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Injection Rates and Components of a Fertigation System

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Common advantages of fertigation, i.e., the application of fertilizers through an irrigation system, include

- considerable savings in the labor and energy costs of application
- chemicals are already in solution form and thus immediately available to the plants throughout the root zone
- flexibility in irrigation timing makes it easier to schedule fertilization
- soil compaction is minimized by avoiding heavy equipment traffic through the field
- small doses of chemical are applied when needed, reducing leaching of water-soluble nutrients during periods of excessive rainfall or over-irrigation (Burt et al. 1998, Boman and Obreza 2002).

Successful fertigation requires precise calculation of injection rates, knowledge regarding solubility of different fertilizer components, and basic knowhow of fertigation equipment. This publication aims to provide necessary information regarding these components.

Basic calculations for fertigation

Basic fertigation calculations involve determining the velocity of a water-soluble chemical, which is directly related to the velocity of irrigation water in the application system. Fertigation time is therefore related to the time needed by irrigation water to travel from the point of injection of the material to the furthest emitter, e.g., of a drip line. Travel time is calculated as T = D/v, where D is the distance traveled by the dissolved nutrient, or the length of pipe through which the irrigation water flows, and v is the velocity of the irrigation water. Fertilizer solution travel time is used to calculate fertilizer injection rate (IR) for a particular irrigation system. For a microsprinkler system, IR can be calculated based on the following relationship (Boman et al. 2004):

$$IR = \frac{A \times Q}{F \times T \times \rho} \times 100,$$

where A is the area to be irrigated (hectares), Q (kg/ha) is the quantity of chemical to be applied per hectare, F is the chemical fraction (fertilizer per liter of fluid injected, %), and ρ (kg/L) is the chemical solution density. Using the above relationship, a quantity of 3 kg/ha of N is applied to a 25-ha orchard with a 10-0-10 5-kg/L dense fertilizer solution that is injected for 1 hour at the rate of 150 L/hr. Because microsprinkler irrigation systems do not irrigate the entire soil surface, the fertilizer applied using these systems is delivered only to the irrigated portion of the soil surface. For a simple case of 50% irrigated soil surface, the N application rate in the irrigated zone (i.e., A/2 = 25/2 = 13.5), using the above revised relationship and the above information, will be slightly less than 6 kg/ha, as follows:

$$Q = \frac{IR \times F \times T \times \rho}{A \times 100} = \frac{150 \times 10 \times 1 \times 5}{13.5 \times 100} = 5.56 \text{ kg/ha}$$

Because micro-irrigation systems do not apply water and chemicals to the entire soil surface, chemical applications to micro-irrigated crops are often made on an individual plant or tree basis, rather than on a gross-area basis. The above relationship for IR on the number of trees on an area basis becomes (Boman et al. 2004):

$$IR = \frac{A \times Q_p \times n}{F \times T \times \rho} \times 100,$$

where Q_p (kg/tree) is the quantity of fertilizer to be ap-

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plied per tree, n is the number of trees per ha, and all other variables are same as previously defined. In a 10-ha grove of young trees, e.g., citrus trees, the quantity of 0.05 kg of N from a 5 kg/L dense 8-0-8 solution, at 1 hr fertigation time for a 100 trees/ha grove will require 125 L/hr IR, calculated as follows:

$$IR = \frac{10 \times 0.05 \times 100}{8 \times 1 \times 5} \times 100 = 125 \text{ L/hr}$$

It is recommended that the duration of injection should be greater than the time the chemical needs to travel from the point of supply tank to the most distant emitter of dripper or sprinkler in the field. Flushing time is also an important consideration, to completely clean the system, and it should also be half of the time of duration of fertilizer injection; nonetheless, excessive flushing time may lead to leaching loss of nutrients.

Solubility of chemicals and soil pH modification

Complete dissolution of solid chemicals (including fertilizers) into irrigation water is termed chemical solubility. Highly soluble fertilizers include NH_4NO_3, KCl, KNO_3, K_2SO_4, urea, MAP, and DAP (Farhat and Abbas 2009). Because chemical solubility increases with temperature (Wolf et al. 1985), it is recommended to dissolve chemicals in hot water prior to their use in a fertigation system (Hanson et al. 2006). Once dissolved in water, the amount of chemical in a solution is referred to as the solution density, which refers to the weight of the known volume of solution compared with the non-chemical solution volume.

Soil pH is not affected by the addition of neutral substances (e.g., KCl, KNO_3, K_2SO_4), but it is increased with basic fertilizers (e.g., $Ca(NO_3)_2$, sodium nitrate [$NaNO_3$]), and decreased with acidic fertilizers (e.g., NH_4NO_3, $[NH_4]_2SO_4$, DAP, MAP, and urea) (Hanson et al. 2006). Neutral irrigation solutions with pH = 6.5–7.5 are ideal for fertigation. Alkaline solutions with pH >7.5 cause the precipitation of P and thus decrease the availability of nutrients to the plant. Chemical solutions that decrease soil pH may increase the salt load beneath drip or sprinkler emitters. To avoid these problems, base dressings are suggested with the some of the basic chemicals (Marsh and Stowell 1993). Fertilizer is usually applied as two dressings, a base dressing followed by a top dressing. Acidic fertilizers are usually corrosive in nature; they therefore pose many health hazards, especially to the skin and eyes of the individuals who handle fertigation equipment. This necessitates periodic prior-to-use inspections of all system components, including pumps, injection devices, lines, filters, and tanks.

Clogging of the system

Since alkaline water forms insoluble compounds, it is not considered favorable for use in fertigation operations. Alkalinity of the water is especially crucial when P is used in fertigation, as the added P forms insoluble tri-basic calcium phosphate that can clog irrigation equipment (Rauschkolb et al. 1976). This necessitates the continuous monitoring of pH of the P-carrying solutions flowing in the irrigation equipment (Koo 1980). Because MAP and DAP are excellent sources of P and N, these compounds are commonly used to enhance crop yield. There is a high possibility of precipitation of insoluble P if MAP or DAP is mixed with irrigation water high in Ca or Mg. The precipitates formed in the irrigation equipment during fertigation can be dissolved and cleared with the use of acidic fertilizers (Bucks et al. 1979).

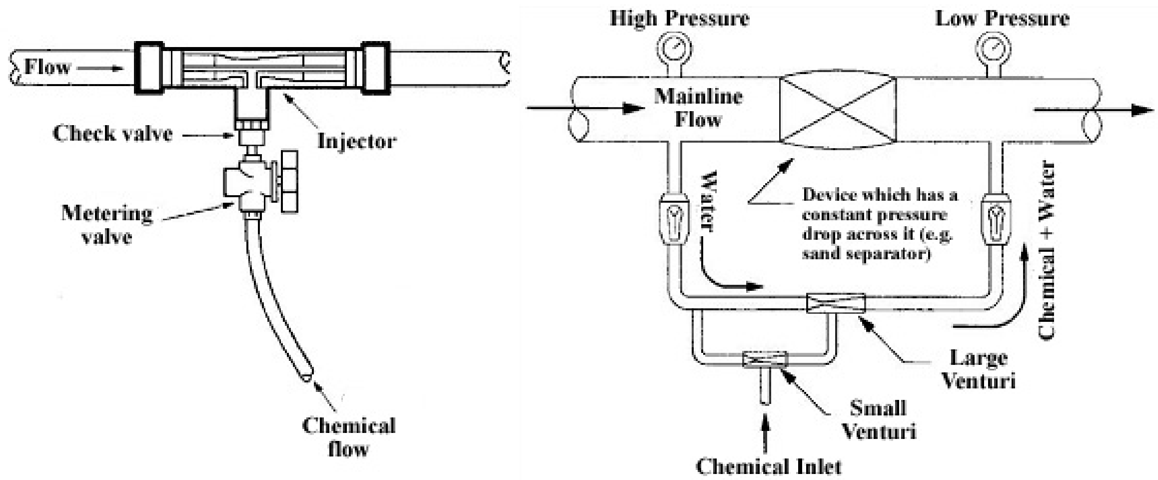
Although acidic fertilizers are corrosive to metallic components of the fertigation system and can potentially damage cement and asbestos pipes, they dissolve the precipitates and help to unclog the system's emitters or drippers. Periodic injection of phosphoric, nitric, sulfuric, or hydrochloric acid into the fertigation system can remove bacteria, algae, and slime trapped in the system. Clogging is particularly crucial for drip irrigation systems because of their small orifices in the emitters (Koo 1980). Chemical solutions or low-quality, brackish water can also cause emitter clogging (Bucks et al. 1982). Very few reports on clogging of sprinklers during or after fertigation operations have been reported. Koo (1980) did not experience emitter clogging while using solution fertilizer in overhead sprinkler systems. However, Koo reported very little difference in the incidence of clogging between pre- and post-fertigation. The use of acidic fertilizers temporarily unclogs the system emitters. The irrigation and chemical injection systems should be thoroughly washed and flushed with fresh water, especially after the injection of acids into the system.

Fertigation system components

Chemical reservoir or supply tank

Chemical reservoirs commonly called supply tanks are usually made of polyethylene or fiberglass. Tank size is an important consideration for a fertigation system. Tank size should be large enough to contain the chemicals

Figure 1. Chemical injectors based on a small venturi metering valve (left) and a large venturi (right) to create adequate pressure differentials for efficient chemical injection (from Burt et al. 1998).



sufficient for at least one fertigation operation. Tank volume, V (L), is determined as V = (R × A) / (C × ρ), where R is the fertigation rate (kg/ha), A is the area to be fertigated (ha), C is the concentration of chemical source (e.g., N-P-K, decimal), ρ is the chemical solution density (kg/L). To fertigate a 50-ha orchard block at the N fertigation rate of 10 kg/ha, the 10.6 kg/L dense 9-2-9 chemical solution of NH_4NO_3, KCl, and H_3PO_4 (i.e., 9% N fraction) will require a tank volume of 524 L. To avoid overflow and to accommodate dead storage, it is always recommended to have a 10% extra tank volume. The size of the tank can be doubled, tripled, or increased to any size depending upon the number of fertigations planned between tank refilling.

Chemical injectors and injection techniques

Fertigation injection devices work either on piston flow (positive displacement pumps) or on vacuum generation (suction or negative pressure, venturi-type) principles. Positive displacement pumps include proportional injectors, rotary pumps, and peristaltic pumps. The injection energy for positive displacement pumps is provided by an electric, gasoline, or hydraulic motor. Accurate chemical application and easy adaptation for automation are among the major advantages of positive displacement pumps.

Rotary and peristaltic pumps can transfer chemicals from the supply tank to the irrigation system; the former transfer the solution through the action of rotating gears, while the latter transfer the solution by creating of partial vacuum. A more or less constant chemical flow is generated, and the chemical injection rate is not affected by the change in irrigation application rate. Peristaltic pumps are used to inject chemicals in microsprinklers. The required chemical injection is achieved by the squeezing action of the rotating rollers on a flexible tube. Because the injected chemical passes through a tube and does not touch the inner components of the pump, the peristaltic pump material is protected against any corrosive impact caused by the chemical.

Because injectors based on the venturi principle utilize differential pressure generated across the device (Fig. 1), the rate of chemical injection varies with the differential pressure generated. Chemical injection rate is influenced by the pressure drop; the larger the pressure drop, the higher the injection rate. Proper operation of these devices requires a pressure drop across the venturi; some minimum pressure for even a low rate of chemical injection is required. This constraint results in poor chemical injection efficiency and problems in quantitative fertigation.

Most centrifugal pumps work on vacuum-generation principles. Advantages of vacuum injection methods include

- simple operation and no moving parts
- easy installation and maintenance
- better control on injection rates
- ideal for dry formulations
- no power or fuel needed for pump operation.

For this injection method, it is necessary that the pressure produced by the centrifugal pump be higher than the pressure in the irrigation line. The flow rate of the chemical from the pump, however, depends on the pressure in the irrigation main line. The higher the pressure, the smaller the flow rate from the injection pump. Hence, centrifugal pumps require periodic calibration to ensure precise injection rates (Boman et al. 2004).

Backflow prevention mechanism for safe fertigation

Fertigation safety requires proper and secure connection of the system components, including the supply tank, injection devices, and irrigation system. The supply tank is connected to the irrigation system via a supply pipeline. Two small open-ended tubes are placed in the supply pipeline; the end of one tube faces upstream, while the end of the other tube faces downstream. The water that flows through the supply tank displaces the chemical stored in the tank, and the displaced chemical is forced into the irrigation supply line. The water pressure causes water to flow into the upstream tube and the chemical to flow out of the downstream tube, as a result of differential pressure between the up- and down-stream ends. The water pressure can be controlled using a pressure-reducing valve that is installed between the inlet and outlet ports in the supply pipeline. There is a high risk of contamination if a proper backflow prevention mechanism is not used. Possible contamination causes include discontinuation in water supply and the simultaneous operation of the chemical injection unit. This situation can worsen if the irrigation water flows back through the injection unit into the chemical storage tank, causing the tank to overflow. Check valves (in the main line and in the injection line), vacuum relief valves, low-pressure drains, and interlocking circuits are among the useful backflow prevention devices.

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