FERTILIZATION COMBINED WITH IRRIGATION (FERTIGATION)

by:

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INTRODUCTION

The term “chemigation” is used to describe the injection of a variety of agricultural chemicals into the irrigation system, usually for the purpose of distributing the chemicals to the soil of the irrigated area along with the irrigation water.

Other, more specific terms are used to describe the application of given materials through an irrigation system, all with the suffix “gation”, indicating the type of material applied: fertigation (fertilizers), fungigation (fungicides), insectigation (insecticides), herbigation (herbicides), etc.

Chemigation also includes the introduction of chlorine, acids or other chemicals for the purpose of water treatment or cleaning the components of the irrigation system. The benefits of chemigation include economical application, the potential for frequent, uniform, precise applications to match seasonal crop needs, a reduction in soil compaction and mechanical damage to the crop, etc.

Fertigation allows a greater flexibility of fertilizer application as compared with traditional methods, due to the possibility of fertilizing at any given time while irrigating. In addition, fertigation is adaptable to all pressurized methods such as sprinkler, drip, micro sprinkler, center pivot, etc. The method is well suited to meet all farmer’s needs, both from an economic as well as an engineering standpoint, with many advantages as compared to traditional methods.

Many accessories have been developed for the control of the chemigation process and to make it more efficient. As these accessories are becoming more sophisticated, and specialized, they require more advanced skills and know-how in order to perform the necessary operations.

It is with this in mind that the current publication has been written and hopefully will benefit chemigation, irrigation planning and implementation.
CHAPTER 1 - ADVANTAGES AND LIMITATIONS

The benefits of applying fertilizers and other chemicals through the micro-irrigation system are widely acknowledged.

Advantages
Higher Efficiency
Better distribution and higher uniformity of fertilizer application as a result of its application dissolved in irrigation water.

Every single plant in the field receives its nutrients accurately.

- Better and immediate penetration into the soil
- The possibility of dividing the yearly amount of fertilizer into many small applications, thus increasing availability.
- Lower nutrient losses from the soil surface, for example, of nitrogen, due to volatilization.
- The possibility of adjusting fertilization to each phase of the crop’s phenological stage, such as vegetative growth, flowering, fruit set, etc.
- Fertigation makes it possible to apply nutrients according to the crop’s needs, with the possibility of changing the ratio between them.
- Dividing the recommended dose into small portions may reduce the total amount of applied fertilizer by one third.
- In drip irrigation systems, fertigation is a must, since this method wets only a small percentage of the soil volume.

Control and dosing:

- Accurate fertilizer quantities may be applied through automatic control systems in accordance with a pre-established schedule.
- The possibility of full control over the process allows the application of micro-elements through the irrigation system. Microelements are usually expensive, and by repeatedly applying small doses during an extended period, we are able to increase their availability significantly. Frequently this may replace foliar applications.
- Fertigation adapts easily to automatic irrigation control systems, increasing accuracy.

Depth control and application timing:

- Frequent applications in small doses avoid fertilizer losses. This reduces losses due to rainfall leaching nutrients below the active rooting zone of the crop. In many tropical areas with very high rainfall, fertigation is practiced for this purpose.
- There are instances in which, depending on soil type, fertilizer and crop, it is important to apply the fertilizer towards the end of the irrigation cycle, to prevent leaching.
- Fertigation allows maintaining a proper nutrient level in poor soils of low nutrient retention capacity, enabling farming of marginal soils.
- Additionally, depth control and timing enables us to prevent chemicals reaching groundwater, thus preventing its pollution.
Saving labor and convenience:
- Operation is fast and convenient.
- Chemigation saves labor and energy.
- No need for special machinery to apply fertilizers.
- A single person can operate the whole system from the control head.

Soil compaction:
- No need to drive tractors towing heavy fertilizer spreaders over the whole area.
- Soil damages due to compaction are prevented, resulting in higher yields.

Additional applications:
- The application of other chemicals is possible through the irrigation system.

Limitations and precautions

Toxicity:
- Many irrigation systems are linked to a potable water supply. Water into which agro-chemicals have been injected should not be consumed by humans nor by domestic animals. All workers, as well as passers-by should be warned, by well displayed signs, about the risk of drinking this water. At the same time a supply of potable water must be made available.

Groundwater contamination:
- Mentioned earlier as an advantage, it may become a limitation when accurate monitoring systems are not used, since chemicals applied through the irrigation system may easily reach the groundwater.

Fertilizer suitability:
- Fertigation is suited for liquid, as well as for soluble fertilizers. Those that are not fully soluble should not be applied through fertigation.

Interactions of injected chemicals with irrigation water:
- All chemicals to be injected into the irrigation system should be checked in order to determine whether they are going to cause any undesired chemical reaction. For example, common chlorine sources are oxidizing agents resulting in calcium and magnesium carbonate precipitation, as well as that of iron oxides (rust), etc.
- Phosphate fertilizers, such as super-phosphate may react with calcium in the irrigation water and create precipitates.
- There are a number of fertilizers that increase the pH of irrigation water, thus enhancing precipitation.

Corrosion hazard:
- Corrosion of irrigation and injection system components can be a serious problem. All parts that come in contact with concentrated solutions and/or the injected chemical should be made of chemically resistant materials as to minimize corrosion.
The chemical injection system and the irrigation system should be thoroughly flushed after each injection of chemicals (other than acids and chlorine). All fertilizers are corrosive to a certain extent.

Safety requirements:
- Many fertilizers have a strong acid reaction; precaution should be taken when handling them.
- Chemigation equipment must include a backflow prevention device, upstream to the point of injection. This device serves a dual purpose, to prevent backflow of irrigation water with or without chemicals to the water source and to break any back siphoning that might occur upon system failure or shutdown.

High initial investment:
- Many accessories are needed to perform fertigation, making the initial investment a costly one.

Correct operation of all system is required:
- If one component of the system is not operating properly, fertigation may not function correctly.
- We depend on the proper operation of the system.
CHAPTER 2 - EQUIPMENT SELECTION CRITERIA

Equipment for fertigation is produced in different types and models, differing in their properties, having advantages, limitations and different prices. On the other hand, conditions and requirements may differ from one place to the other. Therefore it is very important to ponder thoroughly all factors before making a decision.

**Injector discharge**

Knowing the capacity of the injection device enables us to calculate the amount of fertilizer solution we may inject into the irrigation system during the time available. To calculate it we use the following equation (1):

\[
q = \frac{A \times Fv}{t}
\]

- **q** = Injector discharge [liter/hectare]
- **A** = Area [hectare]
- **Fv** = Fertilizer dose [liter/hectare]
- **t** = Fertilization duration [hour]

**Example:**
We want to apply a fertilizer dose (Fv) 150 l/ha of a fertilizer solution to a 2.5 ha plot (A). Fertigation lasts for three hours (t), accordingly the fertilizer injector discharge should be:

\[
q = \frac{2.5 \text{ ha} \times 150 \text{ lt/ha}}{3 \text{ h}} = 125 \text{ lt/h}
\]

**Tank capacity calculation**

The minimum volume of fertilizer solution in the tank, to supply fertilizer during a single irrigation turn is calculated with the following equation (2):

\[
Tv = Fv \times A
\]

- **Tv** = Tank volume [liter]
- **Fv** = Fertilizer dose [liter/hectare]
- **A** = Area [hectare]

**Example 2:**
What is the minimum tank volume (Tv) in order to fertigate a plot of 0.5 ha (A), if we want to apply 200 liters of solution per hectare (Fd)?
Tv = 200 lt/ha * 0.5 ha = 100 lt

**Reliability and accuracy**
It is important to ensure that the equipment operates as intended without the need of intervention by the operator.

**Operation**
The operator should be trained as to be able to deal with the complexity and sophistication of some of the new equipment.

**Energy**
A source of energy is required in order to make the injection possible. This energy may be in the form of hydraulic energy supplied by the pressure in the irrigation system, electricity or an internal combustion engine. The choice will depend upon price and availability.

**Dilution ratio or fertilizer solution concentration.**
This is the relation (in percentage) between the volume of the concentrated fertilizer solution and the total volume of the final solution, as calculated by the following equation (3).

**Equation 3:**

\[ Fc(\%) = 100 \times \frac{q}{Q} \]

- \( Fc(\%) \) = Fertilizer concentration in irrigation system \[ \% \]
- \( q \) = Injector discharge \[ \text{liter/hour} \]
- \( Q \) = Irrigation system discharge \[ \text{m}^3 \text{/hour} \]

**Example 3:**
100 lt/h of a liquid fertilizer (\( q \)) in 1.9 m\(^3\)/h of water (\( Q \)) constitute a dilution ratio of:
\[ Fc(\%) = 100 \times \frac{100 \text{ lt}}{100 \text{ lt} \times 1.9 \text{ lt}} = 5\% \]

The selected equipment must meet this dilution ratio.

**Automation suitability**
The chosen equipment should have the option of being automated in the future.

**Additional applications**
The equipment may be used for additional applications such as acid injection for treating irrigation water and preventing precipitation, which could clog emitters.

**Warranty and service**
The warranty and the kind of service given by the manufacturer or his local dealer, the availability of spare parts, etc. should also be considered.

**Standards**
It is necessary to ensure that all accessories are produced by renowned manufacturers, supervised by accredited institutions that adhere to official
standards.

**Field experience**
Acknowledged field performance should be an essential requirement while selecting the equipment.

**Price**
It is expressed as the annual expense based on the acquisition cost, maintenance and life expectancy of the equipment.
CHAPTER 3: INJECTION EQUIPMENT

The application of fertilizers through the pressured irrigation system involves the injection of the fertilizer solution into the system, overcoming the network pressure. In order to do that, different approaches are used:

- **Pressure differential or batch tank system**: A portion of the mainline flow is diverted through a batch tank which may or may not contain a bladder for holding the chemical to be injected.
- **Suction produced by the Venturi principle**: where a flow constriction, with specific entrance and exit conditions of the pipeline, creates a vacuum due to the increased flow velocity through the constriction.
- **Injection by means of a hydraulic motor**: with water from the irrigation system.

**Fertigation devices and their location at the control head**

1 - Equipment location

The equipment for performing fertigation (batch tank, Venturi injector or pump), should be located downstream from the metering valve and before the filter (Fig 1).

![Diagram of irrigation control head](image)

The distance between points 7 & 8 has to be at least 40 cm

Fig. 1. Schematic representation of irrigation control head onto which an injector of any type may be connected

2 - Injection equipment

Injector selection:
Proper selection of the chemical injector and the chemical solution tank must include the following considerations:

- Type of irrigation system.
- Crop grown.
- Irrigation system flow rate.
- Injection rate.
- Type of chemical to be injected.
- Determination of whether chemigation is to be proportional or by volume.
- Source of power.
- Duration of operation.
- Future expansion expectations.
- Safety considerations.

Some of these considerations were already discussed in chapter 2.

**The batch tank system:**
The principle of operation includes a throttling valve (Fig. 2), forcing some of the mainline’s flow to be diverted through a batch tank, which may or may not contain a bladder for holding the chemical to be injected.

![Batch tank diagram](image)

**Fig. 2. Batch tank**

The batch tank is connected in a loop parallel to the mainline. Materials for the construction of the tank and its fittings, and the installation itself, must be such that the system can safely operate at the mainline operating pressure. Flow diversion from the mainline is accomplished by a pressure gradient of 0.1-0.2 atm. Irrigation water enters the tank through a pipe, 1/2” to 3/8” in diameter, which reaches near the bottom. The tank may be filled soluble solid fertilizer or with a fertilizer solution, prepared in advance, and then closed hermetically. A second pipe, exits from the tank, returning to the mainline downstream from the throttling valve (Fig 2). Irrigation water flows into the tank and water with the chemical in solution flow into the mainline. The higher the pressure differential across the throttling valve, the higher the fertilizer injection rate (Table 1).
Table 1. Injection rate through a batch tank as a function of the pressure gradient and the diameter of the entrance and outlet pipes.

<table>
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<th>Pipe Diameter</th>
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<th>D= 3/8”</th>
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<td>Pressure Gradient [atm.]</td>
<td>Injection Rate [lt/h]</td>
<td>Injection Rate [lt/h]</td>
</tr>
<tr>
<td>0.1</td>
<td>660</td>
<td>320</td>
</tr>
<tr>
<td>0.2</td>
<td>990</td>
<td>500</td>
</tr>
<tr>
<td>0.3</td>
<td>1200</td>
<td>650</td>
</tr>
<tr>
<td>0.4</td>
<td>1350</td>
<td>760</td>
</tr>
<tr>
<td>0.5</td>
<td>1500</td>
<td>850</td>
</tr>
<tr>
<td>0.6</td>
<td>1650</td>
<td>940</td>
</tr>
<tr>
<td>0.7</td>
<td>1800</td>
<td>1030</td>
</tr>
</tbody>
</table>

During the fertigation process, the concentration of the fertilizer solution within the tank diminishes progressively, due to dilution by water. In case a solid fertilizer was put in the tank, the concentration remains more or less constant as long as some solid fertilizer remains in the tank.

Fertigation duration depends on tank volume and its discharge, it can be calculated with the following equation:

**Equation 1:**

\[ t = 4 \times \frac{T_v}{q} \]

\( t \) = fertilization duration \[ \text{hour} \]

\( T_v \) = tank volume \[ \text{liter} \]

\( q \) = tank discharge \[ \text{liter/hour} \]

This equation is based on the following principle:

Four volumes of irrigation water must pass through the tank to carry the fertilizer solution into the irrigation system.

**Example 1:**

If the volume of the tank (V) is 120 liters, then:

\[ 4 \times 120 = 480 \text{ liters of water} \]

are required in order to inject 95% of the fertilizer solution into the irrigation system.

A manometer and a small metering valve enable adjusting the pressure gradient and the discharge rate to deliver the fertilizer solution in the time available, in accordance to the principle described above.

The tank should be large enough to contain enough solution to complete an entire operation.

**Advantages**

- Simplicity in construction and operation.
- Relatively low cost.
- Wide field experience. This equipment has been in use for more than 30 years.
- It does not require any external energy source; it uses the energy of the irrigation water.
- It is mobile and resistant to pressure and discharge fluctuations.
- It allows a broad dilution ratio.

**Limitations**
- There is little or no control of both chemical injection rate and the concentration of the chemical in the irrigation water.
- Materials for its construction and the fittings, as well as the installation itself, must be such that the system can safely operate at the mainline operating pressure.
- Each irrigation turn requires replenishment of the chemical.
- High cost for large tanks.
- Throttling causes a pressure loss.
- All components of the injection system in contact with the chemical solution must be made of materials that withstand the corrosive action of the chemicals in solutions.
- It can be used in automated systems by means of a chemically resistant water meter with electronic output.

Fertilizer tanks are manufactured in a wide range of sizes, Standard from 60 to 220 liters; larger sizes may be delivered on order.

**Operational sequence**
- The bypass hoses are connected to the mainline by two small valves.
- In case the equipment is to be moved from one plot to the next, easily detachable connectors are installed.
- There are three different ways to fill the tank:
  a) directly with liquid fertilizer solution.
  b) Solid fertilizers may be dissolved in advance, in an additional tank, and filtered when refilling the batch tank.
  c) Solid fertilizer may be introduced into the batch tank, but complete dissolution must be achieved during irrigation.

The tank must be filled fully; otherwise there is a risk that the fertilizer will not leave the tank. It is necessary to add a backflow-preventing device at the tank entrance to prevent backflow and to avoid vacuum formation that may disturb the flow.
- Starting the irrigation system must be carried out while the valves connected to the tank are still closed and the throttling valve is fully open.
The connecting valves are opened together with the gradual closure of the throttling valve, monitoring simultaneously the pressure gradient with a manometer, until the desired gradient is achieved.

**The Venturi injector.**

This injector operates on the Venturi principle, where a flow constriction, with specific entrance and exit design, installed on the pipeline, creates a vacuum due to the increased velocity of flow through the constriction. The injection rate that can be achieved with a Venturi depends upon the pressure differential across it. This pressure differential is between 5% and 75%, according to the injector’s design.

![Fig 3. Venturi injector characterization](image)

**Advantages**

- Does not require an external energy source to operate, it operates with the pressure of the irrigation system.
- Very simple to operate, it lacks moving parts, minimal depreciation and almost no malfunction.
- Suitable for injection up to 2 cubic meters/hour, adequate for chemigation of large areas from a central control head.
- Its cost is relatively low compared to alternative devices.
- The chemical solution can be stored in an open (non-pressurized) tank.
- Light and easily transportable.
- Easy to install.
- Easily connected to electronic control systems (it fits any level of automation), with a chemically resistant water meter with electronic output.
- Maintains a constant concentration of nutrient in the irrigation water.
- Withstands corrosive materials.

**Limitations**

- Large pressure losses. Many models loose at least one third of the inlet pressure. For low-pressure systems, such as micro-irrigation there may not be enough pressure available to operate the Venturi.
- Chemical injection rates are affected by variations in the pressure. In this case a booster pump should be installed at the inlet.
Each model has a limited operation range.

A minimum water discharge through the injector is required to meet the Venturi suction principle. This minimum discharge rate varies with the inlet pressure.

From the above it can be concluded that in order to take full advantage of the Venturi injector, the following conditions must be fulfilled:

- Pressure should be high enough to operate the Venturi.
- A constant pressure should be ensured, which may be achieved in different ways.
- Venturis are constructed of chemically resistant materials, such as copper, plastic and stainless steel. For their use in chemigation, they are manufactured in diameters from 3/8” to 2”. Sophistication and prices vary among manufacturers.

**Venturi injector characteristics.**

In order to be able to choose the right model, it is important to define its properties:

- The pressure range at the inlet: Each model has an optimal pressure range specified by the manufacturer.
- Pressure losses: The gradient between the inlet and the outlet (P1 - P3) is expressed as a percentage of inlet pressure. For each model, a given minimum gradient must be attained in order to achieve suction. For most models this gradient is 1/3 of the inlet pressure. Nonetheless there are some that loose up to 50%. Recently bi-phasic models, loosing about 10% were developed. The head loss varies with the inlet pressure differential.

![Fig. 4. Principle of operation of the Venturi](image)

- The suction rate is expressed in liters per hour. It depends on the inlet pressure, the head loss and the size of the constriction. The suction rate may be regulated by means of different accessories (restrictors);
- Water flow range. The inlet pressure and the nozzle (which in some models may be replaced with one of a different diameter), affect water flow through the injector. The manufacturer defines the operation
range. A minimum flow rate is required through the injector in order to start suction.

The manufacturer publishes all pertinent data about the injector in the form of tables and charts, as well as recommendations for installation, operation and maintenance.

There is a wide range of suction discharges, from 2 up to 2,000 l/h (Netafim models). Every injector has a minimum required inlet pressure for its optimal operation, which varies from 14 to 98 meters (with suction hoses 12 mm. in diameter).

**Types of Venturi injectors**

**Simple Venturi**: This includes the basic model only, without any additional accessories.

![Fig. 5. Simple Venturi Injectors](image)

The supply hose from the chemical supply tank to the Venturi must include an automatic, quick-closing check valve to prevent backflow towards the supply tank. This valve must be located immediately adjacent to the Venturi inlet. This same supply hose must also carry either a functional, normally closed, solenoid-operated valve connected to the system interlock, or a normally closed, hydraulic valve which opens only when the main water pipe is adequately pressurized.

Injectors may be installed in-line (when the flow rate in the system is low, or pressure loss is not a problem), or, alternatively, on a bypass.
**Bypass installation.** In bypass systems, an alternative to placing both valves in the line from the chemical supply tank is presented. A check valve is installed in the bypass line immediately upstream of the inlet to the Venturi and either a normally closed solenoid or a hydraulic valve immediately downstream of the Venturi outlet.
Another alternative is to install an auxiliary booster pump on the bypass leading to the Venturi. This pump must be connected to the irrigation pump system interlock, so that it is automatically shut-off when the pump of the irrigation system stops or whenever water pressure falls to the point where chemical and/or water distribution is affected adversely. This setup is mostly recommended for use in greenhouses and detached cultures.

Fig. 8. Venturi injector in a bypass loop boosted by a small centrifugal pump

There are a number of bypass loop systems; it may be around a filter and a pressure regulator, (where the filter contributes to the differential pressure developed by the regulator), a throttling valve, or a pressure regulator.

Fig.9. Venturi injector on a bypass loop around a filter and a pressure regulator
This method is used when the pressure regulator creates less than the minimum required pressure differential and an additional pressure drop is required, which in this case is provided by the filter.

The installation combines the pressure drop within the filter with that of the pressure regulator to operate the injector. This method is particularly suitable for drip irrigation systems. Care should be taken to ensure that the downstream pressure is sufficient to operate the irrigation system.

![Diagram of Venturi injector setup on a bypass around a pressure regulator](image)

**Fig. 10. Venturi injector setup on a bypass around a pressure regulator**

This method is used when the regulator develops a high enough pressure drop without any additional accessories.

In all cases, a filter must be placed on the end of the suction hose, within the tank containing the chemical. Usually the filter has a diameter of ½" to 1" and a 120 mesh screen.

The suction rate can be regulated in one of the following ways: with a metering orifice, a screw, changing nozzles, a needle valve and, in some of Netafim’s models, drippers are installed on the suction pipe, regulating the suction rate.

It is recommended to check the suction pipe periodically for obstructions. These should be removed. The injector should be positioned above the tank containing the chemical, in order to prevent the solution from flowing into the irrigation system by gravity.

Dosing and regulation of Venturi injectors is similar to that of injector pumps, and will be discussed together in chapter 8.

**Injection with pumps**

The chemical injection device is considered to be the heart of any fertigation system. A wide variety of devices are available. They appear in many different models, sizes and materials. They can be classified as either active, meaning an external power source is required, or passive, meaning no external power is needed.
Active type injection devices include positive displacement pumps such as diaphragm, piston, roller, and gear pumps driven by an external energy source. Passive types of injectors depend on the energy of water under pressure from the irrigation system, to inject the chemical solutions into it. The primary passive type of injector operates on the Venturi principle, as explained above.

**Principle of operation.**
The chemical solution is sucked from a tank and injected into the irrigation system by a pump, which creates a pressure higher than that existing in the irrigation system itself. Pumps should be of rugged construction with internal and external components made of materials that resist corrosion. Active injection devices include positive displacement pumps such as diaphragm, piston, roller and gear pumps. Piston and diaphragm pumps are the most commonly used in chemigation, due to their reliability and accuracy. Their connection to automatic controllers is relatively simple. Roller pumps are quite accurate but highly sensitive to dirt, precipitates and corrosive chemicals. Centrifugal pumps are less sensitive to dirt and relative inexpensive. They are used whenever a high discharge of fertilizer solution is required. These pumps are inaccurate at low injection rates. Injection pumps can operate manually or automatically. The chemical tank must be made of chemically resistant materials (usually plastic). Its volume varies from a few hundred liters to 10 cubic meters.

**General advantages**
- Injection pumps can be adjusted over a wide range to provide a continuous and uniform concentration of chemical in the irrigation water. This is important whenever it is desired to maintain a constant concentration of the injected chemical in the irrigation water;
- Injection pumps provide full control on the chemical injection process, such as injection timing and may be completely automated.
- Injection devices allow central fertilization: a single operator may control the whole process from one central point.
- There is no pressure loss in the system.

**General limitations**
- The equipment is relatively complicated to operate.
- High initial cost as compared with other systems (batch tank and Venturi).
- Only fertilizer solutions may be injected.
- In the case of non-hydraulic pumps, an external energy source is required.
- In case the flow of water ceases, injection may continue if the pumps are powered by an external power source.

**C1) Hydraulic pumps**
Hydraulic injectors are considered active injectors although an external energy source is not required. The energy of the pressurized water in the irrigation system is used to drive the injector.
Hydraulically powered positive displacement pumps are operated by water flow past a piston. Injection rates are accurately controlled. Many models allow injection rates to be set proportional to the mainline irrigation flow and pressure. The pump operates within the pressure range defined by the manufacturer. Discharge depends on the water pressure, however it can be regulated by a number of devices. If the water flow ceases, injection will stop immediately. These injector pumps have proven their efficiency under field conditions and they are becoming more popular. Some models exhaust the water used to drive the pump, requiring some means of collecting and recycling or disposing of the drainage water.

C1.1) Diaphragm pumps
A diaphragm hydraulic pump is presented in the next figure.

![Diagram of a diaphragm fertilizer pump](image)

1. Fertilizer valve assembly
2. Suction hose
3. Fertilizer suction check valve
4. Fertilizer injection check valve
5. Upper diaphragm housing
6. Lower diaphragm housing
7. Central shaft
8. Sensor
9. Control stem
10. Pilot valve
11. Drive water inlet
12. Water distributing valve
13. Drive water regulating valve
14. Drain water inlet

Fig. 11. A diaphragm fertilizer pump, Model T.M.B. (250 l/h)

Principle of Operation:
The pump consists of two diaphragm assemblies, an upper and a lower one, connected by a central vertical shaft. One of these assemblies comprises both a chemical and a water chamber, whereas the second assembly consists of a water chamber only. Water from the mainline enters both chambers simultaneously – pushing the central shaft as well as increasing the pressure on the fertilizer solution up to two times the pressure in the mainline. The filling and emptying of both water chambers is caused, according to the
Injector type, due to the flexibility of the diaphragm, or due to a spring. During the downwards stroke, the chemical enters the pump through the suction check-valve, while the delivery check-valve remains closed, thus preventing back flow from the irrigation system into the pump. During the upwards stroke, the delivery check-valve opens and the chemical is injected into the irrigation system while the suction check-valve remains close, thus preventing the chemical from flowing back into the tank. A vacuum-breaker prevents chemical from being suctioned into the irrigation system by gravity.

![Diagram of Diaphragm Pump Installation](image)

**Fig. 12. Installation of a diaphragm pump in the field**

**Advantages**

Diaphragm pumps are more expensive than piston pumps, but offer some advantages:

- They have a small number of moving parts;
- Limited areas of the components are exposed to the chemicals injected. This reduces the potential for corrosion, wear and leakage, lowering maintenance costs and enhancing environmental safety;
- The injection rate is easily adjusted while the pump is operating.

Diaphragm pumps are manufactured in several models, with injection rates ranging from 3 to 1200 l/h. Working pressure ranges from 2 to 8 atm. TMB diaphragm pumps are designed to deliver a maximum of 50, 250 liters or 600 liters of chemical solution per hour, according to model. (See chapter 9).

The ratio between the injected solution and drainage water is 1:2 (for every liter of injected solution, two liters of water are ejected). There is no pressure loss in the mainline and no throttling of the mainline is required.
Two 40 mesh filters should be installed, one on the drive water hose, and the other in the suction valve inlet.

Dosing and regulation:

- With a regulating valve, controlling the number of strokes per minute. In this way the concentration of the chemical in the irrigation water may be regulated.
- Metering the water driving the pump upstream from the regulating valve with a metering valve that closes after a preset water volume has been delivered.
- The amount of solution to be injected into the system can be metered at the outlet from the chemical tank.
- Automation is achieved by a special electronic micro-switch attached to the pump. This device counts the strokes, and transmits this information to the irrigation computer, which is able to translate them into liters of solution injected.

Fig. 13. TMB diaphragm pump 250 lt/h performance curve
C1.2) Piston pumps
Piston pumps are available in single or dual injection heads with a wide range of injection capacities. Piston-operated units require water from the pressurized irrigation system to drive the piston. The drive water, which is expelled from the piston, is usually three times the volume of the solution injected. One of the most popular piston pumps is Amiad’s model.

Principle of operation.
The reciprocating type motor in the cylinder housing consists of two pistons and a main pilot valve. The pump, which is connected to the motor body, draws the chemical solution from the tank and injects it into the pipeline. The interrupter knob is an integral part of the automatic shut-off unit. The shut-off automatically stops the operation of the pump when the level of the chemical drops below the level of the suction head. Two check valves are fitted on the discharge line, and a third one on the chemical intake line. Their functions are to prevent water from the mainline flowing into the chemical tank and to prevent the chemical from returning to the tank.

An air-release valve is manually activated for venting air from the system, mainly for priming the pump. If as a result of an interruption of the water supply a vacuum is created in the mainline, the ball in the air-release valve will automatically open the escape vent and the line will be vented to the atmosphere. When the pump is installed below the level of the chemical in the tank, an additional check and anti-siphoning valve should be installed. These arrangements ensure that siphoning of the chemical into the mainline does not occur.

The suction base consists of a heavy, round plate and a filter containing a plastic ball.
There are four pump models available:
1. The pump is located above the liquid level in the fertilizer tank and the suction head is located at the bottom of the tank.
2. The pump is located below the liquid level in the fertilizer tank and suction is carried out from the tank’s bottom, through a filter.
3. A duplex injector unit made up of two injectors assembled in parallel on one carrier. It has been developed for the injection of large quantities of chemicals, 100-700 l/h.
4. Automatic pump controlled by a computer, or by any other electronic control system.

These pumps inject 33 cubic centimeters of fertilizer solution per stroke, the discharge rate reaching up to 320 l/h, as a function of the pressure in the irrigation system.
Fig. 14. Amiad hydraulic pump installed above the liquid level in the tank (suction feed).

Fig. 15. Amiad hydraulic pump installed below the liquid level in the tank (gravity feed).

These pumps operate in the range of 0.5 to 8 bars of pressure (0.7 to 115 psi).
Command, regulation and control:

- Despite its dependence on the system pressure, flow regulators may regulate discharge. Using these regulators the flow rate may be adjusted from 10 to 80 lt/h. Flow regulators are inserted between the two sections of the connector on the chemical injection hose.

- A suction-type unit furnished with an automatic shut-off valve, which closes when the level of the chemical solution drops below the base of the suction head. In this case, if the container is filled in advance with the required volume of chemical solution, the unit will automatically stop functioning when all the solution has been injected.

- When this is not practical (e.g., when pumping from a large tank), a metering valve may be installed on the hose supplying water to drive the pump, downstream from the ¾” manual control valve. This should be set exactly to three times the required volume of chemical to be injected. The use of flow regulators obviates this alternative.

- By manually operating the shut-off knob.

- By using a hydraulic shut-off valve instead of the automatic shut-off unit. The hydraulic shut-off is operated by water pressure which can be triggered electronically, volumetrically or on a time basis.

Fig. 16. Amiad duplex injector unit
Duplex Model (4-03)
The duplex injector has been developed in order to inject larger volumes of fertilizers or chemicals into the irrigation system.

Although the Duplex is made of two injector units, it has only one water drive, one chemical feed line and one injection outlet. The Duplex and accessories use the same components of the standard injector.

Fig. 17. AMIAD automated pump

These pumps inject 33 cubic centimeters of fertilizer solution per stroke, the discharge rate reaching up to 320 l/h, as a function of the pressure in the irrigation system.
These pumps operate in the range of 0.5 to 8 bars of pressure (0.7 to 115 psi).

**Command, regulation and control:**

- Despite its dependence on the system pressure, flow regulators may regulate discharge. Flow rate ranges from 10 to 80 lt/h, when using these regulators. Flow regulators are inserted between the two sections of the connector on the chemical injection hose.
- A suction-type unit furnished with an automatic shut-off valve, which closes when the level of the chemical solution drops below the base of the suction head. In this case, if the container is filled in advance with the required volume of chemical solution, the unit will automatically stop functioning when all the solution has been injected.
- When this is not practical (e.g., when pumping from a large tank), a metering valve may be installed on the hose supplying water to drive the pump, downstream from the ¾” manual control valve. This should be set exactly to three times the required volume of chemical to be injected. The use of flow regulators obviates this alternative.

By manually operating the shut-off knob.
By using a hydraulic shut-off valve instead of the automatic shut-off unit.

The hydraulic shut-off is operated by water pressure which can be triggered electronically, volumetrically or on a time basis.
In addition, a manual pump can be transformed into an automatic one by attaching a pulse transmitter. The pulse transmitter is an electronic device, attached to the injector and capable of converting its strokes into electric signals. By means of this device, information regarding the quantity of chemical injected into the mainline can be conveyed to an electronic control...
system. Transmitters can deliver pulses each 33cc, 100cc, 1 liter, 10 liters or one US gallon.
The ¾” hydraulic (normally closed) valve, has a wide variety of applications for the control of chemical solutions, and water flow. The control system is completely separate from the chemical, thereby allowing the flow of expensive solutions to be controlled by water under pressure. The normally closed feature ensures that in the case of malfunction of the control system, or damage to the control tube, the valve will remain closed.

C 1.3) Hydraulic pumps that do not eject drain water
Not all models of hydraulic pumps eject drain water during operation. Hydraulic pumps that do not eject drain water operate with a hydraulic motor, a piston and a shuttle valve inverting the direction of flow, transferring the hydraulic pressure, once to the upper part of the piston, and then to its lower part. The piston moves back and forth cyclically. Any amount of water will activate the described process, therefore the number of piston strokes per unity of time, is a function of the water flow through the motor. The lower part of the piston is connected to a suction unit, which moves within a cylinder, so that the length of the stroke can be adjusted, enabling the control of the amount of solution injected into the mixing chamber with each stroke of the piston.

Fig. 19. Schematic representation of the DOSATRON pump

The pump is installed in-line of the irrigation system, resulting in a total dependence of motor speed and the rate of injection of the chemical into the irrigation water, upon system discharge. No water is drained from the system. Continuous injection of the fertilizer into the mixing chamber where it meets the irrigation water, ensures proportional injection without the need of any electronic accessories. Everything is done hydraulically. This is the main advantage of this system.
Installation:
The pump may be installed in three different ways:

- **In line.** In this case the system discharge must be within the allowed range according to the model’s specifications.
- **Two pumps installed in parallel.** This applies when two different solutions must be injected simultaneously;
- **Installed on a bypass.** This allows alternating irrigation and fertigation when the main line discharge is above the capacity of the pump. A constriction valve is used to force part of the water to flow through the pump. In this case, its main advantage is lost.

Model D8R has a maximum water discharge of 8,000 liters/hour, with a working pressure range of 0.15 – 8 atm. For every cubic meter of water from 2 to 20 liters of chemical solution may be injected. The DI210 model has a water discharge range of 10 to 2500 lt/h, with a working pressure of 0.5 - 4 atm, with a solution concentration ranging from 20 to 100 liters for every cubic meter of water.

**Electric pumps**
When electricity is available in the field, it may become more convenient to employ electrical fertigation pumps. Electrical pumps are inexpensive and reliable. They may be operated at low cost and easily combined with automation equipment.

A wide range of models and types are available, starting from small diaphragm pumps able to inject only a few liters per hour, to big pumps connected to volumetric valves able to inject proportionally. Since an external energy source is required, usually electricity, these pumps are installed in greenhouses or near wells.

**D1) Diaphragm pumps:**
Diaphragm dosing pumps are leakage-free and specifically designed for corrosive or toxic media. Depending on the type of drive, the diaphragm can be used at pressures up to 10 bar. Diaphragm pumps are provided with a separating chamber, which, in the event of rupture of the diaphragm due to wear, prevents the chemical flooding the pump itself or other components of the system. Any leakage is discharged by gravity through a hose to a drain or collection tank. Due to their design, diaphragm dosing pumps are more dependent on pressure than piston pumps.

Other pumps work with positive-displacement powered by a single-phase AC motor as prime mover. An overload protected - synchronous motor drives the pump. A precise eccentric / tappet / spring system transforms the revolutions of the motor, through a gearbox, into the suction and injection strokes on the diaphragm. Thus a fixed volume (stroke volume) of the solution is injected via the suction valve into the dosing head and displaced through the pressure valve into the system. The suction and pressure valves are double ball valves. The capacity is adjusted linearly by varying the stroke length with the stroke adjustment knob in a ratio of 1:10.
D2) Piston pumps
These pumps operate in a manner similar to that of the hydraulic piston pumps. They are very precise and less dependent upon pressure than diaphragm pumps. In contrast to diaphragm pumps, dosing changes in proportion to the stroke length and can be controlled to reduce output down to the lowest rate. Twin and multiple piston pumps are thus particularly suited for accurate mixing applications in which fully adjustable, constant proportions of different liquids have to be dosed.
Using variable speed motors the concentration remains constant while quantity injected adjusts to the variable discharge of the irrigation system. Piston pumps operate at a pressure range of 2 - 10 bars, with a flow rate of 55 to 270 l/h.

Fig. 20. Schematic representation of an ALLDOS diaphragm pump
CHAPTER 4: SAFETY EQUIPMENT COMPONENTS

The injection of chemicals into an irrigation system presents a potential hazard to public health. The irrigation system acts as a cross connection between the chemical solution tank and the potable water source. The cross connection can be to an irrigation district mainline, municipal water line, stream lake, river or groundwater.

A cross connection is any connection or structural arrangement between a potable water system and any non-potable water system or chemical source through which backflow can occur. Any temporary or permanent devices through which backflow can occur are considered cross connections. Backflow usually cannot be forecasted in advance. The probability of potable water contamination in the case of cross connection is very high, and the only question is when is it going to happen? The water source can be subjected to the chemical being injected into the irrigation system by two backflow processes, back pressure and back siphonage.

**Examples of cross connection:**

- Water pipe with one end immersed in a tank or contaminant tank.
- Water pipe connected to the bottom of a tank containing contaminants.
- Water pipe connected to a water system treated with chemicals (algae growth inhibitors, anti-corrosive materials, etc).
- One common water pipe for two different water sources, one of them being non-potable (waste water, etc).
- Water pipe connected to an irrigation system in which chemicals such as herbicides, fertilizers, acids are injected.

**Back Siphonage:**

Is caused by low pressure or a reduced pressure in the supply pipeline. Main causes of backsiphonage are:

- Creation of a severe hydraulic gradient by undersized piping in the supply line.
- Pipeline breakage in the district mainline, which is lower than the customer service point.
- Reduced mainline pressure caused by a high water withdrawal rate such as fire fighting or mainline flushing;
- Reduced mainline supply pressure caused by pump or power failure.

**Back Pressure:**

Occurs when the user system is operating at a higher pressure than the potable water supply system. Major sources of backpressure are:

- Booster pumps on the user system used to increase flows and pressure requirements;
- Interconnection with other piping systems operating at higher pressures;
- Connections to pressurized systems such as boilers;
In low-pressure trickle irrigation systems, backpressure can be caused by either difference of topographical elevation of the system or chemical injection pumps.

**Selection of backflow prevention device (BPD):**
BPD is a combination of a check valve, a vacuum breaker, and a low pressure drain valve installed between the point of chemical injection and the water source in order to prevent pollution of the water source by the injected chemical.

Backflow can be prevented by the physical separation (air separation), between the potable water supply system and the water containing the contaminants. This constitutes the ideal means for preventing backflow. Proper air separation may be achieved by preventing direct connection between the water supply system and the consumer one, whenever the linkage between them is carried out through a water reservoir. The vertical separation between the pipe end above the water in the reservoir must be at least double the supply pipe diameter and no less than 25 millimeters. This separation constitutes a simple and safe solution to prevent backflow. It does not require maintenance.

Since usually water is supplied at a given pressure, the solution above may not be applicable. It may be better to use one of the following devices.

There are many types of backflow prevention devices available, some that protect against backsiphonage only and others that protect against both backsiphonage and backpressure. Depending on the water source, chemigation systems must use either a double check valve assembly (as required in Israel by law), or a reduced pressure backflow device.

**Atmospheric vacuum breaker (AVB):**
The AVB allows air to enter the downstream pipeline when the pressure falls to a gauge pressure of zero or less. The AVB must be installed downstream after the last shutoff valve (no valves may be installed downstream of the atmospheric vacuum breaker). A minimum height of 15 centimeters above the highest outlet on the non-potable system The AVB must not be used where operating pressure is maintained continuously for more than 12 hours during any 24 hour period, since the relief valve may get stuck in closed position and cause malfunctioning.

**Pressure vacuum breaker (PVB):**
The PVB consists of a valve, that vents to the atmosphere, and is loaded internally by a spring. The spring assists in opening the valve and therefore the PVB can be installed upstream of a shutoff valve and employed where the system is permanently at operating pressure. A PVB must be installed 30 centimeters above the highest outlet on the non-potable water system (chemigation system, sprinkler, trickle, etc.), which has to be protected. Acceptable uses for PVB as well as for AVB include situations where non-potable water is pumped into an irrigation system that is cross-connected to an irrigation district or municipal pipeline or irrigation system applications that do not have a chemigation system installed.
Common applications are on automatic home or industrial underground sprinkler systems, and agricultural trickle and sprinkler irrigation systems that do not use chemigation systems. It must be installed at an easily visible place. In chemigation systems, where external energy and not water-powered injectors are installed, PVB cannot be used as a replacement for double check valves assemblies, because they may cause backpressure in the system. Vacuum breakers are effective against backsiphonage only and cannot be used in backpressure situations.

![Figure 21. Pressure vacuum breaker installation in a high point in the irrigation system, to prevent backflow and backsiphonage](image)

**Double check valve assembly (DCVA):**

The DCVA consists of two approved check valves, internally loaded by a spring or weight, which are installed as a unit between two tightly closing shut-off valves. The DCVA is effective against backflow caused by backpressure or backsiphonage and provides protection from chemigation systems. The DCVA must be installed upstream of the chemical injection system at a location that is readily accessible for inspecting and testing purposes (Fig. 4.2).

The DCVA shall be installed above ground with adequate space to simplify maintenance and testing. It shall be inspected and tested after installation to ensure it is installed correctly and satisfactory and later on before every irrigation season. If possible, it should not be installed in a pit because any leaky test cocks would then become cross connection when the pit is flooded. If the unit must be installed in a pit, provisions for pit drainage must be provided. Test cocks should also be plugged to reduce the danger of leaks if the device does become submerged. The vault should be large enough to provide free access for testing or repairing the device. DCVAs larger than 2.5” shall have support blocks to prevent damage. A strainer with a blowout tap should be installed upstream to the DVCA. The DVCA must be drained in the fall and protected from freezing.
The lines should be thoroughly flushed before installation. Most failures during testing are caused by debris fouling either the first or second check valves seats.

![Diagram of irrigation system with vacuum breaker](image)

Figure. 22. Pressure (spring loaded) vacuum breaker on the highest point in the irrigation system (not at the control head)

Reduced pressure backflow prevention device (RPBD)
The RPBD consists of two independently acting, internally loaded check valves separated by a zone with reduced pressure. A differential RPBD (Fig. 4.3), consists of two check valves loaded with a spring, acting independently, normally closed, and a relief valve loaded with a spring in a chamber between them. The check valves are designed so that under regular flow and static situation, pressure in the reduced pressure zone is lower, at least by 0.14 atm, below the pressure at the inlet, and higher by at least 0.07 atm above the pressure at the outlet. When the pressure at the outlet rises, near to the pressure at the inlet, both check valves remain closed and prevent backflow. If there is a failure in the device, preventing shut-off of the check valves, the relief valve opens and releases to the atmosphere the water entering the chamber from the zone with reduced pressure. In addition, when the relief valve fails, it opens to the atmosphere, draining the incoming water and ensuring that backflow is not possible.

RPDB constitutes the accessory that provides maximum safety among all those mechanical backflow-preventing devices.
Figure. 23. A double check valve assembly

RPDB characterization:
- The RPDB completely prevents backflow caused by backsiphonage and backpressure.
- It is designed for use in situations that are considered very hazardous.
- In the case of failure, the RPDB alerts the operator by water leaving the system through the relief valve. This feature is unique and differs from any other device in the water system, and from any other device designed to prevent backflow.
- The RPDB does not allow pressure equilibration between the inlet, the intermediate chamber, and the outlet. In fact, the RPDB begins to release water through the relief valve when both pressures equalize, and the pressure gradient decreases below 0.14 atm.
- As a result of its structure and its hydraulic characteristics, a significant head loss in the system is incurred (0.5 to 0.8 atm), which must be considered when designing.

RPDB installation and maintenance
To achieve maximum efficiency special installation conditions should be observed:
- The RPDB is to be installed aboveground with adequate space to ease maintenance and testing. It shall be inspected and tested after installation to ensure it is installed correctly and operating satisfactorily;
- The RPDB is to be installed at least 30 centimeters aboveground;
- If possible, it should not be installed in a pit below ground level. Flooding of the pit could cause a direct cross connection through the relief valve. If installation in a pit is absolutely necessary, adequate drainage must be provided;
- Valves should be installed before and after the RPDB for testing every irrigation season;
- RPDBs larger than 2.5" shall have support blocks to prevent drainage;
- Horizontal installation is suggested;
- It should be sized hydraulically to avoid excessive pressure loss;
- Because of the nature of a reduced pressure backflow prevention device, fluctuating supply pressures, an extremely low flow or static flow condition may cause nuisance, dripping and eventual fouling of the device;
- RPDB drainage should be arranged when installed inside a structure.
- A strainer with a blowout tapping should be installed upstream of the RPDB.
- It must be drained in the fall and protected from freezing.
- The pipelines should be thoroughly flushed before installation of the RPDB. Most failures during testing are caused by debris fouling either the first or second check valve seats.

**Figure 24: A reduced pressure backflow prevention device**
Figure 25. Section through a RPDB

1. Water inlet
2. Isolation valve
3. Pressure measuring point
4. Check valve 1
5. Check valve 2
6. Pressure relief valve

Figure 26. Irrigation control head with backflow prevention device, check valve and vacuum breaker
CHAPTER 5: FERTIGATION MANAGEMENT

For chemigation/fertigation to be effective, proper irrigation management practices must be followed. Irrigation timing and amounts should be determined using scientific irrigation scheduling. Applying more water than the root zone of the crop can hold is not only inefficient use of water but will result in leaching of mobile chemicals and nutrients from the crop’s rooting zone. This has a double negative effect in that valuable chemicals are being wasted and potential pollution of groundwater increases as mentioned before. Chemical applications must be planned according to the irrigation schedule and not vice versa. Water applications must be timed according to crop need and not according to some pre-determined chemical application schedule. Knowledge of the amount of irrigation water to be applied and the duration of irrigation are basic information required for the proper calibration and operation of the injection equipment.

The farmer receives recommendations on the amount of fertilizer he should apply in the form of tables, soil and plant tissue laboratory analysis and by counseling. Data are supplied in different units: fertilizer weight or volume, amount of nutrients to apply per unit area, nutrient concentration in the irrigation water, the concentration of fertilizer in the irrigation water, etc. In order to be able to implement these recommendations, it is important to translate them into practical instructions, in accordance with the equipment available at each farm. Thus, calibration is required.

**Calibration**

Calibration of chemigation systems is relatively straightforward, however it requires time, equipment and accurate calculations to reach the proper chemical application rate.

Calibration involves a number of basic steps:
1. Determine the area to be irrigated (fertilized) in hectares or any other area units,
2. Determine the desired amount of fertilizer to be applied per unit area. If the recommendation was given in kilos of nutrient per hectare we employ Equation 5.

**EQUATION 5:**

\[
F_w = 100 \times \frac{N_w}{N_c} \%
\]

- \(F_w\) = fertilizer dose (by weight) \[kg/hectare\]
- \(N_w\) = nutrient dose (by weight) \[kg/hectare\]
- \(N_c\) = nutrient concentration in the fertilizer \[%\]

**EXAMPLE 5:**

200 kg/ha of Nitrogen are recommended (\(F_w\)), the fertilizer is to be ammonium sulfate, containing 21% of Nitrogen (\(N_c\)), then:
\[ Fw = 100 \times 200 \text{ kg/ha} / 21\% = 950 \text{ kg/ha} \]

3 - Determine the desired volume of fertilizer to be applied per unit area with Equation 6.

**EQUATION 6:**

\[ Fv = Fw / Sw \]

- \( Fv \) = fertilizer volume [liter/hectare]
- \( Fw \) = fertilizer weight [kg/hectare]
- \( Sw \) = specific weight [kg/liter]

**EXAMPLE 6:**

An amount of 65 kg/ha of liquid ammonium nitrate (\( Fw \)) is recommended. The specific weight (\( Sw \)) of liquid ammonium nitrate during summer months is 1.3 kg/lt, then:

\[ Fv = 65 \text{ kg/ha} / 1.3 \text{ kg/lt} = 50 \text{ lt/ha} \]

4 - Determine the total amount of fertilizer required for a single turn. When a certain amount of fertilizer is to be applied in a single irrigation turn, independently of the injection time or of the dilution relation we employ Equation 7.

**EQUATION 7:**

\[ Ft = Fd \times A \]

- \( Ft \) = fertilizer per irrigation turn [liter or kg]
- \( Fd \) = fertilizer dose, (by weight) [kg/ha]
- \( Fv \) = fertilizer dose, (by volume) [lt/ha]
- \( A \) = Area fertigated per irrigation turn [ha]

**EXAMPLE 7:**

If the area is 0.8 ha, and the fertilizer dose (\( Fv \)) is 120 liters/ha, whay would be the total amount of fertilizer for a single irrigation turn

\[ Ft = 120 \text{ lt/ha} \times 0.8 \text{ ha} = 96 \text{ liter per turn} \]
When the fertilizer is applied through a batch tank, or a Venturi injector, this will be the exact amount of fertilizer to be placed in the chemical tank. When the system is automated and control units, such as irrigation computers, operate the injectors, this will be the data to be provided for scheduling fertigation. Although when working with stroke injector pumps, it is necessary to translate fertilizer volume solution into pulses, according to the chemical volume injected per pulse, as provided by the manufacturer (Chapter 3), or by the number of pulses per each signal transmitted to the controller.

**Batch tank discharge**

Since the amount of water that must flow through the batch tank in order to inject the diluted fertilizer is the tank volume times 4, then:

**EQUATION 8:**

\[
q = 4 \times \frac{T_v}{t}
\]

- \( q \) = tank discharge [liter/h]
- \( T_v \) = tank volume [liters]
- \( t \) = fertilization duration [hours]

**EXAMPLE 8:**

The batch tank has a volume of 120 liters (\( T_v \)), and the fertilization duration is 20 minutes (\( t \)), then:

Conversion of minutes into hours:

\[
20 \text{ min} / 60 \text{ min/h} = 0.333 \text{ h}
\]

\[
q = 4 \times 120 \text{ lt} / 0.333 \text{ h} = 1455 \text{ lt/h} = 1.455 \text{ m}^3/\text{h}
\]

**Injector discharge (hydraulic or electric)**

**EQUATION 9:**

\[
q = Fc(v) \times Q
\]

- \( q \) = injector discharge [liter/hour]
- \( Fc(v) \) = fertilizer concentration (by volume) [liter fert / m\(^3\) water]
- \( Q \) = irrigation system discharge [m\(^3\) water/hour]
EXAMPLE 9:

For example, for each cubic meter of water, two liters of solution are required, the system discharge rate being 15 m³/h
The required discharge of the injector will be:

\[ q = 2 \text{ lt fert/} m^3 \text{ water} \times 15 \text{ m}^3 \text{ water/h} = 30 \text{ lt fert/h} \]

**Injector discharge for quantitative dosing**
The required discharge is calculated as follows:

**EQUATION 10:**

\[ q = \frac{Ft}{t} \]

\[ q = \text{injector discharge} \quad [\text{liter/hour}] \]
\[ Ft = \text{fertilizer solution to be injected during an irrigation turn} \quad [\text{liter}] \]
\[ t = \text{Fertigation duration} \quad [\text{hour}] \]

EXAMPLE 10:

For example, on a 5 ha plot, 100 l/ha are to be applied. Thus, if net duration of the injection is 5 hours, (excluding the time required for filling the pipelines and flushing them), then the injector's discharge will be:

First we calculate Ft by means of Equation 7

\[ Ft = Fv \times A = 100 \text{ lt/ha} \times 5 \text{ ha} = 500 \text{ liters} \]

Now we calculate q:

\[ q = \frac{500 \text{ lt}}{5 \text{ h}} = 100 \text{ lt/h} \]

**Solid fertilizer weight per cubic meter of irrigation water**
Whenever recommendations are given in ppm (parts per million, see appendix), the calculation is as follows:

**EQUATION 11:**

\[ Fc(w) = \frac{100 \times Nc(w)}{Nc(\%)} \]

\[ Fc(w) = \text{fertilizer concentration (by weight)} \quad [\text{gr/m}^3] \]
\[ Nc(w) = \text{nutrient concentration in the irrigation water} \quad [\text{ppm}] \]
\[ Nc(\%) = \text{nutrient concentration in the fertilizer} \quad [\%] \]
EXAMPLE 11:

For example, a concentration of 90 ppm nitrogen in the irrigation water is recommended, \( N_c(w) \), and the fertilizer to be used is ammonium sulfate with 21% of nitrogen, \( N_c(\%) \). The amount of fertilizer per cubic meter of irrigation water \( F_c(w) \) is calculated as follows:

\[
F_c(w) = 100 \times 90 \text{ ppm} / 21\% = 429 \text{ grams/m}^3 \text{ or } 0.429 \text{ kg/m}^3
\]

**Liquid fertilizer volume per cubic meter of irrigation water**

This is calculated in the same way as the former, the only change is that when using a liquid fertilizer we also have to take the fertilizer’s specific weight into consideration.

**EQUATION 12:**

\[
F_c(v) = 100 \times N_c(w) / (N_c(\%) \times S_w)
\]

- \( F_c(v) \) = Fertilizer concentration (by volume) \([\text{ liter/m}^3]\)
- \( N_c(w) \) = Nutrient concentration in the irrigation water \([\text{ ppm}]\)
- \( N_c(\%) \) = Nutrient concentration in the fertilizer \([\%]\)
- \( S_w \) = Fertilizer solution specific weight \([\text{ gr/cc]}\)

**EXAMPLE 12:**

For example, if we apply liquid ammonium nitrate, with a 21% nitrogen concentration, \( N_c(\%) \), and specific weight \( (S_w) \) of 1.3 gr/cc, then to obtain a 90 ppm nitrogen concentration in the irrigation water, we will have to apply:

\[
F_c(v) = 100 \times 90 \text{ ppm} / (21\% \times 1.3 \text{ gr/cc}) = 330 \text{ cm}^3/\text{lt}, \text{ or } 0.33 \text{ lt/m}^3
\]

**Discharge ratio of the fertilizer solution**

When the irrigation system and the pump discharge rate are constant, the concentration relation will be:

**EQUATION 13:**

\[
Q_r = q / Q
\]

- \( Q_r \) = discharge ratio \([\text{ liter / m}^3]\)
- \( q \) = injector discharge \([\text{ liter / hour}]\)
- \( Q \) = system discharge \([\text{ m}^3/\text{hour}]\)

**EXAMPLE 13:**

For example, the system discharge is 14 m³/h \( (Q) \), and the injector discharge is 20 l/h \( (q) \), the concentration of the fertilizer solution in the irrigation water is:
\[ Q_r = 20 \text{ lt fert/h} / 14 \text{ m}^3 \text{ water/h} = 1.43 \text{ lt fert/m}^3 \text{ water} \]

**Fertilizer solution dilution percentage**

Sometimes it will be necessary to dilute the concentrated fertilizer solution in the fertilizer tank before injection.

**EQUATION 14:**

\[ D(\%) = \frac{100 \times Fc(v)}{Q_r} \]

- \( D(\%) \) = Dilution percentage \[ % \]
- \( Fc(v) \) = Fertilizer concentration (by volume) \[ \text{liter/m}^3 \]
- \( Q_r \) = Discharge ratio \[ \text{liter/m}^3 \]

**EXAMPLE 14:**

For example, a concentration of 60 ppm nitrogen is recommended in the irrigation water, \( Nc(w) \). The fertilizer to be used is liquid ammonium nitrate, with a nitrogen concentration of 21\% \( Nc(\%) \), with a specific weight of 1.3 gr/cc \( (Sw) \). The system discharge \( (Q) \) is 105 m³/h, and the injector discharge rate \( (q) \) is 150 l/h.

To calculate the dilution percentage \( D(\%) \):

First, we calculate the required concentration of fertilizer in the irrigation water by means of Equation 12:

\[ Fc(v) = \frac{100 \times Nc(w)}{(Nc(\%) \times Sw)} = \frac{100 \times 60 \text{ ppm}}{21 \% \times 1.3 \text{ gr/cc}} = 220 \text{ cc/m}^3 = 0.220 \text{ lt of fert/m}^3 \text{ water} \]

Then we calculate the discharge ratio \( (Qr) \) with Equation 13

\[ Qr = \frac{q}{Q} = \frac{150 \text{ lt fert/h}}{105 \text{ m}^3 \text{ water/h}} = 1.43 \text{ lt fert/ m}^3 \text{ water} \]

Therefore, in order to obtain the dilution percentage \( (Dr) \), we use Equation 14:

\[ D(\%) = \frac{100 \times Fc(v)}{Q} = \frac{100 \times 0.220 \text{ lt of fert/m}^3 \text{ water}}{1.43 \text{ lt fert/ m}^3 \text{ water}} = 15.4 \% \]

In conclusion, 15.4 liters of concentrated fertilizer solution must be added to 84.6 liters of water in the fertilizer tank to achieve the desired final concentration of 60 ppm N during injection.

**The volume of fertilizer in the chemical tank (liters)**

The volume of fertilizer per irrigation turn is calculated with Equation 15.
EQUATION 15:

\[ Ft = Tv \times D(\%) / 100 \]

- \( Ft \) = fertilizer per irrigation turn [liter or kg]
- \( Tv \) = tank volume [liter]
- \( D(\%) \) = Dilution percentage [%]

EXAMPLE 15:

For example, the volume of the chemical tank is 250 liters with a relative dilution of 15.4%, thus:

\[ Ft = 250 \text{ lt} \times 15.4\% / 100 = 38.5 \text{ liters of fertilizer} \]

Consequently, into a batch tank with a volume of 250 liter, 38.5 liters of fertilizer solution should mixed with 211.5 liters of water, since:

\[ 250 \text{ lt} - 38.5 \text{ lt} = 211.5 \text{ lt} \]

Preparation of a compound fertilizer mixture

In order to obtain a given concentration of nutrients in the irrigation water, simple and compound fertilizers (see chapter 6) may be mixed. We calculate the required amount of each fertilizer by means of the following equation:

EXAMPLE 16:

For example, a total concentration of 60 ppm nitrogen, and 20 ppm phosphorus (P) is recommended, \( Nc(w) \). To obtain these concentrations in the irrigation water we need to inject liquid ammonium nitrate and liquid ammonium phosphate.

Since phosphorus concentration in commercial fertilizers is expressed as \( P_2O_5 \), we need to transform P into \( P_2O_5 \). This is carried out by using the factor 2.29 (see Table in the Appendix).

The first step is to convert the fertilizer units:

\[ P_2O_5 = 2.29 \times P \]

Thus: 20 ppm P are equal to \( 20 \times 2.29 = 45.8 \text{ ppm P}_2O_5 \)

Next we calculate the required phosphorus concentration by using Equation 11:

\[ Fc(w) = 100 \times Nc(w) / Nc(\%) = 100 \times 45.8 \text{ ppm P}_2O_5 / 24\% P_2O_5 = 191 \text{ g/m}^3 \]
Therefore 191 gr of ammonium phosphate are required in each m³ of irrigation water.

To convert this amount of fertilizer into volume, we use Equation 6:

\[ F_v = \frac{F_w}{S_w} = \frac{191 \text{ gr/m}^3}{1.3 \text{ gr/cm}^3} = 147 \text{ cm}^3/\text{m}^3, \text{ or } 0.147 \text{ l/m}^3 \]

With Equation 11 we calculate the concentration of nitrogen provided by the liquid ammonium phosphate:

\[ F_c(w) = \frac{100 \times N_c(w)}{N_c(\%)} \text{, therefore:} \]
\[ N_c(w) = F_c(w) \times N_c(\%) / 100 = 191 \text{ gr/m}^3 \times 8 \% / 100 = 15.28 \text{ g/m}^3 = 15.28 \text{ ppm} \]

To complete the required nitrogen concentration (60 ppm), we need:

\[ 60 - 15 = 45 \text{ ppm} = 45 \text{ gr/m}^3. \]

Which will be supplied by liquid ammonium nitrate. With Equation 11:

\[ F_c(w) = \frac{100 \times N_c(w)}{N_c(\%)} = \frac{100 \times 45 \text{ ppm}}{21 \%} = 214.29 \text{ gr/m}^3 \]

To convert this weight to volume we employ Equation 12:

\[ F_c(v) = \frac{100 \times N_c(w)}{(N_c(\%) \times S_w)} = \frac{100 \times 45 \text{ gr/m}^3}{(21 \% \times 1.3 \text{ gr/cm}^3)} = 165 \text{ cc/m}^3 = 0.165 \text{ lt/ m}^3 \]

In conclusion: for each cubic meter of irrigation water 147 cm³ of liquid ammonium phosphate, and 165 cm³ of liquid ammonium nitrate will be needed to meet the above recommendation.
CHAPTER 6: CRITERIA FOR CLASSIFYING FERTILIZERS USED IN FERTIGATION

1. Chemical structure:

Fertilizers used in fertigation appear in two different states: soluble solids and solutions.

A) Fertilizer solutions.
These are true solutions, prepared for immediate use by all fertigation methods. Liquid fertilizers can be single, or complex. Single fertilizers consist of only one chemical compound, for example nitric acid, phosphoric acid, etc. Complex fertilizers are mixtures of two or more compounds. Complex fertilizers can be complete or non-complete. Complete fertilizers include nitrogen, phosphorus and potassium, for example 7-3-7, 5-3-8. Sometimes they may also include other nutrients such as magnesium, and a number of microelements. Non-complete fertilizers include just one or two from the three elements mentioned above, such as ammonium phosphate (8-24-0).

B) Solid fertilizers:
These may be granules or powders; they must be fully soluble. The same as liquid fertilizers, they can be single, or complex. Single fertilizers consist of only one chemical compound, for example ammonium sulfate. Complex fertilizers are mixtures of two or more compounds. Complex fertilizers can be complete or non-complete. Complete fertilizers include nitrogen, phosphorus and potassium, for example 20-20-20, 18-18-18. Sometimes they may also include other nutrients such as magnesium, and a number of microelements. Non-complete fertilizers include just one or two from the three mentioned above, such as mono-ammonium phosphate (MAP), or mono-potassium phosphate (MKP).

2. Color:
The color of most solid fertilizers is white to gray. Most liquid fertilizers are colorless, while liquid fertilizers containing phosphoric acid have a yellowish to brown color, depending on the concentration of the acid.

3. Solubility:
The solubility of chemicals in water is influenced by temperature. Usually the higher the temperature, the higher the solubility. Fertilizers used in fertigation must be completely soluble. Fertilizers of low solubility cannot be used for fertigation.
Table 2 shows a few examples of fertilizer solubility as affected by temperature.
The data in Table 2 represent the highest rate of solubility at different temperatures. Many liquid fertilizers precipitate during winter, this means that solutions become over saturated and the excess salt precipitates out. Under these conditions, the fertilizer should be diluted, generally by some 20%, before the advent of the temperature drop. Since the concentration is now lower, the injection rate must be increased accordingly.

### Table 2: The influence of temperature on the solubility of some fertilizers (grams of fertilizer in 1 liter of distilled water)

<table>
<thead>
<tr>
<th>Temperature</th>
<th>0°C</th>
<th>5°C</th>
<th>10°C</th>
<th>20°C</th>
<th>25°C</th>
<th>30°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizer</td>
<td>Solubility in grams per liter of distilled water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonium sulfate</td>
<td>700</td>
<td>715</td>
<td>730</td>
<td>750</td>
<td>770</td>
<td>780</td>
</tr>
<tr>
<td>Urea</td>
<td>680</td>
<td>780</td>
<td>850</td>
<td>1060</td>
<td>1200</td>
<td>1330</td>
</tr>
<tr>
<td>Potassium chloride</td>
<td>280</td>
<td>300</td>
<td>310</td>
<td>340</td>
<td>355</td>
<td>370</td>
</tr>
<tr>
<td>Potassium sulfate</td>
<td>70</td>
<td>80</td>
<td>90</td>
<td>110</td>
<td>120</td>
<td>130</td>
</tr>
<tr>
<td>Potassium nitrate</td>
<td>130</td>
<td>170</td>
<td>210</td>
<td>320</td>
<td>370</td>
<td>460</td>
</tr>
<tr>
<td>Mono-ammonium phosphate</td>
<td>227</td>
<td>255</td>
<td>295</td>
<td>374</td>
<td>410</td>
<td>464</td>
</tr>
<tr>
<td>Mono-potassium phosphate</td>
<td>90</td>
<td>110</td>
<td>180</td>
<td>230</td>
<td>250</td>
<td>300</td>
</tr>
</tbody>
</table>

4. **Interaction of injected chemicals with irrigation water:**

All chemicals to be injected into the irrigation water should be evaluated to determine if any chemical reactions occur:

- This includes acids, bio acids and materials, such as chlorine, used for micro irrigation system maintenance (discussed in Chapter 7).
- Common sources of chlorine used in micro irrigation are oxidizing agents and result in an increase of water pH. This may result in precipitation of calcium and magnesium carbonates, iron oxides (rust), etc.
- It is not recommended to mix chelates into solutions with a pH lower than 3.5, since chelates decompose and their metallic ions are released at such high acidity levels.
- Phosphate-containing fertilizers react with the metals resulting in compounds of low solubility which will precipitate. In this form metallic ions will not be available to the plants.
- Polyphosphate-containing fertilizers react with calcium and magnesium ions forming precipitates that clog filters and emitters.
- In calcium-rich water, sulfate-containing fertilizers precipitate as gypsum. Since the solubility of gypsum decreases with a rise in temperature, the problem is aggravated in summer.
- Alkaline solutions, like urea, precipitate lime from water rich in calcium and bicarbonate (HCO₃⁻) ions. In this case it is recommended to add acids to avoid, or at least minimize, the precipitation which might clog emitters.
- In some humid regions, irrigation water contain heavy metals and organic matter which react with fertilizers in solution causing precipitates in irrigation systems.
For all these reasons, all chemicals to be injected, as well as any mixtures, should be tested with the irrigation water both at the temperature of the water at the source and at the temperature which might be attained in the laterals (particularly important for aboveground polyethylene laterals). Stock solutions of the chemical should be mixed with the irrigation water at the desired concentration(s) in a glass container and allow to settle overnight. Any chemical precipitate observed is a sign of potential problems with emitter plugging. Other products should be considered or acid treatment of the irrigation water may be required to keep them in solution.

- Corrosion of irrigation and injection system components can be a serious problem. Most chemicals, both solids and liquids, attack these parts. All parts that come in contact with the injected chemical and/or solution should be made of chemically resistant materials to minimize corrosion. The problem is particularly severe in mixing tanks where fertilizer solutions are highly concentrated.
- The injection appliances and the irrigation system should be thoroughly flushed after each injection of chemicals.

5. Volatilization:
Fertilizers containing urea and/or ammonium may loose nitrogen due to ammonia volatilization. These fertilizers should be stored in sealed containers. Acidification of the solution may reduce these losses.

6. Fertilizer reaction:
Fertilizer solutions have a pH range from 2 to 7 (see Table 3). Those having a pH ranging between 6.5 and 7, are considered neutral, those having a pH ranging between 3.5 and 6.5, are considered slightly acids, while those having a pH below 3.5, are considered strongly acids. The pH value of solid fertilizers is measured in solutions prepared by dissolving one gram of the fertilizer in one liter of distilled water. The pH values of solid fertilizers are used in order to compare between fertilizers of different types.

Table 3: pH and EC of some fertilizers at the concentration of 1 gr/lt of distilled water

<table>
<thead>
<tr>
<th>Fertilizer</th>
<th>pH</th>
<th>EC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium chloride</td>
<td>6.5</td>
<td>1.67</td>
</tr>
<tr>
<td>Ammonium sulfate</td>
<td>5.4</td>
<td>1.06</td>
</tr>
<tr>
<td>Urea</td>
<td>8.0</td>
<td>0.001</td>
</tr>
<tr>
<td>Liquid ammonium nitrate</td>
<td>6.6</td>
<td>0.87</td>
</tr>
<tr>
<td>Potassium nitrate</td>
<td>8.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Mono-ammonium phosphate (MAP)</td>
<td>4.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Mono-potassium phosphate (MKP)</td>
<td>4.5-5.0</td>
<td>0.75</td>
</tr>
</tbody>
</table>

7. Contribution to salinity:
With the exception of urea, all liquid fertilizers are salt solutions. They increase the salinity of the irrigation water. Salt concentration in irrigation water is measured by means of an electric resistance bridge. Electrical conductivity (EC) of the solution is measured between two standard
electrodes having an area of one square centimeter each, the distance between them being one centimeter.

EC expresses ionic activity. There is a direct relation between the concentration of dissolved salts, expressed in milliequivalents/liter (see Table A1, in the Appendix), and the EC of the solution. Each 10 milliequivalents of salt per liter contribute one decisiemen per meter (dS/m to EC). Values of EC are determined in solutions of one gram of liquid fertilizers dissolved in one liter of distilled water (Table 3). The increase in EC is not linear versus the increase in the fertilizer solution concentration. Measurements are conducted for comparison of solutions at the concentrations mentioned.

The EC of an irrigation water can be used to estimate the potential for soil salinity problems. Soils have been classified as saline when EC is greater than four dS/m. It is important to remember that more salt-sensitive crops may be damaged by soil EC values of two dS/m or below, depending upon management practices.

8. Hygroscopicity (moisture absorption):
Solid fertilizers have the propensity to absorb moisture from the atmosphere resulting in the formation of clods. Their application is difficult and of low uniformity. Some manufacturers add special additives to prevent this phenomenon. When such fertilizers are dissolved in water, problems occur. Most of the additives are insoluble in water and may clog the filters and/or the emitters.
CHAPTER 7: WATER QUALITY AND ITS INFLUENCE ON CHEMIGATION

Analyses and interpretation

Typical laboratory irrigation water quality analyses should include the determination of electrical conductivity, (EC), total dissolved solids, and the concentration of individual cations and anions, including calcium, magnesium, manganese, sodium, carbonate, bicarbonate, nitrate, chloride, iron, and sulfate. In addition, boron concentration, water pH, and the sodium adsorption ratio (S.A.R., as well as the adjusted sodium adsorption ratio, SARadj) should be evaluated.

The evaluation of water for micro irrigation systems must include the assessment of physical, chemical, and biological contaminants that contribute to orifice plugging. Table 4 provides a summary of the plugging potential of irrigation waters used for micro irrigation.

Table 4: Plugging potential of irrigation water for micro irrigation

<table>
<thead>
<tr>
<th>Degree of problem</th>
<th>Little</th>
<th>Some</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspended solids</td>
<td>&lt;50</td>
<td>50-100</td>
<td>&gt;100</td>
</tr>
<tr>
<td><strong>Chemical</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>&lt;7.0</td>
<td>7.0-8.0</td>
<td>&gt;8.0</td>
</tr>
<tr>
<td>Dissolved solids</td>
<td>&lt;500</td>
<td>500-2000</td>
<td>&gt;2000</td>
</tr>
<tr>
<td>Manganese (ppm)</td>
<td>&lt;0.1</td>
<td>0.1-1.5</td>
<td>&gt;1.5</td>
</tr>
<tr>
<td>Iron (ppm)</td>
<td>&lt;0.1</td>
<td>0.1-1.5</td>
<td>&gt;1.5</td>
</tr>
<tr>
<td>Hydrogen sulfide (ppm)</td>
<td>&lt;0.5</td>
<td>0.5-2.0</td>
<td>&gt;2.0</td>
</tr>
<tr>
<td><strong>Biological</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bacteria population (max. number per ml.)</td>
<td>&lt;10000</td>
<td>10000-50000</td>
<td>&gt;50000</td>
</tr>
</tbody>
</table>

**pH**

The pH of a water sample is probably the most valuable indicator of potential problems. Water pH expresses the concentration of the hydrogen (H⁺) ions and the relative acidity of the water. Water pH values above 7.8 generally indicate potential problems with carbonate (CO₃²⁻) or bicarbonate (HCO₃⁻) ions precipitating within the systems' accessories.

**Electrical conductivity (EC)**

The EC of irrigation water gives an estimate of potential soil salinity problems. Soil salinity is commonly reported in terms of the EC measured on an extract taken from a saturated soil paste. Because of evaporation from the soil surface and transpiration by plants, much of the applied water is lost from the soil, leaving most of the soluble salts behind.
Leaching with excess water is required to maintain the productivity of most irrigated soils in arid and semi-arid regions.

**Dissolved salts**
Many salts are dissolved in typical irrigation waters and a complete analysis will provide the concentration of the individual ions.

**Calcium and magnesium**
Calcium (Ca) and magnesium (Mg) are the principal divalent cations in both irrigation water and in the soil solution. Their concentration will greatly influence soil structure and the infiltration rate. Calcium concentration will also play a critical role in the formation of precipitates from water sprinkled on the plants' foliage.

**Sodium**
The main effect of sodium (Na) is its negative effect on soil structure. Sodium may have also a direct effect on plants when uptake is excessive.

**Potassium**
High levels of potassium (K) in irrigation waters are not common. In some areas water with a very low salt concentration is used, and monovalent K\(^+\) may act like Na\(^+\) and cause a breakdown of soil structure, leading to surface sealing.

**Sulfur and nitrogen**
Water is analyzed for sulfur (S) as sulfate (SO\(_4\)\(^{2-}\)). Sulfate is the form of sulfur absorbed by plants. Irrigation water can supply a significant amount of the plant's requirement of sulfate. Water samples are typically analyzed for nitrate (NO\(_3\)\(^-\)) nitrogen because high nitrate levels can contribute significantly to plant available nitrogen supplies.

**Carbonate and bicarbonate**
Both carbonate (CO\(_3\)\(^{2-}\)) and bicarbonate (HCO\(_3\)\(^-\)) ions have a significant effect on water and soil pH, as well as calcium / sodium relationships. Canal waters carry a large portion of return flow and deep wells may have high HCO\(_3\)\(^-\) levels. The relative concentration of carbon as carbonate and bicarbonate is a function of water pH. At a pH of 10.5, there are approximately equal concentrations of carbonate and bicarbonate in a water sample. As pH decreases, the proportion of bicarbonate increases continuously till all of the carbon is to be found as bicarbonate at approximately pH 8.5. Waters with a high concentration of bicarbonate cause a steady increase of soil pH due to the precipitation of calcium carbonate (CaCO\(_3\)). A high pH may lead to micronutrient deficiencies, especially iron deficiency.

**Boron and chloride**
In many irrigated areas a high concentration of boron and chloride may represent a specific ion hazard. General guidelines for interpretation of water quality can be found in Table 5.
<table>
<thead>
<tr>
<th>Potential irrigation problem</th>
<th>Units</th>
<th>None</th>
<th>Slight to moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity, water availability influence</td>
<td>ECw</td>
<td>dS/m</td>
<td>&lt;0.7</td>
<td>0.7 – 3.0</td>
</tr>
<tr>
<td>TDS</td>
<td>mg/lt</td>
<td>&lt;450</td>
<td>450 – 2000</td>
<td>&gt;2000</td>
</tr>
<tr>
<td>Salinity, infiltration influence</td>
<td>SAR</td>
<td>ECw =</td>
<td></td>
<td></td>
</tr>
<tr>
<td>If 0 – 3 y ECw =</td>
<td>&gt;0.7</td>
<td>0.7-0.2</td>
<td>&lt;0.2</td>
<td></td>
</tr>
<tr>
<td>If 3 – 6 y ECw =</td>
<td>&gt;1.2</td>
<td>1.2-0.7</td>
<td>&lt;0.3</td>
<td></td>
</tr>
<tr>
<td>If 6 – 12 y ECw =</td>
<td>&gt;1.9</td>
<td>1.9-0.5</td>
<td>&lt;0.5</td>
<td></td>
</tr>
<tr>
<td>If 12 – 20 y ECw =</td>
<td>&gt;2.9</td>
<td>2.9-1.3</td>
<td>&lt;1.3</td>
<td></td>
</tr>
<tr>
<td>If 20 – 40 y ECw =</td>
<td>&gt;5.0</td>
<td>5.0-2.9</td>
<td>&lt;2.9</td>
<td></td>
</tr>
<tr>
<td>Specific ion toxicity (affects sensitive crops)</td>
<td>Sodium (Na)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface irrigation</td>
<td>SAR</td>
<td>&lt;3</td>
<td>3-9</td>
<td>&gt;9</td>
</tr>
<tr>
<td>Sprinkler irrigation</td>
<td>meq/lt</td>
<td>&lt;3</td>
<td>&gt;3</td>
<td></td>
</tr>
<tr>
<td>Chloride (Cl)</td>
<td>Surface irrigation</td>
<td>meq/lt</td>
<td>&lt;4</td>
<td>4-10</td>
</tr>
<tr>
<td>Sprinkler irrigation</td>
<td>meq/lt</td>
<td>&lt;3</td>
<td>&gt;3</td>
<td></td>
</tr>
<tr>
<td>Boron (B)</td>
<td>mg/lt</td>
<td>&lt;0.7</td>
<td>0.7-2.0</td>
<td>&gt;3.0</td>
</tr>
<tr>
<td>Miscellaneous effects (affects sensitive crops)</td>
<td>Nitrogen (N-NO₃)</td>
<td>meq/lt</td>
<td>&lt;5</td>
<td>5-30</td>
</tr>
<tr>
<td>Bicarbonate (HCO₃⁻)</td>
<td>Meq/lt</td>
<td>&lt;1.5</td>
<td>1.5-7.5</td>
<td>&gt;7.5</td>
</tr>
<tr>
<td>PH’</td>
<td>Normal</td>
<td>Range</td>
<td>6.5-8.4</td>
<td></td>
</tr>
</tbody>
</table>

(1) ECw = electrical conductivity of irrigation water, a measure of water salinity, in units of deciSiemen per meter at 25°C, or equivalent units: millimhos per centimeter
(2) TDS = Total dissolved solids in milligrams per liter or ppm
(3) SAR = Sodium adsorption ratio. Applicable only in arid and semi-arid zones. Standard SAR only (not adjusted). The relationship between Ec, SAR and infiltration usually does not apply if soil pH is below 7. For a given SAR, infiltration rate increases as water salinity increases.
(4) Most tree crops and woody plants are sensitive to Na and Cl. For surface irrigation use the SAR values shown. Most annual crops are not sensitive. For surface irrigation use salinity tolerance tables by Ayres and Westcot. With overhead sprinkler irrigation and low humidity (<30%), Na and Cl may be absorbed through leaves of sensitive crops.
(5) To convert ppm to meq divide meq by the following values for each component: Na = 23, Cl = 35, HCO$_3^-$ = 61, B = 11
(6) N-NO$_3^-$ means nitrate nitrogen reported in terms of elemental N. N-NH$_4^+$ and organic N should be included when wastewater is being tested.
(7) Fertigation can change water and soil pH and have an effect on the potential toxicity of ions in the irrigation water.

**Improving water quality**

**Dilution**
The dilution of water of poor quality with water of higher quality is generally very effective; however, dilution does not eliminate the total amount of calcium, bicarbonate, and other toxic elements, it only reduces their concentration.

**Sulfur burners**
Sulfur burners or sulfur generators are used to improve water quality. As with acid treatments, the sulfur burner works by removing bicarbonate from the water supply. A sulfur burner burns elemental sulfur to produce acid which neutralizes some of the bicarbonate (HCO$_3^-$) in the water source according to the following reactions:

\[
\begin{align*}
S + O_2 & \rightarrow SO_2 \\
H_2O + SO_2 & \rightarrow H_2SO_3 \\
H_2SO_3 & \rightarrow H^+ + HSO_3^- \\
HCO_3^- + H^+ & \rightarrow H_2O + CO_2
\end{align*}
\]

In the combustion chamber, sulfur burns with atmospheric oxygen, producing gaseous sulfur dioxide (SO$_2$). As can be seen in the second equation, in the gas-scrubbing chamber, the SO$_2$ is dissolved in the irrigation water passing through the chamber. This concentrated solution of hydrated SO$_2$, often referred to as sulfurous acid, reduces the pH to about 2 to 3 units, and is fairly corrosive. However, almost as soon as this concentrated solution forms, it is injected into the irrigation system. Upon injection, half of the acidity is released as H$^+$ (see the third equation).

These H$^+$ ions react with the bicarbonate in solution converting it into H$_2$O and CO$_2$. If enough sulfur is burned to reduce the pH of the irrigation water to about 6.3 - 6.5, much of the bicarbonate and all of the carbonate in the water will be removed. There will still be some bicarbonate remaining in the water and therefore some precipitation potential still persists. It is generally suggested that irrigation water pH be maintained at approximately 6.5 to minimize corrosion problems.

By significantly reducing the level of bicarbonate in the water, the potential of lime (bicarbonate) deposition is significantly reduced.

The remaining acidity from the sulfur burner reaches the soil as the bisulfite(HSO$_3^-$) ion. Once the bisulfite ions enter the soil, they react with oxygen chemically or are transformed by soil microorganisms (Thiobacillus), into SO$_4^{2-}$ ions and H$^+$. These acidic H$^+$ ions can react with and dissolve lime found in the soil. This process is important in soils where sodium from the irrigation water has created sodification problems. The calcium ions will
increase the Ca\(^{2+}\) concentration in the soil solution, replacing Na\(^+\) from the exchange sites. Soil acidification may be beneficial on calcareous soils where micro-zones of lowered pH may increase the availability of micronutrients such as iron.

The acid added to the soil by sulfur burners may have a negative effect on acid soils or poorly buffered soils in which the pH can decrease suddenly.

**Acidification of irrigation water.**
Injecting acids in order to maintain irrigation water pH between 6.5 and 5.5, at which calcium and magnesium carbonate remain in solution, frequently solves problems associated with their precipitation within the irrigation system. The addition of acids removes a portion of bicarbonates by the chemical reaction described above. Acid treatments dissolve precipitates formed in the system such as carbonates, hydroxides and phosphates.

Many technical grade mineral acids may be used, provided they are clean and do not contain any solid particles, gypsum etc. In Israel, the acid most commonly used for dissolving precipitates is hydrochloric acid (HCl, 33\%), due to its low cost. However, phosphoric, sulfuric and nitric acid may also be used. Sulfuric acid is a very strong and corrosive acid and requires special equipment for injection and must be handled with care.

Special procedures should be established for handling acids as to minimize the potential of spills and direct contact between the operator and the acid. Gloves should always be used, the face should be protected, and the whole body should be clothed.

**Never add acid to the tank directly, first pour water into the tank and then the acid!**

Under normal conditions the recommended concentration of acid in the irrigation water is 0.6%. When irrigation water is extremely hard (water with high concentration of calcium and magnesium carbonate), a 1% acid concentration should be used. Injection time should last for about 10 minutes, and after injection, irrigation should be continued for another half an hour to ensure that all of the acid has been flushed from the system.

Injection may be by means of an injector, any pump type, or a batch tank.

If a batch tank is used, the connections must be inverted in order to assure appropriate mixing of irrigation water with the acid, which, due to its high specific gravity, tends to remain at the bottom of the tank.

Two thirds of the tank are filled with water, and 1.5 liters of acid for each cubic meter of system discharge should be added to the water in the tank. In order to create the required pressure gradient for injection, the throttling valve should be closed till an 8-10 meters gradient is achieved. This insures a high concentration of acid in the irrigation system.

When a pump is used, it should be operated at its maximum injection rate, ensuring that the enough acid solution is available for continuous injection for 10 minutes. The solution should be prepared in such a way that one liter of acid is injected for each cubic meter of system discharge. To obtain the
required volume of solution, enough water should be added, taking into account that the acid must always be added to the water and not vice versa.

For example, if system discharge is 20 m³/h, and an “Amiad” piston pump, with a discharge rate of 180 l/h is used, then the volume of solution injected within 10 minutes (1/6 of an hour), is 180/6 = 30 liters. The chemical tank should be filled with 10 liters of water, and then 20 liters of acid should be added to the water (one liter per each m³/h discharged by the irrigation system).

**Chemical and biological treatments**

Iron bacteria precipitate iron from irrigation water plugging emitters. This problem is generally successfully treated with chlorine. Chlorine, injected at a rate of approximately 0.64 times the iron concentration in the irrigation water is able to precipitate the iron out before it reaches the emitters. Injection must be made upstream of the filter. Elbows, valves, and any fittings that create turbulence and mixing assist in the formation of iron oxide precipitates, which are retained by the filter. Automatic filter backflushing should be considered.

Hydrogen sulfide bacteria are controlled by injecting chlorine at a rate of 4 to 9 times the hydrogen sulfide concentration in the irrigation water.

Manganese problems are controlled by injecting chlorine at a rate of 1.3 times the manganese concentration in the irrigation water.

When algae and bacterial populations, which create gelatinous slimes in the system, are a problem, the injection of chlorine into the irrigation system is recommended for their control.

Groundwater may require special treatments including acid injection for pH control, oxidation to precipitate iron, injection of biocides to control bacteria, etc.

For the control of algae and bacterial populations and their byproducts (slimes), chlorine should be injected continuously to maintain a residual concentration of one ppm active chlorine at end of the lateral. Batch doses of chlorine may also be used, injected to achieve a concentration of 10 ppm free residual chlorine at lateral ends during the last 30 to 60 minutes of an irrigation.
CHAPTER 8: EQUIPMENT LOCATION

The equipment used for chemigation may be located at one of the following locations:

1. At a plot’s “control head”.
2. At the beginning of a distributing pipeline or at a derivation from the main pipeline.
3. At the central “control head”.

The selection of the location depends, in general, on economic and local considerations.
The following should be taken into consideration:

1. **At the plot’s “control head”:**
   This is the ideal location for small injection units. The unit’s cost is relatively low, nonetheless, a number of injection units may be required to fertigate a number of plots, so that the overall cost may rise and be higher than a single injection unit located at the central control head. When transportable equipment is considered, although it may reduce the initial investment, it will increase the cost of labor and make automation more complicated and too costly to install.

2. **At the beginning of distributing pipeline:**
   This constitutes an intermediate situation between the former and next one. It suits the fertigation of field crops.

3. **At the central control head:**
   Despite being relatively big and having a high initial cost, in order to serve a large area, it is in many cases the most profitable. It has the advantage of saving labor, and is suited to automation. Its main limitations are: it may not be very accurate when different fertigation rates must irrigate different plots simultaneously.
CHAPTER 9: SCHEDULING FERTIGATION

Scheduling fertigation should be integrated with irrigation scheduling which is much more dynamic and dependent upon uncontrollable factors such as soil and climate which affect crop development and water consumption. Fertigation scheduling should be based on both the crop’s nutrient requirements during the growing season and the soil’s nutrient storing capacity.

Managing fertigation with a single fertilizer for a single crop may be simple and straightforward. However, supplying multiple crops on different plots and selecting among the host of fertilizer solutions available on the market, as well as among the many models of injectors available, may become quite complicated.

These subjects are beyond the scope of the present publication but must always be kept in mind in order to manage fertigation successfully.

Once the farmer has decided upon the quantities of the various nutrients he plans to apply to his crops during every developmental stage and the irrigation schedule is known, the farmer has to decide how to undertake the management of fertigation.

Step 1: Defining the time lapse before starting fertigation.

The first step is to measure the time from the start of each irrigation turn till the system pressure and discharge stabilize. In a greenhouse where each emitter is provided with a “leak preventing device” (LPD), and the pipelines remain full with water throughout, this may take a few seconds. In large irrigated areas this process may take a few minutes for one of the irrigated crops, but up to ½ hour till every emitter is performing at the design pressure and discharge during the same irrigation turn!

The measurement consists of recording the time it takes for the pressure (measured with a reliable manometer) to stabilize at critical points on the irrigation system.

Since fertilizers are expensive and may even damage the crop when applied in excessive quantities – injection should never be undertaken before the system stabilizes.

Step 2: Defining the time lapse at the end of the irrigation turn.

The second step for the farmer is to decide when fertigation should stop.

Many of the chemicals injected into the irrigation system may damage one or more of its components. Probably the most sensitive of these are the membranes of pressure compensated emitters and pressure regulators. Also many parts made of metal may be affected.

Therefore it is desirable to flush the entire irrigation system with water, while refraining from injecting any chemicals, before terminating the irrigation turn.

An exception may be when it is considered convenient to leave residual chlorine in the pipelines in order to inhibit the growth of algae and the development of microorganisms, which may plug emitters and filters.

The farmer has to measure the time required till the remaining chemicals have been flushed completely from the system. This may be conducted by testing some chemical characteristic such as pH, EC, the concentration of chlorine, etc.
This step may be obviated when irrigation frequency is very high (pulse irrigation in greenhouses and detached cultures) on the condition that the system components are immune to the effect of the chemicals injected.

**Step 3: Calculating the time available for fertigation.**

After having undertaken the first two steps the farmer may calculate the time available for fertigation along the season for each crop and plot. Graphically this may be depicted as in Figure 27.

<table>
<thead>
<tr>
<th>total irrigation time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filling of irrigation system</td>
</tr>
</tbody>
</table>

**Figure 27:** Scheduling fertigation during an irrigation turn

**Step 4: Measuring the volume of fertilizer solution.**

The next step is for the farmer to decide how he will measure the volume of fertilizer solution actually injected. As mentioned earlier, this may be conducted by pouring the required volume of fertilizer solution into a batch tank, attaching metering devices to the injector, etc.

Flow meters have been installed on batch tanks, in which a float registers the delivery rate.

Fertilizer metering valves of materials impervious to the chemicals injected. The mechanical model of these valves, installed on the suction hose from the fertilizer tank to the injector, is opened by turning a calibrated dial to the volume of solution to be injected. It closes automatically after the pre-set volume has been delivered.

**Fig 28 Metering devices for injectors**
Fertilizer piston and diaphragm injection pumps deliver the chemical as discrete pulses. In order to cushion the effect of these sudden changes of discharge, which may affect the accuracy of metering, the following instructions should be followed:

a) The volume of the cushioning pipe should be at least 4 times the volume of solution injected at each stroke.

b) The top of the cushioning pipe should be at least 25 cm above the top of the container of the fertilizer solution.

In order to keep dirt out the top of the cushioning pipe should be bent downwards without blocking it in order to allow free entrance of air.
A similar but standard water metering valve may be installed on the hose providing water under pressure to a hydraulic pump. Since water and not the fertilizer solution itself is metered, this requires confirming that a “Amiad” model piston pump delivers one volume of solution for every 3 volumes of water metered or that a TMB diaphragm pump delivers one volume of solution for every 2 volumes of water metered. The dial must be set accordingly.

While batch tanks and Venturis inject the fertilizer solution continuously, hydraulic pumps deliver it in discrete pulses. Magnetic pulse transmitters have been devised for these pumps. At each stroke, the magnet closes an electronic circuit connected to a controller, which translates the pulses into volume and accumulates the data.

![Fig 31 Magnetic pulse transmitter on “Amiad” hydraulic pump](image)

Other fertimeters are also available which operate on the same principle, such as the electronic model of the “Dishnon”.
Box 9.2 Operating principle of the electronic model of the fertimeter “Dishnon”.

The inlet orifice has a square shape which directs a liquid jet at the vanes of a cogwheel. The high velocity of this wheel is reduced by means of a gearbox to a slow rotating disc with two ceramic magnets attached to it. Inside a small housing there is a proximity switch (“Reed switch”) sensitive to a magnetic field. With each revolution of the disk, the electrical circuit is closed twice (once for each magnet) and re-opens when the magnet turns away from the housing. Counting electronically the number of closings of the circuit is equivalent to measuring the volume of the liquid flowing through the fertimeter.

Step 5: Deciding on the number of fertilizer solutions and injector to be employed.

Next, the farmer has to decide upon the number of different fertilizer solutions that he wants to have available on his farm at any time. Also the number of injectors required must be considered (will one injector be able to inject the various chemicals, or is more than one injector required?). As more containers and injectors are employed, managing the systems gets ever more complicated, making automation of fertigation an attractive alternative. This is certainly so for the management of greenhouse fertigation.

Step 6: Deciding how to start and stop fertigation.

The farmer has already made up his mind upon when to start and stop fertigation (see Step 3), now he must decide how to start and stop it.

- The simplest way to do so is to introduce the suction hose into the container with the fertilizer solution when required, and take it out again when the required volume has been injected.
One or more cocks may be opened manually, controlling the flow through a batch tank or Venturi. Once all the fertilizer has been injected, the system continues working without adding any fertilizer to the irrigation water.

The next alternative is to employ a foot valve at the end of the suction hose within the container. This stops the operation of the Amiad hydraulic pump when the level of fertilizer solution is below the level of that valve.

Most modern pressurized irrigation systems depend on hydraulic valves through which the chemical flows without coming in contact with the mechanism responsible for opening and closing the valve. This protects the mechanism from attack by the chemicals employed. There are two basic types of hydraulic valves: normally open (NO) and normally closed (NC). Normally closed valves will remain so till they receive an external command. Therefore they protect the system from malfunctioning, spilling of fertilizer or unintended injection, (see Fig. 9.6).

![Fig 33. The Amiad ¾” NC hydraulic valve.](image)

Hydraulic valves may be operated locally (manually) or remotely. Some are opened manually and close automatically, like the mechanical metering valves described above (see Step 4). Remote operation is usually under the control of “fertigation controllers” of which many models are available on the market to suit the number of fertilizer containers decided upon in step 5, above.
Step 7: Deciding upon the degree of automation.
The size of the farm, the number of irrigated plots, the diversity of crops grown, the availability of soluble fertilizers and/or fertilizer solutions, the technical preparation of the operators are decisive factor affecting the degree of automation to be employed.

When weighing the relative advantages of automation the initial investment in equipment as well as the running costs of labor and energy should be considered. To this, the possibility of saving on fertilizer should be added, but also the cost of the know-how required in order to keep the equipment (including sophisticated electronic devices) in working condition.

- Automation starts, at its simplest, with the semi-automatic metering valves mentioned above (started up manually and closing automatically), up to the most sophisticated computers with complete control over the conditions under which fertigation is started, terminated or interrupted according to predetermined parameters of time, water and fertilizer delivery, system pressure, as well as extraneous inputs (such as rain, temperature, wind, pH, EC, etc.).
Automatic fertigation controllers depend on an internal timer, the input provided by water meters, fertilizer meters, manometers, etc. and hydraulic valves which open and close according to the output processed by the controller.

With fully automated systems fertigation may be started:
* a predetermined time lapse after the initiation of irrigation,
* after a predetermined volume of water has been registered by the water meter
* when a preset minimum pressure has been attained at the control head,
* according to information relayed from the plot being irrigated,
* or by any combination of the above.

Similar considerations hold for the termination of fertigation.

Step 8: Batch and proportional fertigation.
With the equipment at hand – the mode of fertigation should be selected. There are two basic modes: batch and proportional fertigation.

Batch fertigation: This mode is based upon the decision to apply a given volume of fertilizer within the available time according to Fig 27, irrespective of the concentration of the chemical in the irrigation water.

- Once this has been decided upon, injection may start immediately after the irrigation system has stabilized. This is the recommended method for injecting nutrients with low mobility in the soil profile, like orto-phosphate ions (H$_2$PO$_4^-$).
- If the irrigation turn is much longer than the time required for fertigation, it should be carried out towards the end of the irrigation turn. This is the recommended option when an easily leached nutrient, such as nitrate (NO$_3^-$), is to be injected, since the danger always exists that the nutrient may be carried too deep into the soil profile, beyond the most active root system.
- If time is available, two or more different fertilizer solutions may be applied, one after the other, (always respecting the considerations mentioned above).
- It must be clearly understood that with batch fertigation the concentration of the nutrient may remain constant in the irrigation water flow (as with the Venturi injector), or decreasing with time as it is characteristic of fertigation with the batch tank.

| total irrigation time scheduled |
|-------------------|------------------|------------------|
| Filling of irrigation system | Time available for fertigation | Flushing of irrigation system |

<table>
<thead>
<tr>
<th>Batch fertigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A) Batch fertigation starts upon system stabilization, with non-leachable nutrients.</td>
</tr>
</tbody>
</table>
Proportional fertigation: This mode requires maintaining a constant concentration of nutrients in the irrigation water flow as long as fertigation lasts.

- This is the preferred method for greenhouse and detached cultures, where roots are restricted to a very small volume and irrigation is of high frequency.
- Proportional fertigation ensures a higher level of control of the pH of irrigation water, its electrical conductivity (EC) and a proper balance between nutrients, according to the crop’s specific requirements.
- As equipment gets more sophisticated and farmers recognize the advantages inherent in fertigation, proportional fertigation is gaining wider acceptance in orchards and horticulture.
- Proportionality may be achieved and regulated employing the metering devices mentioned in Step 4, above, working independently, or under the command of fertigation controllers.
- Most hydraulic pumps increase their injection rate when pressure (and discharge) of the system rises, and reduce it as it falls. Thus proportionality is nearly adhered to as long as pressure variations are within bounds. Among the models described, the “Dosatron” is the least affected by these variations.
- With sophisticated controllers, proportionality is maintained by supplying an electronic processor continuously with data on the progress of irrigation (information provided by the electronic water meter) and that of fertigation (from the electronic fertilizer meter). The processor sends the corresponding signals to the hydraulic valve on the injector as to control injection rate in correspondence with the discharge of the irrigation system. The processor is pre-scheduled to inject x liters of fertilizer solution A, y liters of fertilizer solution B, etc., for every cubic meter of irrigation water discharged.
- The equipment should be checked periodically for its accuracy.
- Ideally, the constant concentration of the nutrient(s) is maintained during all the time available for fertigation, but other considerations (such as injecting acids or chlorine for the maintenance of the irrigation equipment may restrict the time available).

Proportional fertigation throughout available time. Each bar represents one stroke of the hydraulic pump.
It should be clearly understood that both batch and proportional fertigation may be combined as to correspond to the requirements of farm management. Thus, on a clayey soil, with a high capacity for retaining exchangeable ammonia ($\text{NH}_4^+$) and potassium ($\text{K}^+$) ions, these nutrients may be applied occasionally in large quantities as batches while Urea, which moves freely with irrigation water, may be applied proportionally.

**Fig. 36. Proportional fertigation.**

<table>
<thead>
<tr>
<th>Total irrigation time scheduled</th>
<th>Filling of irrigation system</th>
<th>Time available for fertigation</th>
<th>Flushing of irrigation system</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 37. Comparison of the concentration of the chemical in the irrigation water over time for different methods of chemical injection**
Figure 38. Comparison of chemical concentration in the irrigation water and potential distribution in root zone for different injection methods
APPENDIX. TABLES, DEFINITIONS AND EQUATIONS

Table 6: Ion examples with their equivalent weight

<table>
<thead>
<tr>
<th>Equivalent weight (gr) cations</th>
<th>Equivalent weight (gr) anions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca^{2+} 20.04</td>
<td>Cl^- 35.46</td>
</tr>
<tr>
<td>Mg^{2+} 12.16</td>
<td>SO_4^- 48.03</td>
</tr>
<tr>
<td>Na^+ 23.0</td>
<td>HCO_3^- 61.0</td>
</tr>
<tr>
<td>K^+ 39.1</td>
<td>NO_3^- 62.0</td>
</tr>
<tr>
<td>NH_4^+ 18.0</td>
<td>H_2PO_4^- 97.0</td>
</tr>
</tbody>
</table>

Table 7: pH ratings:

<table>
<thead>
<tr>
<th>Rating</th>
<th>pH range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderately acid</td>
<td>5.6-6.0</td>
</tr>
<tr>
<td>Slightly acid</td>
<td>6.1-6.5</td>
</tr>
<tr>
<td>Neutral</td>
<td>6.6-7.3</td>
</tr>
<tr>
<td>Mildly alkaline</td>
<td>7.4-7.8</td>
</tr>
<tr>
<td>Moderately alkaline</td>
<td>7.9-8.4</td>
</tr>
<tr>
<td>Strongly alkaline</td>
<td>8.5-9.0</td>
</tr>
</tbody>
</table>

Table 8: Useful conversion factors

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Multiply by</th>
</tr>
</thead>
<tbody>
<tr>
<td>P_2O_5</td>
<td>P</td>
<td>0.44</td>
</tr>
<tr>
<td>P</td>
<td>P_2O_5</td>
<td>2.3</td>
</tr>
<tr>
<td>PO_4</td>
<td>P</td>
<td>0.33</td>
</tr>
<tr>
<td>P</td>
<td>PO_4</td>
<td>3.076</td>
</tr>
<tr>
<td>K_2O</td>
<td>K</td>
<td>0.83</td>
</tr>
<tr>
<td>K</td>
<td>K_2O</td>
<td>1.2</td>
</tr>
<tr>
<td>CaCO_3</td>
<td>Ca</td>
<td>0.4</td>
</tr>
<tr>
<td>Ca</td>
<td>CaO</td>
<td>1.40</td>
</tr>
<tr>
<td>CaO</td>
<td>Ca</td>
<td>0.71</td>
</tr>
<tr>
<td>Ca</td>
<td>CaCO_3</td>
<td>2.5</td>
</tr>
<tr>
<td>NO_3</td>
<td>N-NO_3</td>
<td>0.23</td>
</tr>
<tr>
<td>N-NO_3</td>
<td>NO_3</td>
<td>4.4</td>
</tr>
<tr>
<td>NH_4</td>
<td>N-NH_4</td>
<td>0.82</td>
</tr>
<tr>
<td>N</td>
<td>NH_4</td>
<td>1.28</td>
</tr>
<tr>
<td>Mg</td>
<td>MgO</td>
<td>1.66</td>
</tr>
<tr>
<td>MgO</td>
<td>Mg</td>
<td>0.60</td>
</tr>
</tbody>
</table>
GLOSSARY

Equivalent weight:
The weight in grams of any material able to combine or replace one gram of hydrogen. It is equal to the atomic weight of the ion, divided by its valence.
For example: Calcium atomic weight is 40.08, valence = 2.
Equivalent weight = 40.08/2 = 20.04 grams.

Milliequivalent (meq):
The thousandth part of an equivalent (equivalent weight)

Parts per million (ppm):
mg/l, or grams/m³.

pH:
A notation used to designate the relative acidity or alkalinity of soils, liquids and other materials. A pH of 7.0 indicates neutrality, higher values indicate alkalinity, and lower values acidity

Alkaline:
A chemical term referring to basic reaction where the pH reading is greater than 7.0, as distinguished from acidic reaction where the pH reading is less than 7.0.

Available nutrient:
A quantity of a nutrient element or compound in the soil that can be readily absorbed and assimilated by growing plants.

Electrical Conductivity:
The reciprocal of the resistivity. A measure of the ease with which a current will pass through a soil paste or extract. Directly correlated with the salt content of the soil. Measured in millimhos/cm, micromhos/cm, or decisiemens/m.
EQUATIONS

LIST OF EQUATIONS (in alphabetical order)

\[ D(\%) = 100 \times \frac{Fc(v)}{Qr} \quad 14 \]
\[ Fc(\%) = \frac{100 \times q}{q + 1000 \times Q} \quad 3 \]
\[ Fc(v) = \frac{100 \times Nc(w)}{(Nc(\%) \times Sw)} \quad 12 \]
\[ Fc(w) = \frac{100 \times Nc(w)}{Nc(\%)} \quad 11 \]
\[ Ft = Fv \times A \quad 7.2 \]
\[ Ft = Fw \times A \quad 7.1 \]
\[ Ft = Tv \times D(\%) / 100 \quad 15 \]
\[ Fv = Fw / Sw \quad 6 \]
\[ Fw = 100 \times Nw / Cn(\%) \quad 5 \]
\[ q = 4 \times Tv / t \quad 8 \]
\[ q = A \times Fv / t \]
\[ q = Fc(v) \times Q \quad 9 \]
\[ q = Ft / t \quad 1 \]
\[ Qr = q / Q \quad 13 \]
\[ t = 4 \times Tv / q \quad 4 \]
\[ Tv = Fv \times A \quad 2 \]

LIST OF EQUATIONS in numerical order

1  \[ q = A \times Fv / t \]
2  \[ Tv = Fv \times A \]
3  \[ Fc(\%) = 100 \times q / (q \times Q) \]
4  \[ t = 4 \times Tv / q \]
5  \[ Fw = 100 \times Nw / Nc(\%) \]
6  \[ Fv = Fw / Sw \]
7.1 \[ Ft = Fw \times A \]
7.2 \[ Ft = Fv \times A \]
8  \[ q = 4 \times Tv / t \]
9  \[ q = Fc(v) \times Q \]
10 \[ q = Ft / t \]
11 \[ Fc(w) = 100 \times Nc(w) / Nc(\%) \]
12 \[ Fc(v) = 100 \times Nc(w) / (Nc(\%) \times Sw) \]
13 \[ Qr = q / Q \]
14 \[ D(\%) = 100 \times Fc(v) / Qr \]
15 \[ Ft = Tv \times D(\%) / 100 \]
LIST OF SYMBOLS AND EQUATIONS IN WHICH THESE SYMBOLS ARE USED (BY NUMBER).

A = Area [ha] (1,2,7)
D(%) = Dilution percentage [%] (14,15)
Fc(%) = Fertilizer concentration [%] (3)
Fc(v) = Fertilizer concentration, (by volume) [lt/m³] (9,12,14)
Fc(w) = Fertilizer concentration, (by weight) [gr/m³] (11)
Ft = Fertilizer per irrigation turn [lt or kg] (7,10,15)
Fv = Fertilizer dose, (by volume) [lt/ha] (1,2,6,7)
Fw = Fertilizer dose (by weight) [kg/ha] (5,6,7)
Nc(%) = Nutrient concentration in the fertilizer [%] (5,11,12)
Nc(w) = Nutrient conc. in the irrigation water [ppm] (11,12)
Nw = Nutrient dose (by weight) [kg/ha] (5)
q = Injector discharge [lt / h] (1,3,4,8,9,10,13)
Q = Irrigation system discharge [m³/h] (3,9,13)
Qr = Discharge ratio [lt/m³] (13,14)
Sw = Specific weight of fertilizer solution [gr/cc] [kg/lt] (6,12)
t = Fertilization duration [h] (4,8,10)
Tv = Tank volume [lt] (2,4,8,15)
Equation 1

\[ q = \frac{A \cdot F_v}{t} \]

- \( q \) = Injector discharge [liter/hectare]
- \( A \) = Area [hectare]
- \( F_v \) = Fertilizer dose [liter/hectare]
- \( t \) = Fertilization duration [hour]

Equation 2

\[ T_v = F_v \cdot A \]

- \( T_v \) = Tank volume [liter]
- \( F_v \) = Fertilizer dose [liter/hectare]
- \( A \) = Area [hectare]

Equation 3

\[ F_c(\%) = \frac{100 \cdot q}{(q \times Q)} \]

- \( F_c(\%) \) = Fertilizer concentration in irrigation system [%]
- \( q \) = Injector discharge [liter/hour]
- \( Q \) = Irrigation system discharge [m³/hour]

Equation 4

\[ t = 4 \times \frac{T_v}{q} \]

- \( t \) = Fertilization duration [hour]
- \( T_v \) = Tank volume [liter]
- \( q \) = Injector discharge [liter/hour]
**Equation 5**

\[ F_w = 100 \times \frac{N_w}{C_n(\%)} \]

- \( F_w \) = Fertilizer dose (by weight) \([\text{kg/hectare}]\)
- \( N_w \) = Nutrient dose (by weight) \([\text{kg/hectare}]\)
- \( C_n(\%) \) = Nutrient concentration in the fertilizer \([\%]\)

**Equation 6**

\[ F_v = \frac{F_w}{S_w} \]

- \( F_v \) = Fertilizer dose, (by volume) \([\text{liter/hectare}]\)
- \( F_w \) = Fertilizer dose, (by weight) \([\text{kg/hectare}]\)
- \( S_w \) = Specific weight of fertilizer solution \([\text{kg/liter}]\)

**Equation 7**

\[ F_t = F_w \times A \]

\[ F_t = F_v \times A \]

- \( F_t \) = Fertilizer per irrigation turn \([\text{liter or kg}]\)
- \( F_w \) = Fertilizer dose, (by weight) \([\text{kg/hectare}]\)
- \( F_v \) = Fertilizer dose, (by volume) \([\text{liter/hectare}]\)
- \( A \) = Area fertigated per irrigation turn \([\text{hectare}]\)

**Equation 8**

\[ q = 4 \times \frac{T_v}{t} \]

- \( q \) = Tank discharge \([\text{liter/hour}]\)
- \( T_v \) = Tank volume \([\text{liters}]\)
- \( t \) = Fertilization duration \([\text{hours}]\)
Equation 9

\[ q = F_c(v) \times Q \]

- \( q \) = Injector discharge \([\text{liter fert/hour}]\)
- \( F_c(v) \) = Fertilizer concentration, (by volume) \([\text{liter fert/m}^3 \text{ water}]\)
- \( Q \) = Irrigation system discharge \([\text{m}^3 \text{ water/hour}]\)

Equation 10

\[ q = \frac{F_t}{t} \]

- \( q \) = Injector discharge \([\text{liter/hour}]\)
- \( F_t \) = Fertilizer sol. to be injected per irrigation turn \([\text{liter}]\)
- \( t \) = Fertigation duration \([\text{hour}]\)

Equation 11

\[ F_c(w) = 100 \times \frac{N_c(w)}{N_c(\%)} \]

- \( F_c(w) \) = Fertilizer concentration, (by weight) \([\text{gr/m}^3]\)
- \( N_c(w) \) = Nutrient concentration, in the irrigation water \([\text{ppm}]\)
- \( N_c(\%) \) = Nutrient concentration in the fertilizer \([\%]\)

Equation 12

\[ F_c(v) = 100 \times \frac{N_c(w)}{(N_c(\%) \times S_w)} \]

- \( F_c(v) \) = Fertilizer concentration, (by volume) \([\text{liter/m}^3]\)
- \( N_c(w) \) = Nutrient conc. in the irrigation water \([\text{ppm}]\)
- \( N_c(\%) \) = Nutrient concentration in the fertilizer \([\%]\)
- \( S_w \) = Specific weight of fertilizer solution \([\text{gr/cc}]\)
**Equation 13**

\[ Q_r = \frac{q}{Q} \]

- \( Q_r \) = Discharge ratio \([\text{liter/m}^3]\)
- \( q \) = Injector discharge \([\text{liter/hour}]\)
- \( Q \) = Irrigation system discharge \([\text{m}^3/\text{hour}]\)

**Equation 14**

\[ D(\%) = 100 \times \frac{F_c(v)}{Q_r} \]

- \( D(\%) \) = Dilution percentage \([\%]\)
- \( F_c(v) \) = Fertilizer concentration, (by volume) \([\text{liter/m}^3]\)
- \( Q_r \) = Discharge ratio \([\text{liter/m}^3]\)

**Equation 15**

\[ F_t = T_v \times \frac{D(\%)}{100} \]

- \( F_t \) = Fertilizer per irrigation turn \([\text{liter or kg}]\)
- \( T_v \) = Tank volume \([\text{liter}]\)
- \( D(\%) \) = Dilution percentage \([\%]\)