Efficient Use of Nitrogen and Water in High-density Apple Orchards

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SUMMARY. In irrigated apple orchard systems, the magnitude and timing of plant demand for nitrogen (N) and retention of N in the root zone to allow root interception are important factors for efficient management of N fertilizer. Results from five experiments in high-density plantings of apple (*Malus domestica*) on dwarfing ('Malling 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. Labelled 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 (8.8 to 44 kg·ha⁻¹) over the first 6 years after planting and N use efficiency was often low (<30%), likely because supply exceeded demand. Annual growth is supported by N remobilized from storage and taken up by roots. Root uptake of labelled 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 prebloom fertilizer applications ineffective. Thus timing of N supply to periods of high demand is crucial for 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) of irrigation application. 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 [50 ppm (mg·L⁻¹)] fertigated N supply, at 0 to 4 or 4 to 8 weeks following bloom with scheduled irrigation.

Improving nitrogen and water management is important from several perspectives. The potential detrimental effects of misuse of N in agriculture on both the atmosphere (greenhouse and ozone-depleting gases) and groundwater (nitrate leaching) have been well documented in both the scientific and popular press. In irrigated agriculture, leaching losses of excess N to groundwater are partially determined by the way in which water is applied and thus, can probably be more readily controlled than in rainfed systems. There is also growing concern in the Pacific northwestern U.S. and southern British Columbia, Canada, about the long term availability of irrigation water supply, particularly in light of changing hydrograph patterns in snow melt watersheds (Leith and Whitfield, 1998) and the need to maintain minimum stream flows for fish habitat.

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In addition to environmental concerns about agricultural water and N use, there is continued economic pressure on farmers to produce the highest quality fruit and it has been shown previously that excess N can affect fruit quality (Faust, 1989). Effects may include reduced firmness at harvest and after storage, or reduced red color development when internal ethylene production continues to occur, resulting in fruit which are picked overmature (Fallahi, 1997). Incidence of several storage disorders such as cork spot, bitter pit, internal browning and breakdown (Bramlage et al., 1980; Terblanche et al., 1980) has also been linked to excess N supply. Such detrimental effects of excess N have been related to increases in fruit size and to shading from vigorously growing shoots amongst other factors. Increased susceptibility to diseases such as fireblight, caused by *Erwinia amylovora*, has also been attributed to vigorous growth related to N oversupply (Van der Zwet and Keil, 1979).

In apple orchards, as in most agricultural systems, N is applied in greater amounts than any other plant nutrient and often, more frequently. However, fruit trees are 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, for example, have rooting densities which are several orders of magnitude less than those of Gramineae species with which they are in competition (Atkinson, 1980). Even lower rooting densities are found in trees grown on dwarfing rootstocks (Nielsen et al., 1997b). 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. However, responses to N fertilizer additions such as higher leaf N concentration, darker leaf color, increased vigor and increased yield may only occur with trees of low N status as N uptake is likely restricted in trees of high N status (Weinbaum et al., 1992). Moreover, leaf N concentration may be

unaffected by increased uptake of N in response to supply if dilution due to increased leaf growth occurs. Thus, leaf N concentration as a sole method of diagnosis of N requirement is not satisfactory, particularly when tree N status is above deficiency. Consequently other methods have been sought to determine tree N requirements.

Nitrogen is required to support the growth of new tissues of which the developing leaves and fruit are the major sinks. It has been estimated that by midseason, 40% of total tree N may be found in leaf tissue in standard mature apple trees (Batjer et al., 1952) and 40% to 50% in leaves of young potted trees (Forshey, 1963). 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, making the determination of seasonal periodicity and amount of annual uptake difficult. However, they also suggested that in large, mature trees, the amount of N removed in the crop may be a legitimate basis for developing ecologically sound fertilizer recommendations. Attempts have been made to determine the annual demand of apple trees for N based on the removal of N from the orchard. In large, mature trees (14 to 21 years), around 23 to 24 lb/acre (25 to 26 kg·ha⁻¹) N were removed annually in fruit and prunings when fruit yields were high (Greenham, 1980). When the portion of annual N uptake that is incorporated into the framework of the tree was included, annual N removal was estimated as 30 lb/acre (33 kg·ha⁻¹) from 9 to 12-year-old 'Cox's Orange Pippin'/'Malling 7' (M.7) (Greenham, 1980), 47 lb/acre (52 kg·ha⁻¹) from 30-year-old 'Delicious' trees (Batjer et al., 1952) and 55 lb/acre (60 kg·ha⁻¹) from 13-year-old 'Starking Delicious'/seedling (Klein et al., 1989). In a semi-intensive planting of 11-year-old 'Golden Delicious'/'Northern Spy', 23 lb/acre of N was removed in fruit and prunings and a further 30 lb/acre in fallen leaves (Haynes and Goh, 1980). Less information is available for younger trees on dwarfing rootstocks in high-density plantings.

Unlike annual crops, N inputs into woody perennials can affect tree growth and development both in current and subsequent years (Weinbaum et al., 1987). Year to year responses to N fertilization are affected by processes of 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 overwinter 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.

The efficient delivery of N to the root systems of dwarf apple trees is dependent on water management. In the past 10 to 15 years, orchard management in the Pacific northwestern U.S. and southern British Columbia has become increasingly precise with the advent of dwarfing rootstocks and high-density planting systems. In addition, there has been a shift to use of low-pressure microirrigation techniques. Such intensively managed apple orchards with microirrigation systems offer the opportunity to control N and water inputs, by the application of N through the irrigation system at specific times and with scheduling of irrigation to meet evaporative demand (Nielsen et al., 1998). This approach makes it possible to improve the efficiency of both water and N fertilizer use thus reducing leaching losses.

This paper summarizes 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 on tree growth and development and N use in high-density apple orchards typical of the Pacific northwestern U.S. and southern British Columbia, Canada.

Field experiments

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 (2470 to 3300 trees/ha). 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' apple trees were planted on 9 Apr. 1997 (Nielsen et al., 2001b).

Irrigation was applied to meet daily requirements based on previous day's evaporation from an atmometer (ETGage Co., Loveland, Colo.) linked to an irrigation system (Parchomchuk et al., 1996). Nitrogen was applied daily over a 6-week period through the irrigation system at three application timings (N1) 2 to 8, (N2) 5 to 11 and (N3) 8 to 14 weeks after planting as ^{15}N isotope-labelled calcium nitrate [$\text{Ca}(\text{}^{15}\text{NO}_3)_2$] with a ^{15}N concentration of 1.85 atom% (1.85% of total N), to give an average N concentration in the fertigating solution of 112 ppm. Trees were harvested at regular intervals after planting, four times in year 1 at 5, 8, 11, and 14 weeks after planting and in spring (21 May 1998) in year 2. Labelled and unlabelled N and dry matter content were determined.

EXPERIMENT 2. 'Elstar'/M.9 apple trees were planted in 1992 (Nielsen et al., 1997a, 2001a). Irrigation was applied at a fixed rate of 2 gal (8 L) of water per day. In year 3, (1994), N was supplied as ^{15}N isotope-labelled ammonium nitrate ($^{15}\text{NH}_4^{15}\text{NO}_3$ with a ^{15}N concentration of 2.1 atom%) over a 10-week period starting 10 Apr. at the rate of 0.71 oz/tree (20 g/tree) of N. The N concentration in the irrigation water averaged 36 ppm. Detailed, sequential leaf sampling was carried out in 1994 and fruit samples were collected at harvest. In 1995, trees received 0.71 oz/tree of unlabelled N and after harvest the whole trees were removed and partitioned. Labelled and unlabelled N and dry matter content were determined for all samples.

EXPERIMENT 3. 'Gala'/M.9 apple trees were planted in 1997. Irrigation was applied to meet daily requirements based on previous day's evaporation from an atmometer (ETGage Co., Loveland, Colo.) linked to an irrigation system. Nitrogen was applied as $\text{Ca}(\text{NO}_3)_2$ daily, through the irrigation system, at three application timings (T1) 0 to 4, (T2) 4 to 8 and (T3) 8 to 12 weeks after full bloom and at two target concentrations of 50 and 200 ppm in the fertigating solution. The amount of N added varied with the amount of irrigation water applied. In 1999, this ranged from 0.23 to 1.62 oz/tree (6.5 to 45.9 g/tree) and in 2000 from 0.12 to 0.55 oz/tree (3.4 to 15.6 g/tree). Tree growth measured as trunk cross-sectional area (TSA), fruit yield and N content and leaf N content in July and at senescence (October) were measured annually as well as total canopy dry matter. Data for 1999 and 2000 are presented here.

EXPERIMENT 4. 'Gala'/M.9 apple trees were planted in 1993 on a loamy sand soil (Nielsen et al., 1998). In 1993 and 1994, the trees received daily irrigation at 2 gal/tree. From 1995 to 1998, irrigation was applied to meet daily requirements based on previous day's evaporation from an atmometer (ETGage Co., Loveland, Colo.) linked to an irrigation system. Nitrogen was applied as $\text{Ca}(\text{NO}_3)_2$ daily, through the irrigation system for 8 weeks post full bloom. In 1993 and 1994, N was applied at a concentration of 75 ppm and from 1995 onwards at a concentration of 90 ppm. In 1998, each tree received 2.1 oz (59 g) of N. In 1998, fruit yield and N content and leaf N content in July and at senescence (October) were measured as well as total canopy dry matter.

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, Colo.) linked to an irrigation system (scheduled), or applied daily at a fixed rate of 2 gal/tree (unscheduled). Nitrogen was applied as $\text{Ca}(\text{NO}_3)_2$ daily, through the irrigation system at a concentration of 50 ppm in the fertigating solution. In 1998 trees under scheduled irrigation received 0.56 oz (15.9 g) of N and trees under unscheduled irrigation received 1.31 oz (37.1 g) of N. Tree growth (TSA), fruit yield and N content and leaf N content in July and at senescence (October) 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).

Nitrogen management

DEMAND FOR NITROGEN. The total N content of dwarf apple trees was quite low, ranging from 0.08 oz (2.3 g) per tree for newly planted trees to 0.7 oz (19.8 g) per tree for 4-year-old trees (Table 1). At planting densities of around 1336 trees/acre (3300 trees/ha), the tree N content ranged from 7 to 59 lb/acre (7.7 to 60 kg·ha⁻¹). Older trees may have a somewhat higher N content, but maximum tree size is often reached by year 6 in high-density apple plantings. Recommended annual rates of N application for young dwarf apple trees range from 80 to 160 lb/acre (88 to 176 kg·ha⁻¹) (Okanagan Valley Tree Fruit Authority, 1993) indicating a large potential oversupply when compared with actual tree uptake. Weinbaum et al. (1992) estimated that annual overapplication of N to apple orchards in California ranged from about 23 to 335 lb/acre (25 to 369 kg·ha⁻¹).

A large proportion of total tree N is used to support annual growth. Weinbaum et al. (1987) estimated that 40% to 50% of total tree N in large trees is replaced annually by root uptake. Nielsen et al. (2001b) found a similar relationship for young, dwarf apple trees. Thus a useful estimate of tree N demand may be the amount partitioned to annual growth. The amount of N re-

Table 1. Total nitrogen content of young apple trees on 'Malling 9' (M.9) dwarfing rootstock.

Expt.	Variety	N content	
		oz (g)/tree	lb/acre ^z (kg·ha ⁻¹)
1	Golden Delicious/M.9 at planting	0.08 (2.27)	6.7 (7.4)
1	Golden Delicious/M.9 end of year 1	0.29 (8.22)	24.2 (26.6)
2	Elstar/M.9 end of year 4	0.70 (19.85)	58.5 (64.4)

^zAssumes tree density of 1336 trees/acre (3300 trees/ha).

Table 2. Estimates of annual nitrogen requirements of apple trees on 'Malling 9' (M.9) dwarfing rootstock; nitrogen removal in fruit and senescent leaves.

Expt.	Variety	N content	
		oz (g)/tree	lb/acre ^z (kg·ha ⁻¹)
1	Golden Delicious/M.9 end of year 1 ^y	0.10 (2.84)	8.4 (9.2)
2	Elstar/M.9 end of year 4	0.36 (10.21)	30.1 (33.1)
3	Gala/M.9 end of year 3	0.37 (10.49)	31.3 (34.4)
4	Gala/M.9 end of year 6	0.43 (12.19)	36.2 (39.8)

^zAssumes tree density of 1336 trees/acre (3300 trees/ha).

^yLeaves only.

Fig. 1. Sources of nitrogen (A) in shoot leaves throughout the growing season and (B) in shoot leaves, spur leaves, and fruit at the end of the growing season for 3-year-old 'Elstar' apple trees on 'Malling 9' rootstock (Expt. 2); 10⁻⁴ oz = 2.8 × 10⁻³ g; 1.00 oz = 28.35 g.

moved 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 (9.2 to 39.8 kg·ha⁻¹) (Table 2).

SUPPLY OF NITROGEN FOR GROWTH.

Early spring growth of deciduous trees is supported by N remobilized from

storage in woody tissue and N taken up by the roots (Millard, 1996). Data for 3-year-old 'Elstar'/M.9 apple trees (Expt. 2) indicated that remobilization of N from storage was largely completed by the start of shoot extension growth (Fig. 1A) and contributed around 50% of the N in shoot leaves, 90% of the N in

spur leaves that subtend the fruit and about 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 (Expt. 1), around half of the stored (unlabelled) tree N was remobilized from woody tissue and into new roots and shoots by 80 d after planting (Fig. 2A). However, root uptake of fertilizer (labelled) N did not occur until after shoot growth had started (Fig. 2B). Thus, early N fertilizer applications (N1) were likely less efficient than later applications (N2 and N3). It is possible that amino acids circulating within the plant during spring N remobilization may suppress N uptake. Sharp increases in amino acid concentrations have been observed in the xylem sap of apple trees during spring remobilization (Malaguti et al., 2001) and an inverse relationship

Fig. 2. Relationship of N application timing N1, N2 and N3 (2–8, 5–11, and 8–14 weeks after planting, respectively) to (A) remobilization of unlabelled N from woody tissue into new growth (dotted lines represent period when unlabelled N could be both from remobilization and root uptake) and (B) uptake of fertilizer (labelled) N with respect to growth in newly planted 'Golden Delicious' apple trees on 'Malling 9' rootstock (Expt. 1). Vertical bars represent the average ± 1 se; 1.00 oz = 28.35 g.

Table 3. Effect of timing and rate of nitrogen (N) supply on nitrogen inputs and removal in fruit and senescent leaves for three and 4-year-old ‘Gala’ apple trees on ‘Malling 9’ (M.9) dwarfing rootstock (Expt. 3).

Time of application	Annual N additions oz (g)/tree				Annual N removal oz (g)/tree	
	N1 ^z	N2	N1	Efficiency ^x	N2	Efficiency ^x
Year 3						
T1 ^y	0.25 (7.1)	0.57 (16.2)	0.29 (8.2)	116%	0.40(11.3)	70%
T2	0.23 (6.5)	1.09 (30.9)	0.37 (10.5)	61%	0.43 (12.2)	39%
T3	0.40 (11.3)	1.62 (45.9)	0.35 (9.9)	88%	0.41 (11.6)	25%
N removal						
SE				0.03 (0.85)		
N				*		
T				NS		
N × T				NS		
Year 4						
T1 ^y	0.18 (5.1)	0.55 (15.6)	0.25 (7.1)	137%	0.33 (9.4)	60%
T2	0.12 (3.4)	0.36 (10.2)	0.27 (7.7)	223%	0.32 (9.1)	88%
T3	0.18 (5.1)	0.55 (15.6)	0.24 (6.8)	141%	0.36 (10.2)	65%
N removal						
SE				0.02 (0.57)		
N				**		
T				NS		
N × T				NS		

^zN1 = 50 ppm and N2 = 200 ppm nitrogen in the fertigating solution.

^yT1 = 0–4; T2 = 4–8; T3 = 8–12 weeks after full bloom.

^xPercentages of total applied nitrogen found in leaves and fruit.

ns,*,**Nonsignificant or significant at $P < 0.05$ or 0.01, respectively.

has been observed between the concentration of N contained in amino acids in the vasculature of field grown almond trees and the capacity of those trees to take up soil N (Youssefi et al., 2000).

EFFICIENCY OF SUPPLY. In irrigated systems, efficient use of N is de-

pendent 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 labelled fertilizer and whole tree excavation. For

example, in Expt. 2, N uptake accounted for around 22% of added fertilizer (Nielsen et al., 2001b). In Expt. 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 receiv-

Table 4. Effect of timing and rate of nitrogen (N) supply on growth, fruiting and tree N status for 3 and 4-year-old ‘Gala’ apple trees on ‘Malling 9’ (M.9) dwarfing rootstock (Expt. 3).

N time	Trunk cross-sectional area [inch ² (cm ²)]		Yield lb (kg)/tree		Leaf N (% dry wt)	
	N1 ^z	N2	N1	N2	N1	N2
Year 3						
T1 ^y	1.35 (8.71)	1.49 (9.61)	10.2 (4.6)	11.4 (5.2)	2.35	2.63
T2	1.45 (9.38)	1.44 (9.29)	9.8 (4.5)	10.9 (4.9)	2.46	2.60
T3	1.31 (8.45)	1.52 (9.81)	12.6 (5.7)	9.8 (4.5)	2.34	2.40
SE	0.11 (0.71)		1.57 (0.71)		0.069	
N	NS		NS		*	
T	NS		NS		NS	
N × T	NS		NS		NS	
Year 4						
T1 ^y	1.89 (12.2)	1.83 (11.8)	27.3 (12.5)	28.7 (13.0)	2.25	2.37
T2	1.69 (10.9)	1.97 (12.7)	24.0 (10.9)	28.4 (12.9)	2.33	2.35
T3	1.95 (12.6)	1.80 (11.4)	23.6 (12.5)	23.4 (10.6)	2.38	2.40
SE	0.08 (0.52)		2.30 (1.05)		0.037	
N	NS		NS		NS	
T	NS		NS		NS	
N × T	*		*		NS	

^zN1 = 50 ppm and N2 = 200 ppm N in the fertigating solution.

^yT1 = 0–4; T2 = 4–8; T3 = 8–12 weeks after full bloom.

ns,*,**Nonsignificant or significant at $P < 0.05$, respectively.

Fig. 3. Seasonal (A) water and (B) nitrogen losses beneath the root zone for 2-year-old 'Gala' apple trees on 'Malling 9' rootstock in response to irrigation either applied to meet evaporative demand (scheduled) or at a fixed daily rate (unscheduled) (Expt. 5). Vertical bars represent the average $\pm$ 1 SE; 1.00 oz = 28.35 g, 1 gal = 3.8 L.

ing 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 Expt. 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 evapo-

orative 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 (N2) 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 undersupply 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 (3300 trees/ha), N removal rates varied between 20 and 30 lb/acre (22 and 33 kg·ha⁻¹). Higher application rates of N (N2) did not necessarily lead to increases in growth and yield in these trees

(Table 4) as similar growth and yields were obtained with both application rates of N. 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 in year 3, although this effect had disappeared by year 4. However, all trees had leaf N concentrations that were in the sufficient range (British Columbia Ministry of Agriculture, Fisheries and Food, 1996).

In addition to matching N supply 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 Expt. 5, the effects of irrigation applied at fixed rate (unscheduled) and irrigation applied to meet evaporative demand (scheduled) on N leaching and crop N use were compared.

Volume of water and nitrate N concentration were measured throughout the growing season from passive capillary 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 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 (about 50 ppm), N additions were also considerably less (around 43%) for scheduled compared with unscheduled irrigation. Despite differences in the amounts of N

Table 5. Water and nitrogen additions, nitrogen removal in senescent leaves and fruit, growth, yield and leaf nitrogen content of 2-year-old 'Gala' apple trees on 'Malling 9' (M.9) dwarfing rootstock receiving irrigation either applied to meet evaporative demand (scheduled) or at a fixed daily rate (unscheduled) (Expt. 5).

Irrigation	Water added gal (L)/tree	N added oz (g)/tree	N removal oz (g)/tree	TCA ^z inch ² (cm ²)	Yield lb (kg)/tree	Leaf N (% dry wt)
Scheduled	171 (647)	0.56 (15.9)	0.21 (5.6)	0.92 (5.9)	3.75 (1.7)	2.38
Unscheduled	345 (1306)	1.31(37.1)	0.24 (6.8)	0.94 (6.1)	2.65 (1.2)	2.30
SE			0.03 (0.85)	0.05 (0.32)	0.53 (0.24)	0.054
Significance			NS	NS	NS	NS

^zTrunk cross-sectional area.

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 (3300 trees/ha) N removal rates for these second year trees were around 18 to 20 lb/acre (22 to 33 kg·ha⁻¹). Similarly, there were no effects of irrigation method on 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.

Conclusion

Using a variety of techniques to assess plant N demand including whole tree excavations, labelled fertilizer N uptake and removal of N in fruit and senescent leaves, it is apparent that apple trees grown on M.9 rootstocks have low requirements for N, ranging from 8 to 40 lb/acre (8.8 to 44 kg·ha⁻¹) each year, over the first 6 years after planting. This is considerably less than recommended rates of application. It is also apparent that apple trees on M.9 rootstocks are inefficient users of applied N fertilizer over the season, 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 may be inhibited during remobilization, which occurs early in the spring, and rapid uptake of soil N is associated with the initiation of shoot growth. Thus, very early spring applications of N may be ineffective. Another factor which influences efficiency of N fertilizer use is the movement of N through the root zone. In irrigated systems, if water is added to meet plant demand, water and N movement through the root zone can be reduced, and N leaching losses minimized.

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