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Influence of Rootstocks and Microsprinkler Fertigation on Photosynthesis of 'Fuji' Apple Trees

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Abstract

Net photosynthesis (Pn) and transpiration (Tr) of shoot and spur leaves of 'BC-2 Fuji' apple trees (*Malus domestica* Borkh.) as influenced by five different rootstocks, B.9, M.9 NAKBT337, O.3, M.26 EMLA, M.7 EMLA and five different nutrition treatments consisting of 22.4 kg nitrogen (N)/ha (low N), 89.7 kg N/ha (medium N), 156.9 kg N/ha (high N), 89.7 kg N/ha plus 78.5 kg potassium (K)/ha (medium N + K), and 156.9 kg N/ha plus 78.5 kg K/ha (high N + K), applied through a microsprinkler system, were studied in 1998 and 1999. There was no interaction between rootstocks and fertigation treatments. Shoot leaves of trees on O.3 had significantly higher Pn than those on B.9 and M.7 EMLA rootstocks in August of 1998 and in July and August of 1999. Shoot leaves of trees on B.9 had 13% lower Pn than those on other rootstocks in June 1999. Rootstocks had little effect on the Pn of scion spur leaves. Shoot leaves of trees receiving low N had significantly lower Pn than those with medium N or high N on all sampling dates in 1998 and in June of 1999. Also, spur leaves on trees receiving low N had significantly lower Pn than those with high N on all sampling dates in 1998. Shoot leaves had significantly higher Pn than spur leaves with exception of July of 1999.

Introduction

Factors influencing photosynthesis of apple (*Malus domestica* Borkh.) leaves have been studied by several researchers. These factors include cultivars (6, 15), cultural practices (13, 31), fruit load (1, 3), growth regulators (21), light and temperature, (2, 23, 25, 30, 32, 36), nutrients (9, 10, 18, 22, 24), physical factors (3, 19, 26, 33, 37), pest injury (27), and rootstocks (4, 8, 17, 34, 35).

The role of rootstock on scion leaf Pn varies depending on studies. Barden and Ferree (4) reported that the Pn and dark respiration of container grown 'Delicious' trees were unaffected by rootstocks. Other reports (8, 17, 34) found that shoot leaves of trees on more vigorous rootstocks have higher Pn than those on dwarfing rootstocks. Baugher et al. (8) indicated that shoot leaf Pn of 'Golden Delicious' apple trees was higher on M.7 EMLA or MM.111 EMLA than that on M.9 EMLA rootstock. Ferree and Barden (17) found that shoot leaf Pn of apple trees grown on seedling rootstocks was higher than that on MM.106. Schechter et al. (34) reported that trees grown on vigorous rootstocks had higher shoot Pn rates than those on dwarfing rootstocks. However, Marro and Cereghini (28) found that leaf Pn of 'Richared' apple on M.9 was higher than those on seedling. Titova and Shishkanu (38) reported that scion leaf Pn on dwarf rootstock was always greater than those on vigorous rootstocks.

The role of nutrients on shoot leaf Pn of apple trees has also been studied. Nutrition deficiencies reduce shoot leaf Pn of apple trees (10, 18, 22, 24). Kaakeh et al. (24) found that shoot leaf Pn rates increased with increasing urea rates in 'Redchief Delicious'. A relationship between N fertilization and shoot leaf Pn was also observed in peaches (12).

Information on the effect of rootstocks and microsprinkler fertigation on leaf Pn of 'Fuji' is lacking. Therefore, the objective of this study was to examine the influence of rootstocks and microsprinkler fer-

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tigation with different levels of N with or without K on net photosynthesis (Pn), and transpiration (Tr) of shoot leaves and spur leaves in 'BC-2 Fuji' apple trees.

Materials and Methods

Plant Materials

'BC-2 Fuji' apple trees grafted on B.9, M.9 NAKBT337, O.3, M.26 EMLA, or M.7 EMLA rootstocks were planted at 2.43 x 4.87 m spacing at the University of Idaho Parma Research and Extension Center, Parma, Idaho in May 1995. The trees were trained to a central leader with the top of the leader bent in a zig-zag pattern to control growth (5). A 3.65-m supporting post was pounded into the ground next to each tree and the trees tied to the post. 'Snowdrift' crabapples were used as pollinizers. The soil was sandy loam and at the depth of 0-58.8 cm, the soil characteristics were as follow: pH 7.1 to 7.3, NO_3-N 2.74 to 3.14 $\mu g.g^{-1}$, NH_4-N 1.45 to 1.09 $\mu g.g^{-1}$, P 8.0 to 12.4 $\mu g.g^{-1}$, K 306 to 319 $\mu g.g^{-1}$, CEC 16.6 to 18.3, and organic matter 0.48 to 1.03%.

Fertigation Treatments

Five nutrient treatments with the same amount of water were delivered through the microsprinkler irrigation system (fertigation). Liquid urea-ammonium nitrate (UAN-32) and liquid potash fertilizers (0-0-13 K_2O) were used in the experiment. The total nutrient applied each year were as follows: 22.4 kg N/ha (low N), 89.7 kg N/ha (medium N), 156.9 kg N/ha (high N), 89.7 kg N/ha in combination with 78.5 kg potassium (K)/ha, and 156.9 kg N/ha in combination with 78.5 kg K/ha. Each of these nutrient treatments was applied in four equal quantities on 31 May, 8 June, 15 June, and 23 June in 1998, and on 20 May, 27 May, 4 June, and 10 June in 1999.

Photosynthesis and Leaf Area Measurement

Net photosynthesis (Pn) and transpiration (Tr) of shoot leaf and spur leaf from each tree were measured between 8 a.m. and 12 p.m. in the orchard in June, July, and August of 1998 and 1999. In June 1998, leaves of trees on three rootstocks, B.9, O.3, and M.7 EMLA were measured. For other dates, all treatments were included. Shoot leaves, originating from mid-section of the current season shoots, and spur leaves, originating from non-flowering spurs, were measured using a LI COR Model 6200 (LI-COR Inc., Lincoln, NE) and the quantum sensor was held perpendicular to the sun. Measurements were always made under saturating light condition with photosynthesis active radiation (PAR) higher than 1000 $\mu mol\ m^{-2}{\cdot}sec^{-1}$. After measuring Pn and Tr of each type of leaves, the same leaves were collected for leaf area measurements using a leaf area meter (LI-3000, LI-COR Inc., Lincoln, NE).

Leaf Nitrogen, Yield, Yield Efficiency, and Fruit Weight

After terminal buds were formed in about mid-August every year, 30 leaves with petioles attached, from mid-section of the current season shoots and spur leaves of five non-flowering spurs were collected randomly from each tree. Samples were washed with a mild solution of Liqui-Nox detergent (Alocnox, Inc., New York, NY), rinsed in deionized water, dried at 65°C, and ground (Cyclotec 1093, Teactor Inc., Hoganas, Sweden) to pass through a 40-mesh screen. Nitrogen concentration of each sample was measured by Protein and Nitrogen Analyzer (FP-528, LECO Corp., St. Joseph, MI).

Yield per tree was recorded on the harvest day of each year (20 Oct. 1998 and 18 Oct. 1999). Trunk circumference of each tree was measured above 20.3 cm from the graft union to calculate trunk cross-sectional area (TCA) and yield efficiency was calculated as yield per tree (kg)/trunk cross-sectional area (cm^2). Eighteen fruits were randomly sampled from each tree at harvest time each year, and average fruit weight was calculated.

Experimental Design and Data Analyses

The experiment plot was arranged as a randomized complete block split plot design with fertigation (nutrient) treatments as the main plots and rootstocks as subplots. Four blocks were used and each

Table 1. The influences of rootstock on net photosynthesis (Pn), transpiraton (Tr), specific leaf weight (SLW), trunk cross-sectional area (TCA), yield, yield efficiency, and average fruit weight of 'BC-2 Fuji' shoot leaves in 1998 and 1999.

	Shoot leaves									Yield	Average
	Pn ($\mu mol \cdot m^{-2} \cdot s^{-1}$)			Tr ($mol \cdot m^{-2} \cdot s^{-1}$)			SLW	TCA	Yield	efficiency[Z]	fruit wt
Rootstock	June	July	August	June	July	August	(mg cm^{-1})	(cm^2)	(kg/tree)	(kg/cm^2)	(g)
1998											
B.9	12.5 a[y]	9.4 ab	8.3 b	3.5 b	4.0 a	5.0 a	14.3 a	14.2 e	9.4 bc	0.76 a	182.6 c
M.9	—	9.1 b	9.1 b	—	2.9 b	2.9 d	14.2 a	19.2 d	11.0 ab	0.60 b	201.5 b
O.3	12.1 a	10.5 a	10.3 a	3.9 ab	3.4 ab	3.3 cd	13.9 a	21.6 c	12.2 a	0.50 c	202.6 b
M.26 EMLA	—	9.1 b	9.1 b	—	3.5 ab	3.9 bc	13.6 a	31.6 b	9.3 c	0.33 d	204.8 b
M.7 EMLA	12.8 a	9.2 b	8.4 b	4.1 a	3.8 a	4.1 b	12.3 b	41.4 a	8.6 c	0.20 e	211.9 a
1999											
B.9	11.4 b	7.5 b	8.3 b	2.7 c	3.3 a	2.6 b	17.5 a	18.4 e	7.3 c	0.40 a	202.9 c
M.9	13.0 a	8.0 ab	8.8 ab	3.3 b	3.7 a	2.7 b	16.7 b	26.7 d	12.9 b	0.32 ab	225.0 ab
O.3	13.8 a	8.6 a	9.5 a	3.6 ab	3.3 a	3.1 a	16.6 bc	29.8 c	12.2 b	0.29 ab	218.5 ab
M.26 EMLA	13.3 a	7.6 b	8.8 ab	3.4 ab	3.3 a	2.9 ab	16.0 bc	42.7 b	21.6 a	0.26 b	215.6 bc
M.7 EMLA	13.4 a	7.6 b	8.5 b	3.6 a	3.3 a	2.8 ab	15.9 c	58.3 a	10.4 bc	0.12 c	226.7 a

[Z]Yield efficiency = yield per tree (kg)/trunk cross-sectional area (cm^2).
[y]Mean separation within columns of each year by LSD at $\alpha \leq 0.05$ (n = 40).

block had five fertigation treatments and two replications of five rootstocks (total 200 trees were used in this study). Assumption of normality was checked by computing univariate analyses for all tree responses of this study. Data was analyzed by GLM procedures, using SAS (SAS Institute Inc., Cary, NC). Fisher's protected LSD ($\alpha \leq 0.05$) was performed to present mean separations. Since two leaf types were used for measuring gas exchange parameters, measurements from all rootstocks and nutrient treatments were pooled to examine the effects of leaf type.

Results and Discussion

No interactions between fertigation treatments and rootstocks were found in this study. Therefore, the main effects are reported in the following sections.

Rootstock Effects

Rootstocks affected Pn rates of shoot leaves of 'BC-2 Fuji' in July and August of both 1998 and 1999. Shoot leaves of trees on B.9 had significantly lower Pn than those on other rootstocks in June of 1999 (Table 1). In 1998, shoot leaves of trees on O.3 had significantly higher Pn than those on M.9, M.26 EMLA and M.7 EMLA in July and August and than those on B.9 in August. In 1999, shoot leaves of trees on O.3 also had significantly higher Pn than those on B.9 and M.7 EMLA in July and August and than those on M.26 EMLA in July. Trees on M.7 EMLA had higher rate

Table 2. The influence of fertigation and leaf type on net photosynthesis (Pn), transpiration (Tr), and leaf nitrogen concentration of 'BC-2 Fuji' apple shoot and spur leaves in 1998 and 1999.

	Shoot leaves							Spur leaves						
	Pn ($\mu mol \cdot m^{-2} \cdot s^{-1}$)			Tr ($mol \cdot m^{-2} \cdot s^{-1}$)			Leaf N	Pn ($\mu mol \cdot m^{-2} \cdot s^{-1}$)			Tr ($mol \cdot m^{-2} \cdot s^{-1}$)			Leaf N
Fertigation	June	July	August	June	July	August	(% dwt)	June	July	August	June	July	August	(% dwt)
1998														
Low N	10.9 c[y]	7.9 c	8.1 c	4.0 ab	3.0 b	3.3 b	2.19 b	9.8 b	7.1 c	7.1 b	3.6 a	3.7 ab	3.2 ab	2.01 c
Med. N	13.7 a	10.4 a	10.0 ab	4.3 a	4.0 a	3.8 ab	2.31 ab	11.4 ab	8.3 ab	8.0 ab	3.4 a	4.5 a	3.8 a	2.14 b
High N	13.5 ab	11.0 a	10.6 a	3.6 b	3.8 a	4.0 a	2.45 a	11.7 a	8.9 a	8.4 a	3.9 a	3.5 ab	3.3 ab	2.23 a
Med. N + K	11.8 bc	9.7 ab	9.2 ab	3.7 ab	3.5 ab	3.5 ab	2.41 a	10.9 ab	7.5 bc	7.7 ab	3.4 a	3.3 b	3.3 ab	2.18 ab
High N + K	12.7 abc	9.0 bc	9.1 bc	3.6 b	3.4 ab	3.6 ab	2.49 a	9.8 b	7.7 bc	7.4 ab	3.4 a	3.2 b	3.2 b	2.20 ab
1999														
Low N	10.2 c	7.1 b	8.2 b	3.6 ab	3.7 ab	3.4 ab	1.93 c	9.6 b	6.8 a	6.9 b	3.2 abc	2.7 a	3.1 a	1.84 c
Med. N	13.7 ab	8.1 ab	9.5 ab	3.7 a	3.9 a	3.4 a	2.25 b	11.8 ab	7.3 a	7.7 ab	3.7 a	3.2 a	3.4 a	2.19 b
High N	14.8 a	8.8 a	10.0 a	3.6 ab	3.4 ab	2.6 ab	2.37 a	12.1 ab	8.2 a	8.2 ab	3.3 ab	2.8 a	3.2 a	2.26 a
Med. N + K	12.6 b	7.9 ab	8.2 b	3.0 b	3.0 ab	2.3 b	2.24 b	13.3 a	7.9 a	8.5 a	2.7 b	2.5 a	2.7 a	2.16 b
High N + K	13.6 ab	7.1 b	8.2 b	3.1 b	2.9 b	2.3 b	2.38 a	12.3 a	7.5 a	7.6 ab	2.8 bc	3.0 a	3.0 a	2.25 a

[z]Fertigation treatment: Low N, 22.4kg N/ha; Medium (Med.) N, 89.7 kg N/ha; High N, 156.9 kg N/ha; Medium (Med.) N + K, 89.7 kg N/ha plus 78.5 kg K/ha; High N + K, 156.9 kg N/ha plus 78.5 kg K/ha.
[y]Mean separation within columns of each year by LSD at $\alpha \leq 0.05$ (n = 40).

of shoot leaf Tr than those on B.9 in June of 1998 and 1999.

Trees on B.9 had more than 6% smaller fruit than trees on other rootstocks in both years, which could be due to the lower shoot leaf Pn rate of these trees (Table 1). Higher crop load is usually associated with smaller fruit size (14). However, smaller fruit size of trees on B.9 cannot be only due to crop load. Yield efficiency of trees on B.9 was higher than those on other rootstocks in 1998, because these trees were more precocious than M.7 EMLA and had significantly smaller TCA than trees on other rootstocks (Table 1). In 1999, although TCA of trees on B.9 was still significantly smaller than those on all other rootstocks, the yield efficiency of these trees was similar to those of M.9 and O.3 (Table 1). However, similar to the case in 1998, trees on B.9 again had significantly smaller fruit than those on M.9 and O.3 in 1999 (Table 1). Rootstock did not affect Pn of spur leaves (data not shown).

Shoot leaves of trees on M.7 EMLA had significantly lower specific leaf weight (SLW) than those on other rootstocks in both years (Table 1). SLW decreased with the vigor of the rootstock, so that trees on B.9 had significantly higher SLW than those on other rootstocks. These results in part agree with Ferree and Barden (17) where they also reported that 'Delicious' on MM.106 had lower Pn but higher SLW than those on seedling.

Table 3. The influence of leaf type on net photosynthesis (Pn), transpiration (Tr), and leaf nitrogen concentration of 'BC-2 Fuji' apple shoot and spur leaves in 1998 and 1999.

	Month						
	Pn (μmol·m⁻²·s⁻¹)			TR (mol·m⁻²·s⁻¹)			Leaf N
Leaf Type	June	July	August	June	July	August	(%·dwt)
1998							
Shoot leaf	12.7 a[z]	9.5 a	9.3 a	3.8 a	3.6 a	3.6 a	2.37 a
Spur leaf	10.7 b	8.0 b	7.9 b	3.5 a	3.7 a	3.4 a	2.15 b
1999							
Shoot leaf	13.0 a	7.8 a	8.8 a	3.3 a	3.4 a	3.1 a	2.25 a
Sour leaf	12.0 b	7.6 a	7.8 b	3.1 b	2.8 b	2.8 b	2.14 b

[z]Mean separation within columns of each year by LSD at $\alpha \leq 0.05$ (n = 200).

Previous researchers reported conflicting results on the effects of rootstock on apple leaf Pn (4, 8, 17, 28, 34, 38). Barden and Ferree (4) reported that scion leaf Pn was not affected by rootstock in 'Delicious' trees grown in containers. Other researchers (8, 17, 34) reported that the scion shoot leaf Pn increased with vigor of rootstocks. Contrary to these reports, other researchers (28, 38) found that scion shoot leaf Pn was greater on dwarf rootstock than vigorous rootstocks in apples. In our study, shoot leaf Pn was not necessarily related to the vigor of rootstocks in 'Fuji'. Based on our results, shoot leaf Pn may increase or decease with rootstock vigor, depending on which pairs or groups of rootstocks are compared. For example, trunk cross-sectional areas of trees on O.3 rootstock were smaller than those on M.7 EMLA, and they were between M.26 EMLA and M.9 in our study (Table 1) and in other reports (7, 29). However, shoot leaf Pn of trees on O.3 was often higher than those on both M.7 EMLA and M.26 EMLA (Table 1). On the other hand, shoot leaves of trees on O.3 had higher Pn than B.9, which agree with those researchers (8, 17, 34) who reported that Pn increases with rootstock vigor. We did not observe significant differences in scion shoot leaf Pn among M.9, M.26 EMLA, and M.7 EMLA rootstocks, which agrees with Barden and Ferree's results (4) in young 'Delicious' apple.

Tree size, number of branches and side shoots, and thus numbers of leaves on trees are affected by rootstocks (8, 11). Therefore, measurement of the whole tree photosynthesis, rather than individual leaves, may provide a better tool to study the relationship among rootstocks, total carbohydrate partitioning, and productivity in the scion cultivars. Measurement of whole tree photosynthesis is becoming the focus of plant physiologists and several studies in this field are undergoing at the present time (A. N. Lakso, personal communication).

Fertigation Effects

Shoot leaves of trees receiving low N (22.4 kg N/ha) treatment had significantly lower Pn than those with medium N (89.7 kg N/ha) treatment in 1998 or high N (156.9 kg N/ha) treatment in 1998 and 1999 (Table 2). Spur leaves on trees receiving 22.4 kg N/ha had significantly lower Pn than those with 156.9 kg N/ha on all sampling dates of 1998. Lower rates of Pn in the shoot and spur leaves were due to their lower N concentrations (Table 2). Other researchers (16, 24) have also demonstrated a positive relationship between N fertilization rates and Pn in apples that is in agreement with our results.

Many fruit growers in the Pacific Northwest apply extremely low amount of N (22.4 kg N/ha per year or lower) to 'Fuji' trees to produce fruit with better color. However those who have soils with low organic matter and sandy texture, often experience severe N deficiency, resulting in weak trees with low production after few years (Idaho fruit growers, personal communication). In our experiment, application of greater than 89.7 kg N/ha resulted in poor color and higher ethylene evolution and respiration of fruits (Fallahi et al., unpublished data). When fruit color remains green due to excess N application, growers tend to delay the harvest to gain better color. However, advanced internal maturity of these fruits could lead to severe internal breakdown in the storage. Therefore, development of optimum thresholds of N in relation to optimum Pn and ultimately fruit quality deserves further investigation. Application of K had little or no effects on Pn.

Effects of Leaf Type

Shoot leaves had 7.9% to 11% higher Pn than spur leaves in all sampling dates of 1998 and June and August of 1999 (Table 3). Also, shoot leaves had significantly higher leaf N concentrations than spur leaves (Table 3). The results of this study were in agreement with previous results by Ghosh (20) in 'Antonovka Obyknovennaya' and by Schechter et al. (34) in 'Starkspur Supreme Delicious'. The role of each leaf type in relation to the whole-tree photosynthesis and carbohydrate partitioning in 'Fuji' apple deserves further investigation.

Conclusions

Shoot leaves of trees on B.9 had significantly lower Pn than those on other rootstocks in June of 1999. In 1998, shoot leaves of trees on O.3 had significantly higher Pn than those on M.9, M.26 EMLA and M.7 EMLA in July and August and than those on B.9 in August. In 1999, shoot leaves of trees on O.3 also had significantly higher Pn than those on B.9 and M.7 EMLA in July and August and than those on M.26 EMLA in July. Trees on M.7 EMLA had higher rate of shoot leaf Tr than those on B.9 in June of 1998 and 1999. In general, net photosynthesis seemed to be unrelated to the vigor of rootstocks. Application of 22.4 kg N/ha had the lowest CO_2 assimilation in 'BC-2 Fuji' apple trees. Trees receiving higher rates of N by microsprinkler fertigation had higher Pn rates and leaf N concentrations. Potassium had little or no effect on leaf Pn in this study.

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