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Influence of Nitrogen Fertilization and Orchard Floor Management on Yield, Leaf Nutrition and Fruit Quality of 'Fairhaven' Peach

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Abstract

'Fairhaven' peach (*Prunus persica* L. Batsch) trees were subjected to combinations of two rates of nitrogen, single or split application of N, year round or partial annual control of vegetation within the tree row. Yield, leaf nutrient concentration and fruit quality were assessed over six growing seasons. Yield was increased by the higher rate of N in 3 of the 6 years. Vegetation control had little effect on yield. Single applications of N were better for yield than split applications in 2 of 4 years but the reverse was observed in one year. Leaf N tended to increase with higher rates of N application and with split applications of N. Higher rates of N reduced macronutrient concentration, especially leaf P, and tended to increase micronutrient concentration in the leaves. Ground color was greener but fruit firmness was not affected by the higher rates of N application.

Introduction

Peach growers, irrespective of region, strive for a nitrogen fertilization program that promotes good tree vigor, high yields, well-colored fruit and yet does not predispose the trees to winter injury. Higher rates of N fertilization do not always increase yield (1, 2, 11, 12, 13, 20, 22) but can delay harvesting because ground color is too green (2, 6, 10, 15, 20). Nitrogen availability can be influenced by orchard floor management particularly when clean cultivation is practiced. Clean cultivation can increase yield (9, 11) by reducing competition for N between sod and tree roots. High rates of N fertilization can cause excessive vigor which results in shading of the fruit and inadequate color development. Long-term studies are therefore needed to evaluate cultural factors in establishing a fertilization protocol which meets the needs stated above. This paper presents results of a 6-year study on the influence of N fertilization, time of N applica-

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tion, and orchard floor management on yield, leaf nutrient content, fruit quality and tree hardiness for 'Fairhaven' peach.

Materials and Methods

One-year old 'Fairhaven' peach trees (*Prunus Persica* L. Batsch) on Siberian C rootstock were planted in 1986 at 2.5 (within rows) x 4.5 m (between rows). Soil type was a Skaha sandy loam (23). Trees were trained to an open center with the scaffold of branches beginning at 60-70 cm from ground level and were irrigated by an under-tree sprinkler system every 9-10 days during the growing season. Orchard practices were those followed by commercial peach growers (3). Other commercial cultivars were used as pollinizers ('Fairhaven' is self-fertile) at the end of each row or as guard trees between each 'Fairhaven' plot within a row. Each plot contained three 'Fairhaven' trees and constituted an experimental unit. The study was a randomized block design with 6 replicates per treatment. Treatments included two rates of N fertilization (low and high as N1 and N2 respectively), single (T1) or split (T2) applications of N, year round (V1) or partial annual (V2) control of vegetation within tree rows (Table 1).

Rates of N1 and N2 (NH_4NO_3, 34-0-0) were reduced from 150 and 300 Kg N/ha to 30 and 60 Kg N/ha in the fourth year (1990) because of excessive vigor in the trees and a desire to assess the effects of a drastic change in N nutrition. Fertilizer was applied in April (T1) or split into equal amounts and applied in April, early June and early July (T2). Complete control of vegetation (V1) was maintained by applications of dichlobenil (Casoron) at 6 kg/ha plus napropamide (Devrinol) at 4.5 kg/ha in early May. Late season escapes from this treatment were controlled with glyphosate (Roundup) at 1 kg/ha. Seasonal vegetation control (V2) consisted of a single application of glyphosate (1.5 kg/ha) in late April or early May.

A composite of 30 leaves per treatment and replicate was obtained annually in mid-July (the period recommended for leaf sampling in the Okanagan Valley) from the middle portion of new shoot growth. The samples were oven-dried at 65°C and ground (40μ mesh) in a stainless steel mill. N and P concentrations were obtained by colorimetric procedures after Kjeldahl digestion of 0.25 g of ground leaf tissue. Additional one gram samples of the leaf powders were dry-ashed at 475°C for 4h, dissolved in 0.5 M HCl and analyzed by atomic absorption (Varian Spectra AA-400; Varian Canada, Mississauga, ON) for Ca, Mg, K, Mn, Fe, Zn and Cu concentration.

Fruit harvesting commenced when ground color was pale yellow and two harvests were usually required, 3-5 days apart. Total yield was recorded for each treatment and replicate. Samples for fruit quality were taken during the second harvest (third week in August) which was the major harvest in all years. Fifteen fruit selected at random per treatment and replicate were assessed for average fruit weight, ground color, flesh firmness, soluble solids concentration (SSC) and titratable acidity (TA). Percent red skin color was estimated visually in 1993 only. Ground color (L*a*b mode) was read with a Minolta CR-200 chromameter (Minolta Canada Inc., Mississauga, ON). Flesh firmness was taken with a Magness-Taylor penetrometer (7 mm tip) on opposite peeled sides of each fruit within a sample. Single wedges from the same fruit were juiced in a commercial blender and the juice used for SSC and TA determinations. A temperature-compensated refractometer was used for SSC determination and TA was calculated after titration of the juice to pH 8.1. Annual measurements of trunk diameter were taken

0.3 m above the graft union which was located just above ground level.

Data were subjected to ANOVA (SAS Inc., Carey, NC) and analyzed annually as a randomized complete block, 2^2 or 2^3 factorial design with six replicates per treatment. Main effects were two rates of N, two application schedules and two orchard floor management procedures.

Results

Yield and Vigor

Significant increases in yield from a higher rate of N were noted in three of the six years (Table 2). The increase in 1988, the first year of the study, was obtained with 300 kg N/ha (N2) relative to 150 kg/ha for N1. The same rate of N did not affect yield in 1989 or 1990. The higher rate (N2) of 60 kg N/ha in 1991 resulted in better yields compared to trees receiving 30 kg N/ha but the increase was characterized by a significant N x T interaction. A pronounced increase was seen with the higher rate applied over a 3-month period. The significant yield increase in 1992 was obtained with a rate of 30 kg N/ha versus the low rate of 0 kg N/ha.

Split applications of N reduced yield in 1989 and 1990 but an increase in yield for 1991 resulted from a significant NxT interaction (Table 2), the response being greater with the high rate (N2) than with the low rate of N (N1). Orchard floor vegetation management only affected yield in 1992 when complete control (V1) of vegetation resulted in a significantly higher yield than with partial control (V2).

Tree vigor, as measured by trunk cross-sectional area, showed no consistent trends with treatment and three-way interactions persisted in most of the years (data not shown).

Leaf Nutrition

Higher rates of N fertilization did not consistently elevate leaf N concentrations (Table 3). Significant NxV interactions were noted in 1988 and 1990. Leaf N was reduced by partial control of vegetation (V2) when the low rate (N1) of N was applied but vegetation control did not influence leaf N when the high rate (N2) of N was applied. Split applications (T2) of N resulted in a higher leaf N concentration in 1988, 1990 and 1991. Higher leaf N concentrations were also observed with partial control (V2) of vegetation in 1992 and 1993.

Table 1. Treatments imposed upon 'Fairhaven' Peach, 1988-1993.

Treatment	1988	1989	1990	1991	1992	1993
N1 (kg N/ha)	150	150	150	30	0	0
N2 (kg N/ha)	300	300	300	60	30	30
T1 (N applied in April)	yes	yes	yes	yes	no	no
T2 (N equally applied in April, June and July)	yes	yes	yes	yes	no	no
V1 (year round vegetation control)	yes	yes	yes	yes	yes	yes
V2 (herbicide treatment in May only)	yes	yes	yes	yes	yes	yes

Leaf P was reduced by the high rate (N2) of N in all years (Table 4). Those of Ca, K and Mg were reduced in 3, 3, and 2 of the 6 years respectively with the high rate (N2) of N. The latter treatment tended to increase leaf Fe, Mn and Cu in 4, 3 and 2 years respectively of the 6-yr study. Split applications of N had less effect on leaf nutrient concentration except for leaf K which decreased in 3 years and leaf Fe and Cu which increased in 2 of the 4 years this treatment was applied. Orchard floor management had no consistent effect on leaf nutrients.

Fruit Quality

Ground color was greener in the first four years (1988-91) but not in the last two years (1992-93) with the high rate (N2) of N fertilization (Table 5). A NxVxT interaction, however, was

Table 2. Effect of rate (N) and timing (T) of nitrogen fertilization, orchard floor management (V), and summer pruning (P) on yield of 'Fairhaven' peach.

	Yield (kg/tree)						
Treatment	1988	1989	1990	1991		1992	1993
				T1	T2		
N1	17.4	37.4	38.5	19.6	23.0	38.2	40.3
N2	20.3	39.5	36.0	23.2	40.6	42.8	44.1
	*	NS	NS	SE = 2.4		*	NS
T1	19.7	41.3	40.4			–[y]	–
T2	18.1	34.0	34.0			–	–
	NS	*	*				
V1	17.9	37.9	36.5	27.0		44.8	42.9
V2	19.9	38.9	37.9	26.2		36.1	41.6
	NS	NS	NS	NS		***	NS
							NS
Mean	18.9	38.4	37.2	26.6		40.5	42.2

[z]Values for N, T and V are shown in Table 1.
[y]No treatment conducted.
NS, *, *** Non-significant or significant at P ≤ 0.05 or 0.01, respectively.

found for ground color in 1989. Timing of N application had no effect on ground color. Vegetation control affected ground color in 1990, a greener ground color was noted with partial control (V2) of vegetation. The high rate (N2) of N increased flesh firmness in 1988 and 1990 (Table 5). A significant NxT interaction in 1989 for flesh firmness showed that fruit were firmer with the high rate (N2) of N and split application (T2) of N than with any other treatment in the interaction. Values within the interaction were 29N for low (N1) N x single N application (T1), 26N for low N (N1) x split application (T2), 28N for high N (N2) x single N application (T1) and 32N for high N (N2) x split N application (T2), SE = 1.2. Firmness in 1990 was slightly higher with the split application (28 N) of nitrogen than with the single dose (25 N) when clean cultivation (V1) was the treatment. However, the opposite occurred with partial control of vegetation (V2) while fruit from

Table 3. The influence of rate (N) and timing (T) of nitrogen fertilization and orchard floor management (V) on leaf N concentration of 'Fairhaven' peach.

	Leaf N (%/d.w.)							
Treatment[z]	1988		1989	1990		1991	1992	1993
	V1	V2		V1	V2			
N1	3.31	3.15	3.37	3.57	3.36	3.40	3.03	2.24
N2	3.41	3.50	3.49	3.84	3.82	3.60	3.00	2.22
	SE = 0.05*		NS	SE = 0.05		***	NS	NS
T1	3.21		3.35	3.45		3.39	–[y]	–
T2	3.47		3.50	3.88		3.60	–	–
	***		NS	**		***		
V1			3.37			3.53	2.95	2.18
V2			3.50			3.47	3.08	2.28
			NS			NS	*	*
Mean	3.34		3.42	3.66		3.50	3.01	2.23

[z]Values for N, V and T are shown in Table 1.
[y]No treatment conducted.
NS, *, *** Nonsignificant or significant at P ≤ 0.05 or 0.01, respectively.

Table 4. Number of years in which rate (N) and timing (T) of nitrogen fertilization and orchard floor management (V) affected leaf nutrient concentration positively (+) or negatively (-).

Nutrient	Treatment[z] (N2 vs N1)	(T2 vs T1)	(V2 vs V1)	Interactions	Mean values[y]
P	6 yrs (-)	1 yr (-)	2 yrs (+), 2 yrs (-)	none	0.34 ± 0.09%
Ca	3 yrs (-)	none	2 yrs (-), 1 yr (+)	1 yr NxT (N2T1↓)[x]	1.46 ± 0.28%
Mg	2 yrs (-)	1 yr (1)	1 yr (+)	2 yrs NxT (2NT1↓)	0.50 ± 0.07%
K	3 yrs (-)	3 yrs (-)	1 yr (+)	none	2.45 ± 0.11%
Zn	none	1 yr (+)	1 yr (+), 1 yr (-)	1 yr NxV (N2V2↑) 1 yr NxT (N2V2↑)	22 ± 2 ppm
Fe	4 yrs (+)	2 yrs (+)	1 yr (-)	1 yr NxV (N2V2↑)	55 ± 12 ppm
Mn	3 yrs (+)	none	1 yr (+)	3 yrs NxT (N2T1↑) 1 yr NxV (N2V2↑)	36 ± 9 ppm
Cu	2 yrs (+)	2 yrs (+)	1 yr (+)	1 yr VxT (V1T2↑)	9 ± 1ppm

[z]Values for N, T and V are shown in Table 1.
[x]Treatment with the lowest (↓) or highest (↑) concentration.
[y]Mean value ± standard deviation over the 6-yr period expressed on a dry weight basis.

the single dose of N had higher firmness (37 N) compared to the split application of N (32 N).

Soluble solids concentration was affected by rate of N only in 1988 when it interacted with timing of N (Table 6). The high rate of N (N2) x split N application (T2) treatment resulted in a SSC of 11.7% compared to 11.5% and lower for the other treatments within the interaction. Split applications (T2) of N increased SSC slightly in 1991. Partial annual control of vegetation reduced SSC in 3 of the 6 years by 0.4%.

Changes in TA were associated with interactions; NxVxT in 1988, VxT in 1990 and VxP in 1992. Split applications of N (T2) resulted in a higher TA in 1990 with year round control (V1) but not with partial annual control (V2) of vegetation (V1T1 = 610 mg, V1T2 = 676 mg, V2T1 = 708 mg, V2T2 = 703 mg).

Cross-sectional examination of the limbs and trunks in the fall of 1993 revealed brown heartwood in all areas except the last three growth rings. Low winter temperatures in 1989-90 and 1990-91 were probably responsible for the injury. Good growth was evident for the 1991 ring but not for 1992 and 1993 rings. Low nitrogen status (Table 3) could account for the weak growth in 1992 and 1993.

Discussion

The results in this study are consistent with other studies in which high rates of nitrogen usually increase yield. Many of the studies found little or no response in the first year but a response was often seen in subsequent years. Results in our study showed a response in the first, fourth and fifth years but no response was seen in the second, third and sixth year (Table 2). A study by Walsh et al. (22) however, showed no response over a 4-year period.

In 1988 and 1991, higher yield was associated with mean leaf N concentrations of 3.46 and 3.60% with the high rate (N2) of N, respectively, whereas increased yield in 1992 with high N (N2) was associated with a mean leaf concentration of 3.0% for the high N (N2) rate. Yield decreased as a consequence of split N application in year 3 when leaf N averaged 3.88%. Thus optimum leaf N concentration for maximum yield of 'Fairhaven' peach from this data would appear to be about 3.4 to 3.6%. No clear relationship between leaf N and yield was however found under conditions of decreasing N fertilizer regime. In 1993, for example, high yield coincided with the lowest leaf N concentration. Taylor and van den Ende (21) stated that reserve N in under-fertilized mature peach trees was preferentially used for reproductive growth. Mid-season leaf N concentration was an insensitive indicator of tree N status under conditions of low N availability. The sharp decrease in leaf N concentration in 1992 and 1993 supports their conclusion that the amount of reserve N in mature peach trees is rapidly altered in the presence of low N treatments despite a previous history of high N fertilization rates.

Split applications of N reduced yield in 2 years and increased yield in one year (Table 2). The increased yield in 1991 due to split N application was associated with the high rate of N whereas the reduced yields in 1989 and 1990 were independent of rate of nitrogen. There appears to be no explanation for the latter results. No effect of fertilizer timing on yield was noted by Schneider and McClung (18). A study by Bussi et al. (4) also showed no effect on yield when nitrogen was applied as a single dose or applied through fertigation over several months.

Leaf P, K, Mg, Zn, Mn and Cu concentrations were generally adequate throughout the six year study (Table 4) when compared to recommended values (3, 19), all expressed on a dry weight basis. Exceptions were leaf Ca which was low in all years except 1993 and leaf Fe which was below recommended values for 1992. However, leaf Ca has not been correlated with peach tree performance and leaf Fe concentration is of limited value, not even being a reliable indicator of iron chlorosis.

Of the orchard management factors tested, N fertilization affected leaf nutrient concentration more than timing of fertilization or vegetation control. The highest rates of N fertilization tended to decrease leaf P, Ca, K and Mg and increase leaf Fe, Mn and Cu concentrations. Leaf P concentration of 'Fairhaven' peach would appear

Table 5. Effect of rate (N) and timing (T) of nitrogen fertilization and orchard floor management (V) on ground color and flesh firmness of 'Fairhaven' peach.

	Ground colour (hue angle)[y]						Flesh firmness (N)					
Treatment[z]	1988	1989	1990	1991	1992	1993	1988	1989	1990	1991	1992	1993
N1	91.2	77.6	92.5	101.7	85.3	88.0	31	27	27	52	32	22
N2	94.5	83.0	95.0	102.7	85.7	89.3	37	30	33	55	32	24
T1	92.8	79.7	93.8	102.8	-[x]	-	33	29	26	53	-[x]	-
T2	93.0	81.0	93.7	101.6	-	-	35	29	34	54	-	-
V1	92.0	80.8	92.9	101.8	85.5	88.5	33	28	31	55	32	22
V2	93.8	79.8	94.6	102.7	85.4	88.8	34	29	52	32	24	24
Significance												
N	**	***	***	*	NS	NS	*	NS	***	NS	NS	NS
T	NS	NS	NS	NS	-	-	NS	NS	NS	NS	-	-
V	NS	NS	**	NS	NS	NS	NS	NS	***	NS	NS	NS
Interactions	none	NxVxT *	none	none	none	none	none	NxT *	VxT **	none	none	none

[z]Values for N, T and V are shown in Table 1.
[y]Hue angle calculated by arctan b/a.
[x]Treatment not conducted.
NS, *, **, ***, Nonsignificant or significant at $P \leq 0.05$, 0.01 or 0.001, respectively.

Table 6. Effect of rate (N) and timing (T) of nitrogen fertilization and orchard floor management (V) on soluble solids concentrations and titratable acidity of 'Fairhaven' peach.

	Soluble solids concentrations (%)						Titratable acidity (mg) malic acid/100 ml juice					
Treatment[z]	1988	1989	1990	1991	1992	1993	1988	1989	1990	1991	1992	1993
N1	11.3	11.6	11.1	11.6	10.1	10.7	788	615	661	938	549	581
N2	10.9	11.7	11.1	11.6	10.2	10.8	800	642	688	960	538	582
T1	11.1	11.7	10.9	11.4	-[y]	-	786	631	659	948	-[y]	-
T2	11.1	11.6	11.2	11.8	-	-	802	626	689	950	-	-
V1	11.3	11.7	11.0	11.8	10.0	11.0	784	616	643	947	521	578
V2	10.9	11.7	11.1	11.4	10.3	10.6	804	642	706	952	566	585
Significance												
N	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
T	NS	NS	NS	**	-	-	NS	NS	NS	NS	-	-
V	*	NS	NS	*	NS	*	NS	NS	***	NS	*	NS
Interactions												
	NxT*	none	none	none	none	none	NxV* NxVxT*	none	VxT*	none	none	none

[z]Values for N, T and V are shown in Table 1.
[y]Treatment not conducted.
NS, *, **, ***, Nonsignificant or significant at $P \leq 0.05$, 0.01 or 0.001, respectively.

to be particularly sensitive to changes in N availability and leaf K and Ca to a lesser degree. Leece (16) reported similar macro and micronutrient leaf responses to N fertilization for 'Halehaven' peach, the exception being P which was unaffected by N. Cummings (8) also reported decreases in nutrient concentration with higher rates of N fertilization. Inadequate leaf macronutrient concentrations in peach may therefore, result from high rates of N. It is also noteworthy that variation in the duration of herbicide strip treatments had few measurable effects on leaf nutrient concentration. This suggests little to choose between these treatments in terms of effects on nutrients other than N and contrasts with the situation for apple in which herbicide treatments adversely affect tree P and K nutrition (14).

Use of glyphosate in complete control (V1) of vegetation allowed regrowth of some annual weeds which would not compete too vigorously with the tree roots for soil nutrients. Had paraquat been used, greater regrowth of perennial weeds would have occurred and more differences might have occurred between the complete (V1) and partial control (V2) treatments for vegetation management. Ground covers can influence leaf nutrient concentrations (5).

Previous studies have shown little or no effect of high rates of N on average fruit weight (2, 7, 18), but other studies indicated a reduction in red color (16) or no effect on color (20, 22). Our data showed no effect of higher rates of N on average fruit weight while percentage of red color (evaluated in 1993 only) was unaffected by treatment (data not shown). Harris and Boynton (11) noted higher firmness with higher N but Schneider et al. (17) did not. Soluble solids and TA were not affected in other studies by higher rates of N (6, 11, 20, 22) but Schneider et al. (17) reported higher SSC with increasing N. Soluble solids were lower with V2 in 3 of the 6 years in our study (Table 4).

In summary, high rates of N fertilization increase the likelihood of greener fruit and do not always increase yield. Lack of a higher yield may be indicative of the tree's inability to convert the available N into fruit production but rather into excessive shoot growth. Results in this study suggest a N rate greater than 60 kg N/ha but less than 300 kg N/ha for 'Fairhaven' peach spaced at 2.5 m x 4.5 m. A single application of herbicides in the spring appears to suppress vegetation growth sufficiently so that competition in the summer is not experienced. Split applications of N were not better than a single application in terms of yield. The adverse effect of high rates of N on leaf nutrition, particularly P, suggests close monitoring of orchard nutrition through leaf analysis.

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