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Carbohydrate and Nitrogen Partitioning within One-year Shoots of Young Peach Trees Grown with Grass Competition

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Abstract. **Carbohydrate and nitrogen were measured during 1992 and 1993 in shoots of peach [*Prunus persica* (L.) Batsch.] trees that were planted in 1989 and grown in three vegetation-free areas contained within plots planted to tall fescue (*Festuca arundinacea* Schreber), orchardgrass (*Dactylis glomerata* L.), or a mixture of *Lolium perenne* L. and *Festuca rubra* L. Trees grown in 9.3-, 3.3-, and 1.5-m^2 vegetation-free areas had the greatest to the least fruit yield, respectively. Fruit number and mass were negatively correlated with stem mass. Grass type had little effect on mass, carbohydrate, or N partitioning within the tree. Individual sugars and carbohydrate partitioning were not affected by grass competition. In contrast, the proportion of shoot N partitioning into stem and leaves declined markedly as the size of the vegetation-free area increased. Proximity of peach trees to grass may have limited N uptake, which, in turn, reduced fruit yield but not stem and leaf growth.**

Vigorous vegetative growth of mature fruit trees can suppress reproductive growth and development (Chalmers et al., 1981; Dorsey, 1935; Williamson et al., 1992). Excessive growth must be removed to manage tree height, crown shape, and light distribution. Vegetative growth has been controlled without pruning by restricting root growth with physical restraints such as fiber barriers or by competition from ground covers (Glenn and Welker, 1996; Williamson et al., 1992). Selective irrigation of peach trees grown with such root restriction can increase fruit production compared with trees grown without restriction (Chalmers et al., 1981). Thus, root manipulation can be used to regulate biomass distribution within the tree.

Several authors have reviewed species attributes for orchard floor management (Butler, 1986; Hogue and Nielsen, 1987; Skroch and Shribbs, 1986). In general, soil physical properties improve with ground cover, but ground covers vary in competition for water and N, or allelopathic effects may limit tree growth. For example, Shribbs et al. (1986) found that orchardgrass (*Dactylis glomerata* L.) and red sorrel (*Rumex acetosella* L.) inhibited growth of 'Golden Delicious' apple trees (*Malus* ×*domestica* Borkh. 'Smoothee') more than did Kentucky bluegrass (*Poa pratensis* L.). The more competitive ground covers had greater mass, which probably increased N capture. Increased knowledge of the effects of different ground covers on peach tree growth is needed.

Nitrogen availability and root capacity for N uptake can affect shoot growth, metabolism, and development. Burke et al. (1992) found increased shoot and decreased root growth when N was applied to sugar maple seedlings. Foliar starch and soluble sugar concentrations increased with N deprivation during August. Fruit set of mandarin trees (*Citrus iyo hort*, Tanaka) increased with increasing N supply as photosynthate translocation to flowers was promoted (Takagi and Akamatsu, 1991). In the same study, spring weeds accumulated 38.6% of the N applied, suggesting that ground covers can potentially alter fruit production by reducing the N supply. Orchardgrass has been reported to absorb 67% to 86% of the N applied to apple trees in the spring (Sato et al., 1978).

Few experiments have measured the effect of root manipulation or competition on the C and N economy within current-year growth of mature fruit trees. When sampled early in the growing season, levels of total soluble sugars and total carbohydrates were greater in shoots of 'Redhaven' peach trees grown in sod than in those grown in clean cultivated row-middles (Ellis et al., 1993). 'Redhaven' peach trees grown in 0.5-m-wide herbicide strips had shorter shoots compared with those grown in 1.0-m-wide herbicide strips (Williamson et al., 1992), but number of flowers was not affected. Although root management can be used to regulate shoot vegetative growth, its effect on current-year shoot physiology requires further study.

This experiment was designed to determine the effect of orchard floor management on carbohydrate and N partitioning within the current-year growth of peach. The objectives were to determine the effect of three ground covers and three vegetation-free areas on 1) mass distribution, 2) C and N allocation within current-year shoot growth, and 3) total tree growth and yield.

Materials and Methods

The experiment was conducted at the Appalachian Fruit Research Station near Kearneysville, W.Va. The design was a split plot with five single-tree replications per treatment. The main plot was grass type and subplot was the size of the vegetation-free area. Three shoots of each tree served as subsamples. Data were analyzed by analysis of variance and regression with SAS, 1995.

A field was seeded in replicated blocks with 'Kentucky-31' tall fescue, 'Hallmark' orchardgrass, and a companion grass mix of 70% *Lolium perenne* 'Elka' : 30% *Festuca rubra* 'Ensylva' (by weight) at rates of 197, 163, and 163 kg·ha^{-1}, respectively. These grasses are commonly used as ground covers in the eastern United States and, in preliminary experiments, peach tree growth was inhibited more by *L. perenne* and *F. arundinacea* than by *D. glomerata*. Grass type served as the main treatment effect and each block was 15 m wide and 22.5 m long. Seeding was accomplished with a Gandy spreader on 19 Oct. 1987. The entire field was fertilized with 10N–0.44P–0.83K at 562 kg·ha^{-1} in Aug. 1988. In Oct. 1988, paraquat (1,1´-dimethyl-4,4´-bipyridinum) was applied to establish randomly selected, square, vegetation-free areas in each block. Each plot contained three trees with 4.5 m between trees, and the tree in the center was the experimental unit. Vegetation-free areas were 1.22, 1.82, and 3.05 m on a side and served as subplots within each grass main plot. Trees were in the center of each square, and the squares were maintained vegetation-free by applying paraquat each spring. One-half kilogram of 10N–0.44P–0.83K fertilizer was applied uniformly to each vegetation-free area in May and June during 1992 and 1993, respectively. Peach tree roots are restricted by grass and we assumed that each tree received about the same N treatment (Glenn and Welker, 1989).

Two-year-old peach trees ('Loring'/ 'Lovell') were planted in each vegetation-free square in Apr. 1989. The scion was pruned at 0.9 m above the graft, and trees were trained to an open center.

Three shoots per tree located in full sun at the terminal end of separate scaffold limbs were measured monthly from April through October. Fruit were counted and stem length and number of internodes were recorded. Flowers and fruit were not thinned during the 2-year experiment. In August, fruit, leaves, and stems from three randomly selected shoots per tree were harvested, dried, and weighed. Fruit from the whole tree also were counted and weighed in August. Mature fruit were harvested over two dates. Trunk diameter was measured 30 cm above ground level at the end of each growing season. All measurements were re-

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peated during 1992 and 1993.

Fruit, leaf, and stem tissues were lyophilized, ground in a Wiley mill to pass a 40-mesh screen, and analyzed for carbohydrates. Low molecular weight sugars were extracted from 200-mg tissue samples with near-boiling 95% ethanol. Glucose, fructose, sucrose, sorbitol, and starch were then analyzed by the method of Stutte et al. (1994). Total nonstructural carbohydrates were determined as the sum of simple sugars and starch. Ground tissue from each plant part was analyzed for total N with a LECO FP-228 Nitrogen Determinator (LECO Corp., St. Joseph, Mich.).

Results and Discussion

Fruit number and yield per tree and trunk cross-sectional area (TCSA) increased with increasing size of the vegetation-free area (Table 1). There were fewer fruit per tree, and size of the vegetation-free area had greater impact on yield, in 1992 than in 1993. In 1992, yield efficiency increased 38.1% as the vegetation-free area increased from 1.5 to 3.3 m^2, and 20.7% as the area increased from 3.3 to 9.3 m^2. Yield efficiency was not significantly affected by size of the vegetation-free area during 1993. The higher fruit load in 1993 may have reduced the influence of greater resource availability resulting from less grass competition. Increased yield in 1993 may have limited energy for root growth and mineral uptake so that exploitation of edaphic resources may have decreased.

In previous work with yields of 50 kg per tree (Welker and Glenn, 1989), peach yield efficiency decreased when size of the vegetation-free area exceeded 9.0 m^2. In the present study, yield efficiency increased with vegetation-free areas when yields were between 10 and 24 kg per tree (1992), but not when yields were between 31 to 47 kg per tree (1993). This suggests that an optimal vegetation-free area exists for maximum yield efficiency.

Yield and growth were not consistently affected by grass type. During 1992, yield and yield efficiency were greatest in trees grown in orchardgrass. Orchardgrass may have been less inhibitory to peach tree fruit growth than fescue or the fescue and ryegrass (companion) mix because of smaller root mass or less allelopathic interaction. In previous work, young peach trees planted in killed sod also grew more in orchardgrass than in 'Kentucky 31' fescue sod (Welker and Glenn, 1990).

In 1992, stem and leaf dry mass per shoot decreased with increasing size of the vegetation-free area (Table 2), but fruit mass per shoot was not affected. During 1993, masses of stem, leaf, and fruit were not affected by size of vegetation-free area. However, Pearson correlation analysis, combining data from both years, demonstrated that within a shoot, stem mass was negatively correlated with both fruit number ($r = -0.64$, n = 78, $P > F = 0.01$) and mass ($r = -0.71$, n = 78, $P > F = 0.01$). Proximity of grass roots altered the dry-mass distribution within a shoot by modifying fruit number in 1993. The average numbers of fruit per shoot for 1.5-, 3.3-, and 9.3-m^2 vegetation-free area were, respectively, 1.2, 2.2, and 1.6 in 1992 (nonsignificant) and 1.5, 2.9, and 3.5 in 1993 [the 1.5- and 9.3-m^2 areas differed significantly ($P = 0.05$)]. Trees in the 1.5-m^2 vegetation-free areas appeared to have fewer but heavier stems than trees in the 9.3-m^2 vegetation-free areas. These within-shoot effects had the cumulative effect of significantly reducing tree yield (Table 1).

In general, within each shoot, stem and leaf masses were less, while fruit mass was greater, in 1993 than in 1992. Because this was a 2-year study, we cannot determine if this year-to-year variation represents growth periodicity or other developmental processes. Temperature and precipitation were similar from September to August in 1991–92 and 1992–93 and during the May to September period each year (data not shown), suggesting that environmental factors were not the primary cause of variation.

Size of the vegetation-free area had little or no effect on the concentrations of soluble sugars and starch in stem, leaf, or fruit. Average concentrations of sorbitol, sucrose, glu-

Table 1. Effect of grass species and vegetation-free area on annual fruit and vegetative growth in peach trees.

Grass type	Vegetation-free area (m^2)	Fruit per tree (no.)	Yield (kg/tree)	Trunk cross-sectional area (cm^2)	Stem length (cm)	Yield efficiency[z] ($kg{\cdot}cm^{-2}$)	Crop density (no. fruit/cm^2)	Fruit dry mass (g/fruit)
				1992				
Kentucky 31		73 a[y]	15 b	52 b	66 a	0.28 ab	1.3 a	21.4 a
Orchard grass		93 a	20 a	60 ab	65 a	0.34 a	1.6 a	18.5 a
Companion		67 a	15 b	65 a	73 a	0.23 b	1.0 a	22.2 a
	1.5	47	10	49	78	0.21	1.0	20.6
	3.3	74	16	57	68	0.29	1.3	21.0
	9.3	111	24	70	57	0.35	1.6	20.6
				1993				
Kentucky 31		209 a	30 a	70 a	34 a	0.49 a	3.5 a	28.8 a
Orchard grass		315 a	50 a	78 a	39 a	0.68 a	4.4 a	23.0 a
Companion		213 a	37 a	87 a	41 a	0.46 a	2.6 a	30.8 a
	1.5	163	31	67	41	0.48	2.7	30.4
	3.3	250	41	75	37	0.58	3.7	27.7
	9.3	324	47	93	37	0.57	4.1	21.1
Source	df			$P > F$				
				1992				
Rep (R)	4	0.51	0.23	0.14	0.73	0.31	0.60	0.14
Grass type (G)	2	0.09	0.03	0.05	0.41	0.02	0.06	0.09
R × G	8	0.32	0.62	0.04	0.45	0.37	0.24	0.62
Vegetation-free area (V)	2	0.01	0.01	0.01	0.01	0.01	0.01	0.94
Linear	1	0.01	0.01	0.01	0.01	0.01	0.01	0.72
G × V	4	0.08	0.06	0.09	0.88	0.06	0.06	0.12
Error	24							
				1993				
Rep (R)	4	0.08	0.21	0.10	0.04	0.08	0.07	0.15
Grass type (G)	2	0.39	0.24	0.06	0.21	0.34	0.43	0.20
R × G	8	0.04	0.01	0.03	0.33	0.01	0.01	0.01
Vegetation-free area (V)	2	0.02	0.03	0.01	0.60	0.29	0.10	0.07
Linear	1	0.01	0.02	0.01	0.45	0.35	0.07	0.06
G × V	4	0.86	0.89	0.08	0.37	0.90	0.86	0.33
Error	24							

[z]Yield efficiency was derived by dividing the whole-tree fruit weight by the trunk cross-sectional area. Crop density was derived by dividing the whole-tree fruit number by the trunk cross-sectional area.

[y]Mean separation within years and columns by Fisher's protected LSD, $P < 0.05$.

cose, and fructose were, respectively, 30.3, 19.1, 12.4, and 7.4 mg·g⁻¹ dry mass in shoots; 69.3, 41.6, 28.9, and 25.5 mg·g⁻¹ in leaves; and 0, 197.9, 91.7, and 64.4 mg·g⁻¹ in fruit.

With increasing size of vegetation-free area, N concentrations increased in stems during 1992 and in stem, leaf, and fruit during 1993 (Table 2), consistent with previous reports of sod competition reducing N content in tree crops (Goode and Hyrycz, 1976; Shribbs et al., 1986; Smith et al., 1960; Welker and Glenn, 1985). Uniform amounts of N fertilizer were applied to all vegetation-free areas, but N concentration decreased in all shoot parts as size of the area decreased. Previous work indicated that grass roots restricted lateral expansion of peach tree roots (Glenn and Welker, 1989). We do not know if the root density or uptake capacity was altered, but our data suggest that N uptake by peach trees was restricted in smaller vegetation-free areas. In addition, competition from grass roots growing into vegetation-free areas may have restricted peach root growth and decreased soil N content.

Grass type had no significant effect on stem, leaf, and fruit mass per shoot or on the concentrations of soluble sugars, starch, and N (data not shown).

In 1992, mass partitioning into stem and leaf decreased, while partitioning into fruit increased, with increasing size of the vegetation-free area (Table 3). In 1992 the percentages of mass in stems and fruit of trees grown in 1.5-m^2 vegetation-free areas were twice and half, respectively, those of trees grown in 9.3-m^2 vegetation-free areas. The slight differences observed in 1993 were nonsignificant. With fewer fruit in 1992, dry mass was partitioned preferentially to vegetative rather than to fruit sinks when resources diminished due to grass competition. In 1993, the heavy fruit load reduced stem and leaf growth to less than half that recorded in 1992.

Carbohydrate partitioning was not affected by grass competition. In apple, root pruning restricted shoot growth but did not alter carbohydrate distribution within leaves and stems (Ferree, 1989). In the present study, peach roots were probably restricted by competition from ground cover, which altered shoot growth but not carbohydrate concentrations or distribution.

Size of the vegetation-free area had a greater impact on N distribution within a shoot than on N concentration in stem, leaf, and fruit (Tables 2 and 3). Within each shoot, significantly more N was partitioned into fruit and less into stem and leaf as size of the vegetation-free area increased. Partitioning of nonstructural carbohydrates was not significantly affected by size of the vegetation-free area. Carbohydrate availability did not affect N partitioning, paralleling results found in apple (Titus and Kang, 1982).

Proximity of grass had different effects on resource allocation within current-year shoots and the whole tree. When the fruit load was low, as in 1992, dry-mass distribution to stems and leaves increased, while that to fruit decreased, as the vegetation-free area decreased (Table 3). In 1993, the high fruit load diminished this effect. Yield, fruit number per tree, and TCSA decreased with decreasing vegetation-free area in both years (Table 1). Taken together, these results indicate that reducing the vegetation-free area could reduce fruit set, resulting in greater stem and leaf growth. Generally, carbohydrate concentrations and partitioning were not affected by grass competition (Tables 2 and 3). In contrast, N accumulation and partitioning were strongly affected by the size of the vegetation-free area, which, in turn, may have influenced dry-mass distribution. Competition for water and other nutrients, such as potassium (Goff et al., 1991), may also have affected growth.

This experiment demonstrates that competition with grass will reduce fruit yield and yield efficiency in young peach trees, largely by interfering with N availability or uptake. This effect was most pronounced when fewer fruit were present. During the growing season, vegetative sinks may have been more competitive for resources, or became competitive sooner, than fruit sinks. Shoot growth of fruit trees can be altered by root pruning, by root restriction, and by increasing below-ground competition (Atkinson et al., 1976; Ferree, 1989; Richards and Rowe, 1977). Our data demonstrate that internal sink competition and competition among plants can interact to affect the partitioning of dry mass and N within the current-year growth of peach trees. In practical terms, peach trees with more competition from grass may require less fruit thinning than trees with less competition. In addition, greater attention to N status will be required in orchards with grass competition.

Table 2. Effects of size of vegetation-free area on dry mass, nonstructural carbohydrates, and N content in current-year growth of peach trees.

Vegetation-free area (m^2)	1992 Stem	1992 Leaf	1992 Fruit	1993 Stem	1993 Leaf	1993 Fruit
			Dry mass (g/shoot)			
1.5	39	52	24	7	13	35
3.3	25	35	48	3	11	66
9.3	18	28	32	3	10	56
Lin coefficient	*	*	NS	NS	NS	NS
			Soluble sugars (mg·g⁻¹)			
1.5	44	38	116	77	158	373
3.3	48	38	159	65	168	356
9.3	51	37	157	66	169	341
Lin coefficient	*	NS	NS	NS	NS	NS
			Starch (mg·g⁻¹)			
1.5	39	48	ND[z]	45	33	ND
3.3	51	59	ND	46	35	ND
9.3	42	45	ND	43	31	ND
Lin coefficient	NS	NS	---	NS	NS	---
			Nitrogen (mg·g⁻¹)			
1.5	8.5	32.5	11.7	7.3	25.8	6.3
3.3	8.7	30.7	11.5	7.5	26.4	6.9
9.3	9.1	31.8	12.5	7.8	27.5	8.7
Lin coefficient	*	NS	NS	*	*	*

[z]ND indicates none detected.
*Significant linear relationship at $P \leq 0.05$ between the variable and size of the vegetation-free area. NS designates no significant relationship. No significant interactions occurred between grass type and vegetation-free area.

Table 3. Effects of size of vegetation-free area on distribution of dry mass, nonstructural carbohydrates, and N within current-year growth of peach trees.

Vegetation-free area (m^2)	1992 Stem	1992 Leaf	1992 Fruit	1993 Stem	1993 Leaf	1993 Fruit
			Dry-mass distribution (%)			
1.5	25	37	39	6	12	82
3.3	19	30	51	2	10	88
9.3	12	24	65	4	10	86
Lin coefficient	*	*	*	NS	NS	NS
			Nonstructural carbohydrate distribution (%)			
1.5	18	31	52	2	9	89
3.3	7	11	82	1	5	95
9.3	11	18	71	1	6	93
Lin coefficient	NS	NS	NS	NS	NS	NS
			Nitrogen distribution (%)			
1.5	10	64	26	6	41	54
3.3	9	53	38	2	34	64
9.3	6	48	46	1	19	80
Lin coefficient	*	*	*	*	*	*

*Significant linear relationship at $P \leq 0.05$ between the variable and size of the vegetation-free area. NS designates no significant relationship. No significant interactions occurred between grass type and vegetation-free area.

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