation of P and K and postharvest fertigation of N did not affect tree vigor relative to trees receiving medium N during the study.

The effects of fertigation and irrigation treatments affected TCSA, whereas different crop load treatments did not. An inverse relationship between crop load and TCSA increment has previously been reported for crop load management strategies ranging from unthinned to complete fruit removal for 'Bing' sweet cherry on Gisela 5 rootstock (Whiting and Lang, 2004). The lack of response in our study suggests maintenance of 50% rather than 100% of fruiting spurs had less effect on vegetative growth, consistent with the view that although fruiting reduces the vegetative growth of sweet cherry, effects are not as great as for other tree fruits such as apple, which have a long fruit maturation period (Kappel, 1991). Many of the differences in tree vigor were established early in the life of the planting with smaller trees observed for drip-fertigated trees by year 3 and for high N-fertigated trees by year 4 (Neilsen et al., 2004a). The continued existence of these treatment differences during the crop load portion of the study allowed an assessment of effects on a range of tree size, but also suggested fertigation effects would have occurred if initial tree size had been uniform.

Fruit thinning through dormant spur removal reduced per-tree yield each year (Table 2) and cumulatively from 2003 to 2005. Annual yield reduction was relatively modest at ≈11%, 12%, and 8% in 2003, 2004, and 2005, respectively, despite removal of 50% of dormant fruiting spurs in

Table 1. Annual water and fertilizer applications for 'Lapins' on Gisela 5 rootstock, 2003 through 2005.

Treatment	2003	2004	2005
Water applied (L/tree)[z]			
Sprinkler irrigation	19,846	18,425	15,940
Drip irrigation	9,129	9,270	8,915
N applied (g/tree)[y]			
Sprinkler irrigation			
Low N	217	164	137
Medium N	420	327	164
High N	795	588	345
Medium N + annual P[x]	433	377	253
Medium N + annual K[w]	431	359	135
Broadcast N	60	60	60
Broadcast N + postharvest N	60 + 236	60 + 404	60 + 269
Drip irrigation			
Medium N	51	165	48

[z]Irrigation quantities determined from 2 May to 21 Oct. 2003, 29 Apr. to 23 Sept. 2004, and 2 May to 25 Sept. 2005.

[y]Fertigated N applied 5 May to 13 July 2003, 27 Apr. to 21 June 2004, and 3 May to 4 July 2005. Broadcast N applied 5 May 2003, 20 Apr. 2004, and 3 May 2005. Postharvest N fertigated 31 July to 29 Aug. 2003, 23 July to 27 Aug. 2004, and 20 July to 19 Aug. 2005.

[x]Fertigated P at 20 g/tree applied 2 May 2003, 26 Apr. 2004, and 2 May 2005.

[w]Fertigated K applied at 54 g/tree 2 June to 3 July 2003, at 30 g/tree 25 May to 21 June 2004, and 15 g/tree 3 June to 4 July 2005.

Table 2. Average trunk cross-sectional area, Nov. 2002 and 2005, and average yield and fruit size, 2003 to 2005, for 'Lapins' sweet cherry on Gisela 5 rootstock as influenced by nutrition, irrigation, and thinning treatments.

	TCSA (cm^2)		Yield (kg/tree)			Fruit size (g/fruit)			
						2003			
						Thinning			
Treatment	Nov. 2002	Nov. 2005	2003	2004	2005	+	–	2004	2005
Sprinkler									
Low N	82	138	37.8	46.5	12.5	11.4	11.0	9.7	14.9
Medium N (control)	71	126	34.0	37.7	10.7	9.8	10.0	10.1	14.4
High N	54	84	21.5	23.0	10.1	8.6	8.1	9.4	13.8
N—linear	****	****	****	****	NS	**	**	NS	****
—quadratic	NS	NS	*	NS	NS	NS	NS	NS	NS
Medium N (control)	71 abc	126 ab	34.0 ab	37.7 bc	10.7 ab	9.8	10.0	10.1	14.4 bc
+ annual P	77 ab	134 ab	36.4 ab	42.9 ab	8.8 b	10.7	10.3	10.0	14.4 bc
+ annual K	69 bc	115 b	33.4 ab	34.5 cd	9.8 ab	9.5	9.4	10.3	14.8 ab
Broadcast N	60 cd	95 c	27.2 c	28.8 de	9.7 ab	11.3	9.1	9.9	14.8 ab
+ postharvest N	71 abc	124 ab	33.0 b	36.8 bc	10.5 ab	9.3	10.5	10.2	15.1 a
Drip	47 e	76 c	22.4 d	23.1 e	11.2 ab	12.8	11.0	9.5	14.1 cd
P	NS	NS	NS	NS	NS	NS	NS	NS	NS
K	NS	NS	NS	NS	NS	NS	NS	NS	NS
Broadcast versus drip	*	NS	*	NS	NS	***	*	NS	*
Broadcast versus sprinkler	*	**	**	**	NS	NS	NS	NS	NS
Drip versus medium N	****	****	****	****	NS	**	NS	NS	NS
Dormant spur thinning									
Yes	64	109	28.9	32.4	9.6	Interaction (*)		10.3	14.6
No	68	115	32.5	36.3	11.2	SE = 0.5		9.5	14.5
Significance	NS	NS	**	*	*			****	NS
Main effects SE	4	9	1.5	3.2	1.0			0.3	0.2

Means within columns (Duncan multiple range test) or individual degrees of freedom contrasts significant at $P \leq 0.05$ (*), $P \leq 0.01$ (**), $P \leq 0.001$ (***), $P \leq 0.0001$ (****), or not significantly different (NS).

2003 and continued removal of 50% of dormant fruiting spurs on second-year wood in 2004 and 2005. Much larger differences in yield were observed among fertigation and irrigation treatments. In 2003 and 2004, there was a close association between per-tree yield and tree size so that yield was less on treatments with smallest trees (high N, drip-irrigated and broadcast fertilized trees). In 2005, cold, wet weather during pollination and the first month of fruit growth considerably reduced yield, negating all previously observed fertigation and irrigation effects so that only yield reductions associated with fruit thinning were measured. Cumulatively over the 3-year study period, yield was lowest for the high N, drip-irrigated and broadcast fertilized trees with yield reduced by 44%, 41%, and 31%, respectively, relative to trees receiving low N.

A modest yield reduction of 10% over 3 years, despite maintenance of treatments with 50% of fruiting spurs, supports the contention that dormant spur removal results in a compensating growth of fruit on remaining spurs (Lauri and Claverie, 2005). Although reduced tree vigor associated with certain fertigation and irrigation treatments did not affect per tree yield in the first four growing seasons (Neilsen et al., 2004a), by the sixth (2003) and seventh (2004) growing seasons, per-tree yield was reduced on treatments where trees were smaller. Hence, after four growing seasons, yields were reduced for N applications, which were sprinkler-fertigated at high concentrations (168 $mg \cdot L^{-1}$), drip-fertigated at half the concentration (84 $mg \cdot L^{-1}$) or broadcast applied at 75 $kg \cdot N \cdot ha^{-1}$ per year.

The effect of spur removal on fruit size differed by year (Table 2). In 2003, there was an interaction between fertilization treatments and fruit thinning with fruit size only significantly increased for trees receiving broadcast or drip-fertigated N. In 2004, when per-tree yield was the highest in the 3 years, fruit size was increased by 8% across all treatments by fruit removal associated with spur thinning. In 2005, with the lowest per-tree yield in the 3 years, overall fruit size was extremely large, averaging 14.6 g and unaffected by thinning treatment. Fruit size could also be affected by nutrient and water management strategies with linear decreases in fruit size, often the result of increasing the concentration (and hence quantity) of fertigated N. For example, fruit size was reduced for the high N relative to the low N treatment by 25% and 13% in 2003 and 2005 regardless of whether the fruit was thinned or not and despite major differences in per-tree yield between these years. Minor effects included larger fruit on broadcast as opposed to drip-fertigated trees in 2005 (light crop year) and the reverse in 2003 on unthinned trees. The increase in fruit size associated with fruit thinning of drip-irrigated trees in 2003 resulted in larger fruit than on trees receiving N by sprinkler application.

Fruit and blossom thinning treatments have been advocated for sweet cherry on dwarfing rootstocks resulting from their potential to improve cherry quality, especially by increasing fruit size (Whiting et al., 2006). Fruit size was increased in our study by dormant spur removal for some irrigation/fertigation treatments in 2003 and for all treatments in 2004. Yield efficiency (annual yield/previous November TCSA) averaged 465 $g \cdot cm^{-2}$ for affected treatments in 2003 and 450 $g \cdot cm^{-2}$ for all treatments in 2004. In contrast, in 2005, when yield efficiency averaged 118 $g \cdot cm^{-2}$ and yield was low, fruit size was unaffected by spur removal. A negative and close relationship between fruit weight and tree yield efficiency has previously been measured for 9-year-old, mature 'Bing' cherry trees across three rootstocks and four training systems (Whiting et al., 2005). A threshold of 100 g fruit/cm^2 TCSA was proposed, above which 'Bing' fruit size declines. The response of 'Lapins' size to spur removal only, at values exceeding 450 $g \cdot cm^{-2}$ TCSA, suggests a higher threshold for 'Lapins' and that the threshold varies with cultivar. Furthermore, reduced fruit size associated with high N applications implies excessive N may also adversely affect fruit size. The mechanism of this effect is unknown because high N trees were also smaller and apparently less vigorous. The possibility that fertigated application of high N rates may adversely affect the balance of other nutrients, including P and K, has previously been suggested (Neilsen et al., 2004a). Thus, similar to the first 4 years of this planting, when fertigating N, the lowest fertigation rate is most desirable.

Leaf nutrition. Reducing crop load through dormant spur removal had minimal effects on cherry leaf N, P, and K with significant effects limited to an interaction between thinning and fertigation treatment for leaf K in 2005 (Table 3). The 2005 interaction resulted because the response of leaf K concentration to spur removal varied with fertigation treatment. Leaf K increased after thinning for trees receiving postharvest N and decreased for trees receiving high concentrations of fertigated N and was unaffected for all other treatments. In the lowest cropping year (2005), highest leaf K and lowest leaf N concentrations overall treatments were measured. Leaf P concentrations

Table 3. Leaf N, P, and K concentration of 'Lapins' sweet cherry on Gisela 5 rootstock as influenced by nutrition, irrigation, and thinning treatments, 2003 to 2005.

	Leaf N (% dw)			Leaf P (% dw)			Leaf K (% dw)			
									2005	
									Thinning	
Treatment	2003	2004	2005	2003	2004	2005	2003	2004	+	–
Sprinkler										
Low N	3.07	2.88	2.49	0.24	0.21	0.28	1.73	1.47	2.12	2.17
Medium N (control)	3.14	3.08	2.74	0.22	0.19	0.24	1.47	1.35	1.90	1.92
High N	3.27	3.09	2.80	0.19	0.17	0.19	1.24	1.12	1.44	1.79
N—linear	*	**	****	****	****	****	****	****	****	**
—quadratic	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Medium N (control)	3.14 ab	3.08 ab	2.74 ab	0.22 bc	0.19 bcd	0.24 bc	1.47 b	1.35 ab	1.90	1.92
+ annual P	3.31 a	3.04 ab	2.82 a	0.23 a	0.20 bc	0.25 b	1.54 b	1.47 a	1.96	1.90
+ annual K	3.21 ab	3.08 ab	2.60 cd	0.21 c	0.19 bcd	0.23 c	1.45 b	1.34 b	1.94	1.91
Broadcast N	3.07 b	2.94 bc	2.48 d	0.23 ab	0.20 b	0.24 bc	1.44 b	1.23 bc	1.90	1.83
+ postharvest N	3.23 ab	2.96 abc	2.59 cd	0.22 bc	0.18 de	0.22 d	1.44 b	1.20 c	1.84	1.70
Drip	3.19 ab	3.01 abc	2.66 bc	0.23 ab	0.19 bcd	0.20 e	1.19 c	0.89 d	1.40	1.42
P	*	NS	NS	**	NS	NS	NS	*	NS	NS
K	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
Broadcast versus drip	NS	NS	**	NS	NS	****	**	****	**	***
Broadcast versus sprinkler	NS	*	****	*	NS	NS	NS	NS	NS	NS
Drip versus medium N	NS	NS	NS	*	NS	****	***	****	**	****
Dormant spur thinning										
Yes (+)	3.17	3.00	2.67	0.22	0.19	0.23	1.43	1.27	Interaction	
No (–)	3.20	3.02	2.63	0.22	0.19	0.23	1.44	1.25	(*)	
Main effects SE	0.05	0.05	0.04	0.004	0.004	0.008	0.05	0.04		

Means within columns (Duncan multiple range test) or individual degrees of freedom contrasts significant at $P \leq 0.05$ (*), $P \leq 0.01$ (**), $P \leq 0.001$ (***), $P \leq 0.0001$ (****), or not significantly different (NS).

were usually highest in 2005 for all treatments except for those in which trees were small (high N, broadcast N, drip-fertigated).

In contrast to crop load reduction, fertigation treatments strongly affected leaf N, P, and K concentration. Increasing the concentration of fertigated N consistently increased leaf N and decreased leaf P and K concentration throughout the study (Table 3). Phosphorous and K fertigation had less effect on leaf nutrient concentration. Annual fertigation of P increased leaf N and P in 2003 and leaf K in 2004. Potassium fertigation did not affect leaf P and K concentration and in a single year (2005), leaf N concentration was lower for trees fertigated with K relative to those receiving N only. Thus, cherry trees were responsive to fertigating N but not P and K by sprinklers. Lower leaf N concentrations were observed for trees where N was broadcast on the soil surface relative to N fertigated through sprinklers (2004 and 2005) or drip emitters (2005). Broadcast application of N resulted in higher leaf P relative to the sprinkler N fertigation in 2003 and relative to the drip fertigation in 2005. Leaf P concentration in 2005 and leaf K concentrations in all years were higher for trees receiving broadcast applications of N relative to N applied by drip fertigation. Drip fertigation of N resulted in similar leaf N concentrations compared to trees sprinkler fertigated with N and in 2003 resulted in higher leaf P concentrations relative to the sprinkler treatment (Table 3). Leaf K concentrations were, however, consistently lower for trees receiving N by drip as opposed to sprinkler systems and relative to trees receiving broadcast N applications.

In contrast to apple, there is little to no published information concerning the effects of crop load on cherry tree nutrition (Hanson and Proebsting, 1996). The data from our study indicate that yield reduction of ≈10%, as achieved by dormant spur removal, has a minimal effect on leaf N, P, and K concentration. Considering all treatments, 2005 yields averaged ≈30% of 2004 yields. In this light crop year, maximum leaf P and K, but not leaf N, concentrations were measured, suggesting heavily cropping cherry trees would depress leaf P and K but not leaf N concentrations. A heavy crop load in apples decreases leaf K but not leaf N and P (Hansen, 1980). Many of the nutritional consequences of fertigation were also measured in the first four growing seasons (Neilsen et al., 2004a). These included linear increases in leaf N and linear decreases in leaf P and K associated with increased concentration of applied N and minimal effects of P and K fertigation on their respective nutrient concentration, indicating these effects were unchanged as the trees aged into heavier cropping. Beyond four growing seasons, trees receiving broadcast N frequently had lower leaf N relative to those receiving N fertigated through sprinklers. This suggests that to maintain similar leaf N concentrations, broadcast N application rate would have to be increased above 75 kg N ha as trees age and canopy volume increases. Trees receiving drip relative to sprinkler-fertigated N could have relatively higher (2003) or lower (2005) leaf P concentrations, but always had lower leaf K concentrations than sprinkler-fertigated trees. Notable were leaf K concentrations in 2004 for drip-fertigated trees, which were below the 1.0% deficiency threshold for sweet cherry proposed by Shear and Faust (1980). The limited nutritional research on sweet cherry (Hanson and Proebsting, 1996), especially on dwarfing rootstocks such as Gisela 5, reduces confidence in such a threshold value. However, potassium deficiency may have contributed to the smaller size of these trees despite the absence of K deficiency symptoms on the cherry leaves. Although there was a general lack of response to annual K fertigation by sprinklers, drip-fertigated trees would have benefited from application of K to eliminate the possibility of K deficiency. Drip fertigation of N and P has previously been associated with the development of K deficiency in high-density apples grown on dwarfing rootstocks in coarse-textured soils (Neilsen et al.,1998b) and attributed to a restricted rooting volume (Neilsen et al., 2000). A similar leaf K concentration decline was apparent for these 'Lapins' cherries on Gisela 5 rootstock, although apparently deficiency concentrations were not apparent until the seventh growing season (2004) and disappeared in 2005 when crop load was light. Also, cherry trees under drip irrigation may be subject to greater water stress than sprinkler-irrigated trees, which may have adversely affected K translocation to the leaves. The possibility that drip-fertigated cherries, which have roots concentrated beneath drip emitters (unlike trees undergoing sprinkler fertigation), would benefit from P fertigation as a result of greater P uptake also requires further research.

Fruit nutrition. The reduction in crop load associated with dormant spur thinning most affected fruit nutrient concentration in 2003 when thinning increased the concentration of N, P, and K in fruit overall treatments (Table 4). Fruit thinning did not affect fruit nutrient concentration in 2004 when yield was highest and fruit nutrient concentration lowest. In 2005, when per-tree yield was lowest, a significant interaction was observed between

Table 4. Fruit N, P, and K concentrations of ‘Lapins’ sweet cherry on Gisela 5 rootstock, as influenced by nutrition, irrigation, and thinning treatments, 2003 to 2005.

	Fruit N (mg/100 g FW)				Fruit P (mg/100 g FW)				Fruit K (mg/100 g FW)			
			2005				2005				2005	
			Thinning				Thinning				Thinning	
Treatment	2003	2004	+	–	2003	2004	+	–	2003	2004	+	–
Sprinkler												
Low N	151	112	148	150	22.3	18.0	22.5	22.5	206	177	184	183
Medium N (control)	158	133	188	178	20.3	17.9	22.7	22.1	190	172	176	174
High N	184	152	183	201	20.0	16.8	20.0	22.0	197	171	156	179
N—linear	****	****	*	****	**	*	NS	NS	NS	NS	**	NS
—quadratic	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
Medium N (control)	158 b	133 cd	188	178	20.3 c	17.9	22.7	22.1	190 bc	172 ab	176	174
+ annual P	156 b	140 bc	209	189	20.0 c	17.7	23.6	22.4	190 bc	172 ab	182	168
+ annual K	155 b	138 c	178	167	19.3 c	17.4	22.5	22.1	187 bc	172 ab	179	177
Broadcast N	157 b	126 d	175	157	22.3 b	18.6	23.5	21.8	197 ab	171 ab	177	164
+ postharvest N	151 b	133 cd	182	190	20.0 c	17.4	21.4	22.5	191 bc	163 b	165	176
Drip	196 a	150 ab	184	206	24.3 a	18.4	21.1	22.2	181 c	146 c	152	154
P	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
K	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Broadcast versus drip	****	****	NS	****	*	NS	NS	NS	*	****	**	NS
Broadcast versus sprinkler	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
Drip versus medium N	****	**	NS	*	****	NS	NS	NS	NS	****	**	*
Dormant spur thinning												
Yes (+)	170	137	Interaction (*)		19.5	18.0	Interaction (*)		195	168	Interaction (****)	
No (–)	157	134	SE = 7		18.7	17.5	SE = 0.6		189	167	SE = 3.5	
Significance	****	NS			*	NS			*	NS		
Main effects SE	4.1	3.6			0.6	0.4			4.2	2.6		

Means within columns (Duncan’s multiple range test) or individual degrees of freedom contrasts significant at $P \leq 0.05$ (*), $P \leq 0.01$ (**), $P \leq 0.001$ (***), $P \leq 0.0001$ (****), or not significantly different (NS).

thinning and fertigation treatments. Consistent changes in fruit nutrient concentrations across nutrients included increased N, P, and K concentrations for thinned fruit receiving fertigated P and broadcast N application, whereas fruit N–P–K decreased with thinning at the high rate of N fertigation. Fruit nutrient concentration for most fertigation treatments was otherwise unaffected by thinning in 2005 except for decreased fruit N (drip-fertigated trees) and decreased fruit K (trees receiving fertigated N, postharvest) after spur removal.

Increasing the rate of sprinkler-fertigated N linearly increased fruit N concentration, decreased fruit P concentration for 2 years, and decreased fruit K concentration (quadratic response to rate in 2003, linear decrease with N rate in 2005) (Table 4). Fertigation of P and K did not affect their concentrations within the fruit. Broadcast application of N resulted in lower fruit N concentrations than in drip-fertigated trees in 2003 and 2004 and for unthinned drip-fertigated trees in 2005. Fruit from trees to which broadcast N applications were made had lower P concentrations than drip-irrigated trees but higher values than sprinkler-fertigated trees in 2003. Fruit K concentrations from broadcast fertilized trees usually exceeded concentrations from drip-fertigated trees (except unthinned trees in 2005). A comparison of drip- and sprinkler-fertigated trees at the same concentration of fertigated N indicated fruit N was generally higher and fruit K concentration generally lower on trees receiving their N by drippers. In a single year (2003), fruit P concentration was higher on drip-fertigated trees.

There are limited published data concerning factors affecting the mineral nutrient concentration of cherry fruit (Hanson and Proebsting, 1996). In general, fresh weight mineral concentration of N, P, and K for sweet cherry is higher than for apple. Average fruit N, P, and K concentrations were 500, 210, and 150% of their respective average nutrient concentration observed over 3 years in 90 commercial apple orchards containing an equal number of ‘McIntosh’, ‘Spartan’, and ‘Golden Delicious’ sites (Wolk et al., 1998). Crop load reductions of 11% associated with the thinning treatment increased fruit N, P, and K concentrations only in 2003 when the greatest number of dormant spurs was removed to establish treatments. Effects were minor and inconsistent in the remaining years (2004 to 2005) when dormant spurs were only removed from second-year wood. In general, this suggests crop load reductions of ≈10% are unlikely to result in large changes in major nutrient concentration of cherry fruit. Natural variations in crop load, as was apparent in 2005 (≈30% of 2004 yields), indicated that highest fruit N and P but not K concentrations were observed when such large reductions in crop load occur. In contrast, fruit N concentration was readily increased in response to increases in concentration of fertigated N applied immediately postbloom until ≈3 weeks preharvest in early July. This implies that cherry fruit effectively compete at this time with vegetative growth for available N, as suggested previously by Whiting and Lang (2004). A one-time early spring broadcast application of N was less effective at increasing fruit N concentration relative to drip fertigation, likely as a result of reduced residence time of NO_3 in the continuously irrigated soils (Neilsen et al., 1998a). The lack of effect of sprinkler fertigation of P and K on the respective fruit nutrient concentration is consistent with effects on leaves and results from the initial years of this planting (Neilsen et al., 2004a). Noteworthy were reduced fruit K concentrations associated with drip fertigation. When leaf K concentrations reached apparently deficient values in 2004 for this treatment, fruit K concentrations were below 150 mg K/100 g FW. This contrasts with apple fruit K concentrations, which were less than 100 mg K/100 g FW when deficient apple leaf K concentrations were measured (Neilsen et al., 2004b).

Other fruit quality characteristics. In general, fruit quality parameters other than size, including firmness, SSC, and TA, were little affected by fruit thinning (Table 5). An exception was an increase in fruit TA in 2005 when thinning did not affect fruit size. This implies that increases in fruit size, as can occur by crop load reductions of 10%, will not adversely affect other fruit quality parameters.

Increasing the rate of fertigated N consistently decreased fruit TA as yield decreased, but had no effect on fruit firmness or SSC (Table 5). Phosphorus fertigation increased fruit firmness in 2005 when yield was low over all treatments. Potassium fertigation did not affect fruit quality. Fruit from the drip fertigation treatment had higher SSC and lower yield (Table 2) than fruit from sprinkler-fertigated trees in 2003 and 2004 and than fruit from trees receiving broadcast N applications in 2003. Single-year effects after drip fertigation included softer fruit than sprinkler-fertigated fruit in 2003 and firmer fruit than fruit receiving broadcast N applications in 2004. Also, TA of drip-fertigated fruit was higher than fruit receiving broadcast N applications in 2004. Fruit SSC from the broadcast N treatment was consistently

Table 5. Fruit quality parameters of 'Lapins' sweet cherry on Gisela 5 rootstock as influenced by nutrition, irrigation, and thinning treatments.

	Firmness (g/mm)			Soluble solids (%)			Titratable acidity[z]		
Treatment	2003	2004	2005	2003	2004	2005	2003	2004	2005
Sprinkler									
Low N	334	240	232	21.4	17.5	21.4	13.8	10.5	11.2
Medium N (control)	331	245	239	21.2	17.6	20.8	12.2	10.2	10.7
High N	339	251	239	21.2	18.2	21.1	12.4	9.9	10.5
N—linear	NS	NS	NS	NS	NS	NS	***	**	*
—quadratic	NS	NS	NS	NS	NS	NS	**	NS	NS
Medium N (control)	331 a	245 ab	239 bc	21.2 cd	17.6 bc	20.8 b	12.2 b	10.2 bc	10.7 ab
+ annual P	330 a	244 ab	262 a	20.9 d	17.4 c	20.8 b	12.9 b	9.9 c	10.9 ab
+ annual K	338 a	245 ab	246 b	21.1 cd	18.2 ab	21.5 ab	12.1 b	10.0 c	10.7 ab
Broadcast N	327 ab	225 c	242 bc	22.7 b	18.5 a	21.8 a	12.9 b	11.0 a	11.1 ab
+ postharvest N	329 a	233 bc	239 bc	22.2 bc	18.9 a	21.4 ab	12.2 b	10.1 bc	10.6 ab
Drip	307 b	242 ab	233 bc	24.0 a	18.6 a	21.0 ab	12.8 b	10.2 bc	10.8 ab
P	NS	NS	****	NS	NS	NS	NS	NS	NS
K	NS	NS	NS	NS	NS	NS	NS	NS	NS
Broadcast versus drip	NS	**	NS	**	NS	NS	NS	**	NS
Broadcast versus sprinkler	NS	**	NS	**	*	*	NS	***	NS
Drip versus medium N	**	NS	NS	****	**	NS	NS	NS	NS
Dormant spur thinning									
Yes (+)	330	237	242	21.8	18.2	21.2	12.8	10.2	11.0
No (–)	329	244	241	21.8	18.0	21.2	12.5	10.2	10.7
Significance	NS	NS	NS	NS	NS	NS	NS	NS	*
Main effects SE	7	5	4	0.4	0.3	0.4	0.3	0.1	0.3

Means within columns (Duncan multiple range test) or individual degrees of freedom contrasts significant at $P \leq 0.05$ (*), $P \leq 0.01$ (**), $P \leq 0.001$ (***), $P \leq 0.0001$ (****), or not significantly different (NS).
[z]Units mL Na(OH)/10 mL of juice.

higher than SSC for fruit from the sprinkler fertigation treatment and in 2004 had higher TA and lower firmness than this treatment.

The principal goal of cherry fruit thinning has been to improve cherry quality by increasing fruit size. Improvements in other quality characteristics, including increased SSC and firmness, have sometimes been reported after large decreases (68%) in crop (Whiting and Lang, 2004), although effects have not been consistent over years (Whiting et al., 2006). Dormant spur thinning increased fruit size across all fertigation treatments when harvest yield was decreased by 12% in the heaviest cropping year (2004). However, no effects were measured on fruit firmness, SSC, or TA, suggesting adequate photoassimilates were available for these processes (Lenahan and Whiting, 2006). In contrast, it was possible to affect fruit firmness, SSC, or TA by fertigation treatment. The most consistent effects were decreased fruit TA at high rate of fertigated N and increased SSC for drip-fertigated and broadcast fertilized trees, which had reduced yield relative to sprinkler-fertigated trees. The N fertigation rate and the drip fertigation effects were previously observed in the initial fruiting years for this planting (Neilsen et al., 2004a). Most other quality effects were observed only in a single year, consistent with large variations in annual cherry fruit quality characteristics (Proebsting and Mills, 1981).

Conclusions

Adjustment of crop load by removal of 50% of dormant spurs and maintenance of this treatment by annual removal of 50% of spurs on 2-year-old wood decreased yield annually by only ≈10%. Average fruit size of 'Lapins' could be increased as in 2003 to 2004 by such a crop load management strategy at high crop load (in excess of 450 g/cm^2 TCSA). However, when crop load was light (≈100 g fruit/cm^2 TCSA), fruit size was very large and unaffected by thinning strategy. This indicates a major limitation to dormant spur thinning because fruit removal and hence yield reduction is permanent regardless of factors that may alter annual fruit set. The yield reductions of ≈10%, as achieved in this study, were apparently insufficient to markedly alter fruit and leaf N–P–K concentrations or other cherry quality characteristics, including firmness, SSC, and TA. Yield reductions of ≈70%, as occurred naturally between 2004 and 2005, indicated such large-scale crop reductions would be associated with very large, soft fruit, decreased leaf N, and increased leaf P and K and fruit N and P concentrations.

Fertigation treatments, which were initiated in the planting year and applied annually, resulted in a range of tree size and nutritional status by the initiation of the crop load portion of the experiment at the start of the sixth growing season in 2003. A later emerging trend apparent in 2005, but not 2003, was reduced yield and size of trees receiving the standard industry broadcast applications of 75 kg N/ha. Application of high rates (concentration) of N by sprinkler fertigation consistently increased fruit and leaf N concentration and usually decreased fruit and leaf P and K concentration but did not enhance tree performance. Similarly few benefits were associated with sprinkler fertigation of N postharvest. High N applications were counterproductive for fruit quality because size was reduced, fruit TA decreased, and fruit SSC and firmness unaffected by this treatment. Annual P and K fertigation by sprinklers did not alter tree PK nutrition and had few effects on vigor, yield, and quality of sweet cherry. An exception was increased firmness of cherry fruit resulting from P fertigation in 2005, when yield was low. Drip-fertigated trees were smaller, frequently had elevated fruit SSC, but had inadequate leaf and fruit K concentrations relative to sprinkler-fertigated trees.

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