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Fertigation recipes for selected crops in the Mediterranean region

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Contents

SUMMARY

Fertigation increases efficient use of water and fertilizers, produces higher yields, improves quality of the production and protects environment. To ensure uniform distribution of water and fertilizers, the irrigation system must be properly designed and operated. The choice of suitable fertilizers is also very important and must be based on several factors like nutrient form, purity, solubility and cost.

To implement a fertigation program, particularly under intensive greenhouse production, good knowledge is required of water and nutrient requirements over the growing season. The fertigation model developed to be used at farmers level concerns drip-irrigated greenhouse tomato, pepper, cucumber and melon. It takes into account the amount of nutrients which may be available to the crop from soil and calculates for a target yield the quantities of N, P and K fertilizers which may be supplied through the irrigation stream over the growing season.

Starting with soil mass occupied by roots (M, tons) it is estimated from the area of the plantation (A, m^2), root depth (D, m), soil volume occupied by roots (V, %) and soil bulk density (Bd, tons/ m^3) with the following formula:

$$M = \frac{A \times D \times V \times Bd}{100}$$

Concerning the amount of soil available nutrient (SAN, kg/ha) it is estimated from soil mass and the available value for each nutrient (AV, g/ton), as determined by chemical analysis on representative soil samples, according to:

$$SAN = \frac{M \times AV}{1000}$$

The amount of nutrient required to be supplied by fertilizers (NS, kg/ha) is finally estimated from nutrient requirement of the crop (NR, kg/ha), soil available nutrient, safety margin (SM, kg/ha) which is the amount of soil available nutrient to be reserved in soil (for P or K) and nutrient uptake efficiency (Ue, fraction) which depends on the irrigation system and soil type:

$$NS = \frac{NR - SAN + SM}{Ue}$$

The amount of nutrient estimated with the above formula over a certain period, is combined with the respective crop water requirement in order to arrive at nutrient concentration in the irrigation water. The model calculates N, P and K concentration for both the preflowering and fruiting cycles. Taking into consideration the fertigator and irrigation system discharges, as well as the selected combination of fertilizers, nutrient concentrations in the irrigation water are finally converted to concentrations of fertilizers in the stock solution tank.

INTRODUCTION

Irrigated agriculture can be environmentally sustained provided the basic principles of good water and fertilizer management are recognised. Chemical fertilizers are a real asset if they are applied whenever needed by the crop (timing of application) in the appropriate form and amount. The promotion of efficient and effective water and fertilizer use, which means best management of water and fertilizers at farmers level were identified as important contribution to the strategy needed to address problems of water scarcity and practising intensive agriculture. Improving the water and consequently fertilizer use efficiency at farmers level, is the major contributor to increase food production and reverse the degradation of the environment or avoid irreversible environmental damage and allow for sustainable irrigated agriculture (Papadopoulos, 1997a).

Given the limitation to further expansion of irrigated land in most countries, a large part of the future food requirements will need to be covered from a more efficient and sustainable use of irrigation water and fertilizers (FAO, 1993). In this respect, fertigation (application of fertilizers with the irrigation water), is proposed as a means to increase efficient use of water and fertilizers, increase yield, protect environment and sustain irrigated agriculture. Fertigation is directly related with improved irrigation systems and water management. Drip and other micro-irrigation systems, which are highly efficient for water application, are ideally-suited for fertigation. Water-soluble fertilizers at concentrations required by crops are conveyed via the irrigation stream to the wetted volume of soil. Thus the distribution of chemicals in the irrigation water will likely place these chemicals in the desired location, the root zone. This reduces water and fertilizer application (Clark et al., 1991). With a drip-fertigation system uptake of N, P and K are substantially improved. In this respect per unit of fertilizer and water applied, higher yield and better quality are obtained (Papadopoulos, Ristimaki and Sonneveld, 2000).

Potential advantages of fertigation are higher yield, improved quality of produce, improved efficiency of fertilizer recovery, minimal fertilizer losses due to leaching, control of nutrient concentration in soil solution and flexibility in timing of fertilizer application in relation to crop demand based on development and physiological stage of crops. Scheduling fertilizer applications on the basis of needs reduces nutrient-element losses associated with conventional application methods that depend on the soil as a reservoir for nutrients. In addition, fertigation reduces fluctuations of soil solution salinity due to fertilizers, thereby improving soil solution conditions particularly for salt sensitive crops. In general, with fertigation protection of soil and water from fertilizers on a sustainable basis can be achieved (Papadopoulos, 1997b). Eventual disadvantages of fertigation include unequal chemical distribution when irrigation system design or operation is inadequate, over-fertilization in case that irrigation is not based on actual water requirements, and chemical reactions in the irrigation system leading to corrosion, precipitation of chemical materials, and/or clogging of outlets. Most of these problems have been extensively studied and solutions are available.

In this paper N, P and K fertigation of drip irrigated greenhouse crops is discussed, as a means to increase yield and improve quality in the Mediterranean region. A fertigation model based on water and nutrient requirements of selected crops and soil fertility is presented, as well as the methodology used and example of calculations at farmers level.

FERTIGATION EQUIPMENT AND FERTILIZERS

The fertigation unit is composed of a fertigator, a fertilizer tank for the concentrated stock solution, non-return valves, a main filter and water meter (Figure 1). Depending on the model of the fertigator, additional equipment (valves, pressure and flow regulators) may be required. As metal tanks may corrode plastic containers are preferred for the stock solution. Flushing after fertigation is also a good practice in order to reduce both the corrosion hazard and microbial growth in the irrigation system.

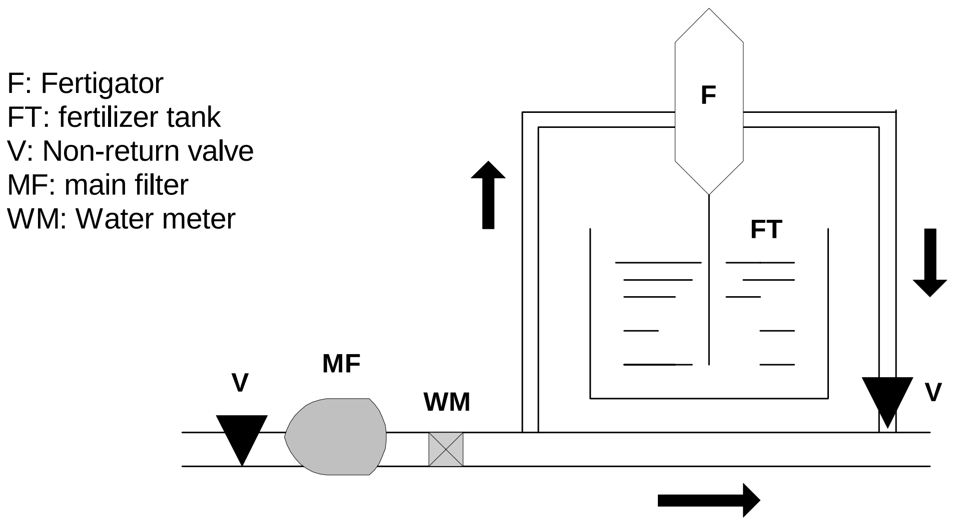

Fig. 1. Fertigation unit

For injection of the fertilizer solution into the irrigation system four different fertigators can be used: Venturi pump, by-pass flow tank, pressure differential system or injection pump. The general advantages of the injection pump system are: the high degree of control of dosage and timing of chemical application, centralised and sophisticated control, portability, no serious head loss in the system, labour-saving and relatively cheap in operation. With this method the solution is normally pumped from an open unpressurized tank, and the choice of type of pump used is dependent on the power source. The pump may be driven by water flow, by an internal combustion engine, by an electric motor or by a tractor power take-off. The equipment for fertigation is summarised by Janos (1995).

Drip fertigation is an attractive concept, as it permits application of nutrients directly at the site of a high concentration of active roots and as needed by the crop. However, following application through drip irrigation, mineral nutrients move into the wetted volume in a manner consistent with the flux of the water in the soil, their solubility and/or reactivity with constituents in the soil solution, and their interaction, if any, with the exchange sites of the soil. Since chemical characteristics of fertilizers differ, mineral nutrients are differently distributed in the soil when applied by drip irrigation systems.

Nitrogen: The nitrate form of nitrogen does not react with the soil exchange sites and is not held in soils. Nitrates move with other soluble salts to the wetted front. This is of particular interest since NO_3-N should always be applied with every irrigation and at that concentration needed by the fertigated crop to satisfy its requirement in N from one irrigation to the other. Under irregular NO_3-N application the fertigated crops might be under the over-fertilization stress at the day of fertilizer application and under deficient stress due to leaching following the irrigation without fertilizer. The ammonium form of N derived from ammonium or urea fertilizers is not nearly so subject to immediate leaching losses because temporarily may be fixed on exchange sites in the soil. Ammonium and urea, however, may induce acidification, which may create higher solubility of nutrients like P and movement in soil. Urea is a highly soluble, chargeless molecule, which easily moves with the irrigation water and is distributed in the soil similarly to NO_3. At 25 ^{o}C it is hydrolysed by soil microbial enzymes into NH_4 within a few days.

Potassium: It is less mobile than nitrate, and distribution in the wetted volume may be more uniform due to interaction with soil binding sites. Drip-applied K moves both laterally and downward, allowing more uniform spreading of the K in the wetted volume of soil. Application of K with the irrigation water is advised since its effectiveness increases substantially and yield obtained is higher.

Phosphorus: Contrary to N and K, phosphorus is readily fixed in most soils. Movement of applied P differs with the form of fertilizer, soil texture, soil pH and the pH of the fertilizer (Papadopoulos and Ristimaki, 1998). Under calcareous conditions P is readily fixed. Phosphorus mobility in soil is very restricted due to its strong retention by soil oxides and clay minerals. Soil application of commonly available P fertilizers generally results in poor utilization efficiency principally because phosphate ions rapidly undergo precipitation and adsorption reactions in the soil, which remove them from the soil solution. Consequently, there is little or no movement of phosphate from point of contact with the soil. Therefore, there is inefficient utilization of applied P fertilizers. Continuous application of P through the irrigation water was shown to be superior to applying P in adequate quantities as basic fertilization (Figure 2). Rauschkolb et al., (1976), found that P movement increases 5 to 10 folds when applied through drip system, indicating that fertigation of P is particularly important.

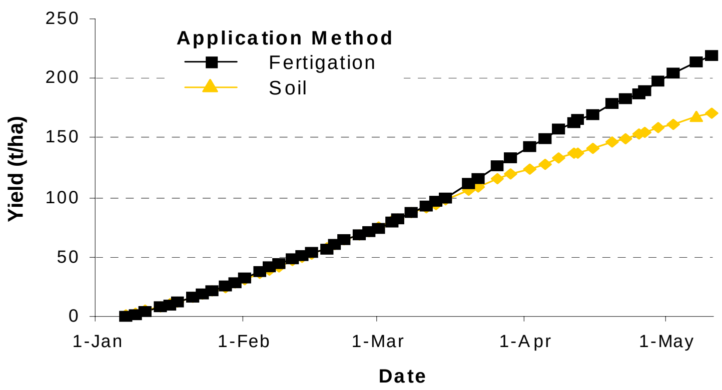

Fig. 2. Accumulated cucumber yield as affected by the method of P-application

A fertilizer to be appropriate for fertigation must be water-soluble (Table 1). However, most of the common P and K fertilizers are not convenient for fertigation due to their low solubility. This is particularly the case with the P fertilizers.

Table 1. Solubility of fertilizers in water (kg fertilizer/m^3)

Type of fertilizer	Solubility (kg/100 litters)
Ammonium sulphate	71
Ammonium nitrate	119
Urea	110
Monoammonium phosphate (MAP)	23
Urea phosphate	96
Potassium sulphate	7
Potassium nitrate	32

Commercial standard P-fertilizers may also precipitate in the irrigation lines in reaction with ions in the irrigation water such as Ca or Mg. Therefore, when choosing the P fertilizer for fertigation, besides solubility, care must be taken to avoid P-Ca and P-Mg precipitation in the tubes and emitters. From this standpoint, acid P fertilizers (e.g., phosphoric acid, urea phosphate or monoammonium phosphate) are recommended.
Different sources of fertilizers, including P fertilizers, have different effects on irrigation water and soil pH. High pH values (>7.5) in the irrigation water are undesirable. Calcium and Mg carbonate and orthophosphate precipitations may occur in the tubes and the drippers. In addition, high pH may reduce Zn, Fe and P availability to plants. The desired pH is below 7 and the range favoured by most cultivated crops is 5.5-6.5. The pH of the irrigation water could be reduced or controlled by using P acid or acid based fertilizers like urea phosphate and monoammonium phosphate.
The use of acid fertilizers in drip systems may be beneficial in many ways other than the direct benefit from the added P, such as increased solubility of soil native P minerals, increased availability of other nutrients and micronutrients and prevention of chemical clogging of the fertigation system.

Nutrient sources (fertilizers)

The choice of fertilizer suitable for a specific application should be based on several factors: nutrient form, purity, solubility, and cost.

A variety of fertilizers can be injected into drip irrigation systems. Soluble NPK fertilizers are available in the market which are appropriate for fertigation but the price might be in certain cases the main constraint. Common N sources include ammonium sulphate, urea, ammonium nitrate, urea-ammonium nitrate, calcium nitrate, magnesium nitrate and potassium nitrate. Potassium can be supplied from potassium chloride, potassium sulfate, potassium thiosulfate, or potassium nitrate. In case that salinity is a problem potassium chloride and potassium sulphate should be avoided. Should also be avoided if are not clean and have extensive impurities. Potassium

nitrate is the preferable form. The choice of phosphorus products is more limited; phosphoric acid, urea phosphate or ammonium phosphate solutions are used most commonly. Monoammonium or mono potassium phosphate are also available.
Liquid P fertilizers, except for good-grade phosphoric acid, may have impurities that complicate the already difficult task of eliminating chemical precipitation in the drip lines. However, with sufficient knowledge and attention to detail, good-grade phosphoric acid and ammonium phosphate solutions can be delivered successfully.

FERTIGATION PRACTICES AND RECOMMENDATIONS

For optimum plant performance under fertigation, all fertilization-irrigation-input factors must be balanced so that none impose a significant limit. Implementing a fertigation program the actual water and nutrient requirements of the crops, together with a uniform distribution of both water and nutrients, are very important parameters.

Crop water requirements, particularly under intensive greenhouse production, are the most critical link between irrigation and sound fertigation. In this respect, the amount of irrigation water needed over the growing season must be precisely determined under the prevailing climatic conditions of the region under consideration. Figure 3 presents evapotranspiration of greenhouse tomato measured in drainage lysimeter at the south coastal area of Cyprus.

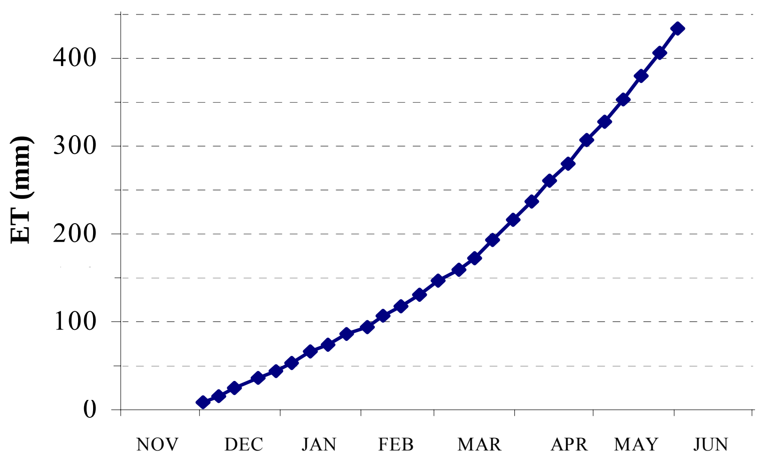

Fig. 3. Accumulated evapotranspiration (ET) of tomato over the growing season as measured by lysimeter.

Significant technical skill and management are required to formulate an appropriate fertigation recipe and achieve optimum agronomic and environmental results. The main elements for formulating and evaluate fertigation are crop nutrient requirement for a certain yield (Papadopoulos, 1997a), nutrients available from soil (Hartz and Hochmuth, 1996) the volume of soil occupied by the rooting system and the irrigation method. Fertigation with drip irrigation, if properly managed, can reduce overall fertilizer and water application rates and minimise adverse environmental impact (Papadopoulos, 1993).

The empirical application of fertilizers is associated with severe limitations, which lead to low recovery of fertilizers by the crop. In general, empirical fertilization is based on farmer's experience and on broad recommendations. The scientific approach, takes into consideration all main factors influencing crop nutrition and soil fertility and provides the individual grower dependable information regarding the fertilizer needs of his field.

The selection of the proper rate of nutrient application is influenced by a knowledge of the nutrient requirement of the crop, the nutrient supplying power of the soil, the efficiency of nutrient uptake and the expected yield. These factors could be taken into consideration and for the same crop, for each field, different fertigation programme could be recommended. When the soil does not furnish adequate quantities of the elements necessary for normal development of plants, it is essential that the required amounts be applied. This necessitates finding a method that will permit the determination of those deficient elements and furthermore help to predict the amount of nutrients needed to supplement the crop requirement.

The quantities of nutrients removed by crop from soil are good information, which can be used to optimise soil fertility level needed for various crops. Part of the nutrients removed by crop is used for vegetative growth (canopy) and the rest for fruit production. It is important to have enough nutrients in the right proportions in the soil to supply crop needs during the entire growing season. Vegetable crops differ widely in their macronutrient requirements and in the pattern of uptake over the growing season. In general, N, P, and K uptake follow the same course as the rate of crop biomass accumulation. Fruiting crops such as tomato, pepper, and melon require relatively little nutrition until flowering, when nutrient uptake accelerates, peaking during fruit set and early fruit bulking. The approximate amounts of N,P,K removed from soil by various crops during the usual growing season (November – June) in the Mediterranean region are given in Table 2. The table indicates the comparative uptake among crops. In addition, they are an indication of the rate at which the reserve or "storehouse" nutrients in the soil are depleted (Papadopoulos, 2000).

Table 2. Nutrients required by selected crops for canopy formation and fruit production in the Mediterranean region.

Crop	Canopy (kg/ha)			Fruit (kg/ton)		
	N	P	K	N	P	K
Tomato	95	12	108	1,80	0,17	3,13
Pepper	90	6	90	2,00	0,26	1,83
Cucumber	60	8	66	1,40	0,35	2,16
Melon	80	11	87	2,00	0,26	2,97

The amounts of nutrients indicated in Table 2 are required to be available in soil. However, not all of the nutrients should necessarily come from fertilizer because part of them could be supplied by the soil. In this respect, estimating the amount of nutrients, which may be available to the crop from soil (nutrient supplying power of soil), is important. This amount is subtracted from the overall amount, which should be

supplied by fertilizers.
Most soils contain substantial quantities of available nutrients. Using a standard drip fertigation program without soil testing will often lead to wasteful fertilizer application or, less frequently, results in a nutrient deficiency. A soil test helps to estimate the nutrient supplying power of a soil and reduce guesswork in fertilizer practises. The results of the soil test could be reliable only if they are based on representative samples. However, this is becoming particularly difficult with drip irrigation. The place and depth of soil sampling relative to the drippers is a sensitive issue of particular importance. Usually it is recommended to get samples beneath the dripper, between the drippers and between the lateral pipes.

In order to estimate the nutrient supplying capacity of a soil, apart from soil analysis, the following parameters are needed:

- Depth of the crop rooting system
- % of soil occupied by the root system under different irrigation systems
- Soil Bulk Density (Bd).

These parameters are used to calculate the weight of soil of a certain area to a depth where the active rooting zone of the crop is developed and estimate the reserves or storehouse available nutrients for the crop.

The amount of available nutrients in soil is estimated up to that depth of soil where roots are active and, therefore, nutrient uptake occurs. The appearance, growth and depth to which roots penetrate in soils are in part species properties but prevailing soil conditions (clay pan, hard pan, compacted layer) usually exert a pronounced influence. Knowledge of the rooting habits of the crops is helpful in determining in satisfactory way soil exploitation and revealing the depth to which the reserve nutrients in the soil could be available and contribute to the overall nutrition of the crop. The volume of soil occupied by roots, however, is less and depends on the crop, spacing of planting and irrigation system. For drip irrigated greenhouse vegetables like tomato, cucumber, pepper, the wetted soil volume is usually 30-50% of total soil volume. The fraction of soil occupied by roots must be taken into account whenever the amount of available nutrients is calculated, otherwise the available amounts could be overestimated.

The mass of soil occupied by roots is estimated with the following formula:

$$\textbf{Soil Mass (tons)} = \frac{\mathbf{A \times D \times V \times Bd}}{\mathbf{100}} \qquad \textbf{(1)}$$

Where:
- A: Area of the plantation (m^2)
- D: Root Depth (m)
- V: Soil volume occupied by roots (%)
- Bd: Bulk density (tons/m^3)

The amount of a nutrients in soil which can be used by the crop is estimated from soil mass and the available nutrient value as determined by soil chemical analysis according to:

$$\textbf{Soil Available Nutrient (kg/ha)} = \frac{M \times AV}{1000} \quad (2)$$

Where: M: Soil Mass (tons)
AV: Available nutrient Value (g/ton)

In calculating the nutrient supplying capacity of a soil, the whole amount of the available nutrient to full depletion of soil can be taken into consideration. However, it is preferable that a certain amount of a nutrient be reserved in soil. For intensive irrigated agriculture as safety amounts of P and K in soil could be considered the 30 and 100 ppm (g/ton), respectively. In other words, the farmers in intensive irrigated agriculture are not encouraged to deplete soil below these values. Moreover, in case that a nutrient is below the safety value, the fertilisation programme may include an amount of nutrient needed to build up soil fertility up to the safety margin. Theses margins are at the same time the pool for increased demand in nutrients at eventual crop critical nutrient stages.

It should be emphasised that the amount of fertilizer-nutrients needed by the crop and the amount of nutrients, which should be applied, are not equivalent. The crop uses not all the nutrients supplied by fertilizers, therefore, the actual amount applied is higher than the amount required by the crop. Uptake of nutrients depends, among others, on the irrigation system and soil type (texture) (Table 3).

Table 3. Fertilizer-N,P and K uptake efficiency (fraction) as influenced by the irrigation system and soil type

Soil Type	Furrow			Sprinkler			Micro-irrigation		
	N	P	K	N	P	K	N	P	K
Clay	0.60	0.20	0.75	0.70	0.25	0.80	0.85	0.35	0.90
Medium	0.50	0.15	0.68	0.65	0.20	0.75	0.80	0.30	0.85
Sandy	0.40	0.10	0.60	0.60	0.15	0.70	0.75	0.25	0.80

The values refer to well-designed and operated irrigation systems

In general, the higher the water use efficiency of a certain irrigation system the higher is the nutrient uptake efficiency. For a well designed drip irrigation system and with good scheduling of irrigation, depending on soil type, the potential N, P and K uptake efficiency ranges between 0.75-0.85, 0.25-0.35 and 0.80-0.90, respectively.

Taking into account the:

- nutrient requirement of the crop, NR (kg/ha)
- soil available nutrient, SAN (kg/ha)
- safety margin (for P or K), SM (kg/ha), and

- nutrient uptake efficiency, Ue (fraction)

the following formula can be used to estimate the amount of nutrient (N, P and K) required to be supplied by fertilizers (NS):

$$NS\ (kg/ha) = \frac{NR - SAN + SM}{Ue} \qquad \textbf{(3)}$$

With the above formula a good estimate of the nutrients required to be supplied by fertilizers over a certain period is obtained. In order to arrive at a proper fertigation program, these amounts of nutrients must be combined with crop water requirements, which, as stressed earlier, must be known during the same period.

FERTIGATION MODEL

A fertigation model was developed to be used at farmers level, based on crop water and nutrient requirements of selected greenhouse crops. It concerns drip-irrigated tomato, pepper, cucumber and melon. The model takes into account the amount of nutrients that may be available to the crop from soil (nutrient supplying power of soil), and aims to determine for a target yield the quantities of N, P and K fertilizers that should be supplied through the irrigation stream over the growing season.

Calculations are performed using equations 1, 2 and 3. Starting with soil mass, the model assumes that 50% of the soil volume is occupied by roots, which develop to the depth of 0.4 m, while soil bulk density is taken as 1.2 tons/m^3. Concerning the amount of N, P and K in soil, which can be used by the crop, it is estimated from soil mass and the available value for each nutrient as determined by chemical analysis on representative soil samples. The soil analysis data used by the model are, NO_3-N and NH_4-N, extractable-P (Olsen method) and exchangeable-K. Soil available N is taken into account only during the fruiting cycle in order to promote development of the young plants during preflowering. The amounts of 30 and 100 g/ton of soil available P and K, respectively, are considered as safety margins. Depending on soil type the uptake efficiency used for N, P and K is 0.75 - 0.85, 0.25 - 0.35 and 0.80 - 0.90 respectively.

The model calculates for the selected crop the required N, P and K concentration in the irrigation water, for both the preflowering and fruiting periods. The length of the usual growth cycle in the Mediterranean region for tomato, pepper and both cucumber and melon is considered to be 34, 30 and 20 weeks, respectively. Taking into consideration the fertigator and irrigation system discharges and the capacity of the stock solution tank, as well as the selected combination of fertilizers, nutrient concentrations in the irrigation water are converted to concentrations of fertilizers in the stock solution tank. Depending on the system design, results are given for two options: Fertigator installed before or after the water meter.

Example of calculations for greenhouse tomato in the south coast of Cyprus during the winter growing season is presented in Figures 4 and 5.

Model Input

1. Selection of the **crop**

2. **Soil chemical analysis**
   (If data not available, zero values should be used)

3. **Soil type**

4. **Expected** (target) **yield**

5. Length of **growing season**
   - Preflowering
   - Total

6. **Irrigation** requirement
   - Preflowering
   - Total

7. **System characteristics**
   - Fertigator and system discharge
   - Solution tank capacity

8. Selection of **fertilizers**

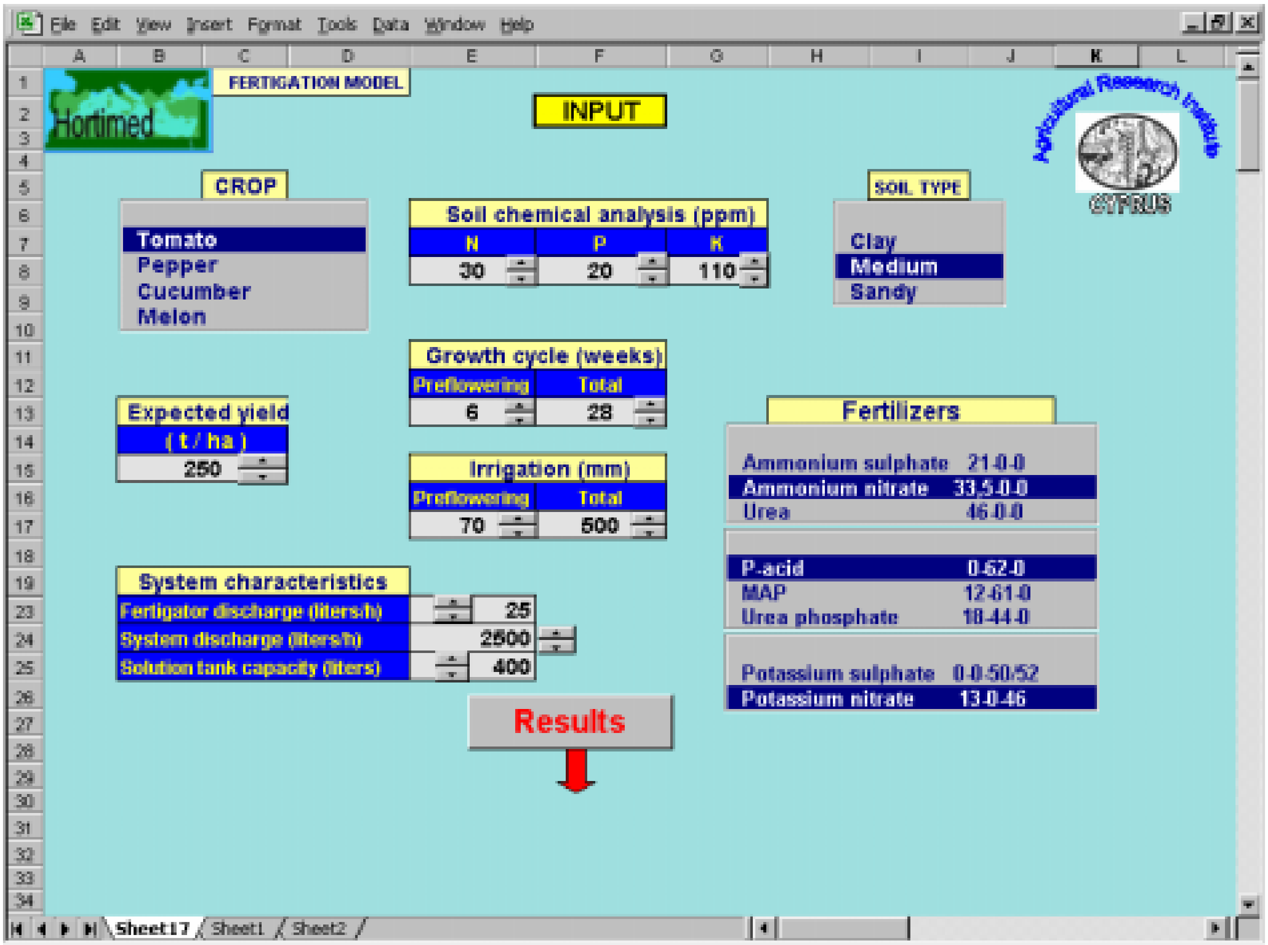

Fig. 4. Model input

Model Output

1. N, P and K concentration in irrigation water
    - Preflowering period
    - Fruiting period

2. Fertilizer concentration in the solution tank

(Two options: Fertigator before or after the water meter)

- Preflowering period
- Fruiting period

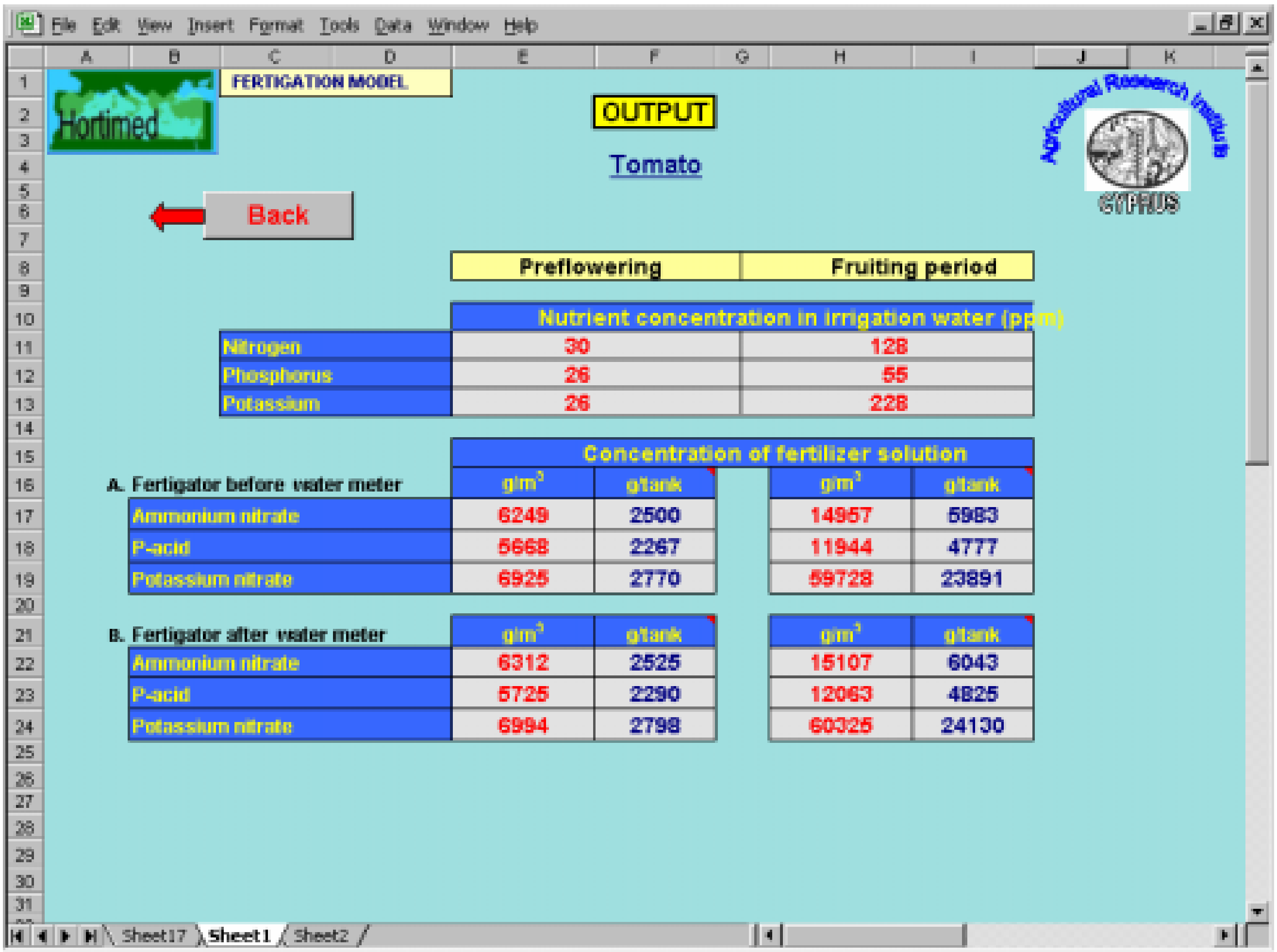

Fig. 5. Model output

RULES OF THUMB

- Fertigation increases efficient use of water and fertilizers, produces higher yields and protects environment.
- No sound fertigation could be practised if not based on good irrigation management.
- Design and operation of the drip irrigation system must be proper to ensure uniform water distribution without losses.
- Sound irrigation based on modern irrigation technology requires sufficient background on crop water requirements.
- For proper nutrient application, good knowledge of crop nutrient requirements

during the growing season is needed.

- To estimate the nutrient supplying power of the soil, chemical analysis on representative soil samples is very important.

- For the selection of the proper type of fertilizers, solubility, purity, soil pH and salinity as well as the cost should be considered.
  Attention should be paid to the fact that solubility considerably decreases with temperature, and it is therefore unwise to leave concentrated fertilizer used in the summer for the winter period, since it may crystallise and block pipes connecting tank and the injection part.

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