

## Leaf N and P in different growth habits of peach: Effects of root system morphology and transpiration

**Running title:** Peach growth habit affects leaf N and P

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### Abstract

Adequate mineral nutrition is critical for high fruit quality and sustained yield of fruit trees. In this experiment peach [*Prunus persica* L. (Batch)] trees with different shoot and root growth habits were evaluated for leaf nitrogen (N) and phosphorus (P) concentrations after fertilizer applications in the greenhouse and field. In the field during 2008, Compact trees had higher root length density than Pillar and Standard trees (6.2, 3.8, and 3.7 mm cm<sup>-3</sup>, respectively). Compact trees also had higher foliar P (0.21%) but the same N (1.3%) as Standard and Pillar trees (P concentrations of 0.14 and 0.11%, respectively) when fertilizer was applied once in the greenhouse. Following multiple applications of fertilizer, compact tree leaves had the same P (approximately 0.21 and 0.29% in the greenhouse and field, respectively) as the other growth habits. After multiple fertilizer applications, Pillar trees had the greatest increase in foliar N and P which was associated with high transpiration rates. Pillar, Compact, and Standard transpiration rates were 3.0, 2.1, and 2.3 mmol H<sub>2</sub>O m<sup>-2</sup> s<sup>-1</sup>. The data indicate that peach trees with fibrous roots systems may have an advantage to absorb nutrients such as P that move primarily by diffusion when the nutrient is present in low concentrations in the soil. However, under conditions of high soil fertility, fibrous root systems did not improve nutrient uptake and trees with greater transpiration rates absorbed greater levels of nutrients. Different growth habits of peach have diverse root systems and transpiration rates that affect nutrient uptake and, consequently, the selection of tree growth habit should be considered in orchard soil management plans. Growth habits with more fibrous root systems may require reduced inputs of nutrients with low diffusion coefficients.

**Key words:** Orchard management, tree root system, tree nutrient uptake, *Prunus persica*

### Introduction

Root systems anchor plants and absorb water and nutrient elements that are vital for growth. As with all crops, successful production of tree fruit crops will depend on the capacity of the tree to obtain soil nutrients that may be available in limited quantities. In the eastern U.S., peach trees are often planted in vegetation-free rows with grass alleys between tree rows so that the ground cover helps prevent soil degradation (Tworkoski and Glenn, 2008). Under such mixed planting schemes, the tree root system morphology and fine root distribution can affect competition among trees within the row and between

trees and grass (George et al., 1996). Competition for nutrients such as nitrogen (N) and phosphorus (P), which are often present in low quantities, can limit plant growth. Fine roots and root hairs are highly important for soil exploitation to acquire less mobile nutrients such as P (Lopez-Bucio *et al.*, 2003). Root proliferation in response to soil nutrient availability appears to be under genetic control and mediated, at least in part, by endogenous hormones (Lopez-Bucio *et al.*, 2003). Selecting and breeding crops that have roots with strong capacity for P foraging can contribute to food production, particularly in regions with low fertility soils and limited availability of fertilizers (Lynch and Brown, 2001).

Trees with different shoot growth habits have been found to also have distinguishing root system characteristics. In greenhouse experiments, peach trees with highly branched shoots (Compact growth habit) had three-times more lateral roots within 10 cm of the root collar than Pillar, which had less branched and more vertical shoots, or Standard growth habits (Tworkoski and Scorza, 2001). In addition, Compact trees had more and longer higher order lateral (i.e. fibrous) roots. If these root traits are expressed under field conditions, the fibrous root system of Compact trees could be beneficial in acquiring nutrient elements with low diffusion coefficients, such as P (Fitter and Hay, 1987). Conversely, a fibrous root system might have less impact on uptake of nutrients with high diffusion coefficients, such as nitrate, that move to roots readily by mass flow.

Fruit trees with improved root systems (own-rooted or as rootstocks) may be beneficial in infertile soils and for efficient use of fertilizer. Experiments were conducted in the greenhouse and field with the objectives to: (1) verify the fibrous root system morphology of Compact peach trees in the field and (2) determine if growth habits with fibrous roots affect leaf concentrations of N and P.

## Materials and methods

**Greenhouse:** Peach trees with different growth habits were grown from seed in a greenhouse in 20-liter pots (Hagerstown silt loam) beginning in February 1998 as described by Tworkoski and Scorza (2001). Trees were put in cold storage in October 1998, and placed back in the greenhouse in May 1999. Fertilizer was applied once to all trees in July 1999. Half the trees received no additional fertilizer while the rest received fertilizer (1.75 g of 20N- 8.8P-16.6K applied per tree) every four days for six weeks. In August 1999, ten leaves per tree were collected from the middle of shoots located throughout the canopy, dried, and total N was determined with a Nitrogen Determinator (LECO Corp., St. Joseph, MI). Total P was measured colorimetrically (Murphy and Riley, 1962) after digestion with HClO<sub>4</sub> (Adler and Wilcox, 1985). Also in August, transpiration and photosynthesis (CIRAS-1, PP Systems, Haverhill, MA) were measured on three leaves of each replication at approximately midday on each of five days. The experimental design included three replications of each level of two main effects (three growth habits and two levels of fertilizer) that were tested by ANOVA with mean separation by the LS Means procedure (SAS, 2001) at the 0.05 level of significance

**Field:** Peach trees with different growth habits that were germinated and grown in the greenhouse in 1998 were planted in the field in the same soil as was used in the greenhouse experiment at Kearneysville, WV on 4 August 1998 (4 x 4 m spacing). Trees were not pruned but received fertilizer (10N- 4.4P- 8.3K, 44 kg ha<sup>-1</sup>) each spring from 1999 through 2006. Diuron (4.4 kg ha<sup>-1</sup>) and solicam (3.3 kg ha<sup>-1</sup>) were applied each spring to maintain a 2-m weed-free tree row. In 2007, trees were fertilized and pruned to remove dead wood. In April 2007 and 2008, urea (4.49 g N) and granulated triple super phosphate (5.6 g P) was applied to each of four 1m<sup>2</sup> ground areas adjacent to the tree trunk and located north, east, south, & west of each tree. Twenty leaves per tree were harvested and pooled in July 2007 and 2008 and leaf nutrient concentrations were measured by the Agricultural Analytical Services Laboratory of the Pennsylvania State University, University Park, PA. Roots were measured in soil samples that were collected in Sept. 1999 and 2008 with two 5 cm-diameter soil cores per tree per year at 0 to 25 cm and at 25-to-50 cm depths. Cores were collected within 50 cm from the tree trunk. After separating roots from the soil, root lengths were measured with a root imaging device (CID, Inc., Vancouver, WA) and root length density (RLD) was calculated as the total root length divided by the total volume of the soil cores. The experimental design included three replications of each level of two main effects (three growth habits and two levels of fertilizer) that were tested by ANOVA with mean separation by the LS Means procedure in SAS at the 0.05 level of significance.

## Results and discussion

In the greenhouse, a significant and meaningful relationship was found between leaf N concentration and transpiration, likely due to N moving in the soil by transpiration-driven mass flow from soil to root (leaf N = 0.7692 x (transpiration) + 0.2263;  $r^2 = 0.74$ ; Fig. 1A). The relationship between leaf P concentration and transpiration was not significant (leaf P = 0.0281 x (transpiration) + 0.1255;  $r^2 = 0.16$ ). Since mass flow contributes more strongly to plant acquisition of N than P, it is logical that transpiration had less impact on P uptake (Cramer *et al.*, 2008). Leaf N concentration significantly affected photosynthesis (photosynthesis = 9.0145 x (leaf N) - 1.5651;  $r^2 = 0.82$ ; Fig. 1B). Peach tree productivity, as represented by photosynthetic capacity, was regulated by leaf N concentration that, in turn, depended on capacity to absorb nutrients.

In the greenhouse after one fertilizer application, Compact trees had higher leaf P than the other growth habits (Table 1). Physiological sufficiency range of P is from 0.15 to 0.3% leaf dry weight; therefore, Compact trees had adequate P after one or ten fertilizer applications. Pillar and Standard trees achieved P sufficiency only after ten fertilizer applications in the greenhouse (Table 1). This supports the hypothesis that the fibrous root system of Compact trees measured in greenhouse conditions (Tworkoski and Scorza, 2001) provided greater access to nutrients that move more by diffusion than by mass flow from soil to root surfaces.

After ten fertilizer applications, Pillar trees had the greatest increase in leaf N and P (Table 1). This result was unexpected since previous results indicated that Pillar trees had a smaller root system and a larger shoot-to-root dry weight ratio than Compact trees

(Tworkoski and Scorza, 2001). However, Pillar trees had greater transpiration rates than other growth habits which may affect mass flow of nutrients in water moving from soil to roots (Table 2). After ten fertilizer applications, leaf transpiration in the greenhouse-grown trees was greatest in Pillar and less in Standard and Compact trees (Table 2). Pillar trees achieved N sufficiency (2.5 to 3.4% leaf N) after ten fertilizer applications in the greenhouse, but Compact and Standard trees did not (Table 1).

Field root studies supported greenhouse experimental findings that Compact trees have more fibrous root systems than Pillar or Standard trees (Tworkoski and Scorza, 2001; Fig. 2). In both 1999 and 2008, Compact trees had greater lengths and weights of roots less than 3 mm diameter than Pillar trees at soil depths less than 25 cm (Fig. 2). The abundance of roots in shallow soil may have contributed to the higher leaf N and P levels in Compact than Pillar trees in the field following one fertilizer application (Table 3). Standard tree root weight density was intermediate between Compact and Pillar trees in 2008. Root abundance in shallow soil can be significant to fruit tree nutrition. Most P uptake in apple (*Malus domestica* Borkh.) was associated with root activity at soil depths less than 30 cm (Atkinson, 1974). In all growth habits in the current field experiment, over 90% of the peach roots were in the 0 to 25 cm soil depth and approximately 98% of the root length was less than 3 mm in diameter (data not shown).

Foliar N and P results from the field and greenhouse generally agree. In the field, Compact trees had greater P leaf concentration than Pillar or Standard trees after one but not two fertilizer applications (Table 3). Pillar trees had less foliar P concentration than Compact trees after one fertilizer application but foliar P concentrations increased most in Pillar trees after two fertilizer applications (Table 3). In the field, all growth habits achieved N and P sufficiency, probably due to fertilizer applications made in the orchard over previous years (Table 3).

In this experiment, differences in root system morphology and transpiration were found among the peach growth habits that may have affected the tree nutritional status and its response to fertilization. Compact trees had greater root length density (Fig 2). Previously, Compact trees were found to have a larger number of root tips compared with Pillar trees (Tworkoski and Scorza, 2001). The large number of fine roots and root tips of the Compact growth habit may facilitate exploration of new soil as peach trees forage for nutrients. In contrast, Pillar trees may not as effectively explore the soil but leaf N and P of Pillar trees increased the most in response to fertilization application. Pillar trees have shorter root axes (links) between lateral roots (Tworkoski and Scorza, 2001) that may facilitate transpiration when soil water is abundant and also may enable Pillar trees to benefit more from a fertilizer drench than the other growth habits. Sorgonà *et al.* (2005) found that genetically-controlled root morphology of citrus affected nutrient acquisition and that nitrate adsorption was greater in trees with large numbers of root tips.

The results of this experiment have implications for orchard productivity and fertilizer inputs. Growth habits with more fibrous root systems may require reduced inputs of some nutrients such as P. Growth habits that acquire N efficiently can provide higher leaf N, increased photosynthesis, and may improve tree productivity (Fig 1). Future

research can compare nutrient use efficiency of peach cultivars on peach root systems with different morphology and transpiration rates. The current research findings suggest that nutrient uptake capacity varies within the peach species. Consequently, fertilization could be modified for a particular growth habit to efficiently use nutrients and to reduce unnecessary nutrient load into the environment.

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Table 1. Leaf N and P concentrations in three growth habits of peach that were grown in the greenhouse and fertilized once or ten times during the 1999 growing season.

	One application		Ten applications		Increase between one and ten applications	
	N	P	N	P	N	P
	(%)					
Compact	1.3 a	0.21 a	2.0 b	0.21 a	0.7 c	0 c
Pillar	1.2 a	0.11 b	2.7 a	0.21 a	1.5 a	0.10 a
Standard	1.1 a	0.14 b	2.1 b	0.21 a	1.0 b	0.06 b

Within each column, means followed by the same letter do not differ at the 0.05 level of significance.

Table 2. Leaf photosynthesis (Pn) and transpiration (Ts) in three growth habits of peach that were grown in the greenhouse and fertilized once or ten times during the 1999 growing season.

	One application		Ten applications	
	Pn ( $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ )	Ts ( $\text{mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$ )	Pn ( $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ )	Ts ( $\text{mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$ )
Compact	7.1 a	1.4 a	16.1 b	2.1 b
Pillar	10.9 a	1.7 a	21.8 a	3.0 a
Standard	7.4 a	1.1 a	20.8 ab	2.3 b

Within each column, means followed by the same letter do not differ at the 0.05 level of significance.

Table 3. Leaf N and P concentrations in three growth habits of nine-year-old peach trees that were grown in the field and fertilized once (2007) or twice (2007 and 2008).

	One application		Two applications		Increase between one and two applications	
	N	P	N	P	N	P
	(%)					
Compact	2.7 a	0.25 a	3.1 a	0.29 a	0.3 b	0.03 b
Pillar	2.4 b	0.21 b	3.3 a	0.29 a	0.8 a	0.08 a
Standard	2.5 ab	0.22 b	3.2 a	0.27 a	0.6 ab	0.05 ab

Within each column, means followed by the same letter do not differ at the 0.05 level of significance.

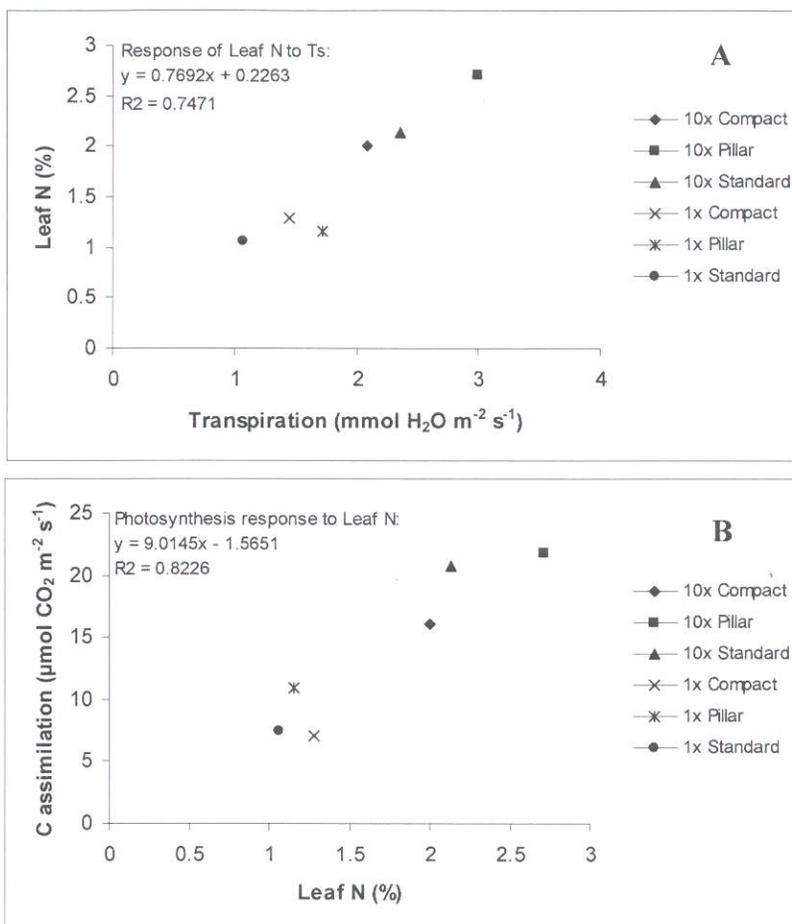


Figure 1. Relationship of leaf nitrogen with translocation (A) and photosynthesis (B) of three growth habits of peach trees that were grown in the greenhouse and fertilized once (1x) or ten times (10x) during the 1999 growing season. Regressions were based on individual replications and mean values are shown.

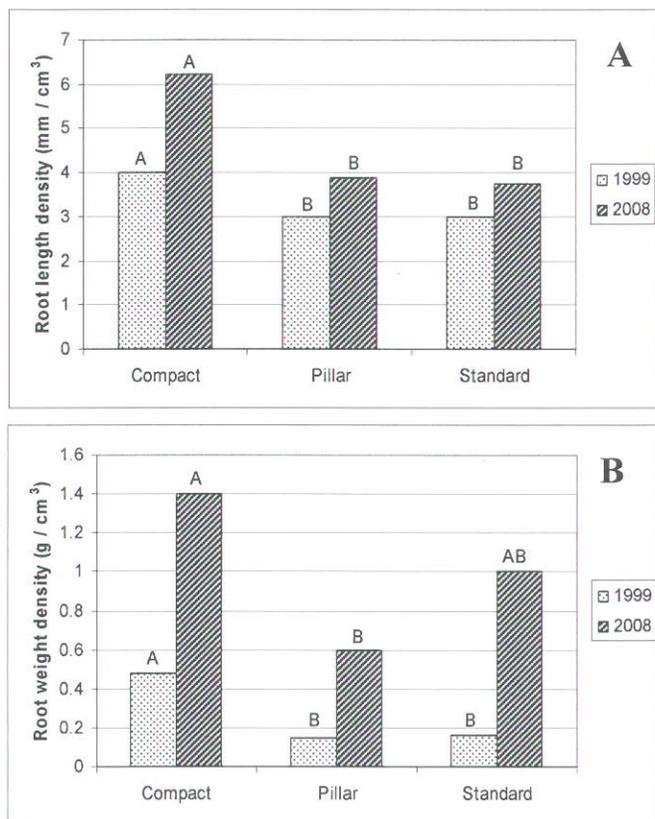


Figure 2. Root length density (A) and root weight density (B) of roots less than 3 mm in diameter in the upper 25 cm of soil within 50 cm of the trunk of three growth habits of peach trees planted in 1998 in the field and sampled in 1999 and 2008. Within the same year, bars with the same letter above them do not differ at the 0.05 level of significance.