Fertigation of Apple Trees in Humid Climates

Terence Robinson[1] and Warren Stiles[2]

[1]Department of Horticultural Sciences, Geneva, NY
[2]Professor Emeritus, Dept. of Horticulture, Ithaca, NY

This work was funded in part by the NY Apple Research and Development Program.

Fertigation has several potential advantages over soil surface applications of fertilizers. These include: rapid application of precise amounts of essential plant nutrients directly to the root zone of the trees, application of nutrient at the exact time of year the tree needs them, and limiting nutrient leaching to ground water and nutrient run-off. An interesting additional benefit from fertigation is an increase in fruit size. With small fruited varieties like Empire and Gala this could greatly improve the economic benefit from fertigation.

Fertigation is the application of dissolved fertilizers through an irrigation system. Most commonly this is done through a drip or trickle irrigation system but it can also be done with under-tree micro-sprinklers or regular under-tree sprinklers. The macro nutrients, nitrogen, potassium, phosphorus and magnesium are the most common nutrients applied by fertigation, but micronutrients such as boron, zinc, iron, calcium manganese and copper can also be applied through the irrigation system.

The concept of applying fertilizers through the irrigation system was developed in arid climates like Israel and California where irrigation water is regularly applied. Increasingly in the more humid climate of the Northeastern US, growers who plant high-density orchards are adding trickle irrigation as an important component to ensure the success of the new planting. Thus, fertigation is increasingly being considered as a way to improve tree response.

Advantages of Fertigation

Fertigation has several potential advantages over soil surface applications of fertilizers. These include:

1. Rapidly applying precise amounts of essential plant nutrients directly to the root zone of the trees.
2. Applying nutrient at the exact time of the year when the tree needs them.
3. Limiting nutrient leaching to ground water and nutrient runoff.

Precise delivery of nutrients to the root zone. Fertigation uses the trickle irrigation water as a carrier for delivering small doses of dissolved fertilizer to the root zone frequently. The fertilizer generally remains in solution and travels with the water through macropores into the soil to the depth the water travels. If the amount of irrigation water is correctly calculated, the dissolved nutrients are delivered to the precise area of the soil where the tree roots are; the nutrients can then be directly absorbed by the roots from the soil solution or they can be adsorbed to the soil clay particles for later uptake by the plant. Since the nutrients are precisely and efficiently delivered to where the tree root zone is, this technique can substantially reduce the amount of fertilizer required to maintain plant nutritional status. Several investigators have estimated that fertilizer usage can be reduced by 50 percent if fertigation is properly done.

Delivery of nutrients at the proper time. Conventional ground applications of fertilizer at the beginning of the season results in high concentrations of fertilizer in the soil followed by lowered amounts as the season progresses. Fertigation allows delivery of what the plant needs nearly on a daily basis. It also allows different nutrients to be delivered to the root zone at different times of the season. As we learn more about which nutrients are involved at various times of the season in essential growth, flowering and fruit growth processes, fertigation programs can be tailored to give the desired plant response. It may be possible to stimulate rapid leaf area development and fruit growth in the spring with fertigation treatments high in nitrogen and then stimulate increased fruit color in the late summer and early fall by the application of other nutrients.

Reduced leaching and runoff of nutrients. With conventional ground applications of fertilizers, a significant portion of the applied fertilizer is lost when it is leached beyond the root zone. Leached nutrients contaminate the ground water or are lost in surface runoff where they contaminate surface water resources including streams, ponds and lakes. Fertigation, if done properly, can limit leaching and runoff of nutrients; however, the success of fertigation in reducing leaching and runoff depends on the precise application of the proper amount of water so that nutrients are not carried too deep in the soil profile. If too much irrigation water is applied it will carry the dissolved nutrients too deep in the soil profile where roots from dwarf apple trees cannot access it. Thus, the irrigation water amount and frequency of application are essential parts of fertigation strategies.

Irrigation in the Northeastern US

The need for irrigation. The root systems of dwarf apple trees and newly planted apple trees are small and do not occupy a large volume of soil. This often leads to water stress especially with newly planted trees. Much of the problem of poor tree growth of dwarf apple trees during the first few years can be traced to inadequate water supply. In an average growing season in the Northeast, rainfall is usually less than that required for optimal tree performance during critical periods of tree establishment and growth (Figure 1). Rainfall average from May-September is 5-6 inches less than evapotranspiration. In addition, in 3 years out of 10, severe water shortages occur during the months of June, July and/or August.

TABLE 1

Crop coefficient for apple that are used to calculate the amount of water needed by an apple orchard.

Month	K_C-pan with cover crop	K_C-pan without cover crop
May	0.68	0.48
June	0.92	0.68
July	1.00	0.80
August	1.00	0.80
September	0.96	0.76

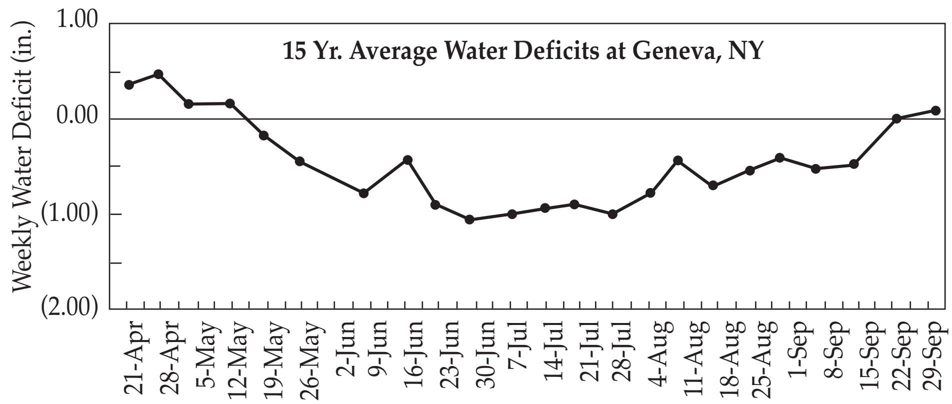

Figure 1. Average weekly water deficits at Geneva NY.

Often during these months the shortfall can be 1.5-2.0 inches per week. Our research over the last 10 years has shown that early tree performance can be significantly improved by the addition of trickle irrigation. In general, our experiments have shown that trickle irrigation increases shoot growth and trunk cross-sectional area especially in the early years. The effect of irrigation is greater in years 1-3 when trees are developing a root system. However, in years 4-6, there continues to be a significant improvement in tree growth with irrigation. Even after 7 or 8 years, irrigated trees were up to 36 percent larger than the unirrigated controls. Ground fertilization did not generally increase tree growth in the first three years when no irrigation water was applied. In two of our experiments, the addition of ground-applied fertilizers to the unirrigated plots significantly reduced shoot growth in the first and second year, (when compared with unfertilized plots). However, with the addition of trickle irrigation water, ground fertilizers significantly improved tree growth compared to either the irrigated trees without fertilization or the unirrigated controls.

Trickle irrigation also has had a significant effect on yield. In one experiment, trickle alone had no effect on yield in years 2-4. But since irrigation increased tree growth during the early years, yields in later years were greater than controls. In a second experiment, there was a consistent improvement in yield in all years from the addition of trickle irrigation. Cumulative yield of irrigated trees has been consistently greater than the un-irrigated trees in all experiments. The addition of ground applied fertilizers without trickle irrigation in experiment one increased yield in the second year, but, because tree growth was reduced, there was no yield advantage in later years from ground fertilizers. However, if water was applied in conjunction with the ground fertilizer, yield was improved considerably.

Average fruit size was in most cases improved by trickle irrigation plus ground fertilizer or fertigation. When averaged over the first six cropping years of our second study, trickle irrigation alone or fertigation increased fruit size by 7-8 percent. This increase in fruit size would have translated into a significant economic difference in packout.

Estimating tree water requirements. Generally, mature apple orchards require approximately 1.5 to 2.0 acre-inches of water per week during periods of peak water use. Young orchards that do not yet fill their allotted space use significantly less. The water supply available to the trees varies with the water holding capacity of soils, the level of weed control during the early season, the amount of mulch and the rooting volume with dwarf apple trees. Mulch can act as a substitute for irrigation. The water holding capacity of the soil varies from as short as four days on sands to 11 days on sandy loams to 15 days on loams and 19 days on silt and clay loams. To calculate how much irrigation water to apply we use one of three methods:

A. Modified Kenworthy Rule: Apply 1 gallon water/tree/day/year of tree age reaching a maximum on the year the tree canopy fills the space between trees. With low-density Central Leader trees, canopies may not fill the space until year 10 resulting in 10 gallons per tree per day at maturity but with high density orchards canopies usually have filled the space by year five resulting in a maximum of five gallons per tree per day.

B. Tensiometers: Apply irrigation when tensiometers read 20 centibars. We suggest placing the tensiometers in the soil at an appropriate distance (usually 18-24") from the emitter in the root zone of the tree (8" deep).

C. Evapotranspiration Models: Calculate the amount of water to apply based on the daily water used by the tree. We use the simple formula:

The Net Weekly Water Deficit = Inches of water evaporated per week from a Class A evaporator pan minus inches of rainfall per week. The SkyBit commercial weather forecasting company gives daily estimates of pan evaporation and rainfall. The Efficiency of an Irrigation System is commonly estimated at 0.60 to 0.70 for sprinkler irrigation and 0.90 for trickle irrigation. The Crop Coefficient $_{pan}$ values vary through the season depending on leaf area and canopy cover. Estimated values for apple orchard crop coefficients in Washington State are given in Table 1. Crop coefficient values with cover crops are where there is grass in the tractor alleys and irrigation water is applied to both the grass and the trees (flood or sprinkler). The values without cover crop are when irrigation water is applied only to the trees and the grass is not irrigated (trickle). In our work with trickle irrigation in New York we have used K_C-pan values of 0.80 in the heat of the summer because we do not irrigate the grass. For young orchards that do not yet fill the allotted space, reduce the crop coefficient proportionally to the percentage of ground covered compared to a mature tree. Never go below about 70 percent of the K_C-pan values listed above.

Fertigation Methods

Irrigation system requirements. The most important requirement of any irrigation system used for fertigation is that the system has good uniformity of distribution (i.e. ≤15 variation among emitters). If uniformity is low, some areas of the orchard will receive too much water and too much fertilizer while other areas will receive substantially less water and fertilizer. This can lead

$$\text{Amount of Irrigation Water (inches/acre/week)} = \frac{\text{Net Weekly Water Deficit (inches/week)} \times \text{Crop Coefficient}_{pan}\ (K_C\text{-pan})}{\text{Efficiency of irrigation system (fraction)}}$$

to significant variability in vigor and fruit quality in an orchard. Variability in topography can often cause pressure differences across an orchard. With trickle systems, pressure- compensating emitters allow uniform distribution on slopes and undulating terrain. Both in-line emitters and plug-in type emitters are currently being used, but the trend is toward the use of tubing with emitters built in at various spacings.

Various types of irrigation systems can be used to deliver water and nutrients to apple orchards in New York but nearly all fertigation systems use either trickle irrigation or microsprinklers.Traditional undertree sprinklers are designed to cover 100 percent of the land area on an acre with water. Microsprinklers are designed to cover 60-80 percent of the land area with water. These spread the dissolved fertilizer over too large an area making precise placement of the fertilizer over the tree root zone impossible. In contrast, trickle or drip-irrigation systems designed to cover only 25-40 percent of the land area with water are ideally suited for precise placement of dissolved fertilizers.

In New York State, one of the most serious limitations to a more widespread adoption of irrigation of orchards is the lack of adequate supplies of water for irrigation in many areas. Because trickle irrigation has an efficiency of >90 percent, and most sprinkler systems have efficiencies from 60-70 percent, most of the recent irrigation systems have been trickle systems. With this method growers can utilize limited water resources much more efficiently. One important limitation of trickle irrigation is that on coarse textured soils the lateral movement of water under a trickle emitter is limited and may require two trickle lines per row (one on each side of the tree).

Types of fertilizer injectors. Several types of fertilizer injectors are used, including bladder tanks, batch tanks, Venturi injectors and positive displacement pumps. With bladder tanks, irrigation-water pressure pushes fertilizer out of the bladder tank and into an irrigation line through a metering valve. The concentration of fertilizer remains the same from the beginning of the injection cycle until the tank is empty. A second system utilizes batch tanks in which the fertilizer to be injected is mixed in the tank and when the tank is closed, water flows through the tank and carries the dissolved fertilizer into the water stream. With this system the concentration of fertilizer is high at first then declines as the tank is diluted.

The Venturi injector systems utilize a venturi restriction in the water line to suck the fertilizer solution into the water stream and therefore they do not require electrical power. Venturi systems require a pressure drop across the injector to function. With Venturi systems the concentration of fertilizer in the water stream remains constant throughout the irrigation cycle. Lastly, positive displacement pumps accurately meter a constant amount of fertilizer into the irrigation water stream thus maintaining a constant concentration of fertilizer in the water stream throughout the irrigation cycle. They can operate with either electricity or water power. They are generally more accurate and easier to use than Venturi but are also more expensive. With positive displacement pumps and irrigation controllers the fertilizer injection process can be automated the relieving the grower of significant management time often associated with fertigation. With all fertilizer injection systems a back-flow prevention valve is essential to avoid contamination of the water source.

Fertilizers applied through fertigation. The most common nutrients applied through an irrigation system include nitrogen, potassium, phosphorus and magnesium but other nutrients including boron, zinc, iron, calcium, manganese and copper can also be applied through the irrigation system.

Nitrogen. Ammonium nitrate or potassium nitrate are preferred sources but rrea is also an alternative. Calcium nitrate has also been used but it has resulted in incompatibility problems if any phosphate or sulfate is present in the solution. Various combinations of urea and ammonium nitrate such as URAN 28 or URAN 32 have been formulated as liquid fertilizers. Such liquid formulations are often the nitrogen fertilizers of choice by many growers because of the ease of use. Bulk loads can be delivered by fertilizer dealers to tanks at the orchard site allowing automation of the fertigation process.

Phosphorus. Although various forms of water soluble phosphates might be used, application of phosphates through drip systems is not considered to be necessary with orchards. Our research to date has shown no beneficial response of apple trees to phosphorus applied through the drip irrigation system. A note of caution is that phosphates are incompatible with magnesium and calcium compounds. It appears that the best approach with apples is to incorporate phosphate during preplant-site preparation if soil tests indicate a need.

Potassium. Muriate of potash (KCl), potassium nitrate (KNO_3) and potassium sulfate (K_2SO_4) are the most common sources of potash used in fertigation. The primary limitation with potassium is its limited solubility. Liquid forms of potassium generally have low concentrations of potash.

Calcium. Calcium nitrate is readily soluble and can be used for both a nitrogen fertilizer and a calcium fertilizer; however the Ca content is too low to allow sufficient calcium without getting excessive amounts of nitrogen. In addition, calcium nitrate is incompatible with other phosphate or sulfate fertilizers.

Magnesium. Epsom salts ($MgSO_4$) or liquid formulations of Magnesium sulfate are the preferred sources. Magnesium sulfate is incompatible with phosphates due to precipitates.

Boron. Since boron is required in very small amounts, the preferred source is Solubor which is readily soluble. An alternative is boric acid or borax.

Zinc. Chelated forms of zinc have been effective in increasing leaf Zn levels in our research trials but the rates required are not economical when compared to foliar applications. Zinc sulfate has been used in greenhouse systems and may be of value in orchards but at much higher rates than chelated forms of zinc.

Copper. Chelated forms of copper have been used successfully in increasing leaf Cu levels in our research trials.

Manganese. Manganese sulfate or chelated forms of manganese are both possible sources for fertigation. Foliar applications may be more economical under most conditions.

Iron. Chelated forms of Iron are the most effective in increasing leaf Fe levels.

Potential application problems. The primary problem encountered with fertigation is the incompatibility of chemicals resulting in precipitates that clog emitters of trickle systems. Calcium, magnesium, iron, zinc and copper materials should not be mixed with phosphates or sulfates because insoluble precipitates are formed. Whenever phosphates are used, an acid should be injected into the trickle distribution system for 30 to 60 minutes at the end of the fertigation cycle to dissolve precipitates. Hydrochloric acid (muriatic) is generally suggested for this purpose. In some cases well water has a high iron content. To avoid incompatibility problems, apply incompatible materials separately being sure to flush the lines thoroughly between injecting each set of materials. Also use separate mixing tanks and injector heads for materials that may be incompatible, and then apply the materials sequentially.

Water that has more than 0.1 ppm iron content can be a problem. To avoid problems with iron precipitates, the water can be aerated to oxidize the iron into an insoluble form that can settle out. This requires a settling basin for water before it enters the trickle system. Alternatively, the water can be treated with chlorine (1 ppm per 0.7 ppm iron) and then the precipitates can be removed at the filter. This will require frequent back flushing of the filter. In addition the system should be treated with acid (muriatic, sulfuric, phosphoric or nitric acid) as described above.

Solubility of materials. Solubility of dry fertilizer materials in water is affected by water temperature. Therefore, problems may be encountered when trying to mix these in cold water. Some means of heating the water is usually necessary when formulating liquid fertilizer solutions. The salt-out temperature, (the temperature at or below which materials will precipitate from the solution) is an important consideration. Information on the solubility of various fertilizer materials is presented in Table 2.

Application strategies. In arid climates where fertigation was developed, the best strategy has been to apply a constant concentration of fertilizer in all irrigation water. Each time irrigation water is applied, fertilizer is also injected into the water. Thus the soil solution that the plant roots are exposed to has a constant concentration of the elements that are applied. With light textured soils, nitrogen is maintained at 100 ppm in the irrigation water for young developing trees and 50 ppm in the water is used for mature trees. For potassium, very little (10 ppm), is applied to young developing trees while 50 ppm is used for mature trees. With heavier, more fertile soils that supply substantial amounts of nitrogen through mineralization, the concentrations in the irrigation water can be reduced to 30-50ppm. This strategy of applying a constant dose of fertilizer in all irrigation water works well when the amount of water applied per week, month or season is predictable; this allows the advance programming of the total amount of each nutrient that will be applied each week, month or season. It also works best in light-textured soils that have low inherent fertility and daily doses of fertilizer help to maintain a constant nutrient supply available to the plant.

In humid climates where the amount of irrigation water needed is variable and depends on the amount of rainfall in any

TABLE 2

Solubility of common fertilizers used in fertigation.

Fertilizer		Solubility (pounds/gallon of water)
Nitrogen Sources	Ammonium Nitrate	9.8 @ 32°F
	Ammonium Sulfate	5.9 @ 32
	Calcium Nitrate	10.2 @ 64°F
	Magnesium Nitrate	3.5 @ 64°F
	Potassium Nitrate	1.1 @ 32°F
	Sodium Nitrate	6.1 @ 32°F
	Urea	5.9 @ 32°F
Potassium Sources	Potassium Chloride	2.9 @ 68°F
	Potassium Nitrate	1.1 @ 32°F
	Potassium Sulfate	1.0 @ 77°F
Phosphorus Sources	Phosphoric Acid	43.2 (liquid)
	Mono Potassium phosphate	2.75 @ 77°F
	Di-ammonium phosphate (DAP)	3.5 @ 32°F
	Mono ammonium phosphate (MAP)	1.9 @ 32°F
Calcium Sources	Calcium Nitrate	10.2 @ 64°F
Magnesium Sources	Epsom Salts (Magnesium Sulfate)	5.9 @ 32°F
	Magnesium Nitrate	3.5 @ 64°F
Boron Sources	Solubor	1.0 @ 32°F
	Boric Acid	0.5 @ 86°F
	Borax	3.8grams @ 32°F
Manganese Sources	Manganese Sulfate	8.7 @ 32°F
	Manganese Chelates	———
Iron Sources	Iron Chelates	———
	Ferrous Sulfate	1.3
Zinc Sources	Zinc Sulfate	8.0
	Zinc sulfate monohydrate	———
	Zinc Chelates	———
Copper Sources	Copper Sulfate	2.6 @ 32°F
	Copper Chelates	——

TABLE 3

Effect of irrigation and fertigation on tree growth and yield of 'Oregon Spur Delicious' /M.7 apple trees over the first 7 years.

Irrigation Treatment	Fertilizer nutrients and application method	Shoot Growth (m) Years 1-3	Shoot Growth (m) Years 4-6	Yield/ tree (kg) Years 2-4	Yield/ tree (kg) Years 5-7	Average Fruit Size (g) Years 2-7
		(% of Control)				
Unirrigated Control	Ground applied NKB	100 c[z]	100 b	100 b	100 b	100 a
Trickle Irrigation	Ground applied NKB	137 b	131 a	98 b	115 ab	101 a
Fertigation	Water applied NKB	171 a	140 a	124 a	127 a	104 a

[z] Means within years followed by the same letter are not significantly different (P=0.05 n=4).

TABLE 4

Effect of irrigation and fertigation on tree growth and yield of 'Redchief Delicious'/M.7, 'Mutsu'/M.9/MM.106 and 'Empire'/M.9/MM.106 apple trees over the first 6 years.

Irrigation Treatment	Fertilizer nutrients and application method	Shoot Growth (m) Years 1-3	Shoot Growth (m) Years 4-5	Yield/ tree (kg) Years 2-4	Yield/ tree (kg) Years 5-6	Average Fruit Size (g) Years 2-6
		(% of Control)				
Unirrigated Control	Ground applied NKB	100 b[z]	100 b	100 b	100 b	100 b
Trickle Irrigation	Ground applied NKB	160 a	139 a	145 a	160 a	107 a
Fertigation	Water applied NKB	153 a	134 a	140 a	135 a	108 a

[z] Means within years followed by the same letter are not significantly different (P=0.05 n=4).

TABLE 5

Effect of irrigation, fertilization, and fertigation on tree growth and yield of 'Empire' apple trees on M.9 and M.7 rootstock over the first 3 years.

Fertilization	Irrigation	TCA increase '92-'93	Total Shoot Length '92-'93	Yield 1994	Yield Eff. 1994	Fruit Size 1994
		(% of Control)				
Preplant Lime only (Control)	None	100	100	100	100	100
	Trickle	114	117	114	105	106
Preplant Lime + NPKB	None	105	103	108	103	106
	Trickle	116	115	117	107	105
Annual NKB	None	106	108	120	115	111
	Trickle	128	135	138	117	112
Annual NKB+FoliarMg,Cu,Zn	None	105	94	114	111	110
	Trickle	117	112	116	105	113
Fertigation	Trickle	115	129	116	107	110
LSD (0.05)		8[z]	16	18	16	5

[z] Least significant difference between means in a column (P=0.05 n=4).

given week, month or year, it becomes impossible to predict in advance the annual amount of fertilizer which will be applied. In wet years when little or no irrigation may be needed, very low rates of fertilizer will be applied; while in very dry years significant amounts of water may be needed and thus significant amounts of fertilizer. More commonly in humid climates such as New York, the total amount of fertilizer to be applied per year is divided by the number of weeks over which the nutrient is to be applied to obtain a weekly dose of each nutrient. The weekly dose is applied in one irrigation cycle on one day of the week. If additional water is needed later in the week it is applied without dissolved fertilizers.

In New York, many soils naturally produce 40-60 lbs. of nitrogen per year through mineralization. With young non-bearing apple trees we suggest an additional 40-60 lbs. of nitrogen per season. Utilizing the weekly application strategy for the first 10 weeks of the season will require 4-6 lbs. N per acre per week. With mature trees we suggest from 20-40 lbs. of nitrogen per season which would be 2-4 lbs. N per acre per week. With potassium we recommend annual rates of 60 lbs. K20 per acre on young trees. When spread over 15 weeks this would be 4 lbs. K20 per acre per week. Mature trees with heavy crops require substantially more potassium. We recommend 80-90 lbs. K20 per season; that would be 5.3-6 lbs. K20 per acre per week. The amount of nitrogen and potassium fertilizers listed above should only be used as guidelines. The actual amount applied to mature trees should be adjusted up or down depending on the levels of each nutrient measured in leaf samples.

Where leaf boron levels are low, small amounts of boron can be applied very effectively through fertigation. This element is efficiently taken up by this method. Our results indicate that 1.5 to 2 pounds of actual boron per acre per year appears to be an adequate maintenance amount. This would translate into 0.15 to 0.2 pounds of Boron per acre per week. Other elements such as magnesium, zinc and copper can be applied via fertigation but current methods cost more than foliar applications of these elements. We continue to recommend foliar sprays of those elements.

Results of Fertigation Research in New York

Results with young trees. Weekly fertigation over the first 10 weeks of the season had a positive effect on tree growth. Ammonium nitrate was the source of nitrogen, muriate of potash was the source of potassium, Epsom salt was the source of magnesium and Solubor was the source of boron. In most years, the fertigated trees had the greatest growth, but often there was little difference between the fertigated trees and the water plus ground fertilizer trees (Tables 3 5). It appears that it is important to have both water and fertilizers to obtain optimum tree growth but the method of fertilizer delivery was not consistently important. After six or seven years the fertigated trees were the largest being 53 percent and 30 percent larger than the unirrigated controls in experiments one and two respectively.

Fertigation also increased yield in both the early and later years. Cumulative yield over six or seven years was increased 25-28 percent by fertigation compared to the un-irrigated controls (Tables 3 and 4). In the early years, fertigation resulted in slightly improved yield compared to the ground-applied fertilizers plus irrigation treatment. However, cumulative yield from fertigation in all three experiments was not statistically greater than the irrigation plus ground fertilizer treatment. In experiment one the fertigation treatment had the greatest yield while in experiments two and three the irrigation plus ground fertilizer treatment had the greatest yield. This indicates that trickle irrigation aids in the utilization of applied fertilizers whether the fertilizers are soil applied or dissolved in the irrigation water (Tables 3-5).

Average fruit size was improved by fertigation. When averaged over the six cropping years of the second study, fertigation increased fruit size by 6-18 percent (Table 4). There was little benefit from supplemental irrigation on fruit size unless it was accompanied by fertigation or ground applied fertilizer.

Results with older trees. In a grower owned plot, sixteen weekly applications of potassium providing a total of 120 lbs. of potash (K20) per acre resulted in a significant fruit size increase. In a Geneva plot, the addition of potassium fertilizer in the trickle system reduced tree growth, and increased yield, fruit size and red color of mature Empire trees (Table 6). The source of potassium (KCl vs. KNO3) did not affect tree growth, yield, fruit size or fruit color. The method of application of the potassium fertilizer did not affect its response. The ground-applied method gave similar results as the fertigation method. The timing of potassium application affected tree growth and fruit size but not yield or red color (Table 7). If potassium was applied through fertigation in the last eight weeks of the season, it produced more tree growth than applications in the first eight weeks of the season. Fruit size was greatest if potassium was applied during the first eight weeks of the season.

Distribution of nutrients in the soil. In our trials, fertigation moved nitrogen deep in the soil to depths between 16 and 32 inches and in a narrow cylindrical pattern with a horizontal diameter of 32 inches. When nitrogen was applied to the soil surface as a dry fertilizer it was concentrated mostly in the top 16 inches of soil. Potassium was found only in the top 8 inches when it was spread on the soil surface but with fertigation, potassium was moved deeper in the soil to depths between 16 and 24 inches and with a horizontal diameter of 24 inches. Copper and zinc chelates were moved in the soil similarly to potassium.

An important deleterious effect of fertigation was found by measuring soil pH under the fertigation emitters. We found that fertigation with ammonium nitrate significantly reduced soil pH under the emitters in a pattern similar to the nitrogen distribution in the soil. After eight years the soil pH beneath the emitters was between 4 and 5. This indicates that liming materials should be banded in the herbicide treated strip along each tree row rather than broadcast over the entire orchard floor.

Conclusions

Taken together, the results of our studies indicate trickle irrigation in the Eastern US can improve tree performance in the first few years after planting. The addition of ground-applied fertilizer or fertigation will improve tree growth even more, and will result in larger trees with greater bearing capacity. The magnitude of the improvement in yields over the first six or seven years appears to justify the investment in trickle irrigation for humid climates such as the Northeastern US, especially in dwarf apple orchards where significant yields are expected in the 2nd-5th years. However, the economic benefit of fertigation versus ground applied fertilizer with trickle irrigation is less clear but still may be justified to improve fruit quality and reduce leaching and runoff of nutrients. An interesting additional benefit from fertigation is the increase in fruit size. With small-fruited varieties like Empire and Gala, this could greatly improve the economic benefit from fertigation.

The improvement in tree performance from trickle irrigation or fertigation can be expected to vary with soil type. With light textured soils, which are more droughty than heavier textured soils, a greater difference between un-irrigated trees and fertigated trees would be expected. Under heavier soil conditions additional irrigation may not be beneficial and may in fact result in excess water and poorer tree performance in wet years. The benefit of trickle irrigation may also depend on the amount and frequency of natural rainfall in any given year. Nevertheless, with high-density orchards the improvement in early tree performance will help ensure the financial benefits of planting high tree densities.

When considering the use of irrigation or fertigation in the Northeastern US, the following points can be gleaned from our experiences:

1) To maximize tree growth, trickle irrigation should be installed as soon after planting as possible. This is especially true with large caliper trees which have large tops relative to their root systems.
2) Trickle irrigation can significantly enhance the uptake and benefit of ground-applied fertilizers. We have shown that without supplemental irrigation there is no benefit derived from soil-applied fertilizers in the first few years if proper preplant land preparation is done. However with trickle irrigation, ground fertilization increased yield and tree growth.
3) Trickle irrigation and fertigation have their largest impact on tree growth and yield in years one-four so should be installed in the first year. If the trickle system is not installed in the first year the loss of potential tree growth will necessarily limit early yields.
4) The application of water for irrigation alone should begin about June 1 in a normal year. In very dry years like 1995, irrigation should begin in mid-May. If the application of water is delayed until drought symptoms develop later in the year much of the potential benefit of trickle irrigation will be lost. In very wet years irrigation should be delayed until late June.
5) When fertigation is used, water and fertilizer applications should begin on May 1. In wet years apply only enough water to get the fertilizer on, while in drier years apply enough water to replace that lost by the trees.
6) In New York, we suggest that nitrogen, and potassium can be applied effectively through the trickle system. Magnesium and boron can be effectively applied through the trickle system or foliarly while zinc and calcium are best applied foliarly. Nitrogen should be applied during the first half of the season while potassium can be applied over the whole season or just in the last half of the season. In either case, the total amount of nitrogen or potassium for the year should be divided into equal amounts each week for the period of time that the nutrient is being applied.
7) Irrigation frequency with trickle should be twice per week during the cooler periods of the growing season and daily during the warmer periods.

TABLE 6

Effect of irrigation and fertigation with Potassium fertilizers on tree growth and yield of mature 'Empire' apple trees on M.9.

Treatment	TCA increase '94-'97	Average Yield '94-'98	Average Fruit Size (g)	Fancy Grade '94-'98
Irrigation and Ground Applied NK	**4.32 z**	**776**	**164**	**65**
Fertigation NK	5.44 NS	785 NS	161 NS	63 NS
Nitrogen Only	5.67	746	159	61
Nitrogen and Potassium Fertilizers	4.63*	798*	166*	65*
KCl	4.59	777	164	65
KNO3	5.03 NS	769 NS	166 NS	63 NS

z Paired mean comparison by LSD (Means followed by * or NS are significantly different or Non Significant, P=0.05 n=4).

TABLE 7

Effect of timing of fertigation with Potassium fertilizers on tree growth and yield of mature 'Empire' apple trees on M.9.

Treatment	TCA increase '94-'97	Average Yield '94-'98	Average Fruit Size (g)	% Extra Fancy Grade '94-'98
Fertigation 16 weeks	**4.36 z**	**789**	**164**	**65**
Fertigation 8 weeks early	4.45	729	167	65
Fertigation 8 weeks late	5.72	743	161	64
Anova	*	**NS**	*	**NS**

z Mean comparison by LSD (Means followed by * or NS are significantly different or Non Significant, P=0.05 n=4).

With microsprinklers, irrigation frequency should be once per week during the cooler periods of the growing season and twice per week during the warmer periods.

8) Calculate how much irrigation water to apply by either the modified Kenworthy rule, tensiometers or evapotranspiration models.

Bibliography

Robinson, T. L. and W. C. Stiles. 1991. Fertigation of dwarf apple trees as a substitute for soil fumigation in replant orchard soils. Reports from the 1990 IPM research, development and implementation projects in fruit. *New York State IPM Program*. Geneva. IPM Publication No. 204:61-62.

Robinson, T. L., W. C. Stiles and A. N. Lakso. 1992. Fertigation effects on apple tree growth, cropping, and dry matter partitioning. *HortScience* 27:620 (Abstr.)

Robinson, T. L., and W. C. Stiles. 1993. Fertigation of young apple trees to improve growth and cropping. *Compact Fruit Tree* 26:61-65.

Robinson, T. L., and W.C. Stiles. 1994. Fertigation of young apple trees to improve growth and cropping. *Proc. N.E. Fruit Meetings* 100:68-76

Robinson, T.L. and W.C. Stiles. 1996. Effect of preplant fertilization, annual fertilization, irrigation and fertigation on 'Empire' apple fruit size and yield. *HortScience* 31:582. (Abstr.)

Robinson, T. L., and W. C. Stiles. 1993. Fertigation of young apple trees to improve growth and cropping. *Compact Fruit Tree* 26:61-65.

Robinson, T. L. and W.C. Stiles 1997. Trickle irrigation and fertigation of young apple trees. *Proc. New England Fruit Meetings* 103: 90-97.

Stiles, W. C. and T. L. Robinson. 1995. Fertilization of apple orchards through drip irrigation systems (fertigation). *New York Fruit Quarterly* 3(3):7-10.

Stiles, W.C. and T.L. Robinson. 1996. Fertigation of young apple orchards. *HortScience* 21:613. (Abstr.)

Terence Robinson is research and extension associate professor in the department of horticultural sciences who specializes in orchard production systems, and leads Cornell's tree fruit extension team. Warren Stiles is an emeritus professor of pomology who formerly led Cornell's fruit nutrition research and extension program. He is still widely recognized as a world authority on fruit mineral nutrition.