Fertigation: An overview of some practical aspects

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(1) ICL Fertilizers

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Introduction

Fertigation is herein defined as the application of solid or liquid (fluid) mineral fertilizers via pressurized irrigation systems, thus forming nutrient-containing irrigation water.

Although the practice of fertigation only started commercially in the mid-20th century, there is evidence that the concept of irrigation with dissolved nutrients was well known in the past. The first reported example dates back to ancient Athens (400 B.C.) where city sewage was used for the irrigation of tree groves (Young and Hargett, 1984).

Liquid ammonia was probably the first commercially produced liquid fertilizer (New York, 1921), but in modern fertigation the use of ammonia as the nitrogen source is negligible. The increased production of ammonia and other nitrogen solutions led to the development of direct application of these solutions into the soil by mechanical means i.e. through drills, knives and injection tubes etc. This mode of application, although probably used on larger areas than fertigation, will not be discussed in this paper.

Fertigation with phosphoric acid was demonstrated by Shell Chemical Company in 1943, and ten years later the first NPK solution was made by mixing phosphoric acid, neutralized with ammonia and with an addition of potash to create ‘4-10-10’ grade solution (Young and Hargett, 1984).

One of the major factors to promote modern fertigation was the development of Micro-Irrigation Systems (MIS) which includes drip, jets and micro sprinklers. Field experiments in Israel in the early 1960’s showed that when only part of the field area is irrigated, as in MIS, the use of standard broadcast application of fertilizers is ineffective. The limited root zone and the reduced amount of mineralization in the restricted wetted zone are the main reasons for the reduced nutrient availability to the plant. Recognition of these facts led to the installation of fertigation facilities with almost all applications of MIS.
Israel presents a unique example of the use of fertilizers by fertigation. The Israeli farmer uses on the average 100, 55 and 75 kg/ha of N, P$_2$O$_5$ and K$_2$O respectively. Over 50% of the N and P$_2$O$_5$ used is applied in fertigation. Out of 33,000 tonnes total consumption of K$_2$O, approximately 10,000 tonnes are applied as clear liquid N-P-K, N-K or P-K solutions or soluble mixture fertilizers, and another 5,000 to 10,000 tonnes K$_2$O are applied as solid KCl dissolved in field. Fertigation is by far the most common, and in some cases the only method of fertilizing greenhouses, orchards, vegetables and drip irrigated field crops such as cotton, maize, jujube etc.

This paper will focus on the practical aspects of fertigation in the field.

**Fertilizers**

Fertigation can be achieved by using single or multiple nutrient fertilizers, in their solid or liquid form. Table 1 lists the typical fertilizers used in fertigation with their nutrient content in the solid and saturated solution forms.

Table 1: Nutrient (N-P$_2$O$_5$-K$_2$O) content of common fertilizers suitable for fertigation in their solid and saturated liquid forms

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Compound</th>
<th>Nutrient content in solid fertilizer (N; P$_2$O$_5$; K$_2$O)</th>
<th>Nutrient content in saturated liquid fertilizer (25°C; 75°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>1. Urea</td>
<td>46-0-0</td>
<td>21-0-0</td>
</tr>
<tr>
<td>N</td>
<td>2. Ammonium Nitrate *</td>
<td>33-0-0</td>
<td>21-0-0</td>
</tr>
<tr>
<td></td>
<td>3. Ammonium Sulfate</td>
<td>21-0-0</td>
<td>10-0-0</td>
</tr>
<tr>
<td>Phosphorous</td>
<td>1. Phosphoric Acid</td>
<td>-</td>
<td>0-61-0</td>
</tr>
<tr>
<td>P</td>
<td>2. Mono Ammonium Phosphate *</td>
<td>12-61-0</td>
<td>4-18-0</td>
</tr>
<tr>
<td></td>
<td>3. Di Ammonium Phosphate *</td>
<td>18-46-0</td>
<td>7-25-0</td>
</tr>
<tr>
<td>Potassium</td>
<td>1. Potassium Chloride *</td>
<td>0-0-62</td>
<td>0-0-15</td>
</tr>
<tr>
<td>K</td>
<td>2. Potassium Nitrate</td>
<td>13-0-46</td>
<td>4-0-12</td>
</tr>
<tr>
<td></td>
<td>3. Potassium Sulfate *</td>
<td>0-0-50</td>
<td>0-0-6</td>
</tr>
<tr>
<td></td>
<td>4. Mono Potassium Phosphate</td>
<td>0-52-34</td>
<td>0-10-7</td>
</tr>
</tbody>
</table>

* only if of “fertigation grade”

It is clear from table 1 that for K fertilizers the solid : liquid ratio is rather low, thus when using K containing liquid fertilizers the K$_2$O concentration is relatively low.

What are the requirements and standards that should be satisfied by fertilizers used for fertigation? This is an important problem for farmers using MIS, and purchasing fertilizers for fertigated plots. Since there are no such standards currently in force, the following points are suggested:
* full solubility
* quick dissolution in irrigation water
* fine grained product
* insolubles of non-clogging mineral and bacterial type
* high nutrient content in the saturated solution
* no chemical interactions between the fertilizer and irrigation water
* minimum content of conditioning agents

**Solubility and some chemical characteristics**

Figures 1 and 2 show the solubility and percent plant nutrients in saturated solutions of N, P and K fertilizers, at a given temperature. This data is useful for farmers who wish to prepare their own solutions in the field, in 100-1000 liter tanks, and calculate the amount of solution to be applied. The use of high nutrient-containing solutions will lead to savings in storage capacities and simplify the pumping or injection equipment used.

**Figure 1: Solubility at saturation of N and P fertilizers at 10°C (50°F).**

(AN = Ammonium Nitrate; AS = Ammonium Sulfate; MAP = Mono Ammonium Phosphate; MKP = Mono Potassium Phosphate)
The solubility of fertilizers is reduced when two or three fertilizers are mixed together. Maximum concentration can be determined by using triangular diagrams, from which any ratio can be calculated for a given temperature (Wolf et al. 1985).

As a practical example, the mixing of urea or ammonium nitrate and potash and phosphoric acid is a common farmer practice, allowing the farmer to change formulas and the ratio of nutrients according to crop needs and local conditions.

A comparison between the solubility and dissolution rate of different potassium fertilizers demonstrated the advantages of KCl over KNO\(_3\) and K\(_2\)SO\(_4\) (Elam et al., 1995). Apart from a higher K\(_2\)O concentration in the saturated solution, the time needed to dissolve 90% of the salt added (t\(_{90}\)) was also significantly reduced (fig. 3). The same study also showed that the rate of stirring (expressed as rounds per minute - rpm) is an important factor of dissolution rate.
Rug and Kahle (1990), studied the quality of potash to be used for liquid application. The quantity of conditioner added (anticaking agent, usually aramin compound) and the particle size of the material are discussed. It is concluded that concentration of the conditioner should not exceed 150 ppm (in the dry material), and particle size range should be 0.15-0.6 mm, both in order to achieve high and rapid dissolution.

Prepared liquid fertilizers

Clear liquid fertilizers used for fertigation include urea, ammonium nitrate, ammonium sulfate, either and individually or in combination as N source, orthophosphate as the P₂O₅ source and KCl, K₂SO₄ and KH₂PO₄ as the K₂O sources. By mixing two or three different nutrients, the solubility of each nutrient declines (table 2). The selection of the most appropriate fertilizer should be according to soil conditions, plant requirements and costs. Table 2 presents some of the characteristics of selected liquid fertilizers.

![Fraction Dissolved vs Temperature](image)

**Fig. 3: Dissolution of K fertilizers (80% saturation, 20°C, 100 rpm)**

<table>
<thead>
<tr>
<th>at equilibrium</th>
<th>KCl</th>
<th>K₂SO₄</th>
<th>KNO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>% K₂O</td>
<td>12.9</td>
<td>4.3</td>
<td>9.0</td>
</tr>
<tr>
<td>t 90</td>
<td>8.0</td>
<td>25.2</td>
<td>15.6</td>
</tr>
<tr>
<td>% Salt</td>
<td>20.4</td>
<td>8.0</td>
<td>19.2</td>
</tr>
</tbody>
</table>
Table 2: Selection of various formulas of liquid fertilizers (source: Sne, Ministry of Agriculture, Israel, 1989).

<table>
<thead>
<tr>
<th>Fertilizers</th>
<th>Formula</th>
<th>Salting out Temperature (°C)</th>
<th>pH (1:1000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH₄NO₃+H₃PO₄+KCl</td>
<td>19-5-0</td>
<td>6</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>7-7-7</td>
<td>15</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td>4-0-12</td>
<td>5</td>
<td>4.5</td>
</tr>
<tr>
<td>Urea+NH₄NO₃+H₃PO₄+KCl</td>
<td>0-10-10</td>
<td>5</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>8-8-8</td>
<td>13</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>8-0-12</td>
<td>12</td>
<td>7.6</td>
</tr>
<tr>
<td>NH₄NO₃+H₃PO₄+KNO₃</td>
<td>7-0-7</td>
<td>14</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>6-6-6</td>
<td>3</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>3-0-9</td>
<td>12</td>
<td>3.5</td>
</tr>
</tbody>
</table>

**Agronomic aspects**

**Uniformity:** The use of fluid fertilizer can result in a more uniform use of fertilizer due to the following characters: a) homogenous composition; b) non-segregation in transportation and storage; c) application via pressurized irrigation system to ensure an application uniformity equal to that of the water.

**Solubility:** Applying all nutrients in their soluble and thus available form to plant’s roots can have distinct advantages under certain conditions, especially in the case of phosphorous and potassium. These two elements undergo precipitation and adsorption processes in the soil, that reduce their availability to plants. Hence by the repeated and often continuous supply of these nutrients in irrigation water these negative phenomena can be minimized.

**Timing of application:** When applying the fertilizer via irrigation system, one can fertigate practically without the use of labor, depending on the irrigation interval (generally between 2 and 20 days), and the irrigation system. It is also possible to change formulas according to the plant’s needs, and to apply fertilizer in a ‘multi-split application’, thus greatly increasing the efficiency of fertilizer use, especially nitrogen.

**Placement:** By combining the fertilizer with irrigation water, it’s placement in the active root zone can be ensured, which in turn, will increase it’s utilization efficiency. Another factor is the depth of placement of nutrients. Under high leaching conditions, some of the nutrients can be washed away, giving rise to environmental hazards. Controlling the depth of the wetted front by proper management of irrigation, will reduce leaching losses and pollution.

**Saline conditions:** Fertigation under saline conditions benefits from the relative low water potential that develops between frequent irrigations, thus the salt concentrations remain low. The possibility of applying small quantities of fertilizer minimizes the chance to burden the soil with a full annual fertilizer application.
**N fertigation:** Nitrogen is the nutrient most commonly used in fertigation with MIS, flood irrigation, moving laterals and overhead sprinkling systems. In general, all N fertilizers cause few clogging and precipitation problems, with the exception of ammonium sulfate, which may cause precipitation of CaSO₄ in ‘hard’, calcium-rich water.

In well aerated soils, nitrification occurs, thus mobility of nitrogen is not restricted and is equal to that at the wetted front (Haynes, 1985). In over-irrigation leaching of nitrate will occur and endanger surface and underground water sources, if present. Monitoring the depth of the wetted front and/or the concentration of nitrate in soil extract can reduce this risk, especially in sandy soils.

**P fertigation:** Application of phosphorous to irrigation water may cause precipitation of phosphate salts. The precipitation of insoluble di-calcium phosphate and di-magnesium phosphate, and Fe-P compounds in irrigation pipes and water emitters is likely in water with a high pH (Bester et al. 1974), and low pH, respectively. Reducing the pH of irrigation water will significantly reduce the risk of Ca-P compounds precipitation, thus the use of phosphoric acid is usually recommended. A more accurate method of predicting precipitation under different conditions of pH, and concentrations of Ca, Mg, Fe and PO₄ is by the use of the computer program GEOCHEM-PC (Parker et al., 1995). The program can predict the precipitation of any salts in irrigation water, and thus play an important role in management of fertigation in various water sources. Laboratory experiments with nutrient solutions showed a good correlation between the program’s predictions and the actual results (Magen, 1995).

The mobility of phosphorous is restricted due to it’s strong retention by soil oxides and clay minerals, but continuous application of orthophosphate through fertigation proved to be superior to applying P as basal dress (Bar-Yosef, 1991). In contrast, in many vegetable fields in Florida, USA, P is applied only as a basal dressing while N and K is applied via fertigation (G. Hochmut, personal communication).

**K fertigation:** Application of K fertilizers does not cause any precipitation of salts, except when using K₂SO₄ with irrigation water containing high concentration of Ca.

Potassium ion is adsorbed at the cation exchange sites of soil colloids, but researchers have shown lateral and downward mobility of potassium when applied via drip irrigation (Goode, et al., 1978; Kafkafi and Bar-Yosef, 1980). Haynes (1985) showed that the distribution of potassium was more uniform then that of either nitrate or phosphate.

**Introducing fertilizers into irrigation systems**

Fertilizers can be injected into irrigation systems by three principal methods - pressure differential (by-pass tank), venturi (vacuum) pump and displacement pump. Each method has it’s advantages and disadvantages. These are summarized in table 3.
Table 3: Advantages and disadvantages of various methods to introduce fertilizers into irrigation systems

<table>
<thead>
<tr>
<th>Property</th>
<th>Pressure differential</th>
<th>Venturi</th>
<th>Displacement pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ease of operation</td>
<td>high</td>
<td>medium</td>
<td>low</td>
</tr>
<tr>
<td>Utilization of solid fertilizer</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Utilization of liquid fertilizer</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Discharge rate</td>
<td>high</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>Concentration Control</td>
<td>limited</td>
<td>medium</td>
<td>good</td>
</tr>
<tr>
<td>Quantity control</td>
<td>good</td>
<td>medium</td>
<td>good</td>
</tr>
<tr>
<td>Head loss</td>
<td>low</td>
<td>very high</td>
<td>none</td>
</tr>
<tr>
<td>Automatic control</td>
<td>low</td>
<td>medium</td>
<td>high</td>
</tr>
<tr>
<td>Price</td>
<td>low</td>
<td>medium</td>
<td>high</td>
</tr>
</tbody>
</table>

Figure 4: Installation scheme of by-pass tank (source: Fertigation. Haifa Chemicals, Israel).
Figure 5: Cross section of venturi apparatus (source: Fertigation. Haifa Chemicals, Israel).

Figure 6: Installation of displacement pump ((source: Fertigation. Haifa Chemicals, Israel).
In conclusion, fertigation is a sophisticated and efficient method of applying fertilizers, in which the irrigation system is used as the carrier and distributor of the crop nutrients. The synergism and combination of water and nutrient leads to an efficient use of both by the plant. The use of solid fully soluble fertilizers seems more economical in the first stages when fertigation is adopted, but the use of prepared clear liquid solutions is very convenient in other cases. Fertigation can be applied via simple systems such as by-pass tanks as well as through sophisticated computer controlled systems.

References


