Fertigation of Deciduous Fruit Trees: Apple and Sweet Cherry

Denise Neilsen, and Gerry Neilsen

Pacific Agri-Food Research Centre, Summerland, B.C., Canada. E-mail: neilseng@agr.gc.ca.

Abstract

Nutrient uptake by trees is determined by root interception, soil availability, and tree demand. Fruit trees have low rooting density, especially in the case of dwarfing rootstocks. Mobility in the soil is a key factor in determining nutrient availability, and good management of nutrients requires that supply is matched to demand, in terms of amount, timing and retention in the root-zone, and that nutrients are placed where they can be accessed by roots. Fertigation allows such flexibility in the timing and precision of nutrient supply. The efficiency of N fertigation is closely related to irrigation management. Scheduling irrigation to meet tree evaporative demand minimizes the drainage of excess water through the root zone and the consequent N leaching. Timing the N supply to coincide with the period of rapid canopy development avoids excess N application when tree growth is supported by remobilization of stored N. Fertigation gives greater P and K mobility than broadcasting, increasing the potential for timely application of these nutrients in the root zone. P fertigation is beneficial at planting and as a single application at bloom. Fertigation with K can prevent the development of K-deficiency in drip-irrigated trees on sandy soil. Fertigation with acidic fertilizers through drip systems can be detrimental in coarse-textured soils, where it can result in soil acidification and nutrient deficiencies, which can develop in as short a period as three years.

Keywords: irrigation, nitrogen, phosphorus, potassium, leaching, acidification.

Introduction

In irrigated horticultural production systems, increased precision in the application of both water and nutrients can potentially be achieved by simultaneous application via fertigation (Bar Josef, 1999; Haynes, 1985; Neilsen *et al*., 1999). This has the advantage of synchronising nutrient supply with plant demand (Millard,1996; Neilsen *et al*., 2001; Weinbaum *et al*., 1992), thus enabling reduction in the amount of nutrients applied and reducing environmental impact (Neilsen and Neilsen, 2002; Tagliavini *et al*., 1997).

Deciduous fruit trees are characterized by a low rooting density, several orders of magnitude lower than that of herbaceous plants (Atkinson, 1980), and apple trees on dwarfing rootstocks have particularly low-density root systems (Neilsen *et al*., 1997a). Consequently, increased efficiency in nutrient supply requires timely, precise placement and high retention in the main rooting zone.

Plant availability of soil nutrients is determined by a number of factors including inherent fertility, soil chemistry and, in irrigated production systems, by water supply and movement. The behavior of nutrients in irrigated production systems is thus highly affected by their solubility and mobility. For highly mobile nutrients such as N, water management practices can be used to retard movement through the root zone (Neilsen *et al*., 1998; Neilsen and Neilsen, 2002). Similarly, fertigation and water management can improve the movement of less mobile nutrients such as K into the root zone (Neilsen *et al*., 2004a; Uriu *et al*., 1980) and even allow immobile nutrients such as P to be introduced into the root zone (Neilsen *et al*., 1999).

Fertigation in conjunction with drip irrigation elicits localised plant and soil responses. The placement of nutrients, as modified by water management techniques, may determine root system development, as roots tend to grow in nutrient-rich environments (Jackson *et al*., 1990). For example, drip irrigation systems concentrated root development in the wetted zone (Bravdo and Proebsting, 1993; Neilsen *et al*., 2000). The combination of localised nutrient availability and trees with dwarfing rootstocks can result in restricted root systems, which are highly dependent on external nutrient sources (Levin *et al*., 1979) and thus are susceptible to nutrient and water deficits. Under drip irrigation, the localised application of fertigated NH_4 based fertilizers reduced soil pH (Haynes and Swift, 1986). Fertigation with ammoniacal N and P fertilizers decreased pH (Parchomchuk *et al*., 1993) and increased cation leaching (Neilsen *et al*., 1995a) within 3 years of planting in high-density apple orchards. The present paper summarises a series of experiments undertaken in British Columbia, Canada and Washington state, USA which examined the role of fertigation in the sustainable production of deciduous tree fruits.

Nitrogen

The high mobility of N in the soil causes the management of water and N to be inextricably linked. Efficient use of either thus requires both conservative methods of delivery which improve retention in the root zone and also knowledge of the timing and magnitude of N and water demand. The combination of high density production and low pressure, micro-irrigation systems allows controlled inputs of both water and nutrients, potentially to meet demand more precisely than in systems which are rain-fed or use high pressure irrigation. Soil solution nitrate-N concentration rapidly decreased under a single application of N fertilizer with sprinkler irrigation and was likely leached beneath the root zone (Fig. 1a). In contrast, nitrate-N concentration could be maintained at a constant level during fertigation (Fig. 1b) Neilsen *et al.*, 1998).

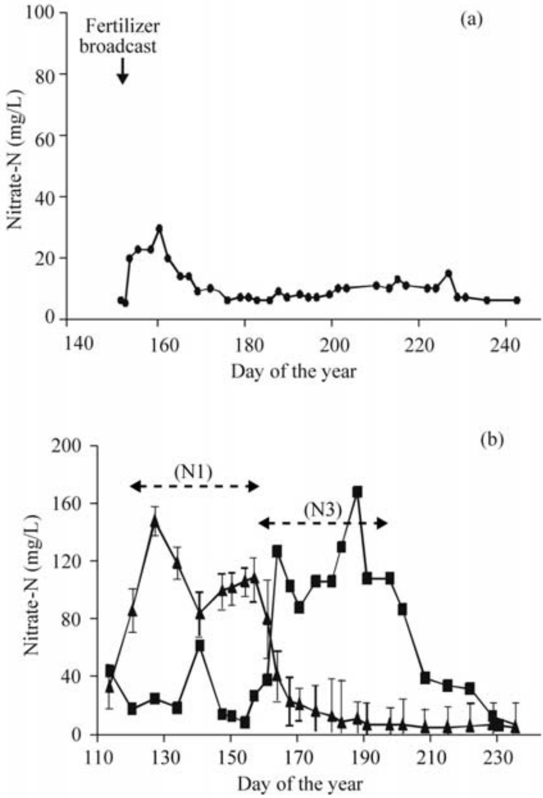

Fig. 1. Soil solution nitrate-N concentration measured throughout the growing season at 30 cm depth in (a) plot receiving a single application of broadcast N fertilizer and weekly sprinkler irrigation and (b) plot receiving daily N fertigation and drip irrigation at different times N1 (▲) and N3 (■).

Water demand is driven by a combination of factors including climate, canopy development and sink requirements for carbon. A range of methods, based on either estimates of evaporative demand imposed by climate (Allen *et al.*, 1998) or soil moisture depletion have been used to determine irrigation water requirements. In the experiments described herein, unless otherwise stated, irrigation was automatically applied each day, based on evaporation, as measured by an electronic atmometer (ETGage Co., Loveland, Co), and modified according to a crop-coefficient curve, based on canopy development. Weekly soil moisture measurements via Time Domain Reflectrometry (TDR) (Topp and Davis, 1985) were used to verify application rates. The amount of water saved by scheduling irrigation to meet demand can be quite large. In an extreme case, where water was applied throughout the season at a constant rate, sufficient to meet peak demand, applications per tree were twice (1,304 L/yr) the amount applied under scheduled irrigation (646 L/yr) (Neilsen and Neilsen, 2002). Losses of water (Fig. 2a) and N (Fig. 2b) beneath the root zone, as measured with a passive, capillary-wick sampling system (Neilsen and Neilsen, 2002) were significantly lower for scheduled than for constant-rate irrigation in the spring and fall, i.e. when evaporative demand was lower than the mid-summer maximum.

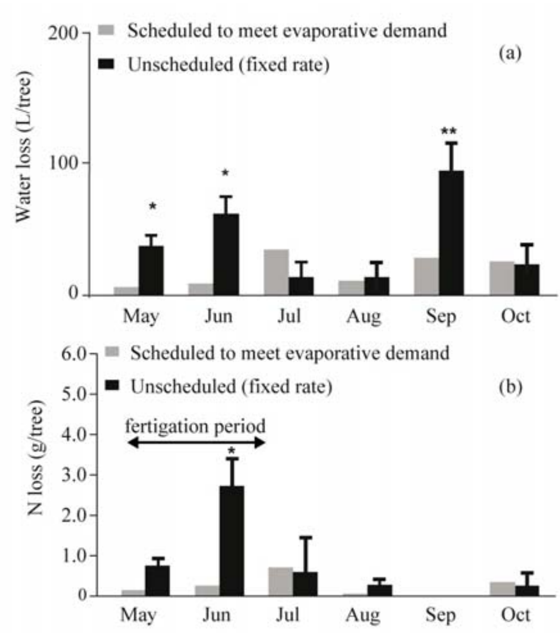

Fig. 2. Water drainage (a) and N flux (b) beneath the root zone in response to drip irrigation applied at either maximum rate or scheduled to meet evaporative demand using an atmometer either maximum rate or scheduled to meet evaporative demand using an atmometer.

In sandy soils, it is also possible to over-apply water when drip irrigation is scheduled to meet evaporative demand. The amount of water applied per tree through micro-sprinklers (20 L/hr) was 31% greater than that applied through drippers (8 L/hr) in a young Braeburn/M.26 planting in British Columbia. Losses of water and N beneath the root zone, as measured in passive capillary-wick samplers, were 12 and 7% of total additions for drippers and micro-sprinklers, respectively (Fig. 3a and 3b). Losses from drip irrigation were higher than for micro-sprinkler during mid-summer, probably because volumes of water, supplied on a twice daily basis to meet evaporative demand measured with an atmometer, exceeded the moisture-holding capacity of the loamy sand soil. An examination of the spatial distribution of water losses indicated that the majority was lost directly beneath the drip emitter.

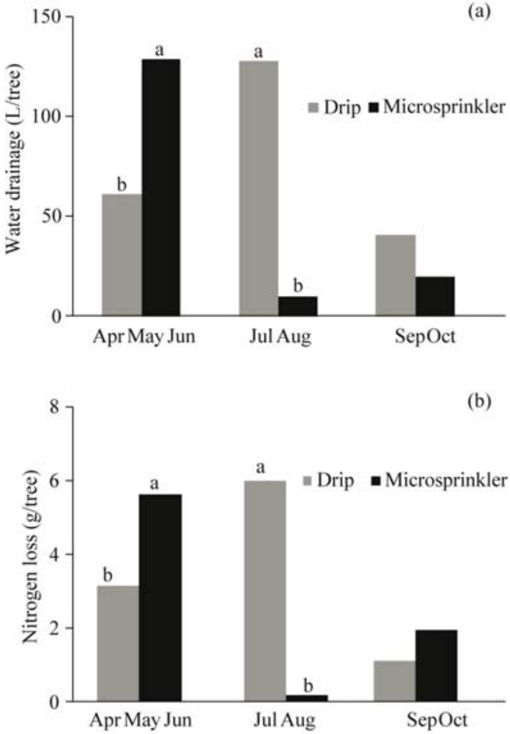

Fig. 3. Water drainage (a) and N flux (b) beneath the root zone in response to drip or micro sprinkler irrigation.

It has been well established that woody perennials withdraw N from foliage in the fall and that N is remobilised from storage in the spring, to support new growth (Millard, 1996; Tagliavini *et al*., 1997, 1998). For apple trees, remobilisation is the major source of N for development of the spur leaf canopy (Neilsen *et al*., 1997a, 2001), whereas the shoot leaf canopy derives N from both remobilisation and uptake, and large-scale root uptake commences around bloom (Guak *et al*., 2003). Thus, application of fertilizer N should be timed to match maximum demand, which occurs during shoot leaf canopy development, that is, during the 6 weeks after bloom.

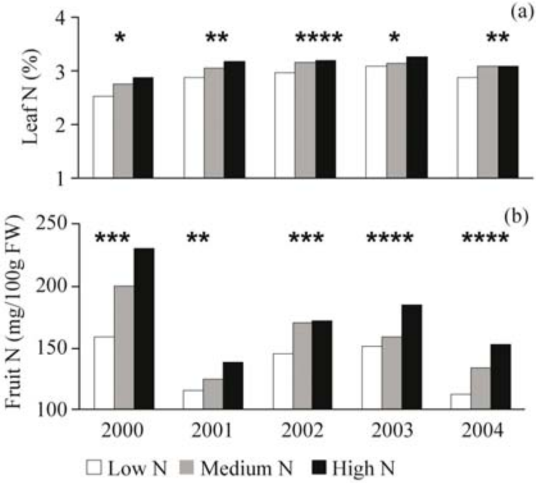

Fig. 4. Leaf (a) and fruit (b) N concentration over five years in Lapins/Gisela 5 sweet cherry trees in response to three levels of fertigated N (low) 42 mg/L (medium) 84 mg/L (high) 168 mg/L.

Nitrogen requirements for sweet cherry are less well understood, and most soils cannot supply sufficient N for sweet cherry orchards. Recommended leaf N concentrations range from 2.4-3.4% and high input levels of N (50-150 kg/ha) may be recommended, particularly on coarse-textured soils (Hanson and Proebsting, 1996). In a recent 5-year study, fertigated N applied at 42, 84 or 168 ppm for 8 weeks after bloom was compared with broadcast N (75 kg/ha) in a planting of Lapins/Gisela 5 sweet cherry (Neilsen *et al*., 2004a). Although leaf and fruit N concentration increased linearly with fertigated N rate (Fig. 4), fruit yield was either unaffected or negatively related to N application rate (Fig. 5) as also was fruit size (data not shown). On average, the low-N fertigation treatment supplied N at about 63 kg/ha, indicating that a lower rate of N, applied daily for eight weeks post-bloom was apparently more effective than a single, broadcast application.

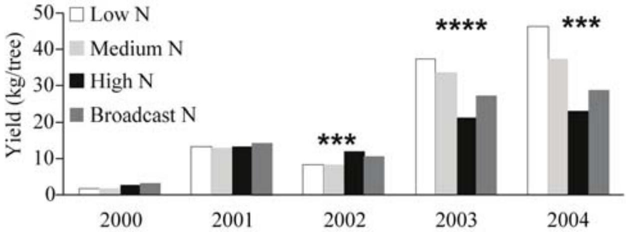

Fig. 5. Yield over five years in Lapins/Gisela 5 sweet cherry trees in response to three levels of fertigated N – (low) 42 mg/L (medium) 84 mg/L, and (high) 168 mg/L – and broadcast N (75 kg/ha).

Potassium

Fertigation with acidifying fertilizers can lead to the depletion of K and other soluble bases to a depth of 30 cm beneath the drip emitter after only 3 years of application (Parchomchuk *et al*., 1993). The susceptibility to K deficiency under drip irrigation has been attributed to the high proportion of roots that are located in the zone of soil K depletion. To improve orchard nutrition, potassium can be effectively applied via fertigation. Daily K fertigation from mid-June to mid-August at a per-tree rate of 15 g/yr maintained a higher K concentration in the soil solution (Fig. 6), and, in response, leaf K concentrations were maintained above deficiency levels, fruit K and Mg concentrations increased, and fruit yield, size, titratable acidity and red color at harvest all increased in the apple cultivars “Gala”, “Fuji”, “Fiesta” and “Spartan” (Neilsen *et al*., 2004b). The form of K fertilizer appeared to have little effect on tree response, as demonstrated in a 3-year experiment with “Jonagold” on M.9 rootstock in which K in various forms was fertigated daily over a 6-week period from late June to mid-August (Table 1). There were no major differences in leaf and fruit K concentration among the K-form treatments, nor was there any effect of the K treatments on bitter-pit incidence, which was generally high.

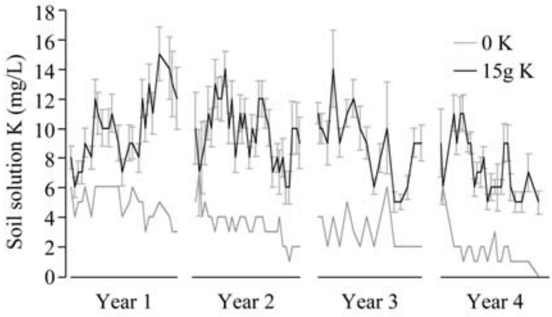

Fig. 6. Soil solution K concentration at 30 cm beneath drip emitters in response to K applications of 0 and 15 g/yr per tree.

Table 1. Effect of K-fertilizer form on K-nutrition and bitter-pit expression for >Jonagold= on M.9 rootstock grown on sandy loam soil, 2000-2002.

Fertigation treatment[y]	Mid-July leaf K concentration			Harvest fruit K concentration			Harvest bitter-pit incidence		
	2000	2001	2002	2000	2001	2002	2000	2001	2002
	-------- *% DW* ---------			*mg K/100 g FW*			---------- % ----------		
Control (no K)	1.38c	1.58c	1.46c	106	105b	101b	8	15	17
KCI (15 g K/tree)	1.60b	1.81b	1.73b	110	124a	115a	2	13	18
KCI (30 g K/tree)	1.67ab	1.96b	1.83ab	112	124a	123a	5	5	18
KMag (15 g K/tree)	1.66ab	1.89ab	1.74b	112	124a	116a	8	10	27
KMag (30 g K/tree)	1.72a	1.98a	1.85ab	119	129a	123a	7	8	20
K_2SO_4 (30 g K/tree)	1.66ab	2.00a	1.91a	116	118a	123a	2	5	10
K thiosulfate (30 g K/tree)	1.76a	2.01a	1.94a	112	124a	122a	8	4	13
	****	****	****	NS	*	****	NS	NS	NS

Phosphorus

Fertigation is known to increase P mobility in sandy soils (O'Neil *et al*.,1979). The improved mobility has been attributed to the movement of P by mass flow with irrigation waters after saturation of sorption sites near the point of application. Therefore, fertigation has the potential for improving the amount of P available at root surfaces, particularly in coarse-textured soils, which have low P sorption capacity. Application of 17.5 g of P per tree in an orchard, as a single dose of ammonium polyphosphate, immediately resulted in elevated extractable P at 30 cm depth (the major rooting depth for this soil) directly beneath the drip emitter (Neilsen *et al*., 1997b). One benefit of improved P nutrition for 1-year-old apple trees have was increased flowering in the second year (Neilsen *et al*., 1990). Fertigation of the same amount of P via 8 weekly applications immediately after planting rather than as a single annual application at planting time was more effective at increasing leaf P and tree vigour in first year for "Mcintosh" and "Jonagold" apple on M.26 rootstock (Neilsen *et al*.,1993). Fertigation with 20 g of P per tree as ammonium polyphosphate, in a single annual application, in conjunction with adequate fertigated N in the 4 weeks immediately post bloom improved fruit yield and quality in a multi-variety apple trial: cumulative yield in years 2 through 6 was higher in the NP- than in the N-treatment for all five apple cultivars ("Ambrosia", "Cameo", "Fuji", "Gala", and "Silken") grown on M.9 rootstock (Table 2). The P-treated fruit also frequently displayed greater membrane stability and resistance to browning when cut (data not shown).

Table 2. Effect of fertigation treatment on yield of five apple cultivars (>Ambrosia=, >Cameo=,>Fuji=,>Gala= and >Silken=) on M.9 rootstock on Skaha sandy loam soil.

Fertigation treatment	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Cumulative
	---------------------------- *Yield (kg/tree)* ----------------------------					
1. N (168 mg N/L, 0-4 weeks post full bloom)	1.9	7.7	10.4	13.5	5.7	39.8
2. N (as above) + P pulsed (20 g P/tree as 10-34-0 1 week post full bloom)	2.0	10.3	13.2	15.3	7.7	47.8
Significane	NS	****	*	NS	**	*

Effects of fertigation on soil properties

Fertigating ammoniacal forms of N and P can affect the base status of soils, because transformation of ammonium to nitrate is an acidifying process that may also accelerate leaching. Fertigation with various combinations of N and P as soluble ammonium nitrate and ammonium polyphosphate decreased extractable soil K in the topmost 30 cm of a sandy loam directly beneath the drip emitter, and redistributed K to the edges of the wetted zone (Parchomchuk *et al.*,1993).

The widespread nature of this problem was indicated in a survey of 20 commercial orchards which had undergone 3 to 5 years of NP-fertigation (Neilsen *et al.*,1995a). Soil pH, extractable soil bases and soil B, as measured in the 0-15 cm layer directly beneath the drip emitter, were all reduced (Table 3). In light of this survey, a soil test was designed to determine the susceptibility of soils to acidification (Neilsen *et al.*, 1995b). The acidification resistance index (ARI) was developed from analysis of buffer curves for 50 soils of diverse composition; it was defined as the amount of acid required to reduce soil pH from initial status to pH 5.0. These values were then compared with common soil test analysis data and a relationship was defined between the acidification resistance index, the soil pH, and soil extractable bases. It was recommended that soils with a low acidification resistance index be fertigated with NO_3-based rather than NH_4–based fertilizers.

Table 3. Soil chemical changes at 30 cm depth directly beneath the emitter, in 20 orchards (3-5 years old) receiving drip irrigation and fertigation with NH_4–based fertilizers.

	^{z}pH	Ca	Mg	K	B
		--------------------	*ppm*	--------------------	
Between rows	7.0	1,235	144	211	0.97
Beneath emitter	6.2	911	114	88	0.19
Significance	***	**	**	**	****

^{z}pH (1:2 soil:water); Ca, Mg, K extracted in 0.25M acetic acid + 0.015M NH_4F (van Lierop and Gough, 1989); B (hot water extractable).
*,**,***,**** significantly different at $p<0.05$, 0.01, 0.001, 0.0001

Conclusions

Fertigation offers the potential to overcome the low fertility of soils by timely delivery of key nutrients to the main rooting zone in orchards. Efficient use of N, however, depends upon reducing excessive drainage of water and improving our understanding of the dynamics of tree N uptake. In irrigated systems this means development of conservative scheduling methods to avoid excessive water application. Understanding the important role of N-remobilization in the growth cycle of apple trees can lead to reduced application of N fertilizers when tree needs are met by internal N-cycling. In contrast, delivery of more immobile nutrients such as P and K directly to the roots is facilitated when these nutrients are supplied in solution. For example, a single annual pulse application of 20 g of P per tree around bloom time has improved apple yield and fruit quality. Application of K in the form of any readily soluble K-fertilizer can increase tree K uptake and so prevent the development of K-deficiency in drip-irrigated trees grown on coarse-textured soils.

However, fertigation has the potential to accelerate soil degradation. In particular, the use of ammoniacal fertilizers and excessive applications of water may cause a reduction in pH in unbuffered soils, and loss of bases and soluble nutrients such as N and B. This is most evident in the soil immediately beneath the emitters of drip irrigation systems.

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