fruit set and boron accumulation in 'Italian' prune flowers. J. Amer. Soc. Hort. Sci. 110:389-392.

Johnson, F., D.F. Allmendinger, V.L. Miller, and D. Polley. 1954. Fall application of boron sprays as a control for blossom blast and twig dieback of pears. Phytopathology 45:110-114.

Kamali, A.R. and N.F. Childers. 1970. Growth and fruiting of peach in sand culture as affected by boron and a fritted form of trace elements. J. Amer. Soc. Hort. Sci. 95:652-656.

Neilson, B.V. and G.W. Eaton. 1983. Effects of boron nutrition upon strawberry yield components. HortScience 18:932-934.

Shear, C.B. and M. Faust. 1980. Nutritional ranges in deciduous tree fruits and nuts. Hort. Rev. 2:142-163.

Shoemaker, J.S. 1928. Cherry pollination studies. Ohio Agr. Expt. Sta. Bul. 422.

Shrestha, G.K., M.M. Thompson, and T.L. Righetti. 1987. Foliar-applied boron increases fruit set in 'Barcelona' hazelnut. J. Amer. Soc. Hort. Sci. 112:412-416.

Thompson, A.H. and L.P. Batjer. 1950. The effect of boron in the germination medium on pollen germination and pollen tube growth for several deciduous tree fruits. Proc. Amer. Soc.

Hort. Sci. 55:227-229.

Whittenberger, R.T., J.H. Levin, and B.F. Cargill. 1969. Weight to volume relationship of sweet cherries in brine. Michigan State Univ. Agr. Expt. Sta. Res. Rpt. 89.

Woodbridge, C.G. 1955. The boron requirements of stone fruit trees. Can. J. Agr. Sci. 35:282-286.

Yogarathnam, N. and D.W.P. Greenham. 1982. The application of foliar sprays containing nitrogen, magnesium, zinc and boron to apple trees. I. Effects on fruit set and cropping. J. Hort. Sci. 57:151-158.

HORTSCIENCE 26(9):1145-1148. 1991.

Rootstock Affects Vegetative Growth Characteristics and Productivity of 'Delicious' Apple

Ido Schechter¹, D.C. Elfving², and J.T.A. Proctor³

Department of Horticultural Science, University of Guelph, Guelph, Ont. N1G 2W1, Canada

Additional index words. shoot and spur leaves, spur density, *Malus domestica*

Abstract. Fruit and leaves were harvested from sample branches in Oct. 1987 and 1988 from 'Starkspur Supreme Delicious' apple (*Malus domestica* Borkh.) trees on nine rootstocks (Ottawa 3, M.7 EMLA, M.9 EMLA, M.26 EMLA, M.27 EMLA, M.9, MAC-9, MAC-24, OAR 1) planted in 1980. Harvested leaves were separated into shoot leaves and spur leaves. Based on a standardized unit (centimeter of limb circumference), rootstocks strongly influenced the number, area, dry weight, and percentage of leaves in each category in both years. Yield per centimeter of limb circumference (limb yield efficiency, LYE) varied widely among rootstocks. LYE was highly correlated with spur density and with spur leaf variables but not with shoot leaf number, dry weight, or area. Rootstock effect on spur density may partially explain their effect on yield characteristics. The rootstock OAR 1 affected some of these characteristics differently than the others.

Apple rootstocks differ in their influence on partitioning of photosynthetically produced dry matter between fruit and wood in the scion (Forshey and Elfving, 1989). Heinicke (1964) suggested that the greater yield efficiency of trees on M.9 compared to more vigorous rootstocks was due to improved light distribution in the canopies of smaller trees. However, yield efficiency varies for diverse rootstocks that produce trees of similar size (Ferree and Morrison, 1975). Rootstock characteristics influence the seasonal vegetative increment in fruiting and nonfruiting

trees (Avery, 1969; Forshey and McKee, 1970). Maggs (1958) suggested that differences in allocation of dry matter among tree parts in the absence of fruit might partially explain the effect of rootstock on tree size.

Apple tree foliage can be divided into shoot and spur leaves. Shoot leaves are larger than spur leaves and often contribute more proportionally to canopy leaf area (Forshey et

al., 1983, 1987; Forshey and Marmo, 1985). Barden and Ferree (1979) reported a slight effect of rootstock on specific leaf weight (SLW) but not on shoot growth or leaf number in 1-year-old, nonfruiting, container-grown trees of two 'Delicious' strains on rootstocks of differing size-control capacity (M.9, M.26, M.7, M.2, MM.106, MM.111, seedling). In a similar study, Ferree and Barden (1971) observed differential effects of MM.106, M.7A, and seedling rootstocks on both scion leaf size and leaf dry weight.

Leaf count, dry weight, and area per tree of shoot and spur leaves can vary with factors such as cultivar, vigor, pruning, and cropping without affecting the total canopy leaf area (Barlow, 1964; Forshey and Marmo, 1985; Lakso, 1984; Palmer and Jackson, 1977). Cropping in apple trees is associated with reduced total canopy leaf area (Avery, 1969; Hansen, 1971; Maggs, 1963; Proctor et al., 1976), more but smaller spur leaves (Forshey and Marmo, 1985; Singh, 1948), and a reduction in shoot leaf count with no change in the area per shoot leaf (Forshey and Marmo, 1985).

The objectives of this study were to determine: 1) rootstock effects on shoot and spur leaf count, dry weight, and area; 2) rootstock influence on spur density; and 3) whether variation in yield efficiency in mature 'Delicious' trees on different rootstocks can be associated with differences in canopy structure.

'Starkspur Supreme Delicious' apple trees on nine rootstocks were planted at Simcoe,

Table 1. Effect of rootstock on trunk cross-sectional area (TCSA) and shoot and spur leaf development, 1987.

Rootstock ^a	Fall TCSA (cm ²)	Per centimeter limb circumference ^a					
		Shoot leaves			Spur leaves		
		No.	Dry wt (g)	Area (cm ²)	No.	Dry wt (g)	Area (cm ²)
MAC-24	168 a	69 a	12 a	913 a	47 bcd	5 bcd	392 ab
M.7 EMLA	92 b	51 b	10 ab	707 b	38 d	4 cd	323 bc
M.26 EMLA	67 c	41 bcd	8 b	540 bc	64 ab	7 a	530 a
OAR 1	62 c	26 cd	4 c	292 de	74 a	5 abc	478 a
Ottawa 3	54 cd	47 b	8 b	520 bc	57 abc	5 abc	434 ab
M.9 EMLA	46 d	39 bcd	7 bc	476 cd	40 cd	4 bcd	320 bc
M.9	29 e	39 bcd	7 bc	440 cde	61 ab	6 ab	452 ab
MAC-9	23 e	42 bc	7 bc	411 cde	49 bcd	4 bcd	334 bc
M.27 EMLA	10 f	23 f	4 c	237 e	34 d	3 d	221 c

^aEach mean contains five observations, except for trees on Ottawa 3 and M.9 EMLA, which contains four observations.

^aMeans within columns separated by LSMEANS ($P = 0.05$).

Received for publication 11 Sept. 1990. This research was supported by operating grant no. A6697 of the Natural Sciences and Engineering Research Council of Canada held by J.T.A.P. We gratefully acknowledge the assistance received from Dean Louttit and Wayne Pierce. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked advertisement solely to indicate this fact.

¹Graduate Student.

²Research Scientist, Horticultural Research Inst. of Ontario, Ontario Ministry of Agriculture and Food, Simcoe, Ont. N3Y 4N5, Canada.

³Professor.

Table 2. Effect of rootstock on trunk cross-sectional area (TCSA), shoot and spur leaf development, limb yield efficiency (LYE), and spur count, 1988.

Rootstock ²	Fall TCSA (cm ²)	Per centimeter limb circumference ²						
		Shoot leaves			Spur leaves			Fruit fresh wt (LYE) (g)
		No.	Dry wt (g)	Area (cm ²)	No.	Dry wt (g)	Area (cm ²)	
MAC-24	199 a	68 a	12 a	787 a	86 c	8 bc	572 bcd	650 bcd
M.7 EMLA	103 b	33 b	6 b	382 b	98 bc	8 bc	610 bc	552 bcd
M.26 EMLA	72 c	24 bc	5 cb	333 b	122 ab	10 ab	808 a	834 ab
OAR 1	72 c	9 c	2 d	88 c	85 c	7 cd	541 bcd	442 cd
Ottawa 3	62 cd	37 b	6 b	366 b	144 a	12 a	819 a	1047 a
M.9 EMLA	50 d	13 c	2 cd	119 c	91 c	7 cd	448 cd	637 bcd
M.9	32 e	12 c	3 cd	146 c	129 a	10 ab	667 ab	724 bc
MAC-9	26 e	7 c	1 d	57 c	91 c	6 cd	415 ed	562 bcd
M.27 EMLA	11 f	7 c	1 d	62 c	70 c	5 d	320 e	415 d

¹Each mean contains five observations, except for trees on Ottawa 3 and M.9 EMLA, which contains four observations.

²Means within columns separated by LSMEANS ($P = 0.05$).

Ont., as single-tree plots in five randomized complete blocks in 1980 as part of the NC-140 cooperative program (NC-140, 1987). The field study reported here was carried out on this planting in the 1987 and 1988 seasons. The rootstocks Ottawa 3, M.7 EMLA, M.9 EMLA, M.26 EMLA, M.27 EMLA, M.9, Michigan Apple Clone 9 (MAC 9), MAC 24, and Oregon Apple Rootstock 1 (OAR 1) were included in the trial. The planting was on a well-drained Tavistock soil, consisting of 40 to 100 cm of sandy-loam material over glaciolacustrine clays, at a spacing of 3.5×5.5 m. Fertilizers, pesticides, and herbicides were applied as required according to standard commercial practices. In mid-Summer 1988, the trees were sprinkler-irrigated whenever tensiometer readings at 30- and 45-cm depths in the orchard reached -40 KPa.

In 1987, a representative limb from each tree was chosen (Forshey and Elfving, 1979a, 1979b). All leaves on each sample limb were harvested in the first week of October, before initiation of leaf drop, and separated into shoot and spur leaves. Bourse shoot leaves were scarce on these cultivar-rootstock combinations; however, shoots shorter than 10 cm were counted as spur leaves. A different sample limb was chosen in 1988. In addition to the above procedures, fruit were harvested at maturity from each sample limb, and yield was recorded. The number of spurs on each sample limb was counted following harvest. The total leaf area as shoot leaves and as spur leaves was determined using a LI-3000 area meter (LI-COR, Lincoln, Neb.) fitted with a LI-3050 transparent belt accessory. All leaves in each category were counted, weighed, and then oven-dried at 80°C to a constant weight. Trunk circumference was recorded in the fall for each tree at a pre-marked location 30 cm above the soil surface.

Leaf count, area, and weight variables were normalized to a per centimeter of limb circumference (CLC) basis before statistical analysis to correct for differences in sample limb size. The data were tested by analyses of variance, with the source of variance partitioned to rootstocks and blocks, using the general linear models (GLM) procedure of the SAS program package (SAS Institute,

Cary, N.C.). Due to the early death of two trees, means were separated using the LSMEANS option, which accounts for missing data. Correlation analyses were carried out between limb yield efficiency (LYE; $\text{g} \cdot \text{cm}^{-1}$ limb circumference) and the following variables for the two leaf types: spur and leaf count, dry weight, and area per centimeter of limb circumference.

Number of shoot leaves (LNFO), dry weight (LFDW), and area per CLC (LFAR) were correlated with trunk cross-sectional area (TCSA) in 1987 (0.67, 0.71, and 0.78, respectively, $n = 43$) and 1988 (0.83, 0.84, and 0.86, respectively, $n = 43$) despite significant differences in crop load between the two years. In contrast, spur leaves showed no correlation of any measurement (LNFO, LFDW, and LFAR) with TCSA.

1987. Shoot and spur LNFO, LFDW, and LFAR differed among rootstocks (Table 1). Final shoot LFAR values were primarily a function of shoot LNFO rather than area per shoot leaf. Trees on OAR 1 developed a substantially smaller shoot leaf canopy relative to their TCSA than did other rootstocks. The OAR 1 trees had about half of the shoot LFAR of trees on M.26 EMLA or Ottawa 3, which are similar in size in terms of TCSA. A similar pattern of dependence of leaf area on leaf count was found for spur leaves, with the exception of trees on OAR 1 and M.27 EMLA, which had considerably smaller mean area per spur leaf. However, spur LNFO, LFAR, and LFDW for OAR 1 were similar to values for M.26 EMLA and Ottawa 3.

In general, individual shoot leaves were $\approx 50\%$ larger in area and twice as heavy as spur leaves in 1987, as reported for 'McIntosh' by Forshey et al. (1983, 1987) and Forshey and Marmo (1985).

Trees on the most vigorous rootstocks (MAC-24, M.7 EMLA) had much larger shoot LFAR than spur LFAR in 1987 (Table 1, Fig. 1). Forshey et al. (1987) reported that the distribution of the final total leaf area per tree in 7- and 10-year-old 'Macspur McIntosh'/M.7 was 55% spur leaf area and 45% shoot leaf area. Shoot and spur leaves on the other rootstocks were divided more or less equally, with the exception of trees on OAR 1. Only trees on OAR 1 exhibited a substantially larger proportion of LFAR as spur

leaves (62%) vs. shoot leaves (38%).

1988. Cropping was very heavy on all trees in 1988 and much heavier than in 1987. Spur LNFO was higher than shoot LNFO for each rootstock (Table 2). This difference was small for trees on MAC-24 but was five times larger for trees on M.26 EMLA and between seven to 13 times greater for trees on OAR 1, M.9 EMLA, M.9, MAC-9, and M.27 EMLA. Shoot and spur leaves of trees on OAR 1 were fewer and smaller in area than those of trees of comparable TCSA (M.26 EMLA and Ottawa 3); trees on OAR 1 had the highest proportion of spur canopy LFAR (86%) (Fig. 1). Trees on MAC-9 showed signs of gall-like growths on the rootstock shank at the soil line as early as 1987. This growth may have contributed to the reduced shoot growth on this rootstock by interfering with normal vascular activity.

1987 vs. 1988. Canopy foliage was largely composed of spur leaves in 1988 for all rootstocks, except MAC-24 (Fig. 1). Trees on MAC-24 had shoot LNFO similar to those in 1987, while other rootstocks exhibited smaller LNFO values (Table 2). The shoot LNFO, LFDW, and LFAR values of trees on the less vigorous rootstocks were very much reduced as compared to the 1987 season. Trees on M.9 and M.9 EMLA had 67% and 75% less shoot LFAR, respectively, than in the 1987 season, while the shoot LFAR of trees on MAC-24 (15% less than 1987 values), M.7 EMLA (46%), M.26 EMLA (38%), and Ottawa 3 (30%) was less affected by the heavy crop in 1988. Trees on OAR 1, which normally produce fewer shoots, had 70% less shoot LFAR than in 1987, placing them with M.27 EMLA (74%), the smallest trees in this trial.

Despite substantial shifts in the proportions of spur and shoot LNFO, LFDW, and LFAR between 1987 and 1988, the total leaf area per CLC remained nearly the same in both years for each rootstock, except MAC-9, in which total LFAR was significantly lower in 1988 than 1987 (Fig. 1). The mean areas per shoot leaf and per spur leaf were smaller in 1988 than in 1987 (data not shown). Forshey and Marmo (1985) found no effect of crop on mean area per shoot leaf but a similar effect on mean area per spur leaf in 'McIntosh'. OAR 1 trees had nearly the same

Fig. 1. The effect of rootstocks on shoot and spur leaf area distribution in 1987 and 1988 and total leaf area per centimeter of limb circumference (marked above each bar). Sequence within bar graph from most to least vigorous as measured by trunk cross-sectional area.

Fig. 2. Correlation between number of spurs per centimeter of limb circumference (CLC) and fruit fresh weight per CLC (LYE). Rootstocks arranged in decreasing order of vegetative vigor as measured by trunk cross-sectional area.

values for spur leaf characteristics in both years, unlike the other rootstocks. Changes in leaf distribution between shoot and spur leaves in the absence of altered total LFAR among several distinct rootstock clones are similar to effects reported for dormant pruning (Forshey and Marmo, 1985; Lakso, 1984) and deblossoming (Forshey and Marmo, 1985).

The spur density (spur count per CLC) varied by 40% among rootstocks and generally was higher for trees on M.26 EMLA,

Ottawa 3, and M.9 (Table 2). Rootstock vigor, as estimated by TCSA, did not correlate with spur density in 1988, but LYE was correlated with this characteristic ($r = 0.65$, $n = 43$, $P = 0.05$) (Fig. 2).

Although not significantly different, the largest trees, grown on MAC-24 and M.7 EMLA, had lower LYE values than the smaller trees, on M.26 EMLA, Ottawa 3, and M.9, with the highest LYE (Table 2) in 1988. Spur leaf LFNO and LFAR were correlated with LYE ($r = 0.75$ and 0.73 , re-

spectively, $n = 43$, $P = 0.05$), but the best correlation was established with spur LFDW ($r = 0.81$, $n = 43$, $P = 0.05$). Barritt et al. (1987) also reported that leaf dry weight was more closely associated with fruit weight than was leaf area. Shoot LFNO, LFDW, and LFAR were not correlated with LYE.

Both shoot and spur foliage characteristics differed significantly among trees on different rootstocks, even in trees of similar size. Trees on vigorous rootstocks produced more shoot LFNO per CLC than trees on smaller rootstocks. In this study, shoot LFNO, LFAR, and LFDW were correlated with tree vigor, while spur leaf characteristics were correlated with LYE. Other studies have shown an inverse relationship between shoot and spur leaves (Forshey, 1989; Forshey and Marmo, 1985; Forshey et al., 1983). Rogers and Booth (1964) reported that the influence of crop on shoot growth diminishes with an increase in tree vigor. Cropping reduced shoot growth during the heavy cropping season of 1988 (Avery, 1975; Barlow, 1975; Forshey, 1982; Forshey and Marmo, 1985; Maggs, 1963), probably by altering assimilate partitioning to developing fruit at the expense of shoot growth.

Hansen (1967b, 1969) suggested that shoot leaves, although relatively distant, play a role in fruit growth. Trees on OAR 1 had considerably smaller shoot LFAR in both years relative to their TCSA and consistently produced small apples throughout this trial (Simcoe, NC-140 1988 report, unpublished). Limited shoot leaf count and area may have restricted the availability of resources for fruit growth in trees on OAR 1 (Hansen, 1967b, 1969). Variation in LYE among rootstocks was related only to spur leaf variables. Removing spur leaves reduced both fruit number per spur and fruit diameter (Ferree and Palmer, 1982). In addition to their importance for fruit set and development, spur leaves may provide carbon assimilates for incorporation into young fruitlets (Ferree and Palmer, 1982; Llewellyn, 1968; Rom and Ferree, 1986). Previous studies with spur leaves showed that apple fruit attracted photosynthates from nearby leaves (Hansen, 1967a, 1970). Early reports suggested that each spur acts independently for flower initiation, being dependent on the leaves in the immediate vicinity of the bud (Auchter et al., 1926; Gourley, 1920; Heinicke, 1917; Roberts, 1920). The results of the present study emphasize the importance of the spur leaf canopy in early spring and before dormancy.

Spur-type strains of apple have greater spur density and larger leaf area per unit branch length than nonspur strains (Westwood and Zielinski, 1966). Ferree (1988) reported differences in spur number per meter of shoot length of up to 30% among 16 strains of 'Delicious' on the same rootstock, M.7. The significant correlation between spur number per CLC and LYE in a single 'Delicious' strain over nine distinct rootstocks in this study suggests that rootstock may influence yield potential in apple, in part, by altering spur density of the scion.

Literature Cited

- Auchter, E.C., A.L. Schrader, F.S. Lagasse, and W.W. Aldrich. 1926. The effect of shade on the growth, fruit bud formation, and chemical composition of apple trees. *Proc. Amer. Soc. Hort. Sci.* 23:368-382.
- Avery, D.J. 1969. Comparisons of fruiting and deblossomed maiden apple trees, and of non-fruiting trees on a dwarfing and an invigorating rootstock. *New Phytol.* 68:323-336.
- Avery, D.J. 1975. Reduction in growth increments by crop competition, p. 103-106. In: H.C. Pereira (ed.). *Climate and the orchard*. Cmlth. Agr. Bur., Slough, U.K.
- Barden, J.A. and D.C. Ferree. 1979. Rootstock does not affect net photosynthesis, dark respiration, specific leaf weight, and transpiration of apple leaves. *J. Amer. Soc. Hort. Sci.* 104:526-528.
- Barlow, H.W.B. 1964. An interim report on a long-term experiment to assess the effect of cropping on apple tree growth. *Annu. Rpt. E. Malling Res. Sta.* 1963. p. 84-93.
- Barlow, H.W.B. 1975. Effects of cropping on the growth of orchard trees, p. 98-102. In: H.C. Pereira (ed.). *Climate in the orchard*. Cmlth. Agr. Bur., Slough, U.K.
- Barritt, B.H., C.R. Rom, K.R. Guelich, S.R. Drake, and M.A. Dilley. 1987. Canopy position and light effects on spur, leaf, and fruit characteristics of 'Delicious' apple. *HortScience* 22:402-405.
- Ferree, D.C. 1988. Role of rootstocks and spur-type scions for controlling vegetative growth of apple and peach trees. *HortScience* 23:464-467.
- Ferree, M.E. and J.A. Barden. 1971. The influence of strains and rootstocks on photosynthesis, respiration, and morphology of 'Delicious' apple trees. *J. Amer. Soc. Hort. Sci.* 96:453-457.
- Ferree, D.C. and C.A. Morrison. 1975. An evaluation of selected cultivars, rootstocks and hardy interstocks. *Fruit Var. J.* 29:26-29.
- Ferree, D.C. and J.W. Palmer. 1982. Effect of spur defoliation and ringing during bloom on fruiting, fruit mineral level, and net photosynthesis of 'Golden Delicious' apple. *J. Amer. Soc. Hort. Sci.* 107:1182-1186.
- Forshey, C.G. 1982. Effects of fruiting, pruning, and nitrogen fertilization on shoot growth of 'Empire' apple trees. *J. Amer. Soc. Hort. Sci.* 107:1092-1097.
- Forshey, C.G. 1989. Measuring the effect of growth regulators on the vegetative growth-fruiting relationship in apple trees. *Acta Hort.* 239:211-219.
- Forshey, C.G. and D.C. Elfving. 1979a. Branch samples for yield and fruit size comparison in apple. *HortScience* 14:143-144.
- Forshey, C.G. and D.C. Elfving. 1979b. Estimating yield and fruit numbers of apple trees from branch samples. *J. Amer. Soc. Hort. Sci.* 104:897-900.
- Forshey, C.G. and D.C. Elfving. 1989. The relationship between vegetative growth and fruiting in apple trees. *Hort. Rev.* 11:229-287.
- Forshey, C.G. and C.A. Marmo. 1985. Pruning and deblossoming effects on shoot growth and leaf area of 'McIntosh' apple trees. *J. Amer. Soc. Hort. Sci.* 110:128-132.
- Forshey, C.G. and M.W. McKee. 1970. Production efficiency of a large and a small 'McIntosh' apple tree. *HortScience* 5:164-165.
- Forshey, C.G., R.W. Weires, B.H. Stanley, and R.C. Seem. 1983. Dry weight partitioning of 'McIntosh' apple trees. *J. Amer. Soc. Hort. Sci.* 108:149-154.
- Forshey, C.G., R.W. Weires, and J.R. VanKirk. 1987. Seasonal development of the leaf canopy of 'Macspur McIntosh' apple trees. *HortScience* 22:881-883.
- Gourley, J.H. 1920. The effect of shading some horticultural plants. *Proc. Amer. Soc. Hort. Sci.* 17:256-260.
- Hansen, P. 1967a. ¹⁴C-studies on apple trees. I. The effect of the fruit on the translocation and distribution of photosynthates. *Physiol. Plant.* 20:382-391.
- Hansen, P. 1967b. ¹⁴C-studies on apple trees. II. Distribution of photosynthates from top and base leaves from extension shoots. *Physiol. Plant.* 20:720-725.
- Hansen, P. 1969. ¹⁴C-studies on apple trees. IV. Photosynthate consumption in fruits in relation to the leaf-fruit ratio and to the leaf-fruit position. *Physiol. Plant.* 22:186-198.
- Hansen, P. 1970. ¹⁴C-studies on apple trees. VI. The influence of the fruit on the photosynthesis of the leaves, and the relative photosynthetic yields of fruits and leaves. *Physiol. Plant.* 23:805-810.
- Hansen, P. 1971. ¹⁴C-studies on apple trees. VII. The early seasonal growth in leaves, flowers and shoot as dependent upon current photosynthates and existing reserves. *Physiol. Plant.* 25:469-473.
- Heinicke, A.J. 1917. Factors influencing the abscission of flowers and partially developed fruits of the apple. *Cornell Univ. Agr. Expt. Sta. Bul.* 393.
- Heinicke, D.R. 1964. The micro climate of fruit trees. III. The effect of tree size on light penetration and leaf area in 'Red Delicious' apple trees. *Proc. Amer. Soc. Hort. Sci.* 85:33-41.
- Lakso, A.N. 1984. Leaf area development patterns in young pruned and unpruned apple trees. *J. Amer. Soc. Hort. Sci.* 109:861-865.
- Llewellyn, F.W.M. 1968. The effect of partial defoliation at different times in the season on fruit drop and shoot growth in 'Lord Lambourne' apple trees. *J. Hort. Sci.* 43:519-526.
- Maggs, D.H. 1958. A comparison of the growth patterns of two apple rootstock varieties during their first year. *Annu. Rpt. E. Malling Res. Sta.* 1957. p. 101-105.
- Maggs, D.H. 1963. The reduction in growth of apple trees brought about by fruiting. *J. Hort. Sci.* 38:119-128.
- NC-140. 1987. Growth and production of 'Starkspur Supreme Delicious' on 9 rootstocks in the NC-140 cooperative planting. *Fruit Var. J.* 41:31-39.
- Palmer, J.W. and J.E. Jackson. 1977. Seasonal light interception and canopy development in hedgerows and bed system apple orchards. *J. Applied Ecol.* 14:539-549.
- Proctor, J.T.A., R.L. Watson, and J.J. Landsberg. 1976. The carbon budget of a young apple tree. *J. Amer. Soc. Hort. Sci.* 101:579-582.
- Roberts, R.H. 1920. Off year apple bearing and apple spur growth. *J. Pomol. Hort. Sci.* 2:16-37.
- Rogers, W.S. and G.A. Booth. 1964. Relationship of crop and shoot growth in apple. *J. Hort. Sci.* 39:61-65.
- Rom, C.R. and D.C. Ferree. 1986. Influence of fruit on spur leaf photosynthesis and transpiration of 'Golden Delicious' apple. *HortScience* 21:1026-1029.
- Singh, L.B. 1948. Studies in biennial bearing. III. Growth studies in "on" and "off" year trees. *J. Hort. Sci.* 24:123-148.
- Westwood, M.N. and Q.B. Zielinski. 1966. Comparative growth habit and leaf composition of a compact mutant and standard 'Delicious' apple. *Proc. Amer. Soc. Hort. Sci.* 88:9-13.