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Crop Load and Rootstock Influence on Dry Matter Partitioning in Trees of Early and Late Ripening Peach Cultivars

P. Inglese[1], **T. Caruso**,[2] **and G. Gugliuzza**[3]
Dipartimento di Colture Arboree, Università degli Studi di Palermo, 90128 Palermo, Italy

L.S. Pace[3]
Dipartimento di Agrochimica ed Agrobiologia, Università degli Studi di Reggio Calabria, 89061 Reggio Calabria, Italy

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Abstract. **Effect of crop load on dry matter partitioning was studied on 3-year-old peach [(*Prunus persica* (L.) Batsch (Peach Group)] trees of the early ripening 'Early May Crest' (EMC) grafted on 'GF677' and Penta (*Prunus domestica* L.) rootstock and the late ripening 'Flaminia' grafted on 'GF677' rootstock [(*Prunus persica* x *Prunus dulcis* (Mill.) D. A. Webb] and grown outdoors in 230-L containers, for 2 years. Fruit thinning was carried out 10 days after fruit set to produce different crop loads. Trees were sampled destructively throughout two growing seasons and divided into above-ground and root components, for dry matter and carbohydrate analysis. At the end of the fruit development period, in the first year, total tree dry matter accumulation was related linearly to crop load even when the increase in crop load greatly decreased vegetative and root growth. Total dry matter accumulation was highest in EMC/'GF 677' at any specific crop load, and EMC trees on 'GF677' allocated relatively more dry matter than EMC/'Penta' trees to vegetative and root growth, even under increasing fruit sink demand. Two consecutive years of heavy crops resulted in an inverse relationship between crop load and dry matter accumulation of trees, due to a major reduction of vegetative, root, and fruit growth. The percentage of dry matter partitioned to fruit decreased with the vigor of the rootstock, and EMC/'Penta' trees had the lowest harvest index at each specific crop load. The early ripening EMC/'GF677' trees which had twice the harvest index of 'Flaminia'/'GF677' trees for any level of crop load. 'Flaminia'/'GF677' trees had the largest canopy size. Starch content in the roots was lowest for cropping trees and depended on the rootstock and on the length of the fruit development period, being highest for the late ripening 'Flaminia'/'GF677' trees. Individual fruit weight decreased with crop load, and the reduction of fruit size was related to rootstock and time of ripening.**

Dry matter partitioning within various peach [(*Prunus persica* (Peach Group)] tree components has been investigated in relation to tree age (Chalmers and van den Ende, 1975), planting system (Caruso et al., 1999), rootstock vigor (Caruso et al., 1997), and root restriction (Richards and Rowe, 1977), on seasonal and multiyear timescales. Miller and Walsh (1988) investigated seasonal dry matter partitioning for thinned and nonthinned trees of 8-year-old 'Loring' peach trees on 'Halford' rootstock, providing evidence that fruiting reduces vegetative and root growth, increasing relative dry matter partitioning to the fruit. Chalmers and van den Ende (1975) reported a reduction of annual increment of dry matter partitioned to root growth as the tree aged. Williamson and Coston (1989) found a temporary inhibitory effect of cropping on peach root growth, that lasted from the final stage of fruit growth to immediately after harvest. Vigorous rootstocks also reduce the dry matter partitioned to the peach fruit (Caruso et al., 1997) and affect the dry matter partitioning into above- and below-ground components in apple [(*Malus sylvestris* (L.) Mill. var. *domestica* (Borkh.) Mansf.] (Stutte et al., 1994), while root restriction reduces canopy growth with no alteration of dry matter partitioning (Richards and Rowe, 1977). In apple, fruiting reduces leaf weight and leaf area but results in greater seasonal dry matter accumulation compared to non fruiting trees, suggesting a greater photosynthetic efficiency (Maggs, 1963; Palmer, 1992).

There is limited information on the effect of crop load on dry matter allocation in peach as influenced by vigor of the rootstock and length of the fruit development period (FDP). Length of the FDP may greatly alter seasonal dry matter partitioning, due to the different sink activities of early and late ripening peach fruit (DeJong et al., 1987). In this respect, three main questions arise. What is the response of tree vigor in terms of dry matter partitioning to canopy and roots, under increasing fruit sink (number of fruit) demand? What is the response of fruit growth to increasing fruit number, in relation to rootstock vigor? How is canopy vs. root dry matter partitioning altered by changing crop loads and rootstock vigor? Therefore, the objectives of this research were to a) study, for a wide range of crop loads, the integrated effect of crop load and rootstock vigor on dry matter partitioning within above and below ground peach tree components, b) examine the relationship between crop load and fruit size in relation to rootstock vigor, and c) understand the effect of the length of the fruit development period on seasonal dry matter partitioning.

Materials and Methods

This research was conducted during the 1998 and 1999 growing seasons at Lamezia, Italy (lat 39°12'N). The effect of crop load was studied on 'Early May Crest' peach (hereafter referred as EMC) grafted on 'GF677' (*Prunus persica* x *Prunus dulcis*) and Penta (*Prunus domestica*) rootstocks. The effect of the length of the fruit ripening period was studied on 3-year-old peach trees of the early ripening (80 d) EMC and the late ripening (180 d), 'Flaminia', both grafted on 'GF677' rootstocks. All trees were planted on Jan. 1997 in 230 L containers filled with a medium of 6 sand : 4 peat (by volume). Fruit were hand thinned 1 week after

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[1] Professor of horticulture and corresponding author; e-mail pinglese@unipa.it.

[2] Professor of horticulture.

[3] Postdoctoral fellow.

fruit set in relation to a fertility index (number of fruit/shoot length) ranging from defruited to nonthinned trees. This resulted in a wide range of crop loads that made it possible to analyze the data using regression analysis, with each tree as a single replicate of a given crop load.

Trees were grown outdoor and received standard horticultural management practices in terms of mineral nutrition, irrigation, and pest control. Trees were sampled destructively twice a year, at dormancy and fruit harvest time, and divided individually into organs for dry matter analysis: fruit, leaves, current season's shoots, 1-year-old wood, trunk, and roots divided into fine (<2 mm diameter) and coarse (>2 mm diameter) roots. A total of 18 trees for each cultivar/rootstock combination was sampled at each sampling date. Two trees per rootstock and crop load were sampled at each sampling date.

Subsamples of each component [30% of each component's fresh weight (FW)] were weighed and then dried in a forced-air oven at 60 °C to constant weight. Total dry weight (DW) of each tree component was calculated from the ratio of FW and DW of the sample and total FW of the component. Samples of 150 mg of ground root tissue was extracted three times with hot 80% (v/v) ethanol and subject to enzymatic assay. Glucose, fructose, and sucrose were determined using, hexokinase and glucose 6-phosphate dehydrogenase, hexokinase, and phosphoglucose isomerase, respectively, and after enzymatic inversion to D-glucose and D-fructose by the enzyme ß-fructosidase test combination 716 260 (Boehringer Ingelhein GmbH, Heidesheim, Germany). The insoluble pellet resulting from ethanol extraction was used for starch determination. Starch was digested for 15 min at 60 °C with amyloglucosidase from *Aspergillus niger* Tiegh and incubated with glucose assay mixture. The absorbance was read at 340 nm by a spectrophotometer (model UV-2100; Shimadzu, Kyoto, Japan) (Caruso et al., 1997).

Trunk diameter was measured during dormancy and at fruit harvest, and trunk cross-sectional area (TCA) calculated. Fruit yield per tree was determined in terms of fruit number and FW (kilograms per tree) at commercial maturity. Crop load was expressed as fruit yield per TCA (number of fruit/cm TCA measured prior to budbreak). Harvest index (HI) was calculated as follows: $HI = DW_{fr}/(DW_{(fr+l+s)} + IDW_{(t+r)})$, where DW_{fr} = fruit (fr) DW; $DW_{(fr+l+s)}$ = fruit (fr), leaf (l), and shoot DW; $IDW_{(t+r)}$ = increment (dormancy 1997–98-harvest 1998) in trunk (t) and root (r) DW. To calculate IDW, 10 trees were sampled destructively at the beginning of the experiment (20 Jan. 1998) and then divided into organs for dry matter component.

Ten fruit per tree were sampled to determine fresh and DW and total soluble solids (TSS). At harvest, the area of a sample of 100 leaves for each tree-canopy replicate was measured with a leaf area meter (LI-3100; LI-COR, Lincoln, Nebr.). Total leaf area per tree was calculated from the ratio of leaf area to leaf DW of the sample and total leaf DW of the tree.

The expriment was set up in a full randomized block design and each tree was used as a single tree replication. Data were subjected to regression analyses, with significance expressed at $P \leq 0.01$.

Results

EMC trees on 'GF677' rootstock accumulated more dry matter than those on 'Penta' in all components (leaves, current season's shoots, 1-year-old wood, trunk, and roots) at each of the harvest sampling dates, and in both years, for thinned and nonthinned trees (Table 1). At fruit harvest, a positive correlation was found between crop load and whole tree dry matter accumulation. The rootstock effect appeared both in the regression slope pattern and in the amount of dry matter accumulated by the two rootstock combinations (Fig. 1A). Indeed, total dry matter accumulation was highest

Table 1. Dry weight (g) of the above-ground and root components of nonthinned and defruited 'Early May Crest'(EMC)/'GF677' and EMC/Penta peach trees sampled during dormancy 1998–99 and at fruit harvest in 1998 and 1999.[z]

Treatment	Fruit	Leaves	Shoot	1-year wood	2-year wood	Trunk[y]	Root	Canopy to root ratio[x]	Total
Harvest 1998									
EMC/'GF677'									
Defruited	---	230.0 ± 18.2	128.5 ± 9.1	175.7 ± 13.2	---	377.7 ± 23.1	333.4 ± 21.3	2.7 ± 0.5	1245.3 ± 107.3
Nonthinned	720.0 ± 25.1	196.7 ± 9.8	47.4 ± 6.6	110.8 ± 17.5	---	194.9 ± 12.6	210.3 ± 11.4	2.6 ± 0.6	1480.1 ± 99.5
EMC/Penta									
Defruited	---	208.7 ± 113.1	53.0 ± 7.6	171.1 ± 9.6	---	345.2 ± 23.7	274.2 ± 17.7	2.8 ± 0.3	1052.2 ± 6.6
Nonthinned	825.0 ± 29.5	150.0 ± 14.5	14.6 ± 2.1	71.4 ± 9.8	---	108.9 ± 8.6	124.3 ± 9.7	2.8 ± 0.8	1294.2 ± 51.1
Dormancy 1998–99									
EMC/'GF677'									
Defruited	---	---	178.6 ± 13.2	200.0 ± 11.3	---	480.7 ± 34.2	398.4 ± 24.5	2.2 ± 0.2	1252.7 ± 47.7
Nonthinned	---	---	75.5 ± 6.5	140.5 ± 7.6	---	270.5 ± 12.9	249.9 ± 19.8	1.9 ± 0.4	736.4 ± 23.3
EMC/Penta									
Defruited	---	---	88.5 ± 10.1	197.3 ± 11.6	---	450.1 ± 36.7	325.6 ± 26.6	2.3 ± 0.3	1061.5 ± 74.3
Nonthinned	---	---	34.5 ± 4.7	104.5 ± 9.2	---	185.2 ± 9.4	148.7 ± 11.1	2.2 ± 0.2	472.9 ± 21.7
Harvest 1999									
EMC/'GF677'									
Defruited	---	551.3 ± 34.6	178.1 ± 21.3	388.9 ± 41.3	1223.4 ± 111.3	1583.0 ± 96.7	2008.7 ± 136.9	1.9 ± 0.4	5933.4 ± 205.5
Nonthinned	1490.0 ± 98.4	280.0 ± 29.6	111.0 ± 9.7	122.1 ± 5.7	550.5 ± 31.4	999.3 ± 75.3	1199.3 ± 106.7	1.7 ± 0.2	4746.2 ±234.6
EMC/Penta									
Defruited	---	435.4 ± 56.9	79.5 ± 11.3	182.7 ± 6.6	595.05 ± 29.6	800.0 ± 66.6	1252.1 ± 97.6	1.7 ± 0.1	3344.8 ± 132.6
Nonthinned	1230.0 ± 105.3	210.5 ± 31.6	35.2 ± 2.3	66.7 ± 3.1	154.4 ± 21.5	358.0 ± 23.6	504.6 ± 37.8	1.6 ± 0.2	2559.4 ± 111.6

[z] Data are means ±SE (n = 5).

[y] The trunk include 2-year-old wood in 1997 and 1998.

[x] (leaves + shoots + 1-year-old-wood + 2-year-old wood + trunk/root).

in EMC/‘GF 677’ at any specific crop load (Fig. 1A).

DW of canopy and root components was inversely related to crop load in both years (only data for 1998 are presented) and for both rootstocks (Fig. 1B and C). EMC/‘GF 677’ always had the highest dry matter accumulation in each canopy and root component for any specific crop load. In 1999, total dry matter accumulated in trees subjected for two consecutive years to light and heavy crop loads was inversely correlated with crop load (Fig. 2), due to scant canopy and root growth (data not presented) as well as to a subsequent reduction of fruit set and development in trees with high crop load.

The length of terminal shoots decreased with crop load (Fig. 3) and fresh and DW of the leaf component followed the same pattern (data not presented). Noncropping trees had higher leaf area and DW partitioned to leaves than fruiting trees (Fig. 4). EMC/‘GF 677’ trees had the highest leaf areas when comparing trees with comparable crop loads. The average reduction (both years) of leaf dry matter in fruiting trees when compared to nonfruiting ones was 45% for EMC/‘Penta’ and 35% for EMC/‘GF 677’ (Table 1).

Root growth was severely limited in heavily cropping trees (Fig. 1C). EMC/ ‘GF 677’ trees had the highest dry matter accumulation in the roots for any specific crop load. The reduction of root dry matter content when comparing defruited and nonthinned trees was 37% and 40% for EMC/‘GF 677’ and 55% and 52% for EMC/ ‘Penta’ trees, respectively, in 1998 and 1999 (Table 1). The extent of the reduction of plant growth (vegetative and root components) that resulted from cropping depended on the vigor of the rootstock, being lower for the vigorous EMC/‘GF677’ than EMC/‘Penta’ trees. At fruit harvest in 1998 and 1999, the combined reduction of vegetative and root growth between thinned and nonthinned trees ranged from 40% to 45%, and 60% to 58%, for EMC/‘GF677’ and EMC/‘Penta’ trees respectively.

EMC trees on ‘GF677’ allocated relatively more dry matter than EMC/‘Penta’ trees to vegetative and root growth, even under increasing fruit sink demand. Thus, EMC/ ‘Penta’ trees had the lowest harvest index at each specific crop load (Fig. 5A).

The root component of dry matter ranged, in 1998 and 1999, from 10% to 25% and from 22% to 37%, respectively, for nonthinned and thinned EMC/‘Penta’ trees, and from 14% to 27% and from 25% to 34%, respectively, for nonthinned and thinned EMC/ ‘GF677’ trees, (Table 1). The early ripening EMC/‘GF677’ trees had twice the harvest index of ‘Flaminia’/‘GF677’ trees for any specific crop load (Fig. 5B). This was related to a lower leaf area and vegetative growth reached at the time of fruit harvest, which occurred in June for EMC and in August for ‘Flaminia’. Indeed, ‘Flaminia’/‘GF677’ trees accumulated more dry matter in the canopy than EMC/‘GF677’ trees (Fig. 6).

Mean individual fruit weight decreased with crop load in both years, and trees grafted on ‘GF677’ showed the highest values of individual fruit FW at each specific crop load (Fig. 7A and B). The effect of crop load on fruit size depended also on the length of the

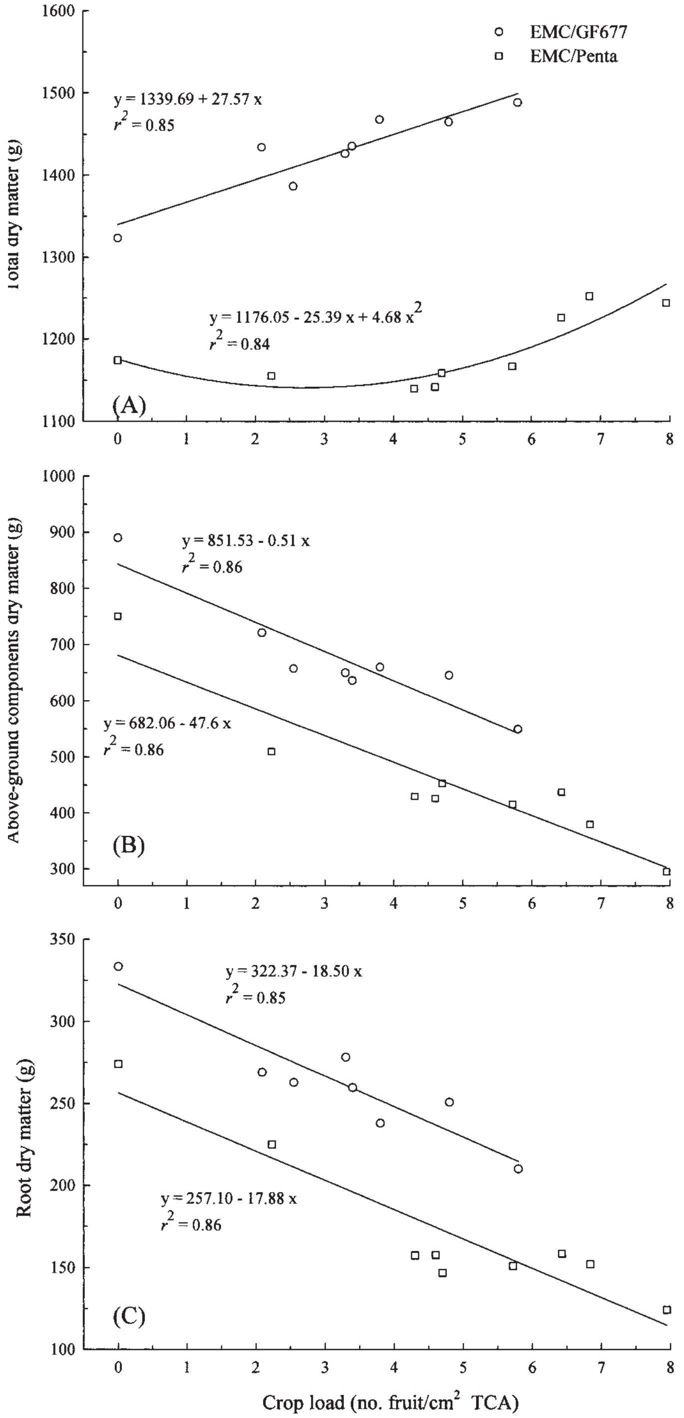

Fig. 1. Relationship at fruit harvest 1998 between crop load and dry matter accumulation for (**A**) whole tree, (**B**) above-ground, and (**C**) roots of ‘Early May Crest’(EMC) peach grafted on ‘Penta’ or ‘GF677’ rootstock.

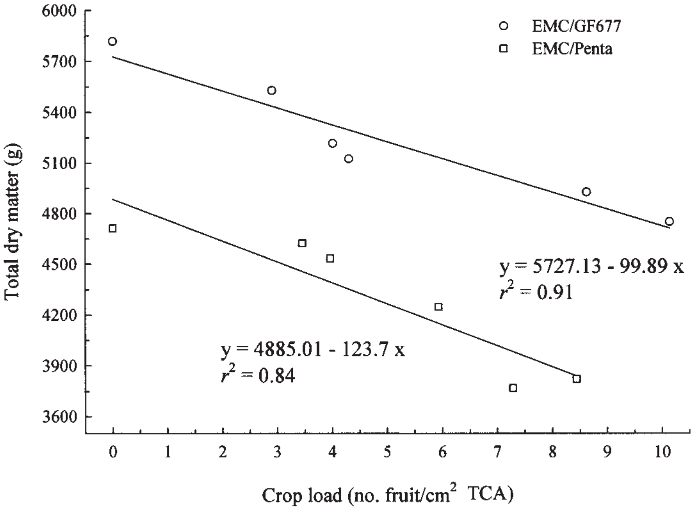

Fig. 2. Relationship at fruit harvest 1999 between crop load and whole tree dry matter accumulation for ‘Early May Crest’ (EMC) peach grafted on ‘Penta’ or ‘GF677’ rootstock.

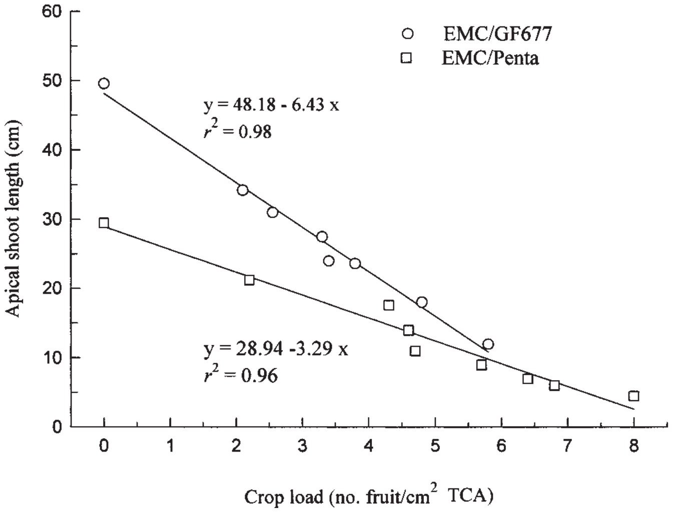

Fig. 3. Relationship at fruit harvest 1998 between crop load and length of terminal shoots for 'Early May Crest' (EMC) peach grafted on 'Penta' or 'GF677' rootstock.

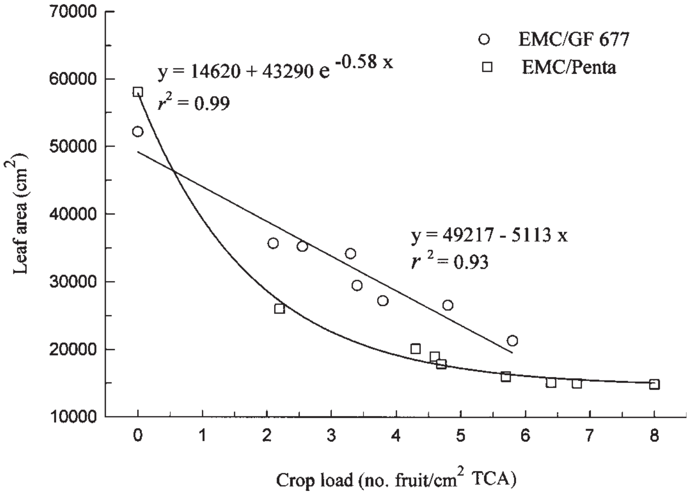

Fig. 4. Relationship at fruit harvest 1998 between crop load and leaf area of 'Early May Crest' (EMC) peach, grafted on 'Penta' or 'GF677' rootstock.

fruit development period since the reduction of fruit size with increasing crop load was much higher for EMC/'GF677' than 'Flaminia'/'GF677' trees (Fig. 8).

Light cropping resulted in advanced fruit maturity as indicated by background color and soluble solids content (data not presented). Starch content was much higher in coarse than in fine roots. Both the rootstock and the cultivar affect were significant, since 'Flaminia'/ 'GF677' trees showed, at fruit harvest, by far the highest starch content in the roots. EMC/'GF677' trees had a much higher starch content in fine and coarse roots than EMC/'Penta' trees (Table 2). Defruited trees had a higher starch content in the roots than nonthinned ones.

Discussion

Crop load reduced plant vigor and the rootstock influenced the extent to which vegetative and root growth were inhibited but not the canopy vs. root dry matter partitioning (excluding fruit) (Table 1). Stem, trunk, and root growth decreased almost linearly with crop load, while dry matter allocation relative to leaves, shoots, and 1-year-wood decreased sharply from nonfruiting to fruiting trees (three to four fruit/cm^2 TCA), with no further increments thereafter (Fig. 9A and B). The more vigorous 'GF677' rootstock accumulated more dry matter in canopy and root components than the 'Penta' rootstock. Differences between the rootstocks appeared in terms of dry matter allocated to 2-year-old wood, trunk, and roots. As indicated by Lenz (1986) for apple trees, the cumulative effect of two consecutive years of heavy crop loads caused reduction of the entire dry matter accumulation. This can also be related to depletion of starch reserves in the roots and in the older canopy components (data not presented). Pace et al. (2000) found a clear effect of cumulative crop load on dry matter accumulation in all plant components from leaves to roots.

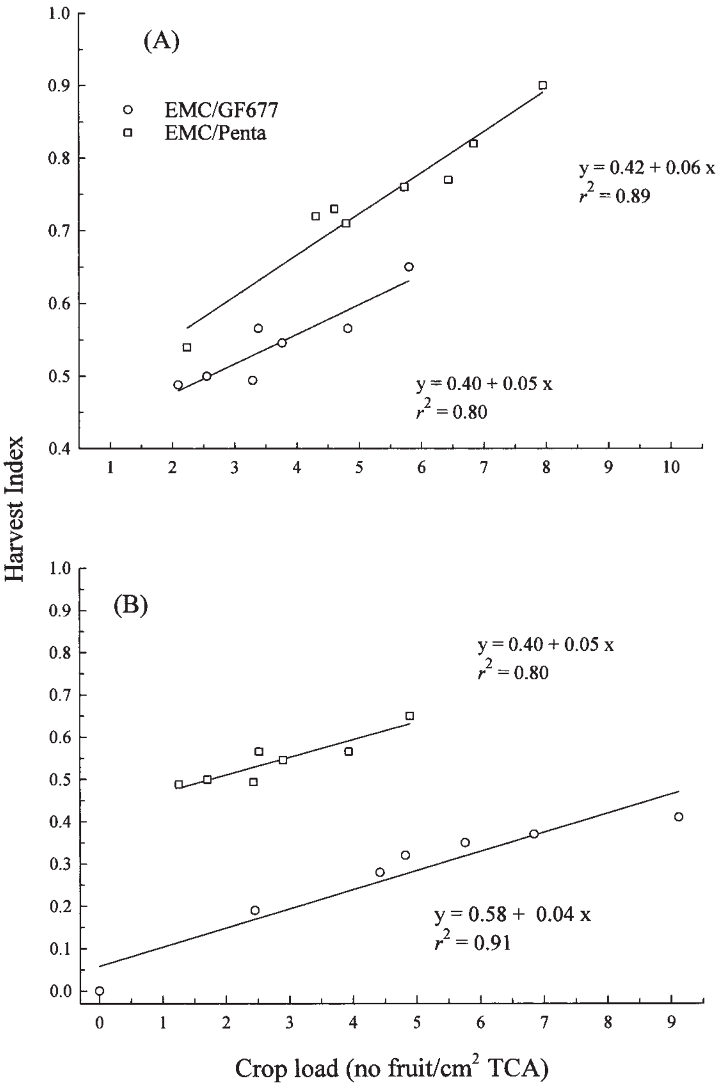

Fig. 5. Relationship at fruit harvest 1998 between crop load and harvest index for (**A**) 'Early May Crest' (EMC) peach grafted on 'Penta' or 'GF677' rootstock, and for (**B**) 'EMC' or 'Flaminia' peach grafted on 'GF677'. HI = $DW_{fr}/(DW_{(fr+l+s)}+IDW_{(t+r)})$ where: DW_{fr} = fruit dry weight; $DW_{(fr+l+s)}$ = fruit, leaves, and shoots dry weight; $IDW_{(t+r)}$ = increment (dormancy 97/98-harvest 98) in trunk and root dry weight.

The rootstock also influenced the crop load effect on fruit size, since the more vigorous rootstock had larger fruits at specific crop loads. The canopy vs. root ratio in terms of dry matter partitioning (excluding fruit) did not change with rootstock and extent of cropping (Table 1), indicating that reduction of vegetative and root growth due to fruiting was distributed evenly between canopy and root components (Table 1). The leaf to fruit ratio, in terms of dry matter, also did not change with the rootstock, while the rootstock affected the increment of dry matter accumulated from 1 year to the next. In 1999, EMC/'GF677' trees accumulated three and five times more dry matter than in 1998, respectively, for thinned and nonthinned trees, while EMC/'Penta' showed a 2- to 3-fold increment in dry matter.

As indicated by Ryugo et al. (1977) with French prunes (*Prunus domestica* L.), cropping reduced starch content in the root components measured at fruit harvest, but our data indicate that the vigor of the rootstock and the time of ripening affect the extent of carbohydrate reserve utilization by the plant. Early ripening peaches depleted almost all the reserves at the end of the fruit growth period, while starch content in the roots of late ripening 'Flaminia' trees was reduced 50% by heavy cropping as compared to nonfruitful trees.

The length of the fruit development period had a large influence on the a) harvest index measured at fruit harvest time, b) dry matter allocated to the canopy, and c) accumulation of starch reserves in the roots. The greater harvest index of the early ripening peach trees compared to the late harvested trees can be explained by the larger canopy development measured at the end of the fruit development period of late ripening peach trees, while the greater starch resources measured at fruit harvest may indicate that early ripening peach fruit depend more than late maturing fruit on carbohydrate reserves stored in the roots. The larger canopy growth measured at the end of the growing season indicate that the late ripening genotype had greater vigor than the late maturing one.

In conclusion, vigor of the rootstock and length of the fruit development period affected response of peach trees to increasing crop loads, with respect to reduction of fruit size and depletion of starch reserves in the roots. However, the balance between vegetative and secondary growth of the above-ground components and root growth was not affected either by cropping or rootstock vigor.

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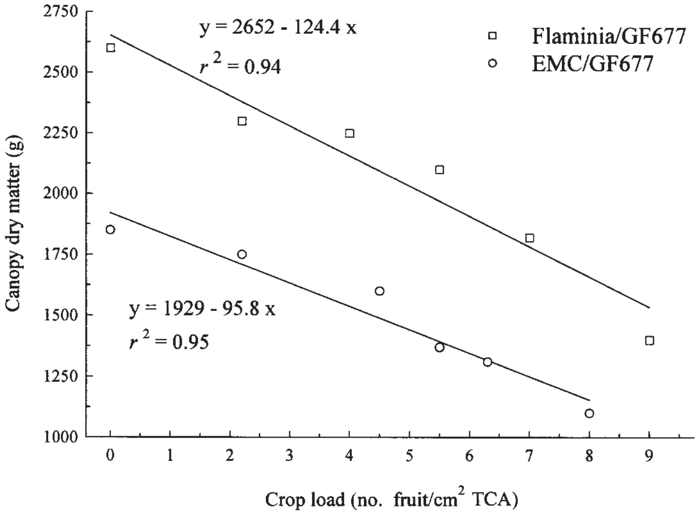

Fig. 6. Relationship at fruit harvest 1998 between crop load and canopy dry matter accumulation for 'Early May Crest' (EMC) peach or 'Flaminia' peach grafted on 'GF677' rootstock.

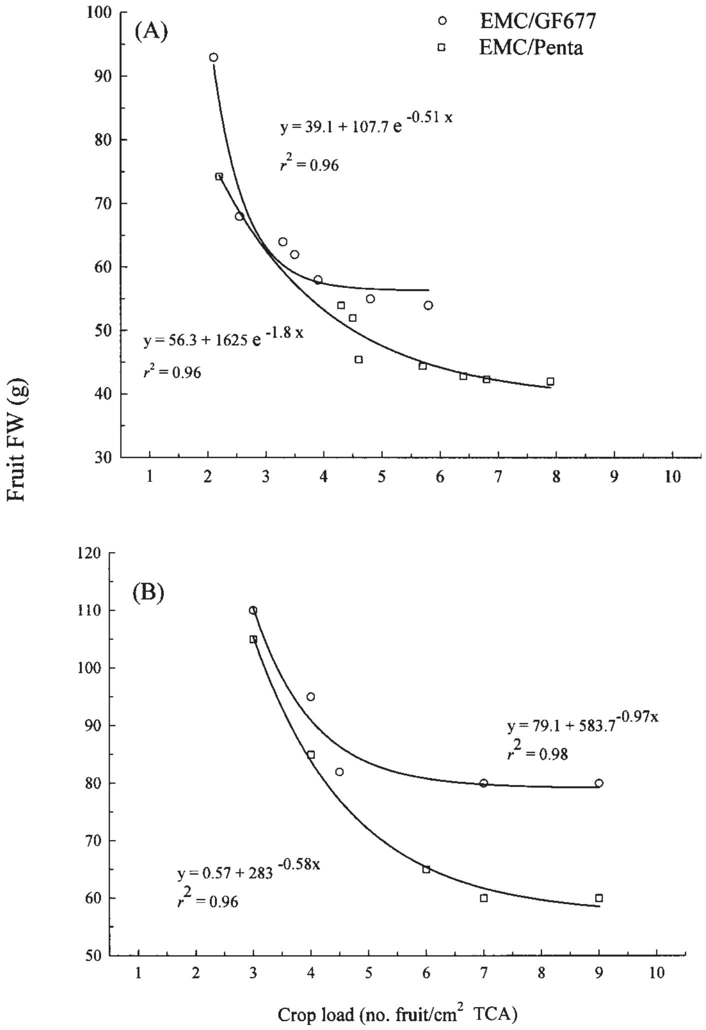

Fig. 7. Relationship at fruit harvest (**A**) 1998 and (**B**) 1999 between crop load and fruit FW for 'Early May Crest' (EMC) peach, grafted on 'Penta' or 'GF677' rootstock.

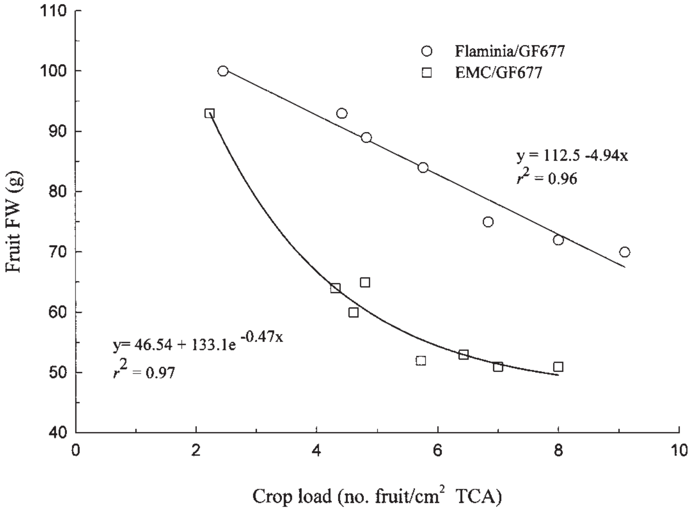

Fig. 8. Relationship at fruit harvest 1998 between crop load and fruit FW for 'Early May Crest' (EMC) and 'Flaminia' peach grafted on 'GF677' rootstock.

Table 2. Starch content in fine and coarse roots of 'Early May Crest'(EMC)/'Penta', Early May Crest/'GF677', and Flaminia/'GF677' peach trees at fruit harvest in 1998 [z].

Cultivar/	Starch (mg·g^{-1} DW)			
	Fine roots		Coarse roots	
rootstock	Nonthinned	Defruited	Nonthinned	Defruited
EMC/Penta	2.2 ± 0.1	9.3 ± 0.1	5.6 ± 0.2	18.3 ± 0.1
EMC/GF677	3.3 ± 0.1	17.3 ± 0.1	9.3 ± 2.3	28.3 ± 0.1
Flaminia/GF677	13.7 ± 2.6	27.3 ± 0.1	33.1 ± 8.6	53.3 ± 0.1

[z] Data are mean ±SE (n = 5).

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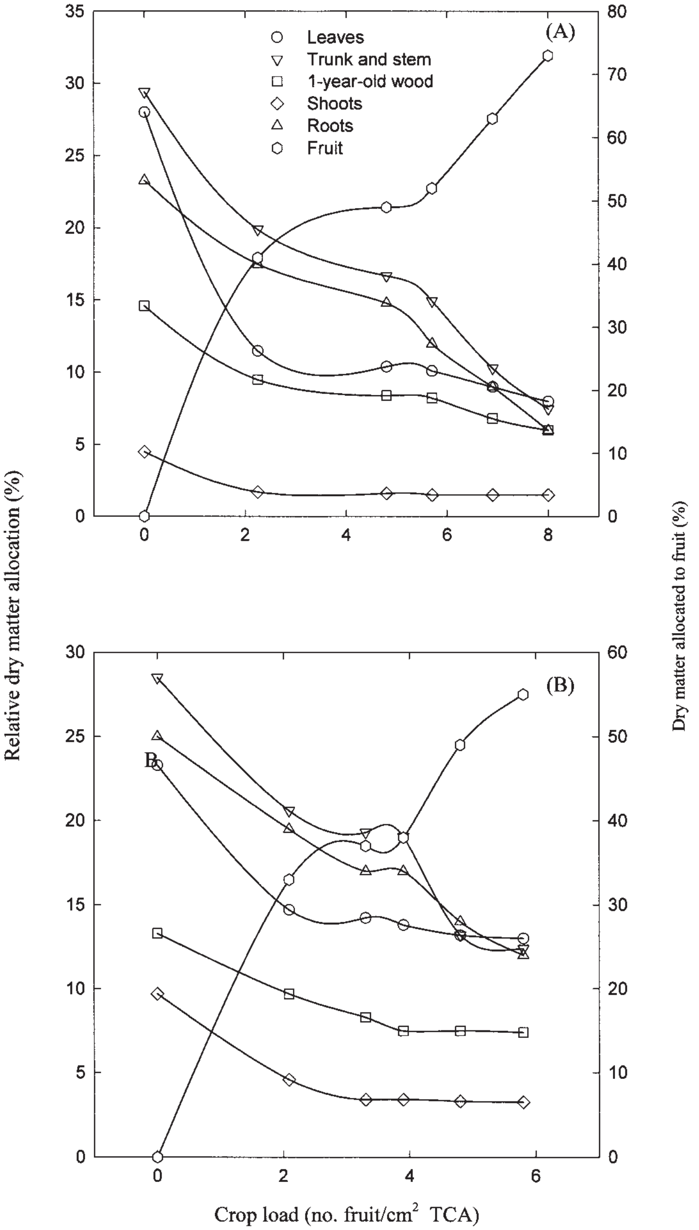

Fig. 9. Relationship at fruit harvest 1998 between crop load and dry matter allocation to leaves, fruit, roots, shoots, 1-year-old wood, trunk and stem for 'Early May Crest' (EMC) peach, grafted on 'Penta' (**A**) or (**B**) 'GF677' rootstock.