Management of Water and Nitrogen in High Density Apple Orchards

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In irrigated production systems the supply of nitrogen and water is closely linked. Nitrate, the most commonly occurring form of nitrogen in the soil, is highly soluble and its mobility is controlled by the movement of water. Consequently irrigation management is key to the retention of nitrate in the root zone and hence to nitrate availability to the tree. Both nitrogen and water can be managed to support and control growth and to improve fruit quality. However, such outcomes require that supply meet demand with respect to the amount and timing of applications. In tree fruit production systems, careful management of water and nitrogen is additionally important because fruit trees are conspicuously inefficient in their use of nitrogen, 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 nitrogen 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 nitrogen and water 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).

The intensification of planting in apple orchards that has occurred in response to the use of dwarfing rootstocks has been accompanied by changes in irrigation systems and irrigation management. Conservative techniques such as micro-sprinkler and drip or trickle irrigation have become more common and allow for more precise targeting of water and nutrients than conventional sprinkler or furrow irrigation. This paper will review some of the work that has been carried out in the Pacific Northwest on management of nitrogen and water in high density apple production systems.

STRATEGIES FOR MANAGING WATER WELL

Several strategies can be employed to reduce the overapplication of water which leads to loss of both water and nitrogen beneath the tree root zone. These include the use of conservative irrigation systems to reduce total water inputs, the use of mulches to reduce water losses from the soil surface through evaporation and the use of irrigation scheduling techniques to match water supply to demand. A fourth option is the use of deficit irrigation techniques to manage the water supply at levels below soil water replacement which may have beneficial effects on excess vigor and fruit quality (Davies et al., 2000), but this will not be covered here as there has been little work done on apple trees in this region.

The most efficient use of fertilizer nitrogen . . . was found for application of a low concentration of nitrogen in the 4 weeks after bloom.

The effect of conservative irrigation systems on water use was measured for 1- and 2-year-old Braeburn/M.9 trees planted in southern Washington. There was considerably less water applied under drip than sprinkler irrigation without any detrimental effect in tree growth or fruiting (Table 1). In the same planting, however, there were some beneficial effects of applying mulches on tree growth (Table 2), although it is not certain whether these effects were due to improved water relations or to other potential benefits derived from mulching, such as increased soil biological activity. Direct measurements of the effects of mulch on tree

TABLE 1

Effects of irrigation method (sprinkler and drip) on water use, tree growth and fruiting for 1- and 2-year-old Braeburn/M.9 (2.6 m x 1.2 m spacing)[z].

Year	2000		2001	
Irrigation method	**Sprinkler[Y]**	**Drip[X]**	**Sprinkler**	**Drip**
Water use (mm)	978	34	899	555
Extension growth (cm)	168	165	295	236
Change TCA[W] (cm^2)	0.84	0.90	0.90	0.90
Yield/tree (kg)			2.45	2.04
Fruit size (g)			268	277

[Z]no significant differences were found in growth.
[Y]under-tree sprinklers delivering 107 liter/hr were spaced at 2.6 m x 12 m.
[X]drip emitters delivering 4 liter/hr were spaced at 2 per tree.
[W]Trunk cross-sectional area.

TABLE 2

Effects of mulch on tree growth and fruiting for 1- and 2-year-old Braeburn/M.9 (2.6 m x 1.2 m spacing).

Year	2000		2001	
Irrigation method	**No mulch**	**Mulch[Z]**	**No mulch**	**Mulch**
Extension growth (cm)	155b[Y]	259a	226A	373A
Change TCA[X] (cm^2)	0.90b	1.42b	0.90B	1.17A
Yield/tree (kg)			2.0	2.2
Fruit size (g)			272	285

[Z]Alfalfa hay mulch applied at 51 t/ha on tree row.
[Y]Within rows and years means followed by the same letter are not significantly different by Duncan's Multiple Range test.
[X]Trunk cross-sectional area.

water use have been made in a drainage lysimeter facility located in Summerland, B.C. Mulch reduced total water use, presumably through a decrease in evaporation from the soil surface (Fig. 1). The effect was more pronounced for smaller trees probably because larger trees provide some shading and reduced heating at the soil surface, resulting in a lower evaporation rate.

Further refinement of watering practices can be achieved by the use of irrigation scheduling. Direct measurement of crop water demand is difficult and can be carried out only in lysimeter facilities where a water balance can be calculated. Consequently, irrigation scheduling requires some estimate of crop water use in order to match the supply of water to crop demand. There are many methods of estimating crop water use. These can be divided into three categories: those that measure plant water status, those that measure soil moisture status and those that measure evaporative demand. In this paper we will discuss the use of an automated system which is based on estimates of evaporative demand using a commercially available electronic atmometer (ETgage Co., Loveland, Colorado) (Parchomchuk et al., 1996). Evaporation is measured on a daily basis and the information is transferred electronically via a datalogger (Campbell Scientific, Logan, Utah) to an irrigation controller (Fig. 2). This system can be used to switch on irrigation systems to either replace soil water on a fixed time interval (e.g., daily) or after a target accumulation of water use has been reached (e.g., number of mm evaporation). The relationship between measured evaporation and crop water use has to be determined before this system can be effective.

The ratio of crop water use to measured evaporation is the crop coefficient (K_c). Some values for tree fruits are available in the literature (Stewart and Nielsen, 1990) but few are available for dwarf apple trees. Crop coefficients for Gala/M.9 have been developed at the PARC Summerland lysimeter facility and vary with canopy size (Fig. 3). The example given here is for a mature tree which would have higher crop coefficients than a newly planted tree. The crop coefficient also increases over the growing season until the canopy is fully developed.

Overapplication of water in plots receiving a constant irrigation rate throughout the growing season is demonstrated in Figure 4. Water losses were greater beneath the root zone of trees receiving a fixed irrigation rate than for those receiving irrigation scheduled to meet evaporative demand as described above. There were no differences in tree growth between these sets of trees.

STRATEGIES FOR MANAGING NITROGEN

In order to match the supply of nitrogen to tree requirements it is necessary to know the size and time of the demand. Responsible management also requires that nitrogen be applied so that leaching beneath the root zone either from precipitation or irrigation is minimized. Retention of nitrogen in the root zone so that it can be intercepted by the tree is difficult to achieve if nitrogen is broadcast on the soil surface and followed by heavy rain or irrigation. This problem is exacerbated if applications are made during periods of low tree demand and uptake. A comparison of retention of applied nitrogen in the root zone under two management practices is shown in Figure 5. Soil solution concentrations of nitrate nitrogen quickly declined when the fertilizer was broadcast and sprinkler irrigation was used. Nitrate nitrogen concentration in the soil solution remained higher when fertigated weekly in combination with daily drip irrigation. An almost constant concentration in the root zone can be maintained when nitrogen is supplied daily through fertigation (data not shown) and consequently nitrogen supply can be managed with precision (Neilsen et al., 1998). All the data described below are derived from experiments in which nitrogen was supplied by daily fertigation through a drip irrigation system.

FIGURE 1

Effect of mulch on water use of Gala/M.9 as measured in a drainage lysimeter at Summerland, British Columbia.

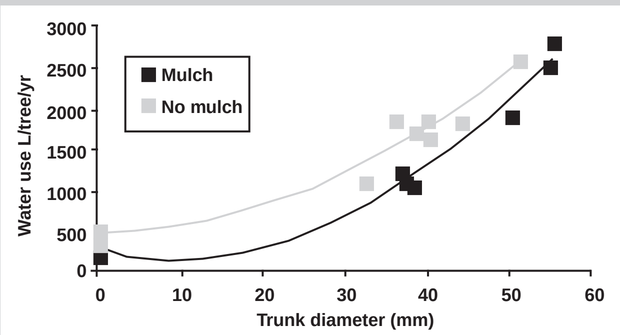


FIGURE 2

Schematic of irrigation system controlled by an atmometer which estimates evaporative demand.

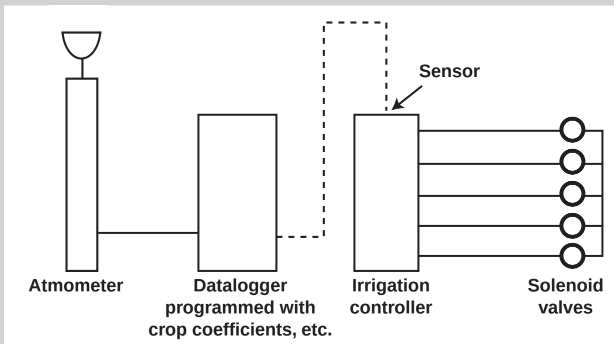


FIGURE 3

Seasonal crop coefficients for mature Gala/O.3 developed using a drainage lysimeter (PARC, Summerland, B.C.).

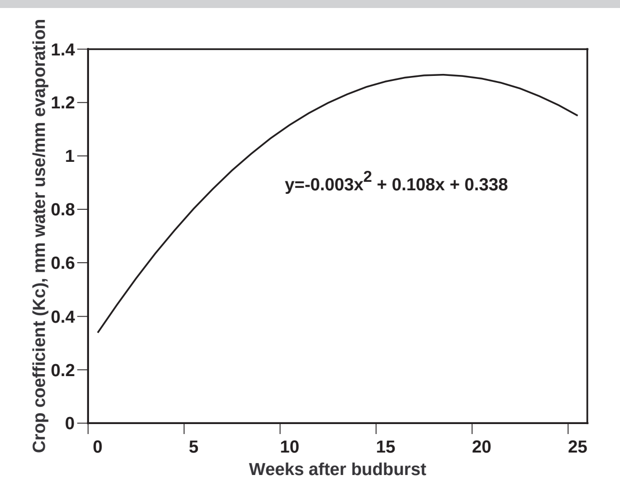
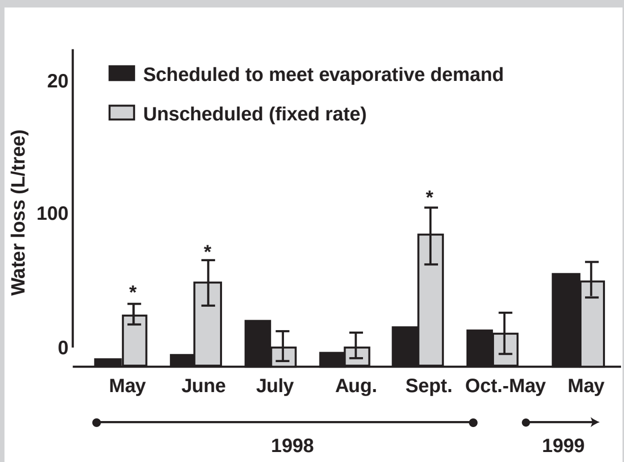


FIGURE 4

Losses of water beneath the root zone of 2-year-old Gala/M.9 in response to irrigation scheduling (data previously published in Neilsen and Neilsen, 2002).



Size of N Demand

We have used a variety of measurements to determine the nitrogen demand of dwarf apple trees including total tree excavation and partitioning, the use of labeled nitrogen fertilizer and assessment of annual removal in leaves and fruit. In these experiments the total nitrogen content of apple trees on M.9 rootstock ranged from 2.2 g/tree at planting to around 20 g/tree in the fourth year. At tree densities around 3300 trees/ha, the tree nitrogen content ranges from 7.3 to 65 kg/ha, respectively. Experiments with 15N labeled nitrogen fertilizer have shown that around 50% of the nitrogen taken up by fertilizer was partitioned to the perennial tissues and about 50% to the annual tissues. In 4-year-old Elstar/M.9, leaves and fruit contained half of the tree's total nitrogen (Fig. 6). As a consequence, we have measured the nitrogen content of fruit and senescent leaves to provide an estimate of the amount of N to be replaced annually. These values ranged from 8.9 kg/ha to 41 kg/ha of nitrogen for trees grown on M.9 rootstock that were newly planted to 6 years old,

FIGURE 5

Soil solution nitrate concentration over time, in response to either a single broadcast application + weekly sprinkler irrigation or fertigation every 5 days + daily drip irrigation (data previously published in Neilsen et al., 1998).

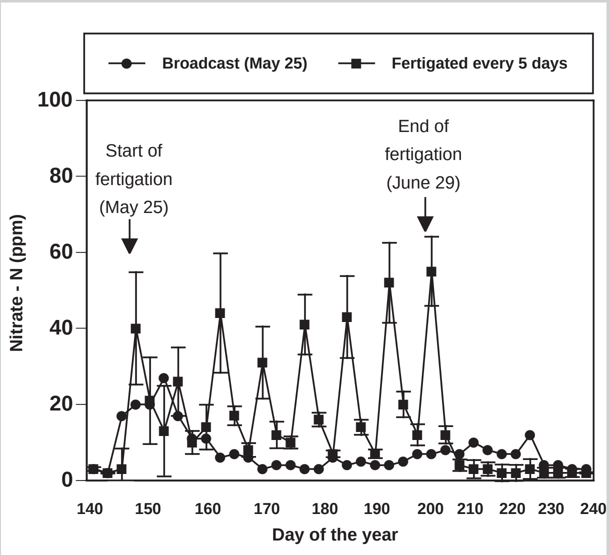


FIGURE 6

Nitrogen content of different tissues in 4-year-old Elstar/M.9 apple trees. Total tree N content = 19.7 g.

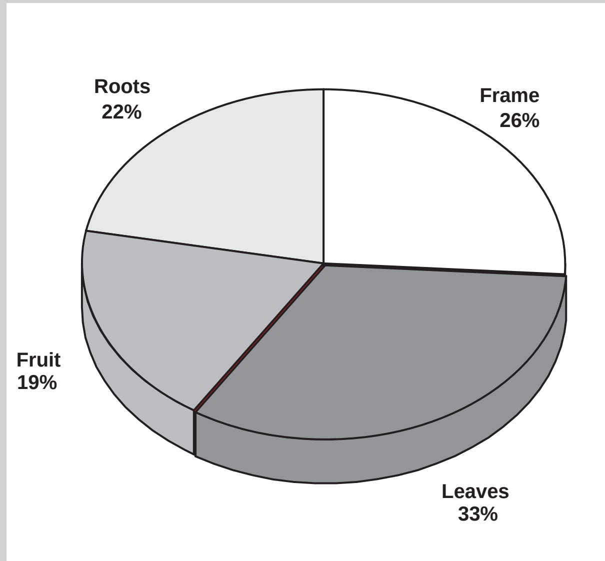


FIGURE 7

Timing of (a) nitrogen remobilization in spur leaves and (b) fertilizer uptake of N into shoots in 2-year-old Fuji/M.9 apple trees.

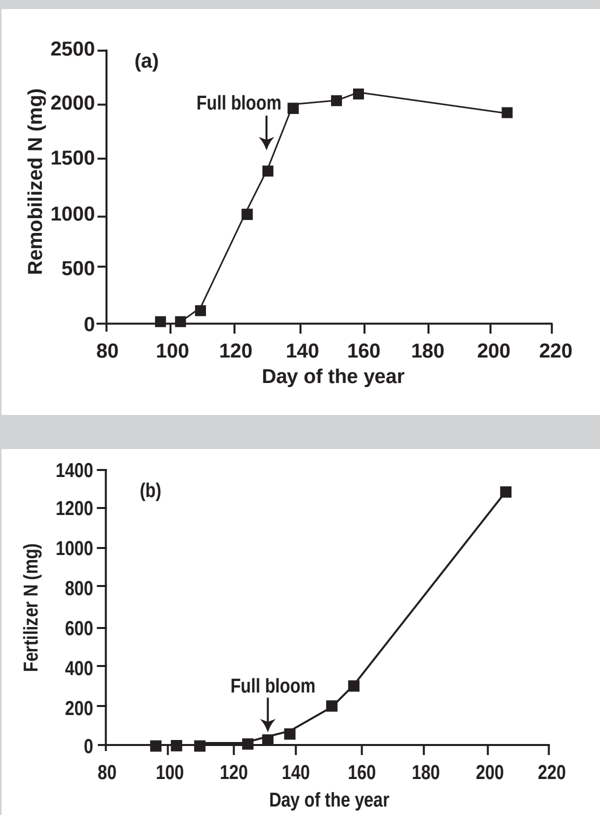
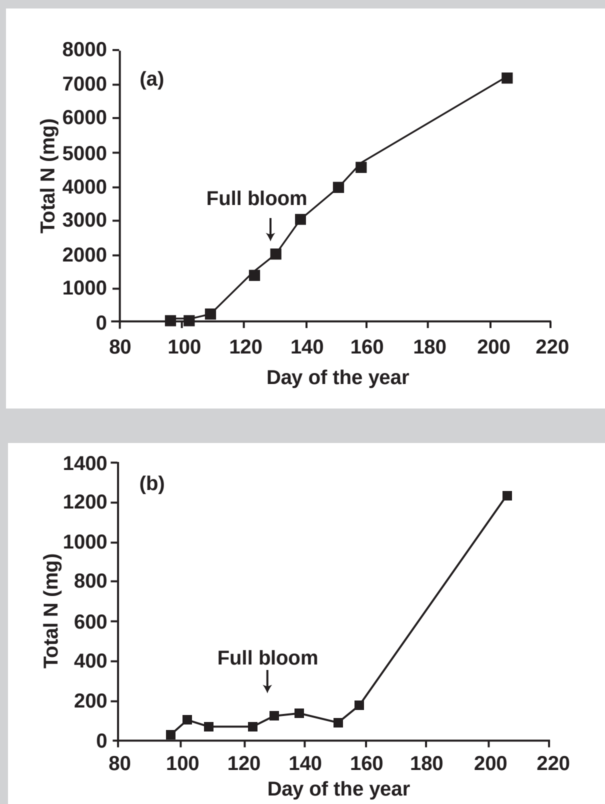


FIGURE 8

Pattern of total nitrogen inflow into (a) vegetative tissue (spur and shoot) and (b) reproductive tissue (fruit + blossoms) in 2-year-old Fuji/M.9.



respectively. Recommended rates of fertilizer often range from 40 to 100 kg N/ha.

Timing of N Demand

Unlike annual crops, the growth of woody perennials such as apple trees is affected by nitrogen stored in the tree from previous year's root uptake or foliar applications and by nitrogen taken up or supplied in the current season. During leaf senescence, nitrogen 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. In considering the timing of nitrogen inputs it is thus important to determine when remobilization and root uptake occur.

We have examined the source of nitrogen for growth in trees between 1 and 4 years old. In general, as demonstrated for 2-year-old Fuji/M.9 in Figure 7a, nitrogen remobilization from storage is largely complete by the end of full bloom (petal fall). In contrast, the onset of nitrogen uptake from the roots, in this case from 15N labeled fertilizer, occurs after full bloom and coincides with the start of rapid shoot growth (Fig. 7b). Thus the supply of root available N should be applied to coincide with this demand. The pattern of nitrogen partitioning also differs over time. In the same 2-year-old Fuji/M.9 trees, total N inflow from both remobilization and root uptake was much higher for vegetative tissues (shoots and spurs) (Fig. 8a) than for reproductive tissues (flowers and fruit) (Fig. 8b).

The onset of rapid inflow was also much earlier for vegetative than reproductive tissues, reflecting differences in the timing of development. The spur leaf canopy developed early and was the first strong sink for nitrogen (mainly from remobilization). This was followed by development of the shoot leaf canopy that derived nitrogen from both remobilization and root uptake. A high rate of inflow into the reproductive tissue did not occur until about 30 days after full bloom, likely at the onset of fruit cell expansion. This type of information can be used to determine when nitrogen should be applied to stimulate or avoid growth or uptake into various sinks.

Responses of various fruiting and fruit quality parameters to the timing of nitrogen supply are shown in Figure 9. In this experiment, nitrogen was fertigated daily as calcium nitrate in an atmometer scheduled drip irrigation system. Fertigation was carried out so that two concentrations (50 or 200 ppm) were maintained in the irrigation water. As a consequence, the amount of nitrogen added was dependent on the amount of irrigation. There were few effects of nitrogen rate on fruiting and fruit quality. Effects of timing of nitrogen supply were more consistent for fruit compositional characteristics such as soluble solids (SS), acidity and starch content than for bloom and yield components (Fig. 9). In general, fruit maturity (more soluble solids, less starch) was greater for trees receiving a later nitrogen supply (8 to 12 weeks after bloom) than for trees receiving an earlier supply (0 to 4 weeks after bloom). However, fruit acidity also increased with later nitrogen applications with a possible decrease in the sugar/acid ratio of the fruit.

Efficiency of Nitrogen Fertilizer Use

The efficient use of nitrogen by the root systems of dwarf apple trees is dependent on matching supply to demand and managing irrigation to retain nitrogen in the root zone. Nitrogen fertilizer use efficiency was measured for two of the experiments described above by comparing the amount of nitrogen removed in senescent leaves and fruit with the amount of nitrogen added in fertilizer. In 4-year-old Gala/M.9, the removal of nitrogen was greater for trees receiving the high rate of fertilizer at all timings (Table 3). There was no significant effect of the timing of nitrogen applications on the amount of nitrogen removed in fruit and senescent leaves. However, lower amounts of nitrogen were applied earlier than later in the season because nitrogen application was dependent on the amount of irrigation water applied.

TABLE 3

Efficiency of nitrogen use in response to rate and timing of application for 4-year-old Gala/M.9 apple trees (data previously published in Neilsen and Neilsen, 2002).

	N additions(kg/ha)		N removal (kg/ha)		Efficiency[Y]	
Time ofapplication[Z]	N1[X]	N2	N1	N2	N1	N2
T1	24	54	27b[W]	37a	116%	70%
T2	21	102	35b	40a	61%	39%
T3	37	151	33b	38a	88%	25%

[z] T1 = 0 to 4, T2 = 4 to 8 and T3= 8 to 12 weeks after full bloom.
[y] Efficiency = (N removal in leaves and fruit/N additions) x 100%.
[x] N1= 50 ppm and N2 = 200 ppm nitrogen in the fertigating solution.
wWithin rows and parameters, means followed by different letters are significantly different at P<0.05% using Duncan's Multiple Range test.

TABLE 4

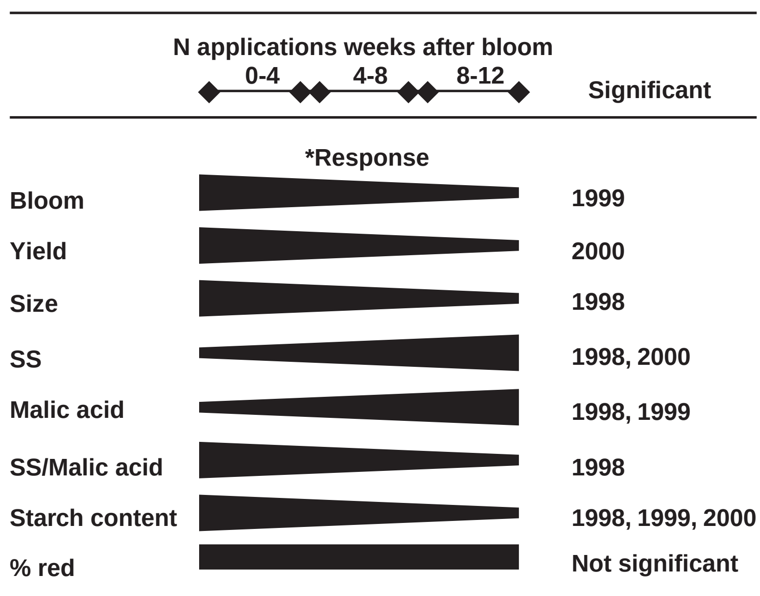
Efficiency of nitrogen use in response to irrigation scheduling for 2-year-old Gala/M.9 apple trees (data previously published in Neilsen and Neilsen, 2002).

Irrigation[Z]	Water added (L/tree)	Nitrogen added (g/tree)	Nitrogen removed (g/tree)	Efficiency[Y]
Scheduled	647	15.9	6.0	38%
Fixed rate	1306	37.1	6.8	18%

[Z]Irrigation scheduled according to evaporative demand estimated from atmometer readings.
[Y]Efficiency = (N removal in leaves and fruit/N additions) x 100%.

FIGURE 9

Effect of nitrogen timing on fruiting and fruit quality for 2- to 4-year-old Gala/M.9 (1998-2000).



***Thickness of the bar represents relative size of response (not to scale). For example, the thickest part of the bar for bloom is at the left-hand side of the bar and indicates that there was a trend for more bloom in response to early timing of N application than to later timings.**

Consequently, the combination of low rate and early timing of N applications resulted in the most efficient nitrogen fertilizer use. Similar results were found in relation to irrigation scheduling. More efficient nitrogen fertilizer use was found for scheduled compared with unscheduled irrigation (Table 4). This was largely because nitrogen uptake was similar in both treatments but, because nitrogen was applied at a fixed concentration in the irrigation water, a larger amount was applied with the fixed rate irrigation treatment. During the period of fertigation, leaching of nitrogen beneath the root zone was also greater under the fixed rate irrigation than under scheduled irrigation (data not shown).

CONCLUSIONS

Substantial savings in irrigation water use without detrimental effects on crop production can be achieved by the use of micro-irrigation systems such as micro-sprinklers or drip when compared with high-pressure sprinkler systems. The use of mulches can also reduce water use by decreasing evaporation from the soil surface. Further control over irrigation water use can be gained by scheduling supply to meet evaporative demand.

Overuse of irrigation results in movement of water and nitrogen out of the tree root zone, leading to inefficiencies in fertilizer use that are exacerbated by the sparse root systems of apple trees. Whole tree excavation and removal of nitrogen in senescent leaves and fruit indicate that apple trees on M.9 rootstocks have a low requirement for nitrogen, around 10 to 40 kg/ha. Targeting of nitrogen supply to periods of high demand can improve nitrogen use efficiency and affect fruit quality. Early spring growth during flowering is supported mainly by nitrogen remobilized from over-winter storage in woody tissue.

The onset of substantial root uptake of nitrogen is associated with the rapid growth phase of shoot development. Nitrogen inflow into fruit is low until the end of cell division. In a 3-year study, application of fertigated nitrogen in the 4 weeks after bloom tended to increase flowering, yield and fruit size when compared with later applications although not consistently. Later applications (8 to 12 weeks after bloom) consistently affected fruit composition, accelerating the conversion of starch to sugars but also maintaining high acidity, thus affecting the sugar/acid balance of the fruit. The most efficient use of fertilizer nitrogen, measured as the ratio of nitrogen removal in fruit and senescent leaves to amount of applied fertilizer, was found for application of a low concentration of nitrogen in the 4 weeks after bloom.

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