1. **Introduction**

It is widely recognized that many countries are entering an era of severe water shortages. Irrigation is considered as one of the major factors for increasing productivity. Increased water efficiency and improved technology offer the prospect of significant water savings.

Micro-Irrigation systems (MIS) are the latest innovation of irrigation. The use of pressure requires energy at the field level and relatively high investment in equipment. Modern MIS are much more efficient in terms of Water Use Efficiency (WUE) thus more land may be irrigated for a given quantity of water.

Fertigation is the application of solid or liquid mineral fertilizers via MIS, creating nutrient-containing irrigation water. Fertigation combines the application of irrigation water and nutrients through MIS, i.e. pressurized irrigation methods (drip, jets, micro jets, etc). It is the most advanced and efficient practice of fertilization.

Fertigation joins the two main factors in plant growth and development, water and nutrients. This method nourishes crops with the appropriate supply of readily available nutrients in the active root zone, throughout their growing season.

A simultaneous application of N, P and K, as a nutrient solution, through the irrigation system not only increases yields and improves quality, but also increases fertilizer use efficiency. Crops get maximum benefit, farmers derive greater profit from their inputs and the environment is better protected.

2. **Advantages of fertigation**

Fertigation allows applying the nutrients exactly and uniformly only to the wetted root volume, where the active roots are concentrated. This remarkably increases the efficiency in the application of the fertilizer, which allows reducing the amount of applied fertilizer. This not only reduces the production costs but also lessens the potential of groundwater pollution caused by fertilizer leaching.

Fertigation allows adapting the amount and concentration of the applied nutrients in order to meet the actual nutritional requirement of the crop throughout the growing season. In order to make a correct planning of the nutrients supply to the crop according to its physiological stage, we must know the optimal daily nutrient consumption rate during the growing cycle that results in maximum yield and production quality. These functions are specific for each crop and climate, and were determined in different experiments for different crops. The optimal curve of consumption of nutrients defines the minimal application rate of a certain nutrient that is required to maintain a constant nutrient concentration in the soil solution. These data constitute the base of the recommendations given to the farmers regarding the fertigation regime for the different crops (Hagin et al, 2002).
Other advantages of the fertigation are: (1) the saving of energy and labor, (2) the flexibility of the moment of the application (nutrients can be applied to the soil when crop or soil conditions would otherwise prohibit entry into the field with conventional equipment), (3) convenient use of compound and ready-mix nutrient solutions containing also small concentrations of micronutrients which are otherwise very difficult to apply accurately to the soil, and (4) the supply of nutrients can be more carefully regulated and monitored. When fertigation is applied through the drip irrigation system, crop foliage can be kept dry thus avoiding leaf burn and delaying the development of plant pathogens.

Drip and MIS have a characteristic not shared by other irrigation methods: fertigation is not optional, but is actually necessary. In drip irrigation, only ~30% of the soil is wetted by the drippers. If fertilizers are applied separately from the water, then fertilization efficiency will decrease because the nutrients will not be dissolved in the dry zones where the soil is not wetted. Consequently, the benefits of irrigation will not be expressed. Therefore, conventional fertilization is not appropriate, not convenient and not efficient with pressurized irrigation methods. Fertigation provides the only good way to apply fertilizers to the crop root zone under MIS.

Fertigation allows changing the program during the growing season, adjusting it to suit fruit, flower, shoot and root development. Thus the fertigation program is tailored to match the actual crop requirements. The recommended doses of each nutrient are different according to the physiological stage of the crop, to the crop growing system (open field, tunnels or greenhouse) and to the soil type.

3. **Chemical and biological guidelines for a sound fertigation**

Effective fertigation requires an understanding of plant growth behavior including nutrient requirements and rooting patterns, soil chemistry such as solubility and mobility of the nutrients, fertilizers chemistry (mixing compatibility, precipitation, clogging and corrosion) and water quality factors including pH, salt and sodium hazards, and toxic ions.

Fertigation can be achieved by using single or multiple nutrient fertilizers, in their solid or liquid form. Solid fertilizers can be applied as a single nutrient (e.g. urea, Table 1), or as multi-nutrient composite of a fertilizer mixture. Liquid fertilizers are of single or multi-nutrient, but due to solubility, the total nutrient concentration is much lower.

<table>
<thead>
<tr>
<th>Fertilizers</th>
<th>Grade</th>
<th>Formula</th>
<th>Other nutrients</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urea</td>
<td>46 – 0 – 0</td>
<td>CO(NH₂)₂</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potassium nitrate</td>
<td>13 – 0 – 46</td>
<td>KNO₃</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonium sulfate</td>
<td>21 – 0 – 0</td>
<td>(NH₄)₂SO₄</td>
<td>22 % S</td>
<td></td>
</tr>
<tr>
<td>Urea ammonium nitrate</td>
<td>32 – 0 – 0</td>
<td>CO(NH₂)₂·NH₄NO₃</td>
<td></td>
<td>Only fertigation grade</td>
</tr>
<tr>
<td>Ammonium nitrate</td>
<td>34 – 0 – 0</td>
<td>NH₄NO₃</td>
<td></td>
<td>Only fertigation grade</td>
</tr>
<tr>
<td>Mono ammonium phosphate</td>
<td>12 – 61 – 0</td>
<td>NH₄H₂PO₄</td>
<td></td>
<td>Only fertigation grade</td>
</tr>
<tr>
<td>Phosphoric acid</td>
<td>0 – 52 – 0</td>
<td>H₃PO₄</td>
<td></td>
<td>Liquid</td>
</tr>
<tr>
<td>Monopotassium phosphate</td>
<td>0 – 52 – 34</td>
<td>KH₂PO₄</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potassium chloride</td>
<td>0 – 0 – 60</td>
<td>KCl</td>
<td>46 % Cl</td>
<td>Only white</td>
</tr>
<tr>
<td>Potassium sulfate</td>
<td>0 – 0 – 50</td>
<td>K₂SO₄</td>
<td>18 % S</td>
<td>Only fertigation grade</td>
</tr>
<tr>
<td>Potassium thiosulfate</td>
<td>0 – 0 – 25</td>
<td>K₂S₂O₃</td>
<td>17 % S</td>
<td>Liquid</td>
</tr>
<tr>
<td>Calcium nitrate</td>
<td>15 – 0 – 0</td>
<td>Ca(NO₃)₂</td>
<td>19 % Ca</td>
<td>Only fertigation grade</td>
</tr>
<tr>
<td>Magnesium nitrate</td>
<td>11 – 0 – 0</td>
<td>Mg(NO₃)₂</td>
<td>9.5 % Mg</td>
<td>Only fertigation grade</td>
</tr>
<tr>
<td>Magnesium sulfate</td>
<td>0 – 0 – 0</td>
<td>MgSO₄</td>
<td>13 % S; 10% Mg</td>
<td></td>
</tr>
</tbody>
</table>
3.1. **Fertilizers solubility**

An essential pre-requisite for the solid fertilizer use in fertigation is its complete dissolution in the irrigation water. Examples of highly soluble fertilizers appropriate for their use in fertigation are: ammonium nitrate, potassium chloride, potassium nitrate, urea, ammonium monophosphate and potassium monophosphate.

The solubility of fertilizers depends on the temperature. The fertilizer solutions stored during the summer form precipitates when the temperatures decrease in the autumn, due to the diminution of the solubility with low temperatures. Therefore it is recommended to dilute the solutions stored at the end of the summer. Fertilizer solutions of smaller degree specially formulated by the manufacturers are used during the winter.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>KCl</th>
<th>K$_2$SO$_4$</th>
<th>KNO$_3$</th>
<th>NH$_4$NO$_3$</th>
<th>Urea</th>
</tr>
</thead>
<tbody>
<tr>
<td>10°C</td>
<td>31</td>
<td>9</td>
<td>21</td>
<td>158</td>
<td>84</td>
</tr>
<tr>
<td>20°C</td>
<td>34</td>
<td>11</td>
<td>31</td>
<td>195</td>
<td>105</td>
</tr>
<tr>
<td>30°C</td>
<td>37</td>
<td>13</td>
<td>46</td>
<td>242</td>
<td>133</td>
</tr>
</tbody>
</table>

3.2. **Interaction between the fertilizers and irrigation water**

3.2.1.- *Water quality:* Many water sources have high contents of calcium, magnesium and bicarbonates (hard waters), the reaction of this water is alkaline with pH values between 7.2 and 8.5. The interaction of these waters with fertilizers can cause diverse problems, such as formation of precipitates in the fertilization tank and clogging of the drippers and filters. In waters with high calcium content and bicarbonates, use of sulphate fertilizers causes the precipitation of CaSO$_4$ obstructing drippers and filters. The use of urea induces the precipitation of CaCO$_3$ because the urea increases pH.

The main problem concerns phosphorus application: the presence of high concentrations of calcium and magnesium and high pH values lead to the precipitation of calcium and magnesium phosphates. Recycled waters are particularly susceptible to precipitation due to its high bicarbonate and organic matter content. The resultant precipitates are deposited on pipe walls and in orifices of drippers and can completely plug the irrigation system. At the same time, P supply to the roots is impaired. When choosing P fertilizers for fertigation with high calcium and magnesium concentrations, acidic P fertilizers (phosphoric acid or monoammonium phosphate) are recommended.

3.2.2.- *Clogging:* This is specially critical for drip systems that must be kept free from suspended solids and microorganisms that plug the small orifices in the emitters. In the case of clogging of the drip system by bicarbonate precipitation, the use of fertilizers with acid reaction partially corrects this problem. However, acid fertilizers cause corrosion of the metallic components of the irrigation system and damage the cement and asbestos pipes. Therefore, the periodic injection of acid in the fertigation system is recommended in order to dissolve the precipitates and to unclog the drippers. The following acids can be used: phosphoric, nitric, sulfuric and chlorhydric. HCl is widely used due to its low cost. Acid injection through the system will also remove bacteria, algae and slime. The irrigation and injection system should be carefully washed after the injection of acid.

3.2.3.- *Fertigation under saline conditions:* Crops vary widely in their tolerance to plants, reference tables are available defining individual crop sensitivity to total soluble salts and individual toxic ions (Maas and Hoffman, 1977). When brackish waters are used for irrigation, we must bear in mind that fertilizers are salts and therefore they contribute to the increase of the electrical conductivity (EC) of the irrigation water. Nonetheless, calculation of the contribution of chloride from KCl to the overall load of chloride from irrigation water shows its relative by low share (Tarchitzky and Magen, 1997).
When irrigation water has an EC > 2 dS/m (with high salinization hazard), and crop is sensitive to salinity, we must decrease the amount of accompanying ions added with the N or K. For example, in avocado - a very sensitive crop to chloride – MKP or KNO$_3$ is preferred on KCl to avoid Cl accumulation in the soil solution. This practice diminishes leaf burning caused by Cl excess. Also in greenhouse crops grown in containers with a very restricted root volume we must choose fertilizers with low salt index.

A correct irrigation management under saline conditions includes water application over the evaporation needs of the crop, so that there is excess water to pass through and beyond the root zone and to carry away salts with it. This leaching prevents excessive salt accumulation in the root zone and is referred to as "leaching requirement" (Rhoades and Loveday, 1990).

### 3.2.4.- Fertilizers compatibility

When preparing fertilizer solutions for fertigation, some fertilizers must not be mixed together. For example, the mixture of (NH$_4$)$_2$SO$_4$ and KCl in the tank considerably reduce the solubility of the mixture due to the K$_2$SO$_4$ formation. Other forbidden mixtures are:

- Calcium nitrate with any phosphates or sulfates
- Magnesium sulfate with di- or mono- ammonium phosphate
- Phosphoric acid with iron, zinc, copper and manganese sulfates

The use of two fertilization tanks allows separating the fertilizers that interact and cause precipitation, placing in one tank the calcium, magnesium and microelements, and in the other tank the phosphorus and the sulfate.

### 3.3. Soil pH

pH values for optimal availability of all the nutrients is in the range of 6-6.5. The main factor affecting pH in the rhizosphere is NH$_4$/NO$_3$ ratio in the irrigation water, especially in sandy soils and inert substrates with low buffer capacity such as rockwool. Rhizospheric pH determines the phosphorus availability since it affects the processes of precipitation/solubilization and adsorption/desorption of phosphates. pH also influences the availability of micronutrients (Fe, Zn, Mn) and the toxicity of some of them (Al, Mn).

The nitrogen form absorbed by the plant affects the production of carboxylates and the cation-anion balance in the plant. When NH$_4$ absorption is predominant, the plant absorbs more cations than anions, H$^+$ are excreted by the roots and rhizosphere pH decreases. Fluctuations of pH of the ground around the roots of the order of ± 1.5 units of pH due to ammonium or nitric nutrition have been reported in the literature (Barber, 1984). According to Ganmore-Neumann and Kafkafi (1980, 1983), NH$_4$ is an undesirable source of nitrogen for tomato and strawberries when the temperature in the root zone is greater than 30°C, due to its adverse effect on root growth and plant development. The pattern of cationic uptake due to ammonium nutrition decreases the uptake of other cations like Ca$^{2+}$, Mg$^{2+}$ and K$^+$.

When NO$_3^-$ anions are absorbed, the plant takes up more anions than cations and the excess of anions is palliated by a greater synthesis of carboxylates. During the carboxylation process dicarboxylic acids (citric, malic, etc.) and OH$^-$ are produced. Both the carboxylates and the hydroxyls can be exuded by the roots to the soil. The exuded OH$^-$ increase the pH of the rhizosphere. The organic acids exuded by the roots increase the availability of phosphorus since the carboxylates are specifically adsorbed to iron oxides and clays of the ground, releasing therefore adsorbed phosphorus to the soil solution. The carboxylates can also increase to the availability of iron and phosphorus by chelation: for example, citrate forms a chelate with calcium, thus releasing phosphorus that is under the calcium phosphate form (Imas et al., 1997).

According to this, NO$_3^-$ nutrition is recommended due to the greater organic acid synthesis and enhanced cations uptake, whereas the ammonium nutrition is detrimental. However, nutrition with 100% nitrates would increase rhizospheric pH up to undesirable values - values of more than 8 have been registered - and this would decrease the availability of P and micronutrients by precipitation.
Therefore it is recommended to use a nitrogen mixture with 80% of nitrates and 20% of ammonium to regulate pH.

3.4. Physiological effects: antagonism and synergism:

When two or more ions are present in external medium, antagonistic and synergetic effects can be observed. Synergism means the increase of the absorption of an ion due to the presence of another ion; antagonism refers to the competition between two ions. There is a competitive antagonistic effect between NO$_3^-$ and Cl anions: the presence of Cl ion reduces the absorption of NO$_3^-$ and vice versa (Imas and Feigin, 1995). Therefore, under saline conditions, the damage by salinity can be reduced fertilizing with NO$_3^-$. The nitrate ions will be more absorbed replacing the chloride ions.

4. Practices of fertigation

To capitalize on fertigation benefits, particular care should be taken in selecting fertilizers and injection equipment as well in the management and maintenance of the system.

4.1. Fertilizer preparation

Application of fertilizers is executed by various methods (Sneh, 1995):

4.1.1. Stock solutions: farmers mix solid fertilizers as ammonium sulfate, urea, potassium chloride and nitrate, and liquid phosphoric acid to prepare a "tailor made" stock solution. The stock solution is then injected into the irrigation system, at rates of 2-10 L/m$^3$, depending on the desired concentrations of N, P and K. Clear NK, PK and NPK fertilizer solutions with at least 9-10% nutrients (N, P$_2$O$_5$, K$_2$O) based on cheap solid fertilizers (urea, phosphoric acid and KCl) can be easily prepared on the farm site with limited facilities under "grass roots" field conditions, with minimal mixing (Lupin et al., 1996).

4.1.2. Compound solid fertilizer mixtures: manufactured for use in fertigation, with different ratios between the three major elements. The first mixture used in fertigation was 20-20-20 and was produced in the mid-sixties. Some compositions contain microelements in the form of chelates.

4.1.3. Compound liquid fertilizer solutions: due to solubility, the total nutrient concentration is much lower (5-3-8; 6-6-6; 9-2-8, etc.). Specified for use in greenhouses. Some compositions contain microelements in the form of chelates.

Nowadays, an ample variety of NPK formulations are available in the market. It is the easiest to buy ready-made soluble fertilizer; however, it is not the cheapest alternative, and not the most flexible. When farmers cannot find an off-the-shelf formulation with the required NPK balance or if they want cheaper fertilizers than the ready-made formulations, then they can prepare their own feeds.

4.2. Dosification

There are two types of fertigation, the type of fertigation chosen depends on the crop grown, the soil type and the farm management system.

4.2.1. Quantitative: is the application of the plant nutrients in predetermined concentrations to the irrigation system. The fertilizer is applied in a pulse after a certain water sheet without fertilizer using a fertilizer tank. The advantages of this method are the low cost and the low required maintenance. The disadvantages are: the system is affected by water pressure changes; the concentration of the fertilizer varies during its application and it does not adapt to work with automation.

4.2.2. Proportional: the nutrients are applied in a constant and proportional ratio to the water sheet, so that the irrigation water takes a fixed concentration of the applied fertilizer. In this case the fertilizers are applied by direct injection through fertilizer pumps. The advantages are: precise control of the dosification and the injection moment, it is not affected by the water pressure changes, and it can be easily
automated. The disadvantages are: high cost and maintenance and complicated operation.

4.3. Fertilizer injection methods

Modern fertigation equipment should be able to regulate:

- Quantity applied
- Duration of applications
- Proportion of fertilizers
- Starting and finishing time

It is important to select an injection method that best suits the irrigation system and the crop to be grown. Incorrect selection of the equipment can damage parts of the irrigation equipment, affect the efficient operation of the irrigation system and reduce the efficiency of the nutrients. Each fertilizer injector is designed for a specified pressure and flow range.

The majority of injectors available today can generally incorporate automatic operation by fitting pulse transmitters that convert injector pulses into electric signals. These signals then control injection of preset quantities or proportions relative to flow rate of the irrigation system. Injection rates can also be controlled by flow regulators, chemically resistant ball valves or by electronic or hydraulic control units and computers.

Suitable antisiphoning valves or non-return valves should be installed to prevent backflow or siphoning of water and fertilizer solution into fertilizer tanks, irrigation supply and household supply.

The three methods of injection are (table 3):

4.3.1. Pressure differential (by-pass tank): It is based on the principle of a pressure differential which forces the water to enter through a by-pass pipe into a pressure tank which contains the fertilizer, and to go out again, carrying a varying amount of dissolved fertilizer.

The nutrients are applied in predetermined concentrations to the irrigation system. The fertilizer is applied in a pulse after a certain water sheet without fertilizer using a fertilizer tank (“quantitative dosification”).

The advantages are: low cost, low required maintenance, very simple to operate, the stock solution does have not to be pre-mixed, easy to install, no electricity or fuel is needed.

The disadvantages are: the system is affected by water pressure changes; the concentration of the fertilizer varies during its application (concentration of solution decreases as fertilizer dissolves), accuracy of application is limited, requires pressure loss in main irrigation line or a booster pump, proportional fertigation is not possible and it does not adapt to work with automation.

The application of nutrients is quantitative and inaccurate, therefore is adapted for perennial crops like citrus, fruit trees and/or crops grown on heavy soil.

4.3.2. Vacuum injection (Venturi): This method uses a venturi device to cause a reduced pressure (vacuum) that sucks the fertilizer solution into the line.

The advantages are: very simple to operate, no moving parts, easy to install and to maintain, suitable for very low injection rates, suitable for both proportional and quantitative fertilization.

The disadvantages are: it requires pressure loss in main irrigation line or a booster pump, automation is difficult.
4.3.3 **Pump injection**: Pumps are used to inject the fertilizer solution from a supply tank into the line. Injection energy is provided by electric motors or hydraulic motors (diaphragm and piston).

The advantages are: precise control of the dosification and the injection moment, it is not affected by the water pressure changes, no pressure loss in the line and it can be easily automated.

The disadvantages are: high cost and maintenance and complicated operation, complicated design, including a number of moving parts (thus wear and breakdown are more likely).

With pumps, nutrients are applied at a constant and proportional ratio to the water sheet, so that the irrigation water takes a fixed and accurate concentration of the applied fertilizer (“proportional dosification”). Pumps supply precise and uniform dosis, suiting in intensive and sophisticated growing of vegetables and flowers (greenhouses, hydroponics).

| Table 3: Injection methods: characteristics and requirements |
|---------------------------------|-----------------|-----------------|
| Fertilizer form | By-pass tank | Venturi | Fertilizer pumps |
| Fertilizer form | Solid or liquid | Liquid * | Liquid * |
| Discharge rate | High | Low | High |
| Pressure loss | Low | Very high | None |
| Fertilizer injection | Quantitative | Proportional |
| Fertilizer concentration control | None (decreasing) | Quite stable (fixed) | Stable (fixed) |
| Automation | No | Possible | Easy |
| Price | Low | Medium | High |
| Operation & maintainance | Simple | Simple | Complex |
| Use | Open field, orchards | Open field, orchards | Greenhouses, hydroponics |

4.4. **Monitoring**

4.4.1 **Plants**: the determination of the nutrients content and dry matter in the whole plant is tedious, destructive and needs laboratory facilities. Therefore plant nutrient status is monitored in the diagnostic organ, whose concentrations are correlated with the total nutrients content in plant and is a good indicator of the nutrition state of the crop. In Israel it was developed calibrated methods of monitoring in diagnostic organs for roses, cotton and different fruit trees.

4.4.2 **Soil**: soil sampling and the determination of the nutrients’ concentrations in the extracts is a difficult and tedious method. Instead, the soil solution can directly sampled by porous ceramic cups permanently inserted in the soil at a certain depth. The solution is collected periodically and sent to the lab for analyzing the different nutrients’ concentrations. This method is easy and cheap.
4.4.3 **Field quick test kits**: allows a quick determination of pH, EC and approximate content of nitrates, potassium and chlorides in the soil solution and in the plant sap without sending the samples to the lab (usually by colorimetric strips).

5. **Nutrients application in fertigation**

With fertigation, nutrients are supplied to the roots in the correct dosage and at the time appropriate for a specific stage of plant growth. Fertilizers are applied according the need for nutrients, following the uptake rate of the crop. On the contrary, under conventional pre-plant fertilizer application, plants get a larger dosage of fertilizer than they require at the time it is applied thus losses may occur.

Fertigation recommendations should be adjusted taking into account main soil parameters, e.g. soil texture, soil pH, nutrient concentrations in the soil and C.E.C. Water supplies sometimes contain enough calcium, magnesium and sulphur to allow these to be left out of the fertigation solution. There is no point in adding nutrients that are already supplied by the irrigation water. pH and EC is useful for assessing water quality. Total alkalinity (concentration of bicarbonate ions in the water) provides information regarding the possible interaction between the fertilizers and the irrigation water.

5.1 **Nutrient rates**

- When a crop is first seeded or transplanted, begin with small amounts of fertilizer as the crop is growing slowly.
- Increase the amounts as the growth rate increases.
- As the crop matures and growth slows, reduce the fertilizer rates accordingly.
- For most crops, is sufficient to program no more than four or five rate changes during the production season.

5.2 **Nutrient ratio**

- Early in the crop's season, apply P and K in small doses for best rooting and plant establishment
- When plants are vegetative, apply adequate quantities of N for best plant growth and development
- As fruit load grow, increase K for best fruit setting, development and quality. High absorption of K is noticed during heavy fruit loads of vegetable crops and a massive stalk development of flower crops. Reduce N doses to avoid lush growth, soft fruit and pests’ problems.

5.3 **Which nutrients?**

- Open field crops: the soil has its own nutrient reserve and CEC to supply indigenous nutrients. Therefore:
  - P is applied as basal application previous to planting
  - Some part of the N&K can be applied in the preplant fertilization. The rest N&K through fertigation during the crop cycle, adapting the doses to the soil testing.
  - Occasional micronutrient deficit can be corrected through foliar application
- Intensive cropping, greenhouses and/or hydroponics: the growing substrate acts as a physical support of the roots and does not have any nutrient reserves or supply power. Therefore:
  - Complete nutrient solution is applied (incl. macro and micronutrients)
  - Special care to the form of the nutrient supplied (micronutrients as chelates, nitrogen at the correct NO$_3$-NH$_4$ ratio, pH of the solution should be slightly acidic for maximum nutrient availability)
Continuous monitoring and adjustments should be done (pH, EC and nutrient concentration of the solution)

6 Sugarcane: nutrients application in fertigation

6.1 Nitrogen: N requirement of sugarcane is 0.8-1.2 kg N/ton (IFA, 1992). N requirement of sugarcane is greatest during the tillering phase. This is required for adequate tiller production and canopy development. Tillering in field grown sugarcane commences around 30 to 45 days after planting. Therefore, adequate N supply should be made available to the crop in the soil from the start of tillering phase. Further, crop requirement for N is higher in early grand growth period. This facilitates cane formation; checks tiller mortality and promote cane growth.

Application of more N at later phase of active crop growth period not only promotes late tiller formation, but also affects sugar recovery due to reduced juice sucrose (Pol) percent, increase in soluble N in juice, water shoot formation besides attracting pests and diseases.

Increase in the rate of N raises yields of stalk and sugar until yield reaches a maximum. If N is applied in excess of the optimum, sugar production may drop. Timing of N application has a profound influence on sucrose content at harvest. N application at beginning of vegetative growth has no negative effect on sucrose content. However, late application can cause a decrease in sugar yield.

6.2 Phosphorus: P requirement of sugarcane is 0.3-0.46 kg P_2O_5/ton (IFA, 1992). P need of sugarcane is greater in the formative phase of the crop. Therefore, the optimum time of P application is during initial stages of crop growth. Higher rates of P application can reduce yield, sugar concentration, pol % and purity, particularly in ratoons and in soils not deficient in phosphorus. On the other hand, in P deficient soils higher P levels increase pol % and purity. The amount of P in cane juice has an effect on clarification.

6.3 Potassium: K requirement of sugarcane is 1.32-1.44 kg K_2O/ton (IFA, 1992). K applications are usually done along with N application. This is because of better utilization of N by the crop in the presence of K; therefore, potassium should be applied along with N. However, late application of K at around six months has also been found to improve sugar recovery.

Potassium application raises milleable stalk yield, sugar % of cane and in brix % juice also. K deficiency impairs sucrose transport from the leaf into the stalk. There is a positive interaction between N and K - the reduction in sugar content caused by high rates of N is ameliorated by an adequate supply of K. Excessive dosages of K i.e., over and above optimal rates may exert a negative effect on apparent sucrose percent in cane (pol % cane) and may promote an increase in the ash content of juice. Increased ash content in cane juice has a negative influence on sugar quality since K is the main constituent of juice ashes. The unfavorable effects of K however, should be anticipated only when excessive rates are used; in low potassium soils improvement in cane quality are to be expected.

The content of the macro and micronutrients in the sugarcane plant obeys the following decreasing order: K>N>P>Ca>S>Mg>Cl>Fe>Zn>Mn>Cu>B>Mo.

7 Results from VSI-IPI project on fertigated sugarcane - a short review

Experiments on fertigated sugarcane are being conducted since 2003 by IPI in collaboration with VSI at VSI experimental farm and on 3 farmers' fields in the operational area of the sugar factories. The objective is to study the effect of various levels of potash application through drip irrigation on yield and quality of sugarcane (Var. Co 86032).

The treatments are: T1:Recommended dose of fertilizers (N:P:K=340:170:170 Kg/ha) in four splits under conventional irrigation (soil application), T2:Recommended dose of fertilizers (N:P:K=
340:170:170 kg/ha) in four splits under drip irrigation, T3:70% of recommended dose of urea + 115% recommended dose of KCl in thirteen equal splits through drip irrigation + recommended dose of SSP in two splits by soil application, T4:70% of recommended dose of urea + 100% recommended dose of KCl in thirteen equal splits through drip irrigation + recommended dose of SSP in two splits by soil application, T5:70% of recommended dose of urea + 85% recommended dose of KCl in thirteen equal splits through drip irrigation + recommended dose of SSP in two splits by soil application, T6:70% of recommended dose of urea + 70% recommended dose of KCl in thirteen equal splits through drip irrigation + recommended dose of SSP in two splits by soil application, T7:70% of recommended dose of urea + 55% recommended dose of KCl in thirteen equal splits through drip irrigation + recommended dose of SSP in two splits by soil application.

The results of the first ratoon crop show that when applying the KCl and urea through drip irrigation, it is possible to attain 30% saving in N and K fertilizers in addition to 27% increase in yield and 2.21 times more water use efficiency as compared to conventional method of irrigation with recommended dose of fertilizers (Table 4).

In addition, fertigation treatment using 70% of the recommended doses of urea and KCl recorded the maximum net return (Table 5). This remarkable return demonstrates at first hand to the farmer the benefits which can accrue by using fertigation in sugarcane crop.

Fertigation ensures that essential nutrients are supplied precisely at the area of most intensive root activity according to the specific requirements of sugarcane crop and type of soil resulting in higher cane yields and sugar recovery.

Table 4: Fertigation experiment at VSI (India) – First ratoon Variety – Co 86032

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Tiller count at earthing up</th>
<th>Milleable cane height (cm.)</th>
<th>No. of internodes (No.)</th>
<th>Cane girth (cm)</th>
<th>Plant population per ha</th>
<th>Yield (t/ha)</th>
<th>CCS (%)</th>
<th>CCS (t/ha)</th>
<th>Increase in yield (%)</th>
<th>Water use efficiency (t/ha-cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drip irrigation 4 splits</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70% urea + 115% KCl</td>
<td>206435*</td>
<td>253.63</td>
<td>21.60</td>
<td>9.13</td>
<td>85876</td>
<td>130.51</td>
<td>14.81</td>
<td>19.33</td>
<td>10.19</td>
<td>0.92</td>
</tr>
<tr>
<td>70% urea + 100% KCl</td>
<td>212315*</td>
<td>262.13</td>
<td>22.30</td>
<td>9.06</td>
<td>115486*</td>
<td>146.92*</td>
<td>14.17</td>
<td>20.75</td>
<td>24.05</td>
<td>1.04</td>
</tr>
<tr>
<td>70% urea + 85% KCl</td>
<td>204907*</td>
<td>269.20</td>
<td>22.95</td>
<td>9.67</td>
<td>108762*</td>
<td>139.27*</td>
<td>14.78</td>
<td>20.60</td>
<td>17.59</td>
<td>0.99</td>
</tr>
<tr>
<td>70% urea + 70% KCl</td>
<td>220185*</td>
<td>270.80*</td>
<td>22.00</td>
<td>9.26</td>
<td>118079*</td>
<td>151.47*</td>
<td>15.03</td>
<td>22.75</td>
<td>27.89</td>
<td>1.07</td>
</tr>
<tr>
<td>70% urea + 55% KCl</td>
<td>201204*</td>
<td>257.95</td>
<td>23.15</td>
<td>9.29</td>
<td>112570*</td>
<td>149.76*</td>
<td>15.05</td>
<td>22.53</td>
<td>26.44</td>
<td>1.06</td>
</tr>
<tr>
<td>70% urea + 55% KCl</td>
<td>225741*</td>
<td>253.20</td>
<td>22.97</td>
<td>9.37</td>
<td>94931</td>
<td>122.81</td>
<td>15.32</td>
<td>18.88</td>
<td>3.69</td>
<td>0.87</td>
</tr>
<tr>
<td>LSD</td>
<td>47203</td>
<td>23.05</td>
<td>N.S.</td>
<td>N.S.</td>
<td>16640</td>
<td>20.88</td>
<td>0.94</td>
<td>2.94</td>
<td>-----</td>
<td>-----</td>
</tr>
</tbody>
</table>

Optimizing Crop Nutrition
Table 5: Cost of cultivation of sugarcane and economic analysis with and without fertigation

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Cost of cultivation (Rs /Ha)</th>
<th>Income @ Rs. 1200/- per MT.</th>
<th>Additional income due to Drip/Yr (Rs.)</th>
<th>Net Return due to Drip/Yr. (Rs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil application N:P:K 340:170:170</td>
<td>37,923</td>
<td>142,128</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Fertilization 70% urea + 70% KCl</td>
<td>31,418</td>
<td>181,764</td>
<td>46,141</td>
<td>29,821</td>
</tr>
</tbody>
</table>

8  **Israel experience**

Israel is a small country with a total area of 21,000 km², from which 20% is arable land. More than half of the area of Israel has an arid to semi-arid climate. Near half of the cultivable area (200,000 hectares) must be irrigated due to the lack of rain and other water resources. Approximately 80% of the irrigated area in Israel uses the method of "fertigation", which combines the application of irrigation water with fertilizers. This practice contributes to the achievement of higher yields and better quality by increasing remarkably the efficiency of the fertilizer application. Greenhouse crops in Israel are fertilized exclusively through the irrigation system. The Israeli production of vegetables, ornamental flowers, plants and spices under greenhouses has experienced an accelerated growth in the last years, with more than 3,000 hectares of greenhouses nowadays. Most of these greenhouses are computerized, allowing the automatic control of the irrigation, the fertilization and the climate. Hydroponics in Israel reaches a total area of 700 Ha, being the main crops tomatoes, cucumbers, strawberries and flowers (roses, chrysanthemum, gerbera and gypsophylla). The most common growing medium is tuff (volcanic stone) which is a reactive substrate with high power of adsorption and high indigenous phosphorus content. Inert substrates as rockwool and vermiculite are also used. At the moment most of the greenhouses have an open system. The aim is to change them by closed systems in which the farmer must collect the leached solution and reuse it thus avoiding groundwater contamination.

Israel is an unequaled example of the use of fertilizers by fertigation. The Israeli farmer is using an average of 115 kg N/Ha, 46 kg P₂O₅/Ha and 57.5 kg K₂O/Ha. Over 50% of the N and P₂O₅, and 65% of the K₂O is applied by fertigation (Tarchitzky and Magen, 1997).

9  **References**


