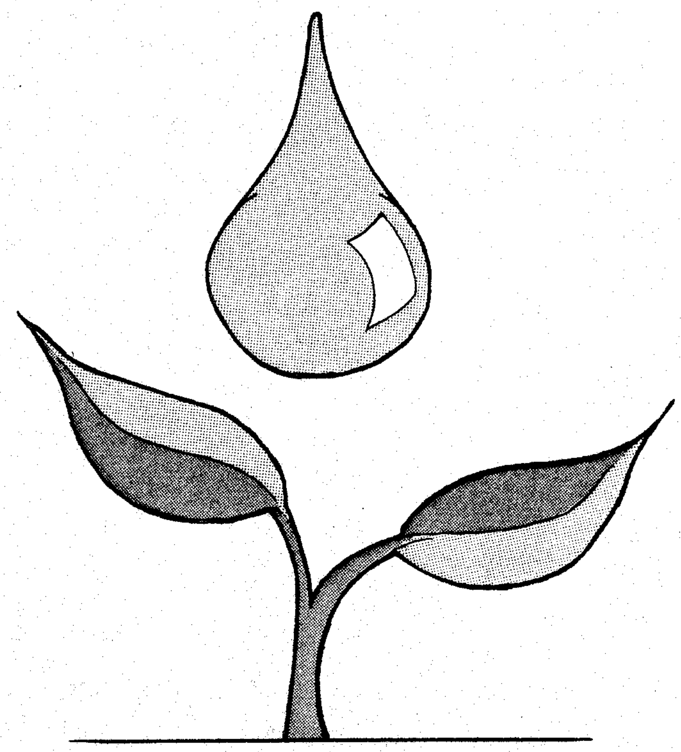
Applying Nutrients and Other Chemicals to Trickle-Irrigated Crops



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Applying Nutrients and other Chemicals to Trickle-Irrigated Crops

The increasing use of trickle irrigation makes it desirable to be able to apply fertilizer and other chemicals along with the irrigation water. Recognized advantage of applying fertilizers and chemicals through the trickle-irrigation system are improved efficiency, labor savings, energy savings, and flexibility of timing nutrient application to crop demand, regardless of growth stages or accessibility of the field to machinery.

Introduction

Plant nutrient or chemicals applied through a trickle-irrigated system must not clog or corrode the system. Thus, one must select fertilizer materials or chemicals which are entirely soluble in water, and which will not react with salts or chemicals contained in irrigation water. Except for anhydrous ammonia, aqua ammonia, and ammonium phosphate, most sources of nitrogen should cause little if any clogging. Application of phosphorus fertilizers through the trickle system can result in extensive clogging, although with certain precautions, phosphoric acid can be successfully applied through the system. The common potassium fertilizers are readily soluble in water and should cause few clogging problems. Micro-nutrients may be applied in the chelated form to reduce possibility of clogging.

Nitrogen moves readily in soil with irrigation water from trickle emitters. Using phosphorus and potassium in trickle-irrigation systems has caused much greater movement below emitters than is made possible by other application techniques. Placement of nutrients within the wetted soil volume and the active root zone by means of trickle-irrigation systems has increased fertilizer use efficiency. Finally, proper management of plant nutrients and chemicals applied by trickle irrigation can improve efficiency, save labor and energy, and provide greater flexibility in timing nutrient applications to crop demand.

Criteria and Methods for Applying Chemicals through Trickle-Irrigation Systems

The over-all objective for applying nutrients and chemicals by means of trickle-irrigation systems is to supply nutrient needs of plants or to control plant pests. Application must not result in clogging or corrosion of the system or of any of its components, and for the method to be efficient, the chemicals must finally be distributed uniformly throughout the field. Such uniformity of distribution is dependent upon efficiency of mixing, uniformity of water application, and the flow characteristics of water and chemicals in the distribution lines.

Fertilizer and chemicals can be injected into the irrigation system by two methods: the pressure differential or venturi system, or a metering pump. Both methods, including several variations of the pressure differential system, are described by Keller and Karmeli (1975) and Goldbert *et al.* (1976). Injecting fertilizers or chemical solutions by means of a pump is probably the more precise way of metering them into an irrigation system. However, with a pump a power supply must be near the injection point.

Distribution of fertilizer or chemicals to a field depends upon the flow characteristics of water in the system and the uniformity of water application by emitters or orifices. Most systems are designed so that the flow rate of water and chemicals in the system is high enough that the chemicals are distributed uniformly throughout the distribution lines. Bester *et al.* (1974) found that distribution of nutrients was fairly uniform if the nutrients were injected after the water-distribution system was full of water.

Variability of water discharge at each emitter may be quite large and is dependent upon the particular system. Davis and Pugh (1974) found that standard deviation varied between 1 and 16 percent of the mean discharge of various kinds of emitters operated at various pressures. Keller and Karmeli (1975) suggested that a trickle-irrigation system be designed with no more than a 5 percent discharge variation (94 percent uniformity of application). As the system clogs, discharge variation will increase and result in more variability in fertilizer or chemical application.

The effect of various chemicals on the system's life expectancy depends greatly on the particular characteristics of the chemicals applied — for example, chemicals of low or high pH may corrode metal parts of the irrigation system.

However, most irrigation systems are constructed entirely of plastic and applied chemicals will not corode their pipes or emitters. Precipitation of applied chemicals is a critical problem and must be controlled carefully to prevent complete clogging of the system. If in doubt about the mixing compatibility of chemicals, one should flush the lines thoroughly before applying a different chemical through the system. (Precipitation and clogging of applied nutrients and chemicals will be discussed more completely in each of the sections on the particular chemicals.)

Another clogging problem is associated with algae and an increase in microbial population; this causes production of slimes because of increased nutrients in the water. Such clogging is one of the major problems confronted in trickle irrigation. To control it, algicides of various types have been tried with varying degrees of success, depending upon conditions of their use.

Sources of Nitrogen

Water-quality-source interactions

Nitrogen can be applied through the system in several forms, such as anhydrous ammonia, aqua ammonia, ammonium sulfate, ammonium phosphate, urea, ammonium nitrate, calcium nitrate, or mixtures of these compounds. Anhydrous ammonia or aqua ammonia injected into irrigation water will cause a pH increase, and, possibly, precipitation of insoluble calcium and magnesium salts. If irrigation water has substantial concentrations of bicarbonate plus calcium and magnesium, precipitates from them may clog the system. Ammonium salts are fairly water soluble and will cause few problems, except for the ammonium phosphate salts. The phosphate in these salts tends to precipitate as calcium and magnesium phosphates if calcium and magnesium are abundant in the water. Salts such as ammonium sulfate, however, cause little clogging or change in the water's pH.

Urea is a highly soluble nitrogen fertilizer which does not react with water to form ions unless the water contains the enzyme urease. This enzyme could be available if the water had large amounts of algae or other biological activity prior to filtration: urease is not removed by a filter and could cause hydrolysis of urea to ammonium ion. However, enzyme concentration is generally low as compared with that in soil and transit time in the system is fast, so the opportunity for hydrolysis is limited. Thus, urea would not be hydrolyzed to any significant degree in the irrigation system. Nitrate salts, such as calcium nitrate, are relatively soluble in irrigation water and will not cause a large pH shift in the system. A mixture of urea and ammonium nitrate in water is a commercially available, concentrated, liquid mixture which should cause only slight pH shifts in the irrigation water.

Nitrogen in Trickle-Irrigation Systems

Nitrogen is the plant nutrient most commonly deficient for crop production and the one most often applied in trickle-irrigation systems. In general, nitrogen in trickle-irrigation systems causes few precipitation or clogging problems. An exception may occur when some dry fertilizers are dissolved and then injected into the system. Inert conditioners used to prevent caking may also cause clogging, but this can be avoided by using soluble materials without conditioners. Nitrogen could increase clogging by microbial growths if it were applied continuously through an irrigation system. Irrigation water from some wells contains considerable amounts of nitrate and this may cause microbial growth.

Influence of soil reactions on nitrogen mobility

Depending on the source of nitrogen fertilizer, reactions differ with soils and should be carefully considered in selecting the best nitrogen source to apply. At low fertilization rates the ammonium cation will adsorb onto the soil colloids and move only a short distance from the point of application. Concentration of ammonium ions immediately below an emitter will be high. The ammonium ions will move deeper into the profile as the ammonium concentration increases sufficiently to overcome the exchange capacity of the soil. Depth of movement depends on the cation-exchange capacity of the soil and the rate of ammonium application. Most of the ammonium will be transformed biologically to nitrate within 2 to 3 weeks at soil temperatures in the 25 to 30°C (75 to 80°F) range. If the soil is kept too wet immediately below the emitter, biological transformation of ammonium to nitrate will be considerably decreased because the process requires oxygen and thus nitrate will form slowly. Application of ammonium fertilizer to the soil's surface can result in some loss into the atmosphere due to ammonia volatilization, especially if soil pH is more than 7. This loss will be increased if the irrigation water has a pH substantially greater than 7 (as would be true if anhydrous ammonia or aqua ammonia were injected into the irrigation system). Although large losses by ammonia volatilization are possible when ammonia is applied at a point immediately below an emitter, only a small part of the ammonium ions are on the exchange sites of the soil at the surface. Thus, since the wetted soil surface below each emitter is generally not greater than 20 to 30 cm (8 to 12") in diameter, ammonia volatilization loss can be expected to be relatively small. Unpublished data of Rolston show that ammonia volatilization was at a low level when ammonium sulfate was applied through emitters to the surface of a Panoche clay loam.

Urea is relatively soluble in irrigation water and is not strongly adsorbed by soil, and thus will move deeper below an emitter than will ammonium salts. Urea has another potential advantage in that its concentration near the soil surface will be small, thereby minimizing ammonia volatilization loss. After hydrolysis of urea to ammonium, ammonium ions react with soil in the same manner as described previously. Because urea is only slightly adsorbed on the soil and moves in the irrigation water, flexibility in urea placement is achieved through management of the water. The availability of urea solutions, which are easily metered into the irrigation system, is also an advantage over some dry nitrogen materials.

Nitrate will move with the water to the wetting front of the irrigation application, and if repeated applications of water are made the nitrate will end up at the periphery of the wetted soil volume (Goldbert *et al.*, 1971). Thus, only part of the root zone will have access to increased nitrogen levels, and fertilizer use may not be as efficient as if the nitrogen were uniformly distributed in the wetted soil and root area.

Any form of nitrogen applied to soil will eventually become nitrate and will be available for movement with irrigation water. The movement of nitrates in irrigation water implies that one application of nitrogen through the system may not be the most efficient way of applying it. There is some evidence to indicate that a more efficient way is to apply fertilizer throughout the season as needed to meet plant needs and growth. Indeed, growers commonly use this practice in applying nitrogen fertilizer to trickle-irrigated crops. Phene and Beale (1976) compared nitrate concentrations in the soil for trickle-, flood-, and sprinkler-irrigated sweet corn when the fertilizer nitrogen was broadcast at preplant and subsequently banded four times at 15-day intervals. Figure 1 shows nitrate concentrations as a function of soil depth and horizontal distance from the crop row center. Nitrate concen-

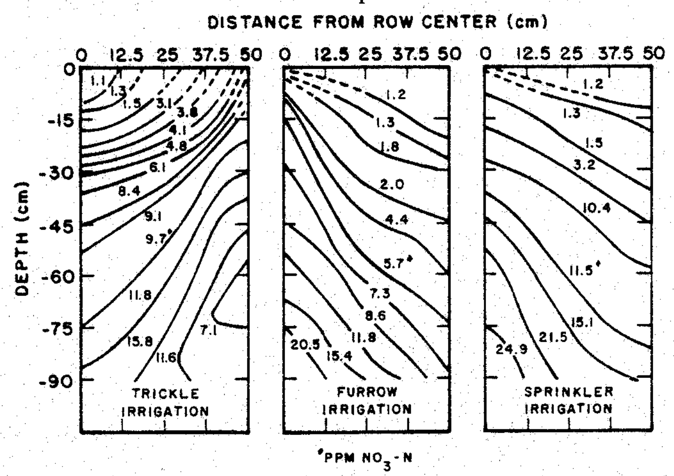

Fig. 1. Soil nitrate content (ppm N) in plots irrigated to maintain soil at the 15 cm (6") depth at a water potential of −150 mbars. Values associated with the lines are parts per million. (Redrawn from Phene and Beale, 1976).

trations remained higher in the root zone of the trickle-irrigated plots than it did in those of the plots irrigated by other methods.

Once nitrogen fertilizer is in the form of nitrate, it is susceptible to other potential losses. One such loss is leaching, which may or may not occur with trickle irrigation. In fact, the ability to more closely manage water with the trickle-irrigation system should result in minimum leaching of applied nitrate (Phene and Beale, 1976). However, a trickle-irrigation system is not 100 percent efficient because of some nonuniformity among the emitters, and it is expected that some nitrate would leach if evapo-transpiration requirements were met on the emitters discharging the smallest amount of water. Another potential loss of nitrogen is through denitrification of nitrate. If enough soluble carbon is available, and if soil water contents approach saturation, oxygen will become exhausted in the soil profile and nitrate may be reduced to volatile gases (such as dinitrogen and nitrous oxide) and diffuse to the atmosphere. Thus, it becomes important that the soil not be allowed to become nearly saturated. It might be expected that a trickle-irrigation system, which keeps soil wet, would result in increased denitrification. However, denitrification occurs over a narrow range in water contents. Rolston and Broadbent (1977) found that little denitrification occurred in a clay loam if soil-water tension was higher (drier) than 10 centibars. There are times when the tension immediately below an emitter may be lower (wetter) than 10 centibars, but little nitrate should be in this zone unless nitrogen is continuously applied with the water. As nitrate moves out of the nearly saturated regions of the soil profile, the potential for denitrification should be reduced.

Plant requirements for nitrogen

For equal fertilizer efficiencies, the required rates of fertilization should be about the same for nitrogen applied through the trickle-irrigation system as for other types of irrigation. Often, fertilizer will be poorly distributed because nitrate moves with water and advances with the wetting front. Thus, it might be expected that fertilizer efficiency would be increased if nitrogen were applied through the trickle-irrigation system. Phene *et al.* (1978) have shown that high-frequency nitrogen application with trickle irrigation improved the efficiency of fertilizer use by potatoes more than twofold over that of conventional fertilization methods with trickle irrigation (fig. 2). Applying fertilizer through the system also increases the timing flexibility, so that nitrogen may be applied at any time independently of the crop-growth stage (Phene and Beale, 1976). This greatly enhances timing the applications to plant requirements and should increase fertilizer-use efficiency.

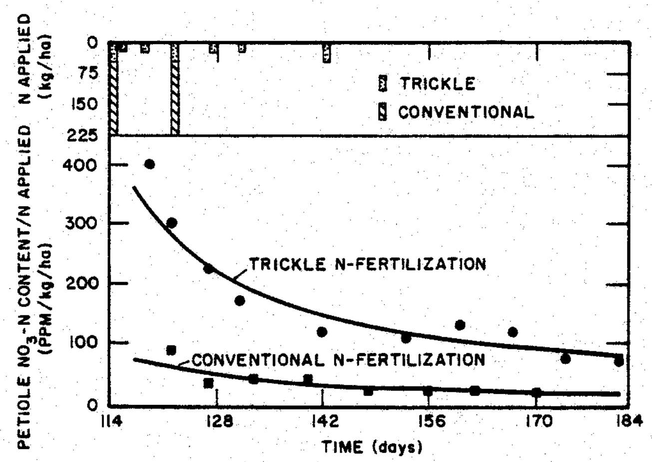

Fig. 2. Petiole nitrate (ppm N) content of potato leaf per unit of N applied for high frequency and conventional nitrogen fertilization methods. (Redrawn from Phene *et al.*, 1978).

Miller *et al.* (1976) compared the efficiency of applying nitrogen through a trickle-irrigation system with the efficiency of various combinations of furrow and trickle plus varied placement and timing on a crop of fresh-market tomatoes grown on Panoche clay loam. Each nitrogen treatment differed in application time and amount (fig. 3). Two treatments received nitrogen banded 10 cm (4") deep and 20 cm (8") to the side of the row at planting time on April 10. One treatment was furrow irrigated and the other was trickle irrigated throughout the growing season. One furrow-irrigated treatment received no nitrogen. The other three treatments received a total of 80 kg (N) per hectare (71 lb/acre) each, applied at various times and in various amounts in solution pumped directly through emitters about 1 meter (1 yard) apart in the plant row. Fertilizer was applied as nitrogen-15-depleted fertilizer (no nitrogen-15) as ammonium sulfate. The nitrogen-15-depleted fertilizer was used as a tracer to determine the percentage of nitrogen uptake from the applied fertilizer. Tomato plants were sampled at thinning, flowering, first fruit, full fruit, and near harvest.

In all treatments, nitrogen content of plants increased between the first and second sampling (fig. 3). This may be because the first sample consisted of whole plants, whereas later samples consisted of leaves. Total nitrogen percentage was initially highest in treatments 0 and 1 because furrow-irrigation water moved the soil-surface nitrogen of treatment 0, and the soil-surface nitrogen and banded fertilizer nitrogen of treatment 1, toward the center of the beds where nitrogen was near the young root system and readily available. Thereafter, total nitrogen percentage differed only slightly for all treatments except treatment 1 on August 12, and treatment 2 tices. The dates and frequency of irrigation are also important factors to consider for the best placement of fertilizer.

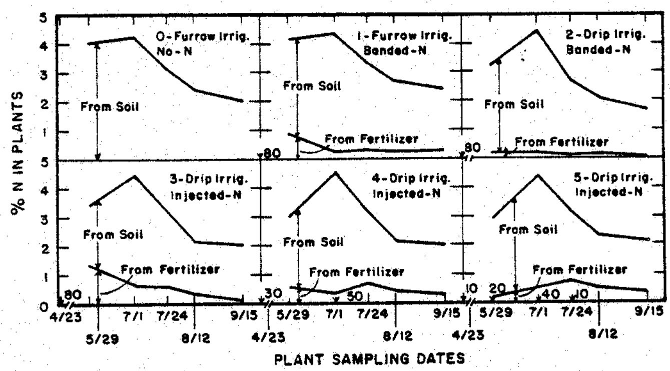

Fig. 3. Relation between soil- and fertilizer-N content in tomato plants at different plant sampling dates for all treatments. Numbers along abscissae indicate date of sampling and numbers by arrows the amount of fertilizer N applied, in Kg/ha. (Redrawn from Miller *et al.*, 1976).

on July 24. Furrow irrigation apparently helped maintain a higher percentage of nitrogen in treatment 1 than it did in the other treatments. Because of nitrogen placement, trickle irrigation in treatment 2 moved some of the soil and fertilizer nitrogen away from the plant row and decreased plant nitrogen content slightly, especially after the July 1 sampling. In treatments 1, 3, and 4, as total nitrogen in the plant increased the percentage of nitrogen from fertilizer decreased between May 29 and July 1, and leveled off between July 1 and July 24. Apparently, soil nitrogen in some treatments was more available to the plant roots during the early part of the season than was the fertilizer nitrogen. After July 1, nitrogen availability was influenced by date and time placement of fertilizer applications.

These results indicate that nitrogen is used more efficiently when applied through the trickle system than when banded and furrow-irrigated or banded and trickle-irrigated. When fertilizer is banded beside the plant row, furrow irrigation is the better irrigation method because the water applied with the trickle system moves the banded nitrogen away from the wetted zone, and therefore results in less efficient use of the fertilizer. However, if banded fertilizer were placed between the plant row and the trickle line the water would move the fertilizer toward the plant. This research also shows that although flexibility and timing are possible with fertilizer applications through irrigation systems, it is important that sufficient nitrogen be available in the root zone early in the season. It also demonstrates that placement of emitters in relation to plant root zones is very critical in that the direction of water movement in the zones will influence the placement of fertilizer applied through the system — or will influence the availability of soil nitrogen from previous cropping practices. The dates and frequency of irrigation are also important factors to consider for the best placement of fertilizer.

APPLICATION OF PHOSPHORUS THROUGH TRICKLE-IRRIGATION SYSTEMS

Water-quality phosphorus-source interactions

If irrigation water is high in calcium and magnesium, application of phosphorus (P) fertlizer through trickle- or sprinkler-irrigation systems is not generally recommended because of possible precipitation of insoluble calcium and magnesium phosphates as dicalcium phosphate or dimagnesium phosphate in the irrigation pipe and emitters. With certain precautions, however, phosphoric acid can be added to a trickle-irrigation system. Because phosphoric acid will form insoluble precipitates if the water has large amounts of calcium and magnesium, the system's pH must be kept low enough for the salts to remain soluble. This can be done by injecting high concentrations of phosphoric acid into the irrigation water, which keeps the pH low enough while the pulse is being applied (note: a highly-acid solution will corrode metal parts in the irrigation system). Rauschkolb *et al.* (1976) applied phosphoric acid through a trickle-irrigation system with no precipitation or clogging problems by using irrigation water relatively high in bicarbonate plus calcium and magnesium; the phosphoric acid was injected at a point beyond any metal connections or filters in order to avoid corrosion. Because precipitates could form at the boundary between the phosphoric acid solution and pure water at the end of the injection cycle, a short pulse of sulfuric acid was added immediately after the phosphoric acid to keep the pH low until all phosphorus was removed from the system. Sulfuric acid addition may not be necessary in most instances.

If irrigation water is low in calcium and magnesium, few problems should be encountered in applying phosphoric acid through drip-irrigation systems. Rauschkolb *et al.* (1976) also applied an organic phosphate compound, glycerophosphate, through the irrigation system. Salts of glycerophosphate such as calcium glycerophosphate are moderately soluble, so to obtain desired amounts of applied phosphorus the application time must be longer than that for phosphoric acid. Although the calcium salts of the organic phosphates are scarcely soluble they will not precipitate in the system unless (a) the organic phosphate is being hydrolyzed to the inorganic phosphate in the irrigation water or (b) the pH of the irrigation water is high. As with urea, hydrolysis will not occur unless the appropriate enzyme is present. Usually, the water is in the system for too short a time for hydrolysis to be significant.

Influence of soil reactions on phosphorus mobility

Phosphorus has not generally been recommended for application in irrigation systems because of plugging, and because of the assumed restricted movement of phosphorus into the root zone when placed on the soil surface (which would mean little movement below the emitters of the trickle-irrigation system [Keller and Karmeli, 1975]). Goldberg *et al.* (1971) raised doubts about the appropriateness of the assumption of limited movement of phosphorus under trickle irrigation. They found that inorganic phosphorus applied at a rate of 20 kg (P) per ha (18 lb/acre) moved approximately 20 cm (8'') both vertically and horizontally from an emitter in a loamy sand soil.

Inorganic phosphate is strongly adsorbed and precipitated in most soils, and if applied uniformly at the surface at normal fertilization rates phosphorus will not normally move more than 2 or 3 cm (0.9-1.5''). Thus, most of the fertilizer would remain at the soil surface where it would be unavailable for plant use. Phosphorus immobility can be alleviated by banding fertilizer at some depth below the seed at planting time: if an adequate band of phosphorus is placed in the root zone the plant can obtain the phosphorus it needs, although even with banding the applied fertilizer is used inefficiently.

Rauschkolb *et al.* (1976) demonstrated that orthophosphate moved a much greater distance into a Panoche clay loam when applied through a trickle-irrigation system than had previously been observed for comparable application rates spread uniformly on the soil surface. When applied at a rate of 39 kg (P) per ha (35 lb/acre), orthophosphate moved 25 cm (10'') horizontally and 30 cm (12'') vertically in the soil profile from emitters placed (fig. 4) 1 meter (36'') apart on beds of 1.7 meters (5'). The data of figure 4 show a 5- to 10-fold increase in movement when the same rates were applied conventionally and uniformly. Movement was greater when applied in the trickle system because of the much greater effective application rate obtained by applying the phosphorus over a small surface area. Thus, the orthophosphate movement resulted from saturation of soil reaction sites near the point of application and the subsequent mass flow of phosphorus with the soil water. Figure 5 shows effective application rates corresponding to various radii of nutrient movement. (figure 4 also shows that the distance of phosphorus movement was proportional to the application rate). Rauschkolb *et al.* (1976) demonstrated that glycerophosphate moved farther than did orthophosphate at low application rates because glycerophosphate must be enzymatically hydrolyzed before it releases orthophosphate ions into the soil solution. Figures 6 and 7 compare orthophosphate and organic phosphate movement in a Panoche clay loam and a Yolo loam at equal application rates. At low application rates phosphoric acid and glycerophosphate apparently move far enough below emitters for trickle irrigation to be a satisfactory means of placing phosphorus in the crop root zone. However, the problem of inorganic phosphate precipitation in trickle lines is of great concern and phosphate applications must be managed carefully. Organic phosphates are not yet commercially available.

Plant requirements for phosphorus

Because only a portion of the total soil volume is wetted under trickle irrigation, it seems likely that efficiency could be increased by applying phosphorus through the system. By doing so the fertilizer will be supplied to only the wetted portion of the soil profile where roots are located and not to that part of the soil which remains so dry that roots cannot proliferate.

But even though Rauschkolb *et al.* (1976) indicate that increased efficiencies might be attainable by applying phosphorus through the trickle-irrigation system, the amount of native phosphorus in soils they studied was so large that efficiency effects were not adequately demonstrated.

The ability to time phosphorus fertlizer applications to meet crop needs throughout the crop season is not as critical as for nitrogen applications. Although there is a slow reaction that tends to remove phosphate from the soil solution and make it less available to plants, there seems to be no great benefit from applying phosphorus either continuously or often throughout the cropping season. A plant generally needs phosphorus early in its growth; therefore, it is important that phosphorus be applied either before planting, at planting, or shortly after planting. There are situations, however, where applying phosphorus through a trickle-irrigation system adds flexibility in correcting deficiency symptoms that might develop in mid- or late-season. Over-all, applying fertilizer through a trickle-irrigation system should make the most efficient use of phosphorus, labor, and energy.

APPLICATION OF POTASSIUM IN TRICKLE-IRRIGATION SYSTEMS

Interactions between water quality and potassium source. Potassium seems to cause few precipitation or clogging problems in trickle lines and emitters. Common potassium sources, such as potassium sulfate, potassium chloride, and potassium nitrate, are readily soluble in water and should cause few precipitation problems.

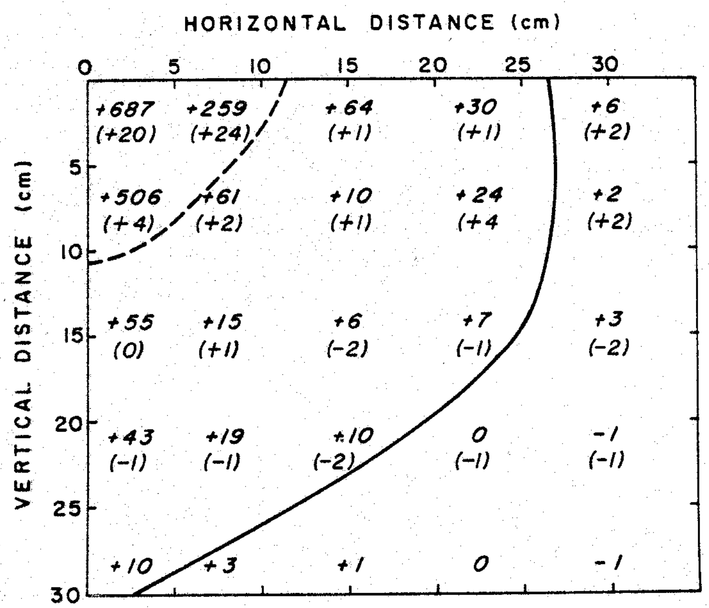

Fig. 4. Influence of application rate on phosphorus distribution beneath a field emitter on Panoche clay loam. Broken and solid curves are approximate maxima for bicarbonate-soluble phosphorus movement at 6.5 (values in parentheses) and 39 kg of P/ha (values not in parentheses) applications of orthophosphoric acid, respectively. (Redrawn from Rauschkolb *et al.*, 1976).

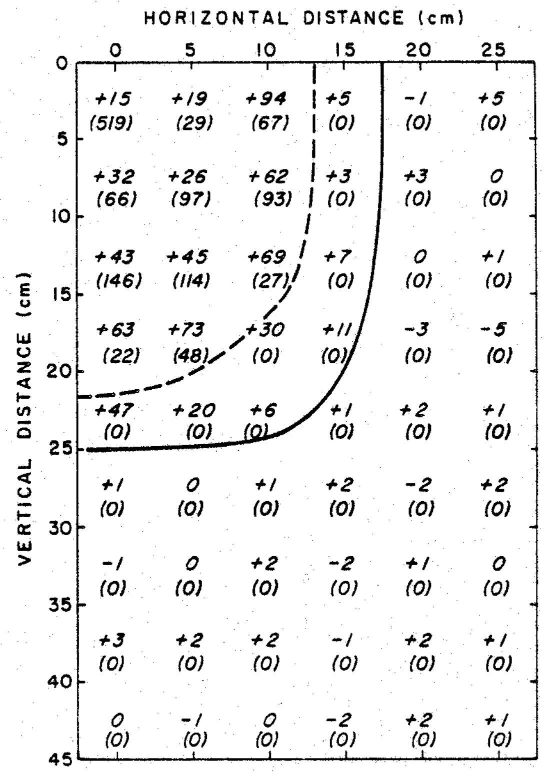

Fig. 6. Comparison of phosphorus distribution beneath a simulated emitter in the laboratory on a Yolo loam soil for two sources of phosphorus. Broken and solid curves are approximate maxima of bicarbonate-soluble phosphorus movement for ortho-phosphoric acid (values in parentheses, and glycero-phosphate (values not in parentheses) at an application rate of 13 kg P/ha (11.6 lb/acre), respectively. (Redrawn from Rauschkolb *et al.*, 1976).

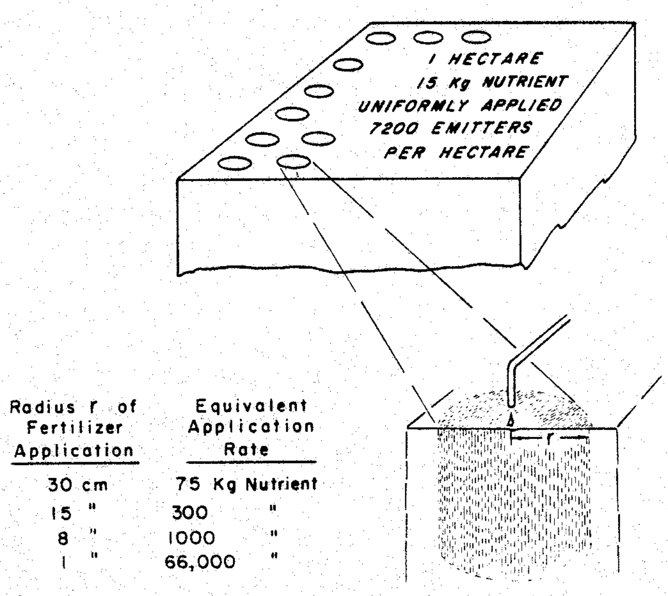

Fig. 5. Radii of fertilizer application and equivalent application rate for nutrient application through a trickle system.

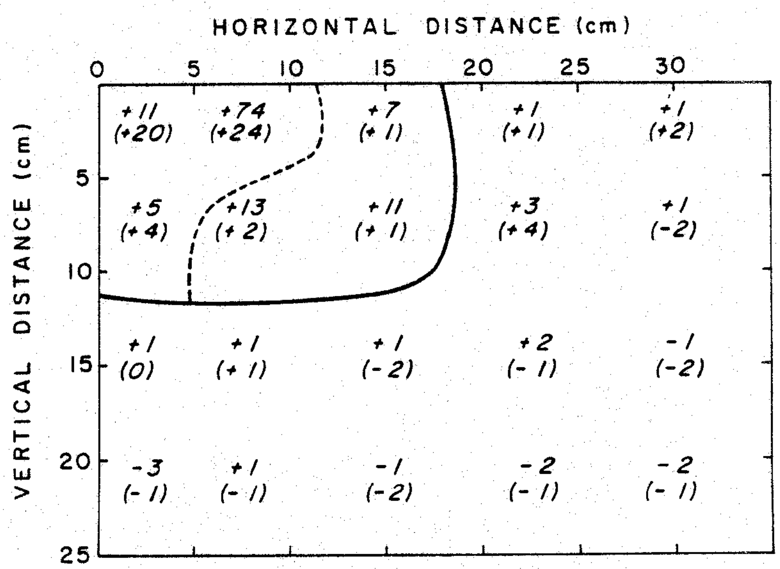

Fig. 7. Comparison of phosphorus distribution beneath a simulated emitter in the field on a Panoche clay loam soil for two sources of phosphorus. Broken and solid curves are approximate maxima for bicarbonate-soluble phosphorus movement for orthophosphoric acid (values in parentheses) and glycerophosphate (values not in parentheses) applications, respectively.

Table 1. Ammonium acetate extractable potassium in soil at Colusa where potassium was applied through the trickle system.*

	Distance from Emitter (cm)				
Soil Depth (cm)	0	30	60	90	120
			ppm K		
0 - 15	919	622	416	268	172
15 - 30	774	264	215	219	121
30 - 45	483	98	119	147	68
45 - 60	567	102	96	84	61
60 - 75	90	76	70	145	66
75 - 90	65	70	70	86	59
90 - 105	66	88	63	72	61
105 - 120	66	65	65	63	61

*Uriu *et al.* (1977). Thirty cm is approximately equal to 1 foot.

Influence of soil reactions on potassium mobility. Once the potassium cation reaches the soil, it is adsorbed on the exchange complex of the soil until the exchange complex is saturated. Movement of potassium below trickle-irrigation systems are expected if applications are concentrated by applying the fertilizer to small soil areas. Research by Uriu *et al.* (1977) demonstrated considerable potassium movement when the fertilizer was applied through a trickle-irrigation system (table 1).

Plant requirements

Plants need comparatively large amount of potassium. Leaf tissues generally should have about 1 percent potassium or more (on a dry-weight basis) depending upon plant species. Adequate potassium must be available throughout the growing period because potassium activates numerous enzymes, is required for stomatal opening, and promotes translocation of photosynthates from leaves. Potassium must be available to fruit trees at least up to harvest, as many crops (e.g., prune, apricot) are high in potassium and their fruit appears to have larger requirements for potassium than their leaves.

With perennials, roots must not only be in soil high in potassium for adequate uptake, but sufficient soil moisture must be present to allow ready movement of potassium from soil to roots. High soil moisture alone (as occurs under the emitter in trickle irrigation) will not result in adequate potassium uptake if the soil is low in available potassium. These soils may not supply enough potassium under trickle irrigation because the actively absorbing roots are generally restricted to wetted soil beneath emitters. Under these conditions soil potassium must be increased by adding fertilizer potassium.

Usually, fruit trees are fertilized commercially by drilling in 1000 to 2000 kg per ha (900 to 1800 lb/acre) of a potassium sulfate. However, this treatment, does not always correct potassium deficiency because the applied fertilizer does not readily move below the application depth into the active root zone.

Potassium applied in trickle-irrigation water is readily absorbed by prune trees and moves 60 to 75 cm (24 to 30'') into the soil, which is well within the active root zone of trees (table 1). In a study conducted in a mature prune orchard on Sycamore clay loam near Colusa, a solution of potassium sulfate was injected into the trickle-irrigation system to give a continuous potassium concentration of about 190 ppm in the irrigation water throughout the irrigation season for a season total of 2.1 kg of K per tree (4.6 lb/tree).

This treatment was compared with a control in which no potassium was added to the trickle-irrigation water and with a treatment in which 9.1 kg (20 lb) of potassium sulfate per tree had been placed in the bottom of several parallel trenches alongside the tree (to simulate commercial application). The latter treatment was sprinkler irrigated. The irrigation season began June 4.

Figure 8 shows that the leaves in the trickle-applied-potassium plots began increasing in potassium content less than a month after treatment was begun, whereas trench-applied-potassium plots took 3 months before an increase in leaf potassium was detected. The highest potassium concentration found in prune leaves for the trickle-applied, trench-applied, and trickle-control was 2.2, 1.7 and 1.5 percent respectively.

At the end of the second season, after 9.1 kg (20 lb) of potassium sulfate had been applied per tree through the trickle-irrigation system, soil samples were taken under and alongside an emitter, and the amount of ammonium acetate-extractable potassium determined (table 1). The extraction procedure consisted of leaching 5 g of soil with 250 ml of neutral 1.0 N ammonium acetate. Potassium under the emitter extended laterally about 90 cm (35'') and vertically about 75 (30''), producing a high-potassium soil volume shaped

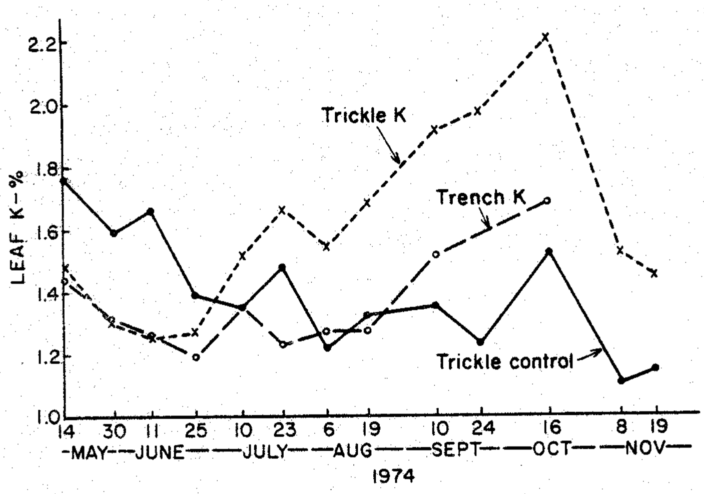

Fig. 8. Season leaf potassium levels at Colusa. Trench K received 2.1 kg (4.6 lb) K as potassium sulfate applied per tree in mid-May in parallel trenches 15 to 20 cm (6 to 8") deep and sprinkler-irrigated. Trickle K received potassium sulfate applied in trickle-irrigation water at 192 ppm K concentration from June 4 to September 10 with a total of 2.1 kg (4.6 lb) of K as potassium sulfate applied per tree. Trickle control received no potassium. (Redrawn from Uriu *et al.*, 1977).

like an inverted cone, indicating potassium had moved well into the root zone. Potassium levels in plots that did not receive fertilizer through the trickle system were much lower (table 2).

In the Colusa experiment, potassium uptake in the trickle-applied potassium treatment was detected in prune leaves a few weeks after treatment began. A second experiment was conducted near Gridley in an orchard on a Wyman clay loam showing severe potassium deficiency symptoms (fig. 9). In both experiments this corresponded to the time when about 1.1 kg (2.4 lb) of potassium sulfate per tree had passed through the emitters in contrast to the 4.5 to 9.1 kg (10 to 20 lb) of potassium sulfate per tree applied in soil. The larger movement can be attributed to the large amount of nutrient applied over a small area (fig. 5) and to saturation of exchange sites which resulted in movement of potassium to greater depths.

In the Gridley experiment, soil samples at the end of the season showed that even though only a total of 3.5 kg (7.7 lb) of potassium sulfate had been applied in the water, downward movement was extensive. Table 3 show that potassium was distributed laterally about 30 cm (12") and vertically about 60 cm (24"). Table 4 shows that levels of potassium in the trickle control plots were much smaller.

Because leaf potassium in this orchard was low, considerable deficiency symptoms were present. However, by the end of the year the trees in the trickle-applied-potassium plots were green, showing excellent correction of deficiency symptoms. The trickle controls still showed severe leaf yellowing and scorch, the characteristic symptoms of potassium deficiency.

Table 2. Ammonium acetate extractable potassium in trickle-irrigated soil at Colusa with no potassium applied.*

	Distance from Emitter (cm)				
Soil Depth (cm)	0	30	60	90	120
			ppm K		
0 - 15	221	248	307	276	315
15 - 30	123	147	188	174	151
30 - 45	88	98	98	195	92
45 - 60	63	63	80	63	72
60 - 75	63	66	55	63	61
75 - 90	61	65	55	55	51
90 - 105	68	61	57	45	51
105 - 120	56	61	59	55	61

*From Uriu *et al.* (1977).

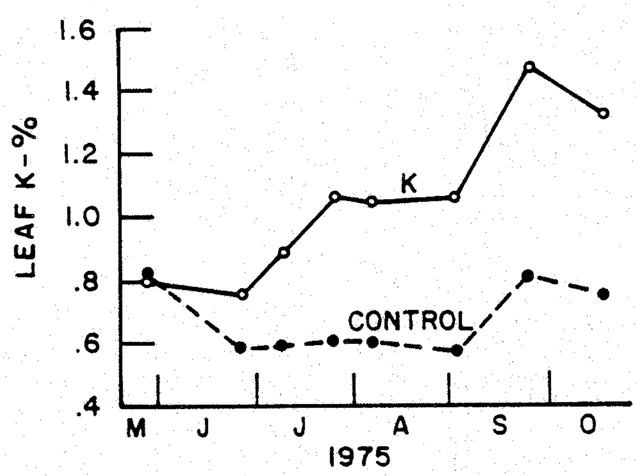

Fig. 9. Season leaf potassium levels at Gridley. Line K received potassium sulfate applied in trickle-irrigation water at 180 ppm K concentration from May 30 to the end of August. A total of 1.6 kg (3.5 lb) of K as potassium sulfate was applied per tree. The control line was trickle-irrigation water only, with no potassium applied. (Redrawn from Uriu *et al.*, 1977).

Table 3. Ammonium acetate extractable potassium in soil at Gridley where potassium was applied through the trickle system.*

	Distance from Emitter (cm)				
Soil Depth (cm)	0	30	60	90	120
			ppm K		
0 - 15	1181	673	90	125	98
15 - 30	927	86	74	74	74
30 - 45	547	74	70	74	78
45 - 60	98	70	70	78	78
60 - 75	78	86	74	90	86
75 - 90	90	98	90	94	78
90 - 105	125	102	98	106	98
105 - 120	94	129	90	86	86

*From Uriu *et al.* (1977).

Table 4. Ammonium acetate extractable potassium in trickle-irrigated soil at Gridley with no potassium applied.*

	Distance from Emitter (cm)				
Soil Depth (cm)	0	30	60	90	120
			ppm K		
0 - 15	98	102	102	110	106
15 - 30	86	86	66	66	63
30 - 45	86	78	66	63	66
45 - 60	86	78	74	63	74
60 - 75	82	82	82	74	94
75 - 90	82	82	94	78	82
90 - 105	86	86	82	85	74
105 - 120	90	78	90	90	82

*From Uriu *et al.* (1977).

Micronutrients

Water-quality-source interactions

Micronutrients such as iron, zinc, copper, and manganese may react with salts in the irrigation water and cause precipitation and clogging, However, many of the micronutrients can be applied as chelates such as iron or zinc EDTA (ethylenediamine tetraacetate dihydrate). Chelates are generally highly water soluble and, consequently, will cause little clogging or precipitation. Chelates or sulfate salts of micronutrients can be predissolved and metered into the trickle-irrigation system as a liquid; this allows more precise control over the amounts applied.

Influence of soil reactions on nutrient mobility

Because of the generally greater mobility of chelated micronutrients in soils, it might be desirable to use this form for surface application of micronutrients. However, not enough research has been done to know if cationic micronutrients will move sufficiently through soil under an emitter to achieve proper placement in root zones. Intuitively, one would suspect that because of the small quantities needed, and the high affinity for exchange sites, that the cationic micronutrients would move relatively little.

Plant requirements

Little research has been done on the efficacy of applying micronutrients through trickle-irrigation systems. Lindsey and New (1974) conducted several field tests on applying zinc EDTA through the irrigation system to pecan trees in west Texas, and found that these applications generally resulted in good growth of trees at a lower cost than foliar application. However, leaf concentrations of zinc were generally lower than when using foliar applications.

Pesticides

Much work has been done on applying chemicals in water to control clogging of trickle-irrigation systems, but little research has been conducted on applying chemicals through trickle-irrigation systems to control soil pathogens. Zentmyer *et al.* (1974) applied ETMT through a trickle-irrigation system in an attempt to control Phytophthora root rot of avocado trees.

Lange *et al.* (1974) applied herbicides through trickle-irrigation systems to control weeds around emitters. Most of the herbicides tended to break down rather quickly in continually moist soil and thus become ineffective. Herbicides usually tend to adsorb on the soil and thus do not move with the irrigation water; and the result is that herbicide does not reach the entire wetted zone. Phene *et al.* (1978) applied EPTC herbicide in a trickle-irrigation system to control weeds on twin-row potato beds which could not be cultivated. Several post-emergence applications improved weed control without affecting the potato yields. The applications of EPTC at one-half rate were as efficient as those at full rate, which suggests that it may be possible to improve the efficiency and effectiveness of herbicides by applying them in trickle-irrigation systems.

Application of soil fumigants through trickle-irrigation systems was evaluated by Overman (1974, 1976). Application of DBCP (1,2-dibromo-3-chloropropane) and MBC-33 (67 percent methyl bromide plus chloropicrin) through a bi-wall linear irrigation system (either buried or laid on the surface beneath a plastic mulch) effectively controlled nematodes in a sandy soil. The DBCP was applied with the irrigation water prior to planting; the MBC-33 was applied in the trickle system with irrigation water and without water in the trickle tubes. Yields of okra when MBC-33 was applied with the water were greater than that without water. The successful application to other soils of this method for controlling both soil nematodes and cropping situations could substantially decrease costs of fumigation.

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