The Effect of Temperature on Year-Round Development of Rose Shoots Initiated Using Cutting or Bending

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Abstract

The development of greenhouse-grown cut roses (*Rosa hybrida* 'Kardinal' and 'Fire 'N Ice') in relationship to temperature was tracked during nine cycles of growth from December 2003 to May 2005. Hourly leaf canopy air temperatures were monitored continuously and used to compute the accumulated thermal units to each of five developmental stages. During cycles 1-3 all shoots on a plant were cut back, while during cycles 4-7 shoots were cut back or bent to initiate a new flush of shoot growth. For cycle initiation via cutting versus bending there was a significant difference in the thermal units required for development in only one of the four cycles. Results suggest that a thermal unit model developed for 'Kardinal' or 'Fire 'N Ice' can be applied whether cutting or bending is used for shoot initiation. The thermal units from cycle initiation to harvest were greatest during cycles 1 and 2 (750-770), significantly less for cycles 5 and 6 (680-700) and least during cycles 3, 6, and 7 (615-625) for 'Fire 'N Ice'. For 'Kardinal' the thermal units required from cycle initiation to harvest were 680-700 for cycles 1, 2, and 7 when mean daily light integral was less than 17 mol m^{-2} d^{-1}. While for cycles 3 to 6, the accumulated thermal units to harvest was significantly less, averaging 615 °C d^{-1} when mean daily light integral ranged from 20 to 33 mol m^{-2} d^{-1}. In cycles 8 and 9 plants were grown under 3 light levels to test different hypotheses on factors causing seasonal variation in thermal units. The effects of increasing light were largely explained by temperature at shoot level rising proportionally greater than temperature recorded within the leaf canopy. A software program has been developed to aid in rose crop scheduling which uses projected greenhouse temperatures to schedule when cycle initiation and other developmental events should occur.

INTRODUCTION

Past researchers have used thermal units, also known as heat units or degree days, to describe crop age in terms of physiological age (response to temperature) rather than age in days (Wang, 1960). The development of roses is strongly dependent on temperature. A thermal unit (TU) model was used to predict development of greenhouse grown cut flower roses (Pasian and Lieth, 1994, 1996). They reported the rate of 'Cara Mia' flower shoot development during bud break to harvest increased linearly with temperature between 5 and 30°C. They also reported that the number of accumulated TUs from bud break to harvest differed significantly by variety for 'Cara Mia', 'Royalty', and 'Sonia' with 545, 580, and 510 (°C day) required, respectively. Base temperature (T_b) did not differ significantly across variety; T_b of 5.2 was used in all calculations. This information can be used by growers to determine when to initiate a new crop cycle so that a flush of roses will be ready for a target sales date. A similar concept was used to develop production schedules for bare-root roses from planting till buds were in color (Burgess et al., 2000). On average, crops required 772 degree days (T_b of 4°C) from planting until buds were in color. As potting date progressed from February to July, and as average daily temperature increased, the number of days from potting to bud color decreased from 145 to 50. Development of a TU model has also been constructed for miniature roses 'Candy Sunblaze' and 'Red Sunblaze' (Steininger et al., 2002). The TU model was adapted to

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account for nonlinearity in the rate of development for ‘Red Sunblaze’ with temperatures greater than 25°C.

In previous work (Pasian and Lieth, 1994, 1996) rose plants were cut or pinched back to initiate new flower stem growth. Many growers now bend rose stems to initiate a cycle as this can increase quality of flower stems. This raises the question as to whether bending influences the TU response of flower stems.

Increasing MDLI from 17.8 to 21.0 $mol{\cdot}m^{-2}{\cdot}d^{-1}$ decreased the number of days from cutback to flower from an average of 49.2 to 45.0 days for single stem cut-flower roses (Bredmose, 1997). However, the influence of supplemental light on air temperature was not reported. Pasian and Lieth (1994) concluded that MDLI influenced development of shoots through its influence on air/tissue temperature.

The objectives of this experiment were to determine if bending versus cutting influences the accumulated TUs required for rose developmental stages for varieties ‘Fire ‘N Ice’ and ‘Kardinal’; determine if ‘Fire ‘N Ice’ and ‘Kardinal’ shoot development in terms of TUs varies seasonally; and if variation is found, to identify whether the cause for this variation is light level, stem quality, or node number.

MATERIALS AND METHODS

A greenhouse project was undertaken for nine crop cycles from December 2003 to May 2005 to determine the number of TUs required to reach rose shoot developmental stages. During the first three cycles, 40 plants of each cultivar were used. Plants were grown in coconut coir in 20 L ‘Dutch buckets’ with two plants per container. Plants were irrigated three times daily with half-strength Hoagland’s solution plus micronutrients (Hoagland and Arnon, 1950). Plants were cut back (CT) at the second five leaflet leaf to a uniform height to initiate a growth cycle. Five shoots were tagged on each plant at bud break (new buds, 1 cm tall) and these were monitored three times a week. The date that each shoot reached bud break (BB), first unfolded leaf (L1), visible bud (VB), last unfolded leaf (LL) and harvest (sepals separating from flower bud, HV) were recorded. In this paper a phase of development is denoted as the beginning stage followed by the ending stage, separated by a colon (for example, ‘CT:HV’ is the phase from CT to HV). Copper-constantan thermocouples were placed within the plant canopy (to shield thermocouples from direct sunlight) and connected to a datalogger to record temperature every 10 minutes. The number of accumulated TUs per day was calculated by subtracting T_b (5.2°C) from the average daily temperature (Pasian and Lieth, 1994). Daily TUs were summed to calculate the TUs required to reach each stage.

The above methods were followed for cycles four to seven with the modification that twenty plants of each variety were cut back to initiate a cycle and shoots on twenty plants were bent at the second five leaflet leaf to break apical dominance and initiate a cycle.

The experiment was modified for cycles eight and nine. The modifications were designed to test whether or not light itself may be responsible for decreasing the length of a crop cycle; or whether light affects cycle length only by its affect on shoot temperature. In this portion of the experiment, plants were grown under 3 light treatments: control (C, ambient light only), +70 (S1, ambient light plus 70 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ of supplemental light from HPS lamps), +200 (S2, ambient light plus 200 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ supplemental light from HPS lamps). Supplemental lighting was from 0400 to 2400 h daily. There were five plants per light treatment and five labeled shoots per plant. Four temperature sensors were used within each light treatment. Placement of these thermocouples was within the leaf canopy (location code: “canopy”), air at the level of flower buds, (“air”), surface of a flower bud (“bud”), and underside surface of an upper leaf (“leaf”). The number of TUs required to reach each developmental stage was calculated using each of the thermocouples. In addition, number of nodes on flower stems (leaf number) was recorded at harvest.

All statistical analyses were conducted with Statistical Analysis System (SAS release 8.02). Analysis of Variance tests (SAS Proc GLM) were conducted to reveal significant differences in TUs across the two varieties, production cycle, method of cycle initiation (cutting or bending), light treatment, and temperature sensor position. When significant differences were found, Tukey's Honestly Significant Difference method was used to conduct pairwise comparisons. Linear regression models (SAS Proc REG) were fit to data sets to determine the influence of quantitative variables (light levels, leaf number) on TUs.

RESULTS

Cutting versus Bending

For 'Fire 'N Ice' the only significant difference for accumulated TUs whether cutting or bending was used for cycle initiation was during cycle five for the phase from cutting or bending to bud break; which required 187 TUs for CT and 241 TUs for bending (Table 1). For 'Kardinal' the only significant difference between initiation method existed in phase L1:VB for cycle seven, which required 214 TUs for CT and 149 TUs for BT. The data for CT and BT initiated plants were pooled to make comparisons across cycles one through seven.

Seasonal Variation

Average daily temperature (ADT) and mean daily light integral (MDLI) during each cycle varied from 19.0 to 22.0°C and 6.7 to 32.4 $mol{\cdot}m^{-2}{\cdot}d^{-1}$, respectively (Table 2). Analysis of Variance showed TUs from CT:BB, CT:L1, CT:VB, CT:LL, CT:HV varied significantly across variety and cycle with a significant variety by cycle interaction. For example, cumulative TUs required for CT:BB varied from 160 to 220 TUs for 'Fire 'N Ice' (Fig. 1a) and from 120 to 200 TUs for 'Kardinal' (Fig. 1b) across cycle. The TUs for CT:HV for 'Fire 'N Ice' was greatest during cycles one and two (750-770 TUs), significantly less for cycles five and six (680-700 TUs) and least during cycles three, six, and seven (615-625 TUs). There was not significant linear correlation for CT:HV TUs with varying MDLI for 'Fire 'N Ice'. For 'Kardinal', 680-700 TUs were required for CT:HV for cycles one, two, and seven; during these cycles, MDLI were 7, 17, and 15 $mol{\cdot}m^{-2}{\cdot}d^{-1}$, respectively (Fig. 1b and Table 2). During the summer cycles (cycles three to six) cumulative TUs for CT:HV was significantly less, varying from 605 to 630 (MDLI during these cycles ranged from 20 to 33 $mol{\cdot}m^{-2}{\cdot}d^{-1}$).

Supplemental Light, Temperature Sensor Position, and Node Number

Supplemental light influenced ADT during cycles eight and nine, with the influence being somewhat shielded when thermocouple position was within the leaf canopy (Fig. 2). For example, during cycle eight, as light levels increased, canopy ADT increased from 18.7°C to 19.6°C, while air ADT increased from 19.7 to 21.5°C. During cycles eight and nine the lowest ADTs were recorded in the canopy. Greatest ADTs were recorded at shoot air level under all light treatments for cycle eight and under S1 and S2 for cycle nine, and at leaf surface for cycle nine, C. Bud and leaf ADTs were usually intermediate between canopy and air ADTs.

The influence of light level on the number of calculated TUs from CT:HV varied depending on which sensor was used to make calculations (Fig. 3). When canopy sensors were used to make calculations, increasing light levels significantly shortened TUs for CT:HV, but this trend was dampened when sensors outside of the canopy were used. For example, for 'Kardinal' cycle nine, TUs for phase CT:HV decreased significantly from 670 to 610 under increasing light level. But when air or leaf sensors were used, light levels did not affect calculated CT:HV TUs (Fig. 3d).

The number of nodes per flower stem was not affected by light treatment (data not shown), suggesting that the two varieties do not flower earlier with increasing light levels. The number of nodes at flowering did not significantly influence the number of TUs required for CT:HV for 'Fire 'N Ice' and 'Kardinal' during production cycles eight or nine as the regression of TUs against node number resulted in slopes that were not significantly different from 0. For example, an average of 715 TUs were required for

CT:HV as node numbers varied from 4 to 15 for ‘Kardinal’ during cycle 9 (Fig. 4a). However, there was a weak positive correlation between node number and TUs during the period of leaf unfolding (L1:LL) (slope significantly different from 0) for both varieties during cycles eight and nine. For example, as node number of a stem increased from 4 to 12 the average number of TUs for L1:LL increased from 139 to 290 (Fig. 4b).

DISCUSSION

Cutting versus Bending

Little difference existed for TU benchmarks whether a cut (CT) or bending action (BT) were used to initiate a cycle. This suggests that a TU model developed for ‘Kardinal’ or ‘Fire ‘N Ice’ shoots that were cut back for initiation can be applied by growers using either CT or BT for cycle initiation. Bending shoots is reported to improve stem quality in terms of stem length (Lieth and Kim, 2001). In our experiment we found that stem quality in terms of node number (which correlated well to stem length or dry mass, data not reported) did not influence CT:HV TUs. This may explain why BT versus CT was not a significant source of variation for TU benchmarks.

Sources of Seasonal Variation

Variation existed in TUs required to reach developmental benchmarks for both ‘Fire ‘N Ice’ and ‘Kardinal’ across cycles one through seven. It appeared that seasonal changes in light levels could explain this variation for ‘Kardinal’, but not fully for ‘Fire ‘N Ice’. However, in examining the data set for cycles eight and nine, we found that the effects of MDLI were primarily explained by temperature at shoot level (air/tissue) rising proportionally greater than temperature recorded within the leaf canopy. Others also report that the primary influence of light on rose scheduling was its effect on temperature (Pasian and Lieth, 1994; Burgess et al., 2000). In our experiment increasing light did not cause stems to flower with a reduced node number at flowering, also suggesting that the primary effect of light is its influence on temperature or assimilate supply.

The period of leaf unfolding (L1:LL) requires less TUs when fewer leaves are present on the stem (lower node number); but even for such weaker stems, the TUs from CT to HV were the same as stronger stems. Perhaps weak stems required a greater number of TUs outside of the leaf unfolding stage to gain the appropriate assimilate levels for development. More experimentation is needed to discern the cause.

Sensor location is an important factor in using TUs to schedule rose production. TU benchmarks developed using temperature sensors within the canopy will underestimate the number of TUs required compared to benchmarks developed using thermocouples located at shoot tip level. It is recommended that thermocouples are positioned near shoot tip level to more accurately account for the influence of light on shoot air/tissue temperature. Additional factors not included in this experiment (such as greenhouse relative humidity, air flow, and density of flower stems) likely also influence air/tissue temperature.

A software program has been developed which uses projected greenhouse temperatures to schedule the date developmental events should take place to reach harvest on a target date. The program also includes a tool for users to calibrate TU models for other varieties using data on greenhouse temperature and date developmental events occurred. Based on our research we recommend that users calibrate the model specifically for each variety and set of growing conditions.

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Tables

Table 1. Thermal units during intervals CT:BB, BB:L1, L1:VB, VB:LL, and LL:HV for 'Fire 'N Ice' and 'Kardinal' flower shoots during production cycles 4-7; bud break initiated using cutting or bending.

Cycle	Variety	Initiation Method	Thermal Units (°C d) CT:BB	BB:L1	L1:VB	VB:LL	LL:HV
4	Fire 'N Ice	cutting	167b[1]	111a	73b	91a	238a
		bending	183b	104a	81b	92a	216a
	Kardinal	cutting	158b	92a	111b	88a	176ab
		bending	154b	92a	124b	89a	163ab
5	Fire 'N Ice	cutting	187b	94ab	96b	76ab	223a
		bending	241a	102a	85b	73a	238a
	Kardinal	cutting	157b	79ab	123b	70a	188a
		bending	164ab	91a	126b	78a	174ab
6	Fire 'N Ice	cutting	159b	81b	84b	85a	227a
		bending	144b	79b	75b	86a	230a
	Kardinal	cutting	166ab	72abc	120b	66a	182a
		bending	168ab	82ab	111b	65a	181a
7	Fire 'N Ice	cutting	173b	48c	140a	75a	179b
		bending	165b	38c	166a	73a	172b
	Kardinal	cutting	217a	52c	214a	75a	167ab
		bending	205ab	64bc	149b	87a	139b

[1] Letters denote mean separation comparisons for each interval across production cycles and initiation method within each variety utilizing Tukey's HSD (*P*=0.05).

Table 2. Dates, average daily temperature (ADT), and mean daily light integral (MDLI) during seven production cycles for 'Fire 'N Ice' and 'Kardinal' flower shoots.

Cycle	Dates	ADT (°C)	MDLI (mol·m^{-2}·d^{-1} PAR)
1	Dec 19, 2003 – Feb 11, 2004	19.1	6.7
2	Feb 12, 2004 – Mar 31, 2004	20.4	16.8
3	Mar 31, 2004 – May 10, 2004	20.9	22.0
4	Jun 02, 2004 – Jul 11, 2004	22.0	32.4
5	Jul 11, 2004 – Aug 22, 2004	21.8	22.1
6	Aug 22, 2004 – Oct 02, 2004	20.4	19.7
7	Oct 02, 2004 – Nov 16, 2004	19.0	14.4

Figures

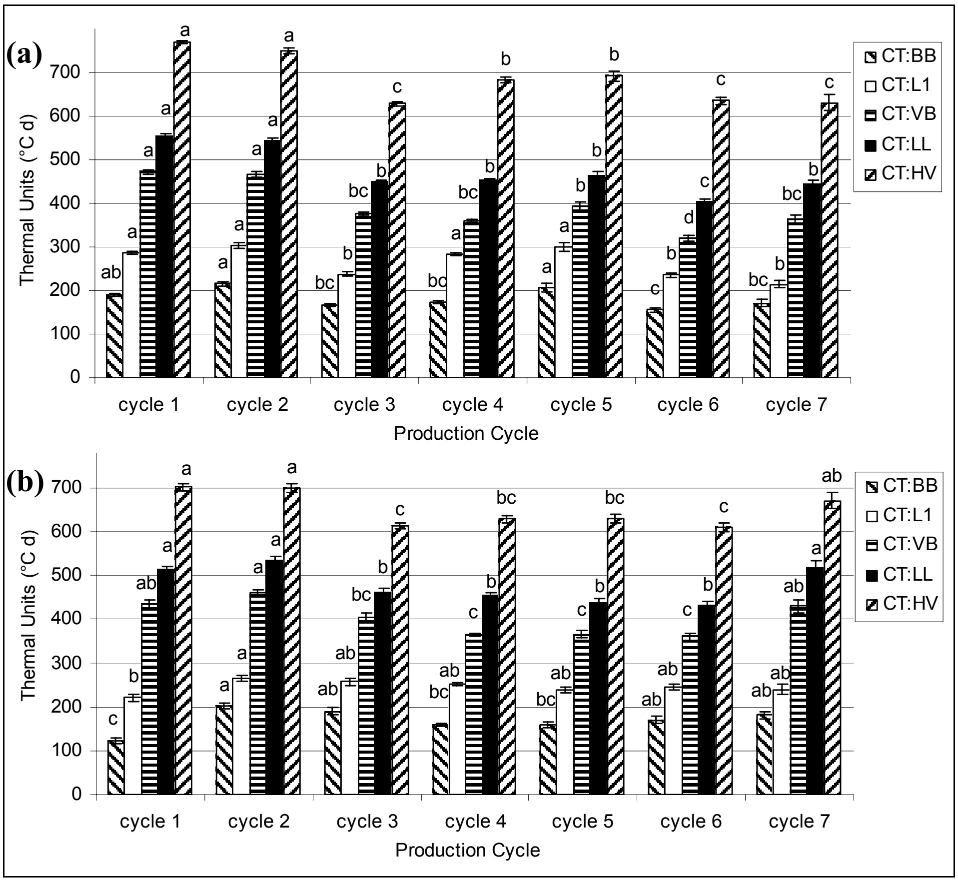

Fig. 1. Mean thermal units (± SE) for 'Fire 'N Ice' (a) and 'Kardinal' (b) flower shoots for the stages CT:BB, CT:L1, CT:VB, CT:LL, and CT:HV across seven crop cycles.

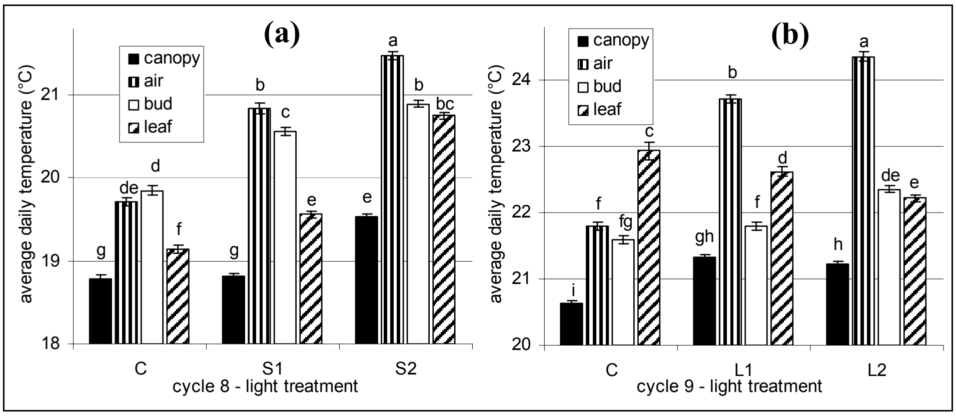

Fig. 2. Influence of light level: ambient (C), +4.9 (S1) and +14.0 (S2) mol·m^{-2}·d^{-1}; and thermocouple position: within the leaf canopy (canopy), air at the level of flower buds (air), surface of a flower bud (bud), underside surface of an upper leaf (leaf) on recorded temperature (± SE) during cycle 8 (a) and 9 (b).

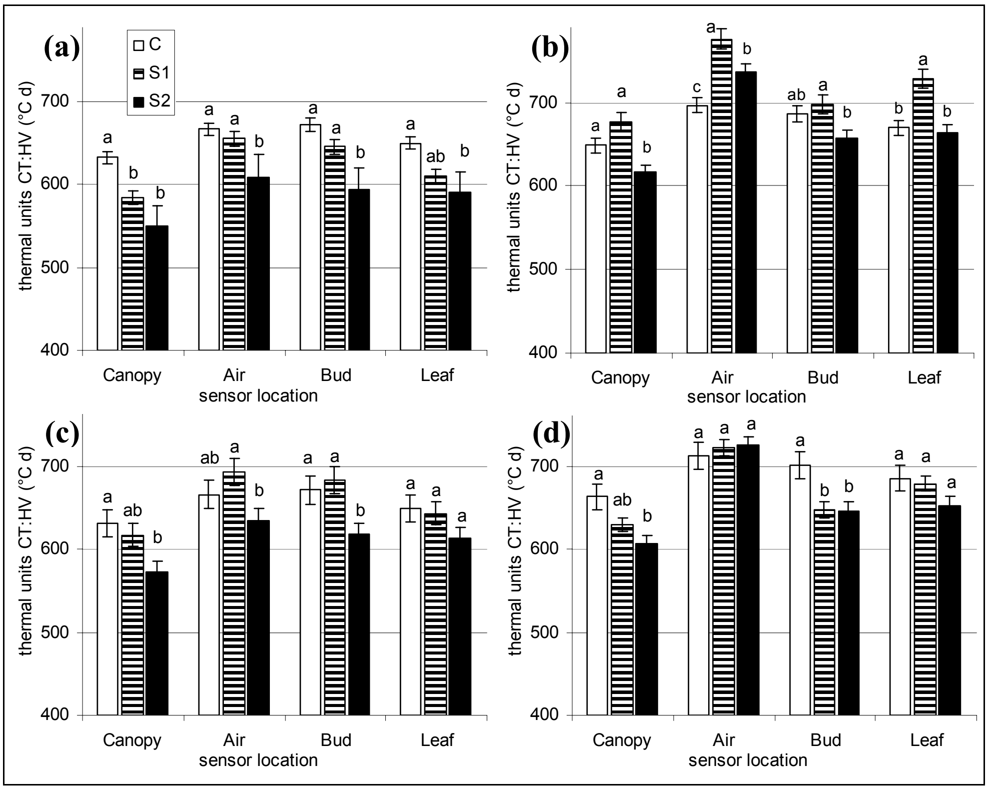

Fig. 3. Mean thermal units (± SE) for CT:HV for 'Fire 'N Ice' cycles 8 and 9 (a,b) and 'Kardinal' cycles 8 and 9 (c,d), calculations conducted using four different thermocouples within each light treatment (as described in Fig. 2). Plants were grown under three light levels: ambient (C), +4.9 (S1) and +14.0 (S2) mol·m^{-2}·d^{-1}).

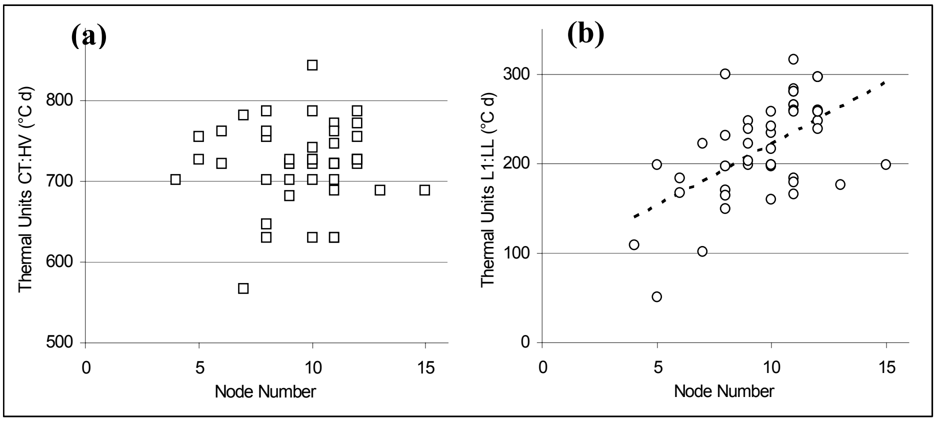

Fig. 4. Mean thermal units for CT:HV (a) and L1:LL (b) versus node number. There was not a significant relationship for CT:HV; for L1:LL there was a significant linear relationship (dashed line) L1:LL = 13.73 × node number + 84.4, R^2=0.32.