Fertigation for Apple Trees in the Pacific Northwest

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Fertigation is the application of nutrients through irrigation lines, during watering. In general, it is more readily adapted for use in micro-irrigation systems such as micro-sprinkler, micro-jet and drip than to more extensive systems such as sprinkler or furrow. It has the advantage of allowing flexibility in the timing of nutrient additions, and under micro-irrigation, targeting the nutrients into the tree root zone with higher precision than possible with high-pressure irrigation or rain-fed watering. It is particularly well suited to high-density production systems. Injection of nutrients into the irrigation line can be either passive (Venturi-type) or through pumps, which can proportion the amount of nutrient added to the flow. This paper will emphasize nutrient management with fertigation, not the design of fertigation systems.

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Nutrient uptake by trees is determined by the availability of nutrients in the soil, interception of nutrients by the roots and by tree demand. Nutrient availability in the soil is related to native soil fertility. Soils with a coarse texture (sandy and gravelly) or with low organic matter content tend to be less fertile than soils that are fine textured (loamy, silty, clayey) or have high organic matter content. Delivery of nutrients to the tree is affected by nutrient mobility. Mobile nutrients such as nitrogen and boron are dissolved in soil solution and move easily to roots. Less mobile nutrients such as calcium, magnesium, sodium and potassium are somewhat soluble but are also easily detached from soil particles. In some soils, potassium also falls into the class of immobile nutrients, which includes, phosphorus and zinc. The immobile nutrients are fixed onto soil particles, have low soil solution concentrations and tend to move slowly to the root by diffusion. Apple trees also have sparse roots and so cannot easily intercept immobile nutrients. A final factor is retention in the root zone. For mobile nutrients, movement of nutrients out of the root zone with water prevents interception; for immobile nutrients the issue is retaining the nutrient in solution long enough for root interception and uptake to occur.

Mobile Nutrients

Nitrogen (N). Careful management of water and nitrogen is important because fruit trees are very inefficient in their use of nitrogen. A comparison of retention of applied nitrogen in the root zone is shown in Figure 1 and shows how fertigation might help N fertilizer use efficiency. Soil solution concentrations of nitrate nitrogen quickly declined when the fertilizer was broadcast and sprinkler irrigation was used (Figure 1a). In contrast, an almost constant concentration in the root zone was maintained when nitrogen was supplied daily through fertigation at different times (Figure 1b) allowing nitrogen supply to be managed with more precision than when broadcast.

In irrigated production systems the supply of nitrogen and water are closely linked. As nitrate is highly mobile, irrigation

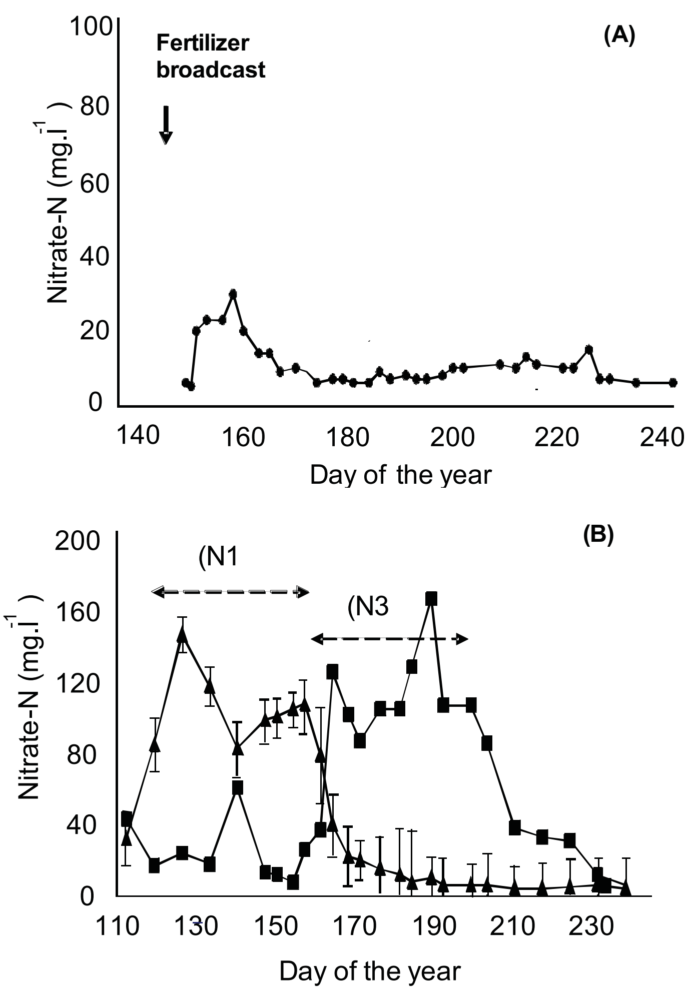

Figure 1. Soil solution nitrate-N concentration measured throughout the growing season at 30cm depth in (A) plot receiving a single application of broadcast N fertilizer and weekly high impact sprinkler irrigation and (B) plot receiving daily N fertigation and drip irrigation at different times N1(triangle) and N3 (square).

management is key to the retention of nitrate in the root zone and hence to nitrate availability to the tree. Several strategies can be employed to reduce the over application of water which leads to losses of both water and nitrogen beneath the tree root zone. These include the use of conservative micro-irrigation systems to reduce total water inputs (Figure 1), the use of irrigation scheduling techniques to match water supply to demand and mulching to reduce water losses from the soil surface through evaporation. The effect of scheduling irrigation to meet crop water demand and thereby reducing nitrate losses beneath the root zone illustrates the relationship between water and nitrogen management (Figure 2). In this example an automated system, which is based on estimates of evaporative demand using a commercially available electronic atmometer (Etgage Co., Loveland Colorado) was used to control irrigation. Water (Figure 2a) and nitrate-nitrogen (Figure 2b) 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 the sets of trees receiving the two types of irrigation.

Efficient use of nitrogen requires an estimate of the size and timing of tree N demand. We have used a variety of measurements to determine the nitrogen demand of dwarf apple tree including total tree excavation and partitioning, the use of labeled nitrogen fertilizer and assessment of annual removal in leaves and fruit. During the first few years after planting, these values ranged from 8 lb/acre to 38 lb/acre of nitrogen for trees grown on M.9 rootstock that were newly planted to six year-olds respectively. Recommended rates of fertilizer are often higher ranging from 40 to 100 lb N/acre.

It has been well documented for apple and other fruit trees that N is withdrawn from foliage prior to leaf fall, stored in woody tissues and roots and that in spring N is remobilised from storage to support new growth. For apple trees, development of the spur leaf canopy is largely dependent on remobilised N. Both remobilisation and current season uptake supply N for shoot leaf canopy growth and high root uptake commences around bloom. Fruit N requirements are met mainly by remobilisation during cell division, but mainly by root uptake during cell expansion. Thus application of fertilizer N can be timed to match maximum demand for shoot leaf canopy development, that is, during the six weeks after bloom, without necessarily having a potential negative impact on fruit quality by elevating fruit N concentration.

Less Mobile Nutrients

Potassium (K). The mobility of K in soil is generally reduced compared to N but greater than P. The mobility of surface-applied K is highest in sandy soils, reduced for soils with high exchange capacity (higher clay and organic matter content) and very limited for soils known to fix K. Potassium deficiency can be increased in drip-irrigated orchards on sandy soils where root distribution can be restricted by poor lateral spread of applied water. Deficiency symptoms appear first in spur leaves adjacent to fruit. These leaves develop an irregular chlorotic leaf surface during midsummer which progresses into interveinal browning and marginal leaf scorch by fruit harvest.

However, soil K status at the main rooting depth can be easily altered. Daily fertigation of K from mid-June to mid-August at a rate of 15 g (0.83 oz) /tree/year increased the concentration of K in the soil solution (Figure 3). These application rates were

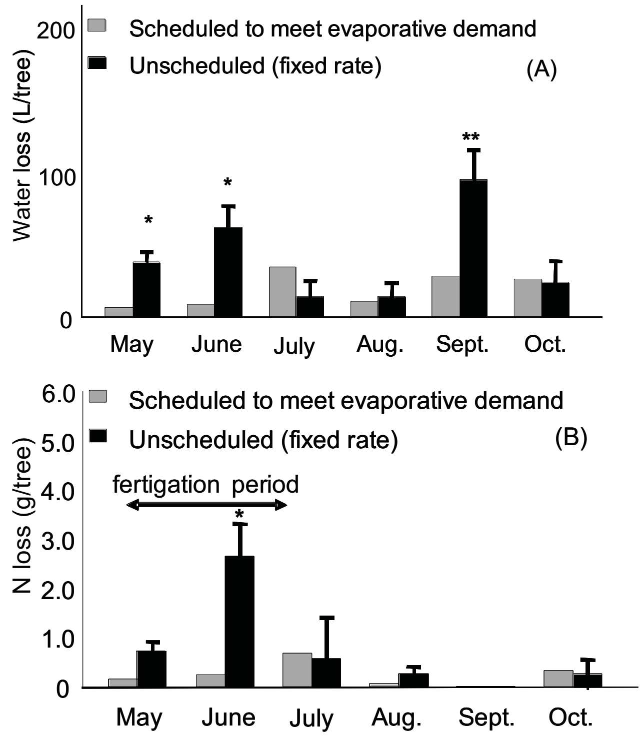

Figure 2. Water drainage (A) and N flux (B) beneath the root zone in response to drip irrigation applied at either maximum rate or scheduled to meet evaporative demand using an atmometer either maximum rate or scheduled to meet evaporative demand using an atmometer.

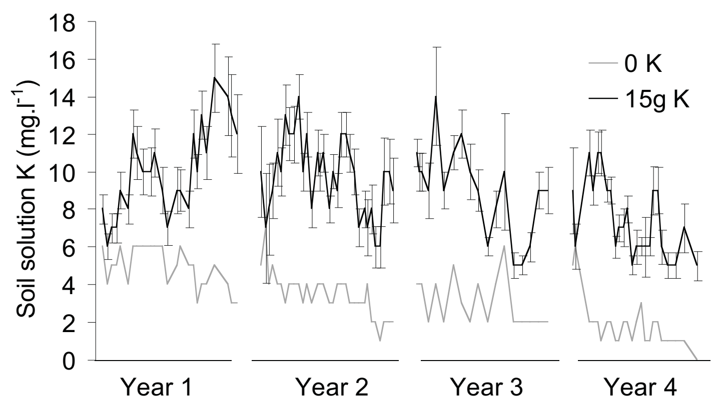

Figure 3. Soil solution K concentration at 30cm beneath drip emitters in response to K applications of 0 and 15 g.year-1 per tree.

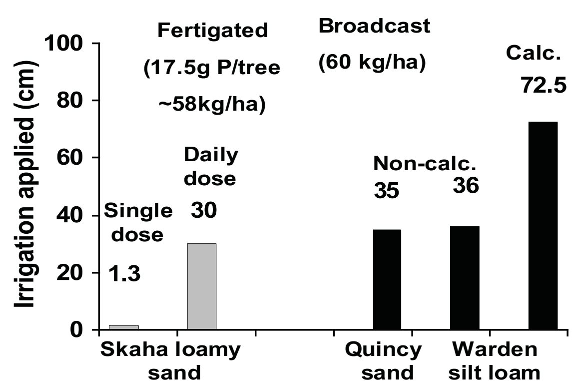

Figure 4. Fertilizer phosphorus mobility in the soil in response to irrigation. Amount of water required to move the same amount of fertilizer 6 inches into the root zone.

sufficient to prevent the development of deficient leaf K concentrations during the first five years for four apple cultivars on M.9 rootstock.

There appears to be little effect of the form of K fertilizer on tree response as demonstrated in a three year experiment with 'Jonagold' on M.9 rootstock in which K in different forms was fertigated daily over a six week period from late June to mid-August (Table 1). There were no major differences in leaf K concentration among K forms which was generally above leaf deficiency levels (1.3%) regardless of treatment.

Immobile Nutrients

Phosphorus (P). Poor downward movement of surface applied P-fertilizer into the root zone of many orchard soils has long been recognized. The mobility of P through soil can be further reduced in finer-textured and other soils with a high P-sorption capacity.

This is illustrated from field studies in Washington State and British Columbia which measured changes in soil P values with depth after surface fertilizer application (Figure 4). To move P-fertilizers distances as short as six inches requires the application of large quantities of water, particularly for calcareous fine textured soils such as the Warden silt loam (Figure 4). Around 30 times the amount of water was required to move P using daily fertigation or a broadcast application compared with a single fertigated dose. The single fertigated application temporarily saturates the P fixing sites in the soil allowing more downward movement of P. Similar responses occur with high rates of mono-ammonium phosphate-fertilizer mixed in the planting hole, especially on fumigated, replanted orchard sites or in orchards with low available P.

Few responses to broadcast fertilizer P have been reported. However, fertigation of P in first year results in the same beneficial effects associated with planting hole P applications, namely increased leaf P concentration and improved tree establishment and initial fruiting. A single annual pulse application of fertilizer P to five different apple cultivars (Gala, Fuji, Cameo, Ambrosia, Silken) planted on M.9 rootstock at high densities (3 foot by 10 foot spacing) improved cumulative yield performance of these cultivars during the first five growing seasons. The experiment tested a range of fertigation treatments including low (28 ppm N in irrigation water) and high (168 ppm) nitrogen applications, each applied for four weeks at three different times after bloom including early (first 4 weeks postbloom), mid season (four-eight weeks postbloom) and late applications (8-12 weeks postbloom). The treatment involving high early N plus a pulse of P (4.6 oz/tree of ammonium polyphosphate (10-34-0)) in the week immediately following bloom has produced the most fruit over all cultivars (Table 2).

Zinc (Zn). Zinc deficiency is a common problem in apple. Symptoms of Zn deficiency are most usually observed in the spring and include chorosis (yellowing) of the youngest shoot leaves that are often somewhat undersized and narrower than normal (referred to as little leaf). The deficiency may also result in blind bud and rosetting (small basal leaves which form on shortened terminals and lateral shoots of current year's growth).

Zinc occurs in the soil in relatively insoluble forms and is easily precipitated on solid surfaces of carbonates and iron and manganese oxides. As a result, it is considered relatively immobile in the soil and a large fraction of Zn applied to the soil is absorbed by soil particles unless extremely high application rates are made. There are some differences among soils with less adsorption on noncalcareous sandy soils, which have reduced capacity to fix Zn.

There have been limited studies investigating fertigation of Zn. Zn fertigation research has been undertaken in an experimental block of four different apple cultivars on M.9 rootstock at the Pacific Agri-Food Research Centre at Summerland, BC (Figure 5). If no Zn was applied (1992 and 1993) all trees, regardless of cultivar, had leaf Zn concentrations below the 14 ppm deficiency threshold. In 1994, application of dormant zinc sulphate and foliar Zn chelates, postbloom in early summer, resulted in very high leaf Zn concentrations across cultivars, probably through contamination from surface residues from the foliar Zn sprays. Commencing in 1995, efforts were made to fertigate Zn as zinc sulphate (36% Zn) dissolved in the irrigation water and applied for four weeks during the growing season. The application rate ranged from 0.34 oz liquid zinc sulphate (36% Zn) per tree (3.5 g Zn per tree) in 1995 and 1996 to double these rates in 1997 and to 1.7 oz liquid zinc sulphate per tree (17.5 g Zn per tree) in 1998. Regardless of the fertigated Zn application rate, leaf Zn concentration did not generally increase above deficiency thresholds for any

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

Fertigation treatment (Kg/tree) [y]	Mid-July leaf K concentration (% DW) 2000	2001	2002
Control (0g)	1.38c	1.58c	1.46c
KCl (15 g)	1.60b	1.81b	1.73b
KCl (30 g)	1.67ab	1.96b	1.83ab
KMag (15 g)	1.66ab	1.89ab	1.74b
KMag (30 g)	1.72a	1.98a	1.85ab
K2SO4 (30 g)	1.66ab	2.00a	1.91a
K thiosulfate (30 g)	1.76a	2.01a	1.94a
Significance	****	****	****

[y] 15g = 0.83 oz; 30g = 1.66 oz
*,**,***,**** significantly different at $p<0.05$, 0.01, 0.001, 0.0001
Within columns different values followed by different letters are significantly different

Table 2. Cumulative yield per tree of apples from 2nd - 5th leaf for selected treatments averaged over all cultivars (Silken, Cameo, Fuji, Gala and Ambrosia).

Fertigation Treatment	Cultivar	Cumulative yield (pounds/tree)
High early N + P pulse	All	86.5a
High N (all times)	All	73.5b

Within columns different values followed by different letters are significantly different

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 NH4–based fertilizers

	pH[z]	Ca (ppm)	Mg (ppm)	K (ppm)	B (ppm)
Between rows	7.0	1235	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 NH4F; B (hot water extractable).
*,**,***,**** significantly different at $p<0.05$, 0.01, 0.001, 0.0001

cultivar. Since the site was a sandy soil, these results imply that correction of inadequate Zn nutrition via fertigation of mineral zinc sulphate will be difficult. Fertigation of more expensive chelated Zn forms may be more effective but have not undergone extensive testing.

Effects Of Fertigation On Soil Properties

Fertigating ammoniacal forms of N and P can affect the base status of soils as transformation of ammonium to nitrate is an acidifying process, which may also accelerate leaching. The widespread nature of this problem was indicated in a survey of 20 commercial orchards on coarse-textured soils which had undergone three to five yrs. of NP-fertigation in British Columbia. Soil pH, extractable soil bases and soil B measured at 0 to 15 cm depth directly beneath the drip emitter, were all reduced (Table 3). In response to this survey, a soil test was designed to determine the susceptibility of soils to acidification An acidification resistance index (ARI) was developed from analysis of buffer curves for 50 soils of differing composition and was defined as the amount of acid required to reduce soil pH from initial status to pH 5.0. These values were then compared to common soil test analysis data and a relationship defined between the acidification resistance index, 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.

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