

Cultivar Differences in Carbon Assimilation and Partitioning of Primocane-Fruiting Raspberry

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Abstract

Field experiments were conducted during 1994 to examine the influence of genotype and ground-cover on leaf gas exchange, leaf chlorophyll content, and carbon partitioning of primocane fruiting (PF) raspberry. A split-split plot experimental design was used with the whole plot, split plot, and split-split plot factors consisting of cultivar (cvs. Autumn Bliss, Heritage, and Summit), infrared transmitting plastic film, and straw mulch, respectively. Significant cultivar (CV) effects on carbon partitioning were present at the end of the growing season with 'Autumn Bliss' and 'Heritage' having 37 and 34% less total dry weight, 38 and 52% less dry shoot weight, and 83 and 92% less dry berry weight respectively, than 'Summit.' Differences in root architecture were also present at the end of the growing season with the roots systems of 'Autumn Bliss,' 'Heritage,' and 'Summit' being shallow and diverse, slightly deeper and diverse, and very deep and nondiverse respectively. Significant differences in reproductive yield components were also present with 'Autumn Bliss,' 'Heritage,' and 'Summit' having a total floral number of 13.7, 3.09, 1.62; from which 12.2, 1.28, and 24.4 berries were harvested; with a berry weight of 2.65, 2.32, and 2.61 g respectively. Leaf gas exchange rates among the cultivars also differed with 'Summit' having the highest net photosynthesis (Pn) and transpiration rates, followed by 'Heritage' and 'Autumn Bliss.' These cultivar differences in Pn (source supply) observed may have been regulated by assimilate demand (i.e., sink strength) with the total plant dry weights complimenting the Pn rate of the three cultivars examined. Ultimately, this study provides valuable insight into the genotypic regulation of carbon assimilation and partitioning, and illustrates the importance for the continued selection of earlier fruiting, heavier cropping primocane fruiting cultivars with important physiological traits such as carbon, water use, and yield efficiency, and stress and pest tolerance.

Introduction

Understanding the fundamental biology of a plant is an integral part of designing methods for its culture. Crop productivity depends upon the genetic components, physical environment, and an interaction between these two factors (9, 20, 23). Although raspberries have been commercially cultivated for more than 500 years, little information is available on how genotype and the physical environment influence C-assimilation, partitioning, or yield components (2, 20). Optimum C assimilation and vegetative growth occur at cool air and warm root temperatures (i.e., 17 °C) (21, 23) and is decreased by drought stress (7, 19).

During the establishment year, the formation of the root system is critical with the root system being a major carbohydrate storage organ and the major source

of primocanes which originate from root adventitious buds (3). Transplants are exposed to abiotic environmental stresses during the establishment year with no wind protection, or partial shade present (20). High evapotranspiration rates from the soil surface and plant (18) contribute to the onset of drought stress and a subsequent reduction in C assimilation and dry matter production. During establishment, plants are also frequently exposed to severe weed competition which can have a negative effect on raspberry growth and productivity (23) especially with micro-propagated (MP), plug transplants (12, 13, 14, 16).

Therefore, the use of supplementary irrigation (IR) and groundcovers is an attractive method in the establishment of raspberries for eliminating drought stress and modifying root-zone temperature while simultaneously minimizing cultiva-

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tion and herbicide applications (18, 23). Hence, the specific objectives of this field project were to examine the combined effects of genotype and groundcover on carbon assimilation, carbon partitioning, plant nutrient content, and yield components of primocane-fruiting (PF) raspberries.

Materials and Methods

Plant Material and Preplanting Care. Actively growing, genetically diverse (4), tissue culture plantlets (Sakuma Bros., Burlington WA) of the PF cultivars 'Autumn Bliss' [(*Rubus idaeus*) x (*R. arcticus* x *R. occidentalis*)], 'Heritage' (Durham) x (Milton x Cuthbert)], and 'Summit' [(Fallred x ORUS1347) x (NY600 x OR1347)] were used to produce plants of minimal initial variability in growth patterns. On 24 March 1994, plug plantlets ranging in shoot height from 8 to 12 cm were potted in 10 cm diameter pots containing Promix-BX (70% peat, 20% perlite, 10% vermiculite + micronutrients) (Les Tourbières Premier LTÉE, Rivière du Loup, Que.), placed on benches in a greenhouse with 22 ± 3 °C day and 17 ± 1 °C night temperatures, and maintained at one unbranched primocane per pot. Plants were exposed to an 18-h photoperiod with supplemental supra-compensation point irradiance (photosynthetic photon flux of $\approx 60 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) provided by overhead 1000 W, high pressure sodium (HPS) lamps (Lumalux LU1000; GTE Sylvania Canada Ltd, Drummondville, Que.) and were watered as required. Plants were fertilized on a biweekly basis with a 2% (v/v) water soluble fertilizer (20 N - 8.7 P - 16.6 K) applied at 200 ml plant⁻¹. Prior to transplanting, the plants were acclimatized as a result of placing the plants in the nursery compound of the Department of Horticultural Science from 0900 h to 1600 h. The raspberries were actively growing prior to transfer to the field for transplanting, and had attained approximately 12 nodes and a height of 20 cm.

Experimental location. Experiments were conducted during 1994 at the Cambridge Research Station which is located at 43°27' N and 80°23' W, at an elevation

of 308 m, on Typic Hapludalf, sandy loam soil. Heat unit accumulation for the entire 1994 season was unavailable, but was approximately equal to the 25-year average of 1879 GDD. All experimental sites were preplant fumigated with Basamid Granular (BASF, Rexdale, Ont.) at a rate of 5 kg 100 m⁻².

Preconditioned plants were transported from the greenhouse to the field and transplanted on 30 May 1994, at a plant density of 60 cm x 3 m (plant x row spacing). A split-split plot experimental design consisting of four replications was used with the whole plot, split plot, and split-split plot factors consisting of PF cultivar ('Autumn Bliss,' 'Heritage,' and 'Summit'), IRT-76 plastic film (+/-), and straw mulch (+/-), respectively. Therefore, four groundcover treatments were used for each cultivar within a replication consisting of a control (i.e., no plastic film or straw mulch: -/-), plastic film (+/-), straw mulch (-/+), and plastic film which was also covered with a layer of straw mulch (+/+). Each of the PF cultivar/groundcover treatment combinations within a replication consisted of six plants, and supplementary trickle irrigation was provided to all plants to minimize transplant shock and assist in establishment. Both surface trickle irrigation lines and infrared transmitting (i.e., IRT-76) plastic film (120 cm wide) were installed prior to planting. The straw mulch (120 cm wide, 8 cm deep) was placed around the plants immediately after planting, and the 4 L h⁻¹ trickle irrigation emitters (Canadian Hydrogardens, Ancaster, Ont.) installed. All plants were watered with approximately 200 ml per plant of a 10-52-10 (N P K) starter fertilizer solution applied at 500 ppm N concentration per plant, and were irrigated for 5 days after transplanting to minimize transplant shock.

Root-zone water content was monitored throughout the growing seasons with irrometers. The irrometers were placed at a depth of 15 cm in order to correspond to the mid-depth of the raspberry root system (26). Supplementary irrigation was provided daily at 0900 h only when irrometer

measurements were greater than 0.12 MPa which corresponded to an available water depletion of approximately 30% (10). Standard cultural practices for pest and weed control were also followed (12) throughout the 1994 growing season.

Leaf gas exchange. Ambient and leaf chamber CO₂ concentration, air and leaf temperature, saturated vapour pressure deficit and photosynthetic photon flux (PPF) were measured with a LI-6200 portable Pn system equipped with a 0.25 L leaf chamber (LI-COR, Lincoln NB). Foam inserts were used within the leaf chamber to ensure that the leaf gas exchange measurements were obtained from a fixed leaf area (i.e., 48 cm²). Air flow rates were manually adjusted to maintain uniform saturated vapour pressure deficits within the chamber during leaf gas exchange measurement (ca. 270 to 500 μmol•s⁻¹). Calculations of net CO₂ assimilation rate (A), stomatal conductance (gs), leaf temperature and intercellular CO₂ concentration (Ci) were accomplished with a LI-6200 datalogger and supporting software. Nondestructive leaf gas exchange measurements (i.e., the leaves were not harvested after measurements were recorded) were recorded between 0500 and 2200 H on 15 July, 17 August, and 16 September 1994. Within each cultivar, leaf gas exchange measurements were monitored from three groundcover treatments consisting of a control (no plastic film or straw: -/-), plastic film (+/-), and straw mulch (-/+). At each of the seven or eight sample intervals (n = 8, 8, and 7 for 15 July, 17 August, and 16 September 1994 respectively), one fully expanded and exposed trifoliate leaf per plant was randomly selected from 4 plants within each cultivar and groundcover treatment being monitored within a replication. The presence of light saturating condition for Pn measurements was present between 0900 and 1800 h for all dates examined.

Leaf chlorophyll. Leaf disk samples (i.e., 8 disks per cultivar/groundcover treatment within a replication) were collected from all treatments on August 5, 1994. Leaf disk samples were collected by

punching a 7.4 cm² leaf disk sample from each side of the mid-rib of fully expanded and exposed trifoliate leaves. The leaf disks for each cultivar/groundcover treatment in a replication were bulked, placed in test tubes surrounded with crushed ice, and brought back to the laboratory where the chlorophyll was then extracted under non-illuminated conditions in 80% aqueous acetone (10).

Vegetative and reproductive yield components. Vegetative and reproductive data were collected on four representative canes per plot (i.e., treatment within a replication) as outlined by Daubeny et al. (5) with all vegetative and reproductive components being measured on a per cane basis. All plants were dug at the conclusion of the growing season with a front-end-loader tractor equipped with 1.80 m wide stone forks, and the root systems washed with a power-washer to maximize root system recovery. Data were collected on root weight, inorganic nutrient content, and the number of adventitious shoots originating from root nodes.

Data analysis. Analysis of variance for the three field experiments was completed using the General Linear Model procedure of SAS (SAS Institute, Cary, NC).

Results and Discussion

The physical environment surrounding both the root and shoot system were important factors regulating leaf gas exchange in raspberry. No significant influence of PF or straw mulch on raspberry leaf gas exchange, inorganic plant nutrition, or growth and development were observed, and all plants contained sufficient levels of the macro- and micronutrients examined (i.e., N, P, K, Ca, Mg, Cu, Zn and B). These results have been a result of the negating influence of supplementary irrigation which increased soil water content and minimized the effects of drought stress. This caused an increase in soil heat capacity and reduction in root-zone temperature fluctuations (18). Pn results similar to those obtained in controlled environment (19, 21) and field studies (20) were observed with maximum Pn rates of ≈ 17

$\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ being observed under saturated irradiance ($>500\ \mu\text{mol}\ \text{m}^{-2}\ \text{s}^{-1}$) (21), cool temperatures (16 to 20 °C) (21, 23), and a low vapour pressure deficit (<1.0 kPa) (21). Unlike the results of Goulart who observed little variation in light response curves generated from the leaves of five primocane fruiting cultivars (Goulart, unpublished), large cultivar differences in leaf Pn and transpiration were present in this study. 'Summit' had the highest Pn ($\approx 20\ \mu\text{mol}\ \text{m}^{-2}\ \text{s}^{-1}$) and transpiration rates ($\approx 6\ \mu\text{mol}\ \text{m}^{-2}\ \text{s}^{-1}$), followed by 'Heritage' and 'Autumn Bliss' respectively (Figures 1 and 2). The mechanisms causing this difference in leaf gas exchange among cultivars were not related to chlorophyll content since 'Autumn Bliss,' 'Heritage,' and 'Summit' had similar total chlorophyll contents (i.e., 48, 39, and $46\ \mu\text{g}\ \text{cm}^{-2}$). The large differences in Pn rate among cultivars may have been governed by assimilate demand (Schechter, 1991) and allocation dynamics. Although the leaf gas exchange rates (i.e., Pn and transpiration) were closely related to the total plant dry weights of the three cultivars being examined (Figure 1, Table 1), the differences in assimilate demand and allocation dynamics may have been more specifically influenced by the relative sink strength or the developing root system and reproductive tissues (22). Upon comparing 'Heritage' to 'Autumn Bliss,' the root system accounted for 74 and 59% of the total plant dry matter, and the reproductive tissues accounted for only 2.7 and 1.6% of the total plant dry matter (Table 1). Therefore, given the presence of approximately equal total plant dry weights, the higher Pn rates observed with 'Heritage' were probably due to the large sink strength present in the developing root system. With 'Summit' having a similar root dry weight to 'Heritage,' and more than 140 floral and berry structures than 'Heritage' and 'Summit,' the high Pn rates observed with 'Summit' may have been governed by the high demand for assimilates by the developing reproductive tissues (Figure 1, Table 1). Such differences between leaf Pn rates on fruiting and non-fruiting plants have been reported previ-

ously (1) and may have been the predominant factor causing the large differences in leaf gas exchange among the 3 cultivars.

No decline in Pn occurred within the growing season (i.e., from July to September), probably because plants in the establishment phase of production do not have the same source/sink relationship or endogenous plant growth regulator balance as established summer bearing raspberries. With the presence of a rapidly growing root system, endogenous cytokinin levels may have been sustained longer in the growing season resulting in hormonal control over seasonal Pn decline (20).

Large vegetative yield component differences existed among the cultivars at the conclusion of the 1994 establishment season with 'Autumn Bliss' and 'Heritage' having 37 and 34% less total dry weight, and 38 and 52% less shoot dry weight than 'Summit' (Table 1). The root dry weights of 'Heritage' and 'Summit' were not significantly different (i.e., 57.9 and 57.1 $\text{g}\cdot\text{plant}^{-1}$ respectively), but were 24% higher than 'Autumn Bliss' (Table 1). Differences in root system architecture were also present with 'Autumn Bliss' having a very shallow, diverse root system, 'Heritage' having a slightly deeper and more diverse root system than 'Autumn Bliss,' and 'Summit' having a very deep, non-diverse and almost dichotomous (17) root system. Such differences in root-system architecture greatly contribute to the growth habit and management practices used. 'Autumn Bliss' and 'Heritage' are managed in continuous, hedgerow plantings, whereas 'Summit' is more suitable for discontinuous stool plantings. These differences in root-system architecture may also influence the magnitude of IR and groundcover responses among cultivars, and can also greatly affect cultivar response drought stress (8, 9) and winter hardiness. Such effects were apparent in a genotype x environment study by Privé *et al.* (23) with 'Autumn Bliss' being the most sensitive cultivar examined to soil moisture, temperature, and winter injury.

Large differences among cultivars were also present in reproductive yield compo-

Table 1. Influence of cultivar on dry matter distribution, root:shoot ratio, vegetative and reproductive yield components of 3 primocane-fruiting raspberry cultivars during the 1994 establishment season.

Parameter (per cane basis)	Cultivar			Significance ^z
	'Autumn Bliss'	'Heritage'	'Summit'	
	Dry weight (g)			
Root	43.5b	57.9a	57.1a	***
Shoot	36.3ab	28.2b	59.0a	***
Fruit	2.03ab	0.898b	12.0a	***
Total	74.2b	78.0b	118a	***
	Root:shoot ratio			
	1.45ab	2.11a	1.01b	***
	Vegetative yield components			
Cane height (cm)	51.7a	48.5ab	39.3b	***
Node number	23.6ab	27.8a	21.7ab	***
Cane diameter (mm)	8.15b	8.92a	7.99b	*
Vegetative lateral number	1.83b	0.832b	4.07a	***
Vegetative lateral length (cm)	30.1a	7.25b	29.3a	***
Actively growing adventitious shoot number	3.98a	2.15b	0.98 c	**
Dormant adventitious shoot number	6.59b	11.1a	9.07a	***
	Reproductive yield components			
Flowering lateral number	6.77b	1.14c	19.5a	*
Fruit-zone length (cm)	12.2b	1.85c	23.7a	***
Total floral number	13.7b	3.09c	162a	***
Fruit number harvested	12.2b	1.28c	24.4a	***
Fresh fruit weight (g)	2.65a	2.32b	2.61a	***

^zAnalysis of variance results presented within each row represent factors that were nonsignificant (NS) ($P > 0.05$) or significant at $P = 0.05$ (*), $P = 0.01$ (**), or significant at $P = 0.0001$ (***). Mean separation was completed using Duncan's New Multiple Range Test ($P = 0.05$).

ments. 'Summit' was the most precocious cultivar with flower initiation occurring by mid-June, having the greatest number of total flower and berry number ($n = 162$) of which 24.4 berries were harvested (Table 1) resulting in a total cumulative fresh berry weight of 64 g plant⁻¹. Although visible symptoms of flower initiation in 'Autumn Bliss' were present soon after Summit (June 24), fewer flowers were produced resulting in a cumulative fresh berry weight of 32 g plant⁻¹. Visible symptoms of flower initiation were the latest in 'Heritage' (July 9), and this resulted in only 3.09 flowers being present and a total cumulative fresh yield of only 2.96 g plant⁻¹. Although these results are from an establishment trial, they do reflect the impact of flower initiation on vegetative

yield components (i.e., reduced cane length and dry shoot weight in 'Summit'). These results also provide insight on yield efficiency differences among cultivars (i.e., 'Summit' versus 'Autumn Bliss') (1, 5), the inherent problem of late flower initiation and subsequent berry yield with 'Heritage' (20), and also provide an indication of the vast genotype variability present in *Rubus* spp. (1, 4, 5). Improvements in yield efficiency are a particular priority in raspberry production with actual harvest indexes being less than 5% of preharvest yield components (2, 5). In both primocane fruiting and summer bearing raspberries, this may have been partially due to a simultaneous convergence of a large sink demand in the middle of the growing season consisting of growth and development

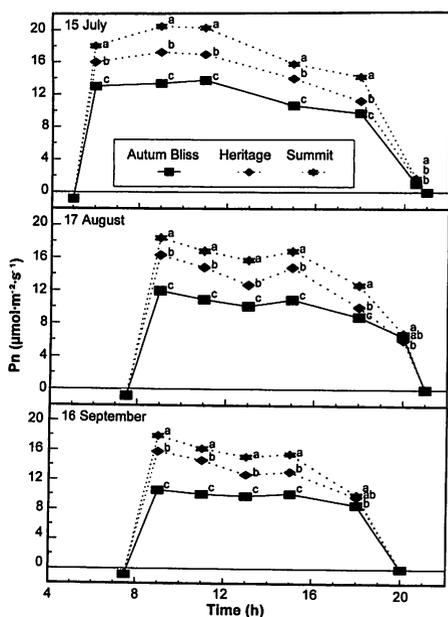


Figure 1. Cultivar differences in net photosynthesis (Pn) observed during the 1994 establishment season. Each value represents the mean of 4 groundcover treatments (n = 24). Mean separation was completed using Duncan's New Multiple Range Test ($P = 0.05$).

of the root, apical meristem and reproductive structures (6). Therefore, even with a large leaf:fruit ratio, raspberries exhibit characteristics of a source limited plant with strong yield component compensation (6).

Summary and Conclusions

A field experiments consisting of three diverse PF raspberry cultivars (cvs. Autumn Bliss, Heritage, and Summit), IRT-76 plastic film (PF), and straw mulch was conducted to determine the influence of genotype and physical environment on leaf gas exchange and carbon partitioning. Leaf gas exchange measurements indicated that there was no decline in Pn or transpiration throughout the duration of the study, and that significant cultivar differences in leaf gas exchange were apparent with 'Summit' having the highest Pn and

transpiration rates, followed by 'Heritage' and 'Autumn Bliss.' These cultivar differences in Pn (source supply) were not related to chlorophyll content and may have been caused by differences in assimilate demand (sink strength) with 'Summit' having greater total, shoot, and berry dry weights than either 'Autumn Bliss' or 'Heritage' and a greater number of flowering laterals, flowers and berry number harvested. No cultivar x environment interactions in leaf gas exchange were present in this study suggesting that the three cultivars responded similarly to environmental conditions including irradiation, air and root-zone temperature, and saturated vapour pressure deficit. Root architecture differed between cultivars with 'Summit' non-diverse and deep rooted, 'Heritage' diverse and the moderately deep rooted, and 'Autumn Bliss' diverse and shallow rooted.

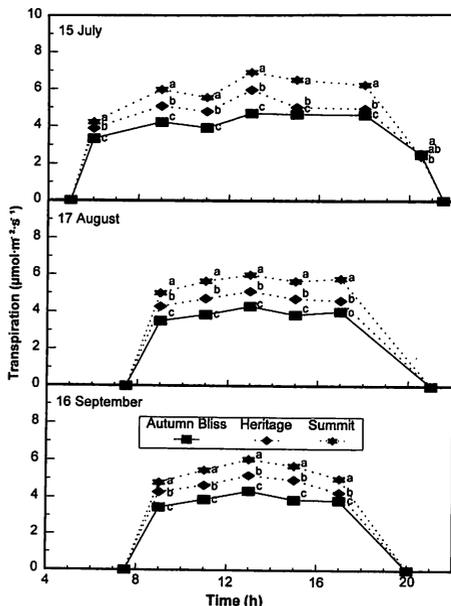


Figure 2. Cultivar differences in leaf transpiration observed during the 1994 establishment season. Each value represents the mean of 4 groundcover treatments (n = 24). Mean separation was completed using Duncan's New Multiple Range Test ($P = 0.05$).

This field study provides additional knowledge into the fundamental biology of the raspberry, and valuable insights into management strategies to attain improved vegetative growth and subsequent yield efficiency. The plants used in this study had supplementary irrigation provided, and consequently, the changes in soil temperature brought about by the use of groundcovers were negated as a result of increased soil moisture and soil heat capacity. However, the plastic film and straw groundcover treatments did provide excellent weed protection, and even in the presence of supplementary irrigation, should be considered for use in the establishment year.

Modifications to the physical environment however, are not the only methods to improve yield efficiency and distribution of photoassimilates. This can also be achieved through proper cultivar selection and continued exploration and improved utilization of the vast genetic resources in *Rubus* spp. Proper cultivar selection is a particular concern in eastern Canada and Southern England, with the full crop potential of the late maturing, most extensively used, PF raspberry 'Heritage' rarely being achieved due to fall frosts or disease (7, 20). Therefore, with primocane fruiting raspberries there is a need for the continued selection of earlier fruiting, heavier cropping PF cultivars with genotypes with physiological advantageous traits such as yield and tolerance to abiotic and biotic factors (1, 2, 15). Other examples of factors that would enhance tolerance to abiotic stresses would include the selection of thornless cultivars that would enable the maintenance of leaf area throughout the growing season, tolerance to drought, and ultraviolet radiation (15). Improved biotic stress tolerance could be achieved by selection for resistance to factors such as root rot caused by *Phytophthora fragariae* var. *rubi* (Wilcox & Duncan) and root lesion nematodes (*Pratylenchus penetrans* Cobb.). However, to achieve these goals breeding programs will have to extend far beyond the limited genotypic variability so far utilized (1, 3) which consists primarily

of the five founding cultivars Lloyd George, Newman, Latham, Cuthbert, and Newburgh (3, 4).

Literature Cited

1. Braun, J. W., Garth, J. K. L. and C. A. Brun. 1989. Distribution of foliage and fruit with light microclimate in the red raspberry canopy. *J. Hort. Sci.* 64:565-572.
2. Cameron, S., S. F. Klauer, and C. Chen. 1993. Developmental and environmental influences on the photosynthetic biology of red raspberry (*Rubus idaeus* L.). *Acta Hort.* 352:113-119.
3. Dale, A. 1989. Productivity in red raspberries. *Hort. Rev.* 11:185-228.
4. Dale, A., P. P. Moore, R. J. McNichol, T. M. Sjulín, and L. A. Burmistrov. 1993. Genetic diversity of red raspberry cultivars throughout the world. *J. Amer. Soc. Hort. Sci.* 118:119-129.
5. Daubeny, H. A., A. Dale, and C. McGregor. 1986. Estimating yields of red raspberries in small research plots. *HortScience* 21:1216-1217.
6. Fernandez, G. E. and M. P. Pritts. 1994. Growth carbon acquisition and source-sink relationships in 'Titan' red raspberry. *J. Amer. Soc. Hort. Sci.* 119:1163-1168.
7. Goulart, B. 1989. Influence of three soil water levels on micropropagated greenhouse grown red raspberry. *Acta Horticulturae* 262:277-283.
8. Jennings, D. L. 1988. Raspberries and blackberries. Their breeding, diseases and growth. Univ. Park Press, Baltimore, MD.
9. Jones, H. G. and J. E. Corlett. 1992. Current topics in drought physiology. *J. Agric. Sci.* 119:291-296.
10. Kirk, J. T. O. 1968. Studies on the dependence of chlorophyll synthesis on protein synthesis in *Euglena gracilis*, together with a monogram for determination of chlorophyll concentration. *Planta* 78:200-207.
11. Ley, T. W. 1994. Soil water monitoring and measurement. pp. 51-64. *In*: K. M. Williams and T. W. Ley (Eds.). *Tree fruit irrigation*. Good Fruit Grower, Yakima WA.
12. Louws, F. J. 1990. Growing red raspberries in Ontario. *Ont. Min. Agr. Food, Publ.* 105.
13. Lutz, J.M. and R.E. Hardenburg. 1968. The commercial storage of fruits, vegetables and florists and nursery stocks. U.S. Dept. Agric. Handbook 66.
14. Meador, D. B. 1985. Impact of herbicides on field-planted, succulent, tissue-culture propagated, red raspberry plants. *HortScience* 20:48 (Abstr).
15. Mudge, K. W., C. A. Borgman, J. C. Neal, and H. A. Weller. 1987. Present limitations and fu-

CULTIVAR DIFFERENCES IN CARBON ASSIMILATION

- ture prospects for commercial propagation of small fruits. Proc. Int. Plant Prop. Soc. 36:538-543.
16. Neal, J. C., M. P. Pritts, and A. F. Senesac. 1990. Evaluation of preemergent herbicide phytotoxicity to tissue culture-propagated 'Heritage' red raspberry. J. Amer. Soc. Hort. Sci. 115:416-422.
 17. Nielsen, K. L., J. P. Lynch, A. G. Jablokow, and P.S. Curtis. 1994. Carbon cost of root systems: an architectural approach. Plant and Soil 165:161-169.
 18. Nobel, P. S. 1991. Physicochemical and environmental plant physiology. Academic Press Inc., New York.
 19. Percival, D. C., J. T. A. Proctor, and J. P. Privé. 1998. Gas exchange, stem water potential, and leaf orientation of *Rubus idaeus* are influenced by drought stress. J. Hort. Sci. and Biotech. 73:831-840.
 20. Percival, D. C., J. T. A. Proctor, and J. A. Sullivan. 1998. Supplementary irrigation and mulch benefit the establishment of 'Heritage' primocane-fruiting raspberry. J. Amer. Soc. Hort. Sci. 123(4):518-523.
 21. Percival, D. C., J. T. A. Proctor, and M. J. Tsujita. 1996. Whole-plant net CO₂ exchange of raspberry as influenced by air and root-zone temperature, CO₂ concentration, irradiation, and humidity. J. Am. Soc. Hort. Sci. 121(5):838-845.
 22. Privé, J. P., J. A. Sullivan and J. T. A. Proctor. 1994. Carbon partitioning and translocation in primocane fruiting raspberries (*Rubus idaeus* L.). J. Amer. Soc. Hort. Sci. 119:604-609.
 23. Privé, J. P., J. A. Sullivan, J. T. A. Proctor, and O. B. Allen. 1993. Climate influences vegetative and reproductive components of primocane fruiting red-raspberries. J. Amer. Soc. Hort. Sci. 118:393-399.
 24. Richards, D. 1980. Root-shoot interactions: effects of cytokinins applied to the root and/or shoot of apple seedlings. Scientia Horticulturae 12:143-152.
 25. Schectar, I. 1991. Photo-assimilate production and partitioning in apples as affected by fruiting. Ph.D. Diss. Dept. Hort. Sci., University of Guelph, Guelph, Ontario.
 26. Trinka, D. L. and M. P. Pritts. 1992. Micro-propagated raspberry plant establishment responds to weed control practice, row cover use and fertilizer placement. J. Amer. Soc. Hort. Sci. 117:874-880.

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An Evaluation of 'Melrose' Strains and Selections¹

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Abstract

Trees produced from irradiated 'Melrose' scion wood were selected for improved fruit color and yield. These selections were compared to improved commercial color strains from France and experimental selections from England and a mutation from a commercial orchard. After 10 years, none of the selections differed from standard 'Melrose' in tree size or yield. Fruit color of standard 'Melrose' declined during the study and several irradiated selections and the strains from France and England had a higher percentage of red fruit surface. 'Dugast' and 'Melrouge' had consistently well colored fruit with darker and more intense red than standard 'Melrose' and are recommended for future plantings of 'Melrose.'

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