[1]NITROGEN AND WATER MANAGEMENT IN HIGH DENSITY APPLE ORCHARDS

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ABSTRACT
Efficient management of N fertilizer in irrigated apple orchard systems requires a knowledge of the magnitude and timing of plant demand and retention of N in the root zone to allow root interception. Results from five experiments in high density plantings of apple on dwarfing (M.9) rootstocks are reported. All experimental plots received daily drip irrigation and N applied through the irrigation system (fertigation) with different regimes according to experimental design. Labeled fertilizer applications, whole tree excavation and partitioning and removal of N in fruit and senescent leaves were used to assess tree N demand. Nitrogen requirements ranged from 8 to 40 lb/acre over the first six years after planting and N use efficiency was often low (<30%). Annual growth is supported by N remobilized from storage and by root uptake. Root uptake of labeled fertilizer was negligible during early spring and the commencement of rapid uptake was associated with the end of remobilization and the start of shoot growth, rendering early spring fertilizer applications ineffective. Thus timing of N supply to periods of high demand is crucial to improving efficiency. Comparisons were made to determine the effects on N leaching and tree N utilization of irrigation scheduled to meet evaporative demand and irrigation applied at a fixed rate. Water losses beneath the root zone were greater for fixed rate than scheduled irrigation during the coolest months (May, June and September) when irrigation was applied. Nitrogen leaching followed a similar pattern during times of N fertigation (May and June). Greater N use efficiency was also measured for trees when irrigation was scheduled to meet evaporative demand rather than applied at a fixed rate. The most N efficient management system was for trees receiving a low (50ppm) fertigated N supply, at 0-4 or 4-8 weeks following bloom with scheduled irrigation.

INTRODUCTION

In apple orchards, as in most agricultural systems, N is applied more frequently and in greater amounts than any other plant nutrient. However, fruit trees are conspicuously inefficient in their use of N, recovering around 20% of applied fertilizer (Weinbaum et al., 1992). Although this may be partially a function of the coarse textured soils in which fruit trees are often grown, delivery of applied N to the sparse root systems of fruit trees is also an important factor. Apple trees have rooting densities which are several orders of magnitude less than graminaceae species and this is compounded in trees grown on dwarfing rootstocks (Neilsen et al, 1997). Thus, management of N in apple orchards to meet plant needs and avoid environmental contamination, requires that plant demand is understood and that supply methods are efficient (Tagliavini et al., 1996).

Assessing the amount of N required by deciduous fruit trees has traditionally been based on leaf N concentrations. Weinbaum et al., (1992) noted that the large woody biomass of field grown fruit trees acts as a deterrent to plant excavation and nutrient analysis, thus the determination of seasonal periodicity and amount of annual uptake is difficult. However, they also noted that in large, mature trees, the amount of N removed in the crop may be a legitimate basis for developing conservative and ecologically sound fertilizer recommendations. Less information is available for

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younger trees on dwarfing rootstocks.

Unlike annual crops, N inputs into woody perennials can affect tree growth and development both in current and subsequent years (Weinbaum et al., 1987), thus key processes involved in year to year responses are storage and remobilization. Nitrogen can be considered to be in storage if it can be remobilized from one tissue and subsequently used for the growth of other tissues (Millard, 1988). During leaf senescence, N stored in the leaves during the summer is withdrawn, stored over-winter in woody tissue and subsequently remobilized and used for growth in the spring (Millard, 1996). In considering the timing of N inputs it is thus important to determine when remobilization and root uptake occur.

In the Pacific Northwest, the efficient delivery of N to the root systems of dwarf apple trees is dependent on irrigation management. Intensively managed fruit orchards with micro-irrigation systems offer the opportunity to control N and water inputs, by the application of N through the irrigation system at specific times and scheduling of irrigation to meet evaporative demand (Neilsen et al., 1998). This approach should improve the efficiency of both water and N fertilizer use thus reducing leaching losses.

The aim of this paper is to summarize the results from a series of experiments designed to determine the effects of the role of N from tree storage and root uptake; rate and timing of N supply and irrigation management applications on tree growth development and N use in high density apple orchards.

METHODS

Five field experiments were conducted at the Pacific Agri-Food Research Centre, Summerland British Columbia with several varieties of apple grafted on Malling 9 (M.9) dwarfing rootstock. Planting densities were between 1000 and 1336 trees/acre. All experiments were planted on Skaha or Osoyoos loamy sand soil (Wittneben, 1986) and received daily drip irrigation. All trials had a randomized complete block design. Only experimental details pertinent to data presented in this paper are given.

Experiment 1: Golden Delicious/M.9 were planted April 9^{th}, 1997. Irrigation was applied to meet daily requirements based on previous day's evaporation from an atmometer (ETGage Co., Loveland, CO) linked to an irrigation system. Nitrogen was applied daily over a six week period through the irrigation system at three application timings (N1) 2-8, (N2) 5-11 and (N3) 8-14 weeks after planting as $Ca(^{15}NO_3)_2$ (1.85 atom%). Trees were harvested at regular intervals after planting (H1-H4) in year one and in spring (H5) year 2. Labeled and unlabeled N and dry matter content were determined. For further details see Neilsen et al. (2001b).

Experiment 2: Elstar/M.9 were planted 1992. Irrigation was applied at a fixed rate of 2 gal water/day. In year 3 (1994) N was supplied as $^{15}NH_4{}^{15}NO_3$ (2.1 atom%) over a 10 week period starting April 10^{th}. Detailed, sequential leaf sampling was carried out in 1994 and fruit samples were collected at harvest. In 1995, trees received unlabeled N and after harvest the whole tree was removed and partitioned. Labeled and unlabeled N and dry matter content were determined for all samples. For more details see Neilsen et al. (2001a).

Experiment 3: Gala/M.9 were planted in 1997. Irrigation was applied to meet daily requirements based on previous day's evaporation from an atmometer (ETGage Co., Loveland, CO) linked to an irrigation system. Nitrogen was applied as $Ca(NO_3)_2$ daily, through the irrigation system, at three application timings (T1) 0-4, (T2) 4-8 and (T3) 8-12 weeks after full bloom and at two target concentrations of 50 and 200 ppm in the fertigating solution. Tree growth (trunk cross-sectional area-TCSA), fruit yield and N content and leaf N content in July and at senescence were measured annually as well as total canopy dry matter. Data for 1999 are presented here.

Experiment 4: Gala/M.9 were planted in 1993. Irrigation was applied to meet daily requirements based on previous day's evaporation from an atmometer (ETGage Co., Loveland, CO) linked to an irrigation system. Nitrogen was applied as $Ca(NO_3)_2$ daily, through the irrigation system for 8 weeks post full bloom. Fruit yield and N content and leaf N content in July and at senescence were measured as well as total canopy dry matter. Data for 1999 are presented here. For more details see Neilsen et al. (1998).

Experiment 5: Gala/M.9 were planted in 1997. Irrigation was applied to meet daily requirements based on previous day's evaporation from an atmometer (ETGage Co., Loveland, CO) linked to an irrigation system, or applied at a fixed rate of 8L/tree/day. Nitrogen was applied as $Ca(NO_3)_2$ daily, through the irrigation system at a concentration of 50 ppm in the fertigating solution. Tree growth (trunk cross-sectional area-TCSA), fruit yield and N content and leaf N content in July and at senescence were measured annually as well as total canopy dry matter. Data for 1998 are presented here. Losses of N and water beneath the root zone were measured using passive capillary wick samplers (Boll et al. 1992).

RESULTS AND DISCUSSION

DEMAND FOR N. The total N content of dwarf apple trees is quite low, ranging from 0.08 oz/tree for newly planted trees to 0.7 oz/tree for four year-old trees (Table 1). At planting densities of around 1336 trees/acre the tree N content/acre ranges from 7-59 lb. Older trees may have somewhat higher N content, but maximum tree size is often reached by year 5 in high density apple plantings. Recommended annual rates of N application for young dwarf apple trees range from 80 to 160 lb/acre (Okanagan Valley Tree Fruit Authority, 1993) indicating a large potential oversupply when compared with actual tree uptake. Weinbaum et al. (1992) estimated that annual over-application of N to apple orchards in California ranged from about 23 to 335 lb/acre.

Table 1. Total N content of young apple trees on dwarfing rootstocks

		N Content	
Experiment	Variety	oz/tree	lb/acre[z]
1	Golden Delicious/M.9 at planting	0.08	6.7
1	Golden Delicious/M.9 end of year 1	0.29	24.2
2	Elstar/M.9 end of year 4	0.70	58.5

[z] assumes tree density of 1336 trees/acre

A large proportion of total tree N is used to support annual growth. Weinbaum et al. (1987) estimated a 50% annual removal of total tree N in large trees and Neilsen at al. (2001b) found a similar relationship for young, dwarf apple trees, and also showed that root supplied N was similarly partitioned. Thus a useful estimate of tree N demand may be the amount partitioned to annual growth. The amount of N removed in fruit and senescent leaves has been calculated for dwarf apple trees of different ages and ranged from 8.4 to 36.2 lb/acre (Table 2).

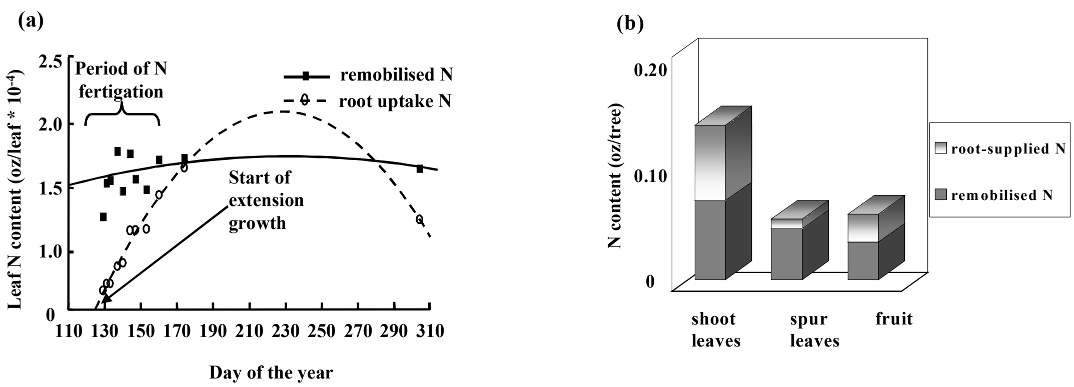
SUPPLY OF N FOR GROWTH Early spring growth of deciduous trees is supported by N remobilized from storage and by N taken up by the roots. Data for three year-old Elstar/M.9 (experiment 2) indicated that remobilization of N from storage was largely completed by the start of shoot

Table 2. Estimates of annual N requirements of dwarf apple trees: N removal in fruit and senescent leaves

		N Content	
Experiment	Variety	oz/tree	lb/acre[z]
1	Golden Delicious/M.9 end of year 1[y]	0.10	8.4
2	Elstar/M.9 end of year 4	0.36	30.1
3	Gala/M.9 end of year 3	0.37	31.3
4	Gala/M.9 end of year 6	0.43	36.2

[z] assumes tree density of 1336 trees/acre
[y] leaves only

Figure 1. Sources of N for (a) shoot growth (b) shoot leaf, spur leaf and fruit growth in three year old Elstar/M.9 apple trees at the end of the growing season (experiment 2).



extension growth (Fig. 1a) and contributed around 50% of the N in shoot leaves, 90% of the N in spur leaves which subtend the fruit and around 60% of the N in the fruit (Fig. 1b). Although fertilizer N was available before shoot development it is apparent that little was taken up until shoot development started (Fig. 1a). Thus, as the shoot leaf canopy is the largest sink for N in most dwarf apple trees, application of N before root uptake occurs is likely to result in inefficient fertilizer use. In newly planted Golden Delicious/M.9 (experiment 1), around half of the stored (unlabeled) tree N was remobilized from woody tissue and into new roots and shoots (Fig. 2a). However, root uptake of fertilizer (labeled) N did not occur until after shoot growth had started (Fig. 2b). Thus, early N fertilizer applications (N1) were potentially less efficient than later applications (N2 and N3).

EFFICIENCY OF SUPPLY In irrigated systems, efficient use of N is dependent on matching supply (amount and timing of applications) to demand, and also on retaining N in the root zone in order to facilitate interception by the plant. Nitrogen use efficiency can only be directly assessed by use of labeled fertilizer and whole tree excavation. For example, in experiment 2, N uptake accounted for

Figure 2. Relationship of N application timing (N1, N2 and N3) to (a) remobilization of N from woody tissue into new growth and (b) uptake of fertilizer N with respect to growth in newly planted Golden Delicious/M.9 apple trees (experiment 1).

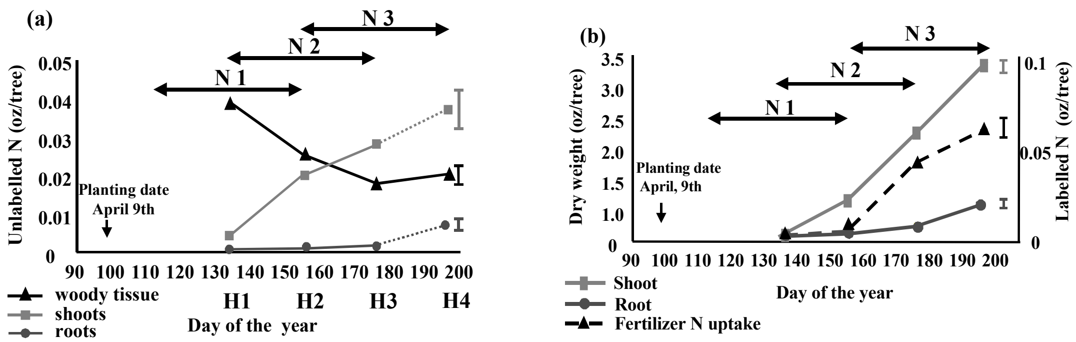


Table 3. Effect of timing and rate of N supply on N inputs and removal in fruit and senescent leaves for three and four year-old Gala/M.9 apple trees (experiment 3)

	Year3				Year 4			
N time	N additions oz/tree/year		N removal oz/tree/year		N additions oz/tree/year		N removal oz/tree/year	
	N1[z]	N2	N1	N2	N1	N2	N1	N2
T1[y]	0.25	0.57	0.29(116%)[x]	0.40(70%)	0.18	0.55	0.25(137%)	0.33(60%)
T2	0.23	1.09	0.37(161%)	0.43(39%)	0.12	0.36	0.27(223%)	0.32(88%)
T3	0.40	1.62	0.35(88%)	0.41(25%)	0.18	0.55	0.24(141%)	0.36(65%)
SE			0.03				0.02	
N			*				**	
T			ns				ns	
N*T			ns				ns	

[z] N1 = 50 ppm and N2 = 200 ppm N in the fertigating solution
[y] T1 = 0-4; T2 = 4-8; T3 = 8-12 weeks after full bloom
[x] values in brackets are percentages of total applied N found in leaves and fruit

around 22% of added fertilizer (Neilsen et al., 2001b). In experiment 1, whole tree analysis in the second year indicated that the amount of fertilizer N taken up by trees receiving N at time N3 was 1.58 times greater than trees receiving N at time N1 (Neilsen et al., 2001a), as the earlier (N1) application time coincided with the period of N remobilization and low root uptake (Fig 2).

In experiment 3, losses of N in senescent leaves and fruit were used to characterize annual N demand and to relate demand to timing and rate of N supply (Table 3). As N additions were based on the concentration of N in the fertigating solution (N1) and (N2) and because irrigation was scheduled to meet evaporative demand, the amount of N applied varied in each of the 4-week fertilizer timing treatments (T1,T2,T3). The amount of N removed in senescent leaves + fruit was higher in both years for trees receiving the higher rate of N (Table 3). However, taking into account the percentages of added N removed in the senescent leaves+fruit, there was potential oversupply of N in the high N treatment and potential under-supply in the low N treatment. There was no effect of timing (T) of N supply on N removal. Assuming a tree planting density of 1336 trees/acre, N removal rates varied between 20 and 30 lb/acre. Higher application rates of N (N2) did not necessarily lead to increases in growth and yield in these trees (Table 4). Similar growth and yields were obtained from low and high applications of N, except when low N was applied at 8-12 weeks after bloom (T3). This is likely because rapid canopy development, which occurs in the period just after full bloom, was retarded in trees with low N status and no N was supplied at this time. The major effect of extra N supply was on N storage in leaves. Leaf N concentrations were higher for trees receiving the higher N rate. However, all trees had leaf N concentrations that were in the sufficient range.

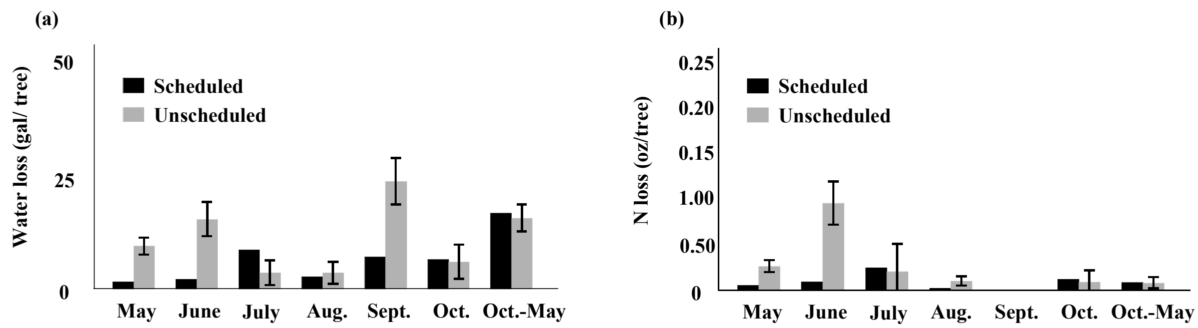
Table 4. Effect of timing and rate of N supply on growth, fruiting and tree N status in three and four year-old Gala/M.9 apple trees (experiment 3)

	Year 3						Year 4					
N time	TCSA (in^2)		Yield (lb/tree)		Leaf N (%)		TCSA (in^2)		Yield (lb/tree)		Leaf N (%)	
	N1[z]	N2	N1	N2	N1	N2	N1	N2	N1	N2	N1	N2
T1[y]	1.35	1.49	10.2	11.4	2.35	2.63	1.38	1.61	19.3	20.6	2.25	2.37
T2	1.45	1.44	9.8	10.9	2.46	2.60	1.57	1.46	19.9	18.2	2.33	2.35
T3	1.31	1.52	12.6	9.8	2.34	.40	1.25	1.52	16.2	19.4	2.38	2.40
SE	0.11		1.57		0.069		0.08		0.99		0.037	
N	ns		ns		*		ns		ns		ns	
T	ns		ns		ns		ns		ns		ns	
N * T	ns		ns		ns		*		*		ns	

[z] N1 = 50 ppm and N2 = 200 ppm N in the fertigating solution
[y] T1 = 0-4; T2 = 4-8; T3 = 8-12 weeks after full bloom

In addition to matching N additions to demand at times when N uptake is most likely, retention of N in the root zone is an important factor in efficient fertilizer management. In experiment 5, the effects of irrigation applied at fixed rate (unscheduled) and irrigation applied to meet evaporative demand (scheduled) on N leaching and crop N utilization were compared. Volume of water and nitrate N concentration were measured on a monthly basis throughout the growing season from passive apillary wick samplers. Differences in water losses beneath the root zone were greatest in the coolest months, May, June and September when fixed rate applications greatly exceeded evaporative demand (Fig. 3a). There was little effect of irrigation method on water losses over

Figure 3. Seasonal water and N losses beneath the root zone for two year-old Gala/M.9 apple trees in response to irrigation either applied to meet evaporative demand (scheduled) or at a



fixed daily rate (unscheduled) (experiment 5).

winter, from mid- October through May. Losses of N beneath the root zone were greatest for fixed rate irrigation during the period of fertilizer application at times when water applications were poorly matched with demand i.e. May and June (Fig. 3b).

The total amount of water applied with irrigation scheduled to meet evaporative demand was 50% of that applied under fixed rate irrigation (Table 5). As N was applied at a fixed target concentration in the fertigating solution (around 50 ppm), N additions were also considerably less (around 43%) for scheduled compared with unscheduled irrigation. Despite differences in the amounts of N added, there was no difference in the amount of N removed in leaves and fruit between the trees receiving the two types of irrigation. However, 38% of the amount of added N was found in leaves and fruit of trees receiving scheduled irrigation compared with 18% in trees receiving unscheduled irrigation. Using a tree planting density of 1336 tree/acre N removal rates for these second year trees were around 18-20 lb/acre. Similarly, there were no effects of irrigation method on either growth, yield or leaf N concentration in these trees. The more effective use of applied N under scheduled irrigation in this experiment can likely be attributed to longer retention time in the root zone. This is of particular importance for sparsely rooted dwarf apple trees.

Table 5. Water and N additions, N removal in senescent leaves and fruit, growth, yield and leaf N content of two year-old Gala/M.9 apple trees receiving irrigation either applied to meet evaporative demand (scheduled) or at a fixed daily rate (unscheduled) (experiment 5).

Irrigation	Water added (gal/tree)	N added (oz/tree)	N removal (oz/tree)	TCSA (in^2)	Yield (lb/tree)	Leaf N (%)
Scheduled	171	0.56	0.21	0.92	3.75	2.38
Unscheduled	345	1.31	0.24	0.94	2.65	2.30
SE			0.03	0.05	0.53	0.054
Significance			ns	ns	ns	ns

SUMMARY
Using a variety of techniques to assess plant demand including whole tree excavations, labeled fertilizer N uptake and removal of N in fruit and senescent leaves, it is apparent that dwarf apple trees have low requirements for N, ranging from 8 to 40 lb/acre/year over the first six years after planting. This is considerably less than recommended rates of application. It is also apparent that dwarf apple trees are inefficient users of N fertilizer, thus matching the timing of supply to periods of high demand is important. Annual growth of apple trees is supported by both N remobilized from storage in the tree and N supplied by the roots. Root uptake of N is inhibited during remobilization, which occurs early in the spring, and rapid uptake is associated with the initiation of shoot growth. Thus early spring applications of N may be ineffective. The third factor, which influences the efficiency of N fertilizer use is retention in the root zone. In irrigated systems, greater efficiency can be achieved when water is added to meet plant demand than when applied at a fixed rate. Scheduling irrigation to meet plant demand also minimizes losses of N and water beneath the root zone.

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